ANALYSIS AND RESULTS OF WEIGHT GAIN OF EASTERN BLUEFIN TUNA (*THUNNUS THYNNUS*) IN FARMS

M. Ortiz[1], C. Mayor, F. Alemany and A. Pagá

SUMMARY

Fattening of bluefin is the main operation and destination of the catches of eastern bluefin in the Mediterranean Sea at present. Since 2008 a regional observer program (ROP-BFT) collects size and weight measures of harvested bluefin. Data from 2015-2022 harvest operations were reviewed to estimate the weight gain of eastern bluefin in farming operations. The potential growth associated with farming was estimated as function of days-at-farm, and size at initial caging, evaluating differences by regional areas or farms. Results from in situ tagging experiments and from size-mode progression analysis data from stereoscopic camera experiments indicated an increase in somatic growth rates of the farmed fish compared to the wild ones for E-BFT fish. Analysis and results estimating a farm-growth model equation are presented. This study addressed part of the 2018 ICCAT Commission request on the maximum expected growth of farmed E-BFT.

RÉSUMÉ

L'engraissement du thon rouge est actuellement la principale opération et destination des captures de thon rouge de l'Est en mer Méditerranée. Depuis 2008, un programme d'observateurs régionaux (ROP-BFT) collecte les mesures de taille et de poids des thons rouges mis à mort. Les données des opérations de mise à mort de 2015-2022 ont été examinées afin d'estimer la prise de poids du thon rouge de l'Est dans les opérations d'élevage. La croissance potentielle associée à l'élevage a été estimée en fonction des jours à la ferme, et de la taille à la mise en cage initiale, en évaluant les différences par zones ou fermes. Les résultats des expériences de marquage in situ et des données d'analyse de la progression du mode de taille provenant des expériences des caméras stéréoscopiques indiquaient une augmentation des taux de croissance somatique des thons rouges de l'Est d'élevage par rapport aux spécimens sauvages de cette même espèce. L'analyse et les résultats de l'estimation d'une équation du modèle croissance dans les fermes sont présentés. Cette étude a répondu à une partie de la demande de la Commission de l'ICCAT de 2018 sur la croissance maximale escomptée des thons rouges de l'Est d'élevage.

RESUMEN

El engorde de atún rojo es la principal operación y destino de las capturas de atún rojo oriental en el Mediterráneo en la actualidad. Desde 2008, un programa regional de observadores (ROP-BFT) recopila mediciones de talla y peso del atún rojo capturado. Se examinaron los datos de las operaciones de sacrificio de 2015 a 2022 para estimar la ganancia de peso del atún rojo oriental en las operaciones de cría. El crecimiento potencial asociado a la cría se estimó en función de los días en la granja y de la talla en el momento de la introducción inicial en jaulas, evaluando las diferencias por zonas regionales o granjas. Los resultados de los experimentos de marcado in situ y de los datos del análisis de la progresión moda-talla de los experimentos con cámara estereoscópica indicaron un aumento de las tasas de crecimiento somático de los peces de granja en comparación con los salvajes en el caso de los ejemplares de atún rojo del este. Se presentan el análisis y los resultados de la estimación de una ecuación del modelo de crecimiento en granjas. Este estudio abordó parte de la solicitud de la Comisión de ICCAT de 2018 sobre el crecimiento máximo previsto del atún rojo del este en granjas.

KEYWORDS

Bluefin tuna, Thunnus thynnus, farm, growth, size distribution

[1] ICCAT Secretariat Calle Corazón de Maria 8, Madrid 28002 Spain. Mauricio.ortiz@iccat.int

1. Introduction

Fattening of bluefin is one of the main operations and objectives for the catches of eastern bluefin in the Mediterranean Sea and East Atlantic during the last decades. Based on catches from purse-seine vessels about 75% of the annual catches of eastern bluefin are intended for farming operations currently. Farms hold the fish for a few months to over 2 years, depending on the size and other factors including market conditions.

Bluefin for farming operations is almost all caught with purse-seine vessels that transfer the live fish to holding pens, which are slowly towed and finally transfer to sea-cages in the farms. A relatively small portion of caged fish is caught from BFT traps which are then transferred to holding cages for fattening. Because of the nature of the fishing operations, it is difficult to obtain estimates of the catch in both numbers, weight, and size/age distribution of the wild fish caught. However, since the full implementation of stereo-camera systems in 2015, more reliable estimates of the number of fish and their size distribution have been available.

As with most aquaculture operations, farming bluefin enhances the somatic growth compared to wild populations. Early research studies with small bluefin tuna in the Adriatic Sea have confirmed and reported increases in growth rates of both size and weight for farmed Eastern Atlantic bluefin (Katavic *et al.*, 2010). Earlier studies with medium and large bluefin tuna kept in farms reported only increases in weight (Gordoa, 2010; Deguara *et al.*, 2011). However, recent experimental studies using *in-situ* tagging experiments, and analysis of size-mode progression (MPA) from periodic monitoring of size distribution within cages with stereoscopic cameras, indicated increases in the Eastern BFT intrinsic growth compared to the wild fish (SCRS/2021/145, SCRS/2021/150). Similarly, in farming operations with Pacific BFT (*Thunnus orientalis*) they have also reported increases in intrinsic growth rates, both in length and weight, when compared to wild populations (Masuma *et al.*, 2009; Vergara-Solana, 2019).

There are however large variations in size/weight gains among BFT farms in the Atlantic and the Mediterranean Sea, likely in response to differences in husbandry and environmental conditions. The present study updated estimates of potential growth for farmed E-BFT as function of the initial size at caging and the time on the farm, using results from three tagging experiments *in-situ* (Lino *et al.*, 2019; Lino *et al.*, 2021; Anonymous, 2021) and MPA experiments carried out between 2019 and 2021 within GBYP programme (Alemany *et al.*, 2021). This study is part of the SCRS response to the 2018 ICCAT Commission request on the maximum expected growth rates for farmed E-BFT (Rec. 20-07, para 8).

2. Data

The size and weight of sacrificed bluefin tuna from farms started to be reported in June 2008, following the Rec 08/05. In 2014 a database was created identifying each harvesting operation (per day when available) by registered farm and auxiliary data such as the date of catch, or the bluefin catch document (BCD) number where the details of the catching operations are recorded. Harvest operations at farms require the presence of an observer from the ICCAT Regional Observer Program (ROP-BFT) currently operated by MRAG/COFREPECHE Consortium, which collects and registers the data into a database and provided it to the ICCAT Secretariat. For 2015-2022 there were 12,047 harvest operations (e.g. per flag, farm, cage, and date of harvesting) monitored in 37 farms of eight CPCs; EU-Croatia (10 farms), EU-Spain (5 farms), EU-Malta (6 farms), EU-Italy (1 farm), EU-Portugal (2 farms), Morocco (2 farms), Albania (1 farm), Tunisia (3 farms) and Turkey (7 farms). The reports for 2022 are partial (until April 2022) and were included in this analysis. Of the 12,047 harvest operations monitored between 2015 and 2022, size and weight measures were collected with over 270 thousand fish measured and weighed, with a total harvested weight monitored of 224,349 t (**Table 1**, **Figure 1**).

At harvest size measurements are reported as straight (SFL, 42%) or curved (CFL, 51%) fork length, with 16,681 fish where both measures were recorded. This data subset was used to estimate an at-harvest conversion factor for CFL measures using a robust linear function, to convert all size measures to standard SFL (cm) units (**Figure 2**). Size conversions by farm were explored but no statistical differences were found compared to the combined data, or published reports (Farrugia-Drakard and Gatt, 2018). The weight of harvested fish is mainly reported as whole round whole weight (RWT kg, 92.4%), with few reports of gutted head off (3.6%), or gilled and gutted (0.05%) (**Figure 3**). For this analysis, only RWT observations were used. Over 95% of the harvest operations have their corresponding bluefin catch documentation record (about 1,702 BCDs) and by linking with the BCD database it was possible to obtain the date of the caging and or date of catch if missing caging information. In a few instances (2,235 records out of 309,840) the date of harvest was before the date of catch/caging, and these records were excluded. Days at farm were calculated for each observation. Harvesting included fish being caught as early as 2012 however, most of the fish are harvested during the 1st or 2nd year after caging (**Figure 4**), for this analysis were excluded records of fish that were held in farms for more than 3 years. **Figure 5** shows the size distribution (SFL) of the harvested bluefin by the flag of the farms 2015 - 2022.

A careful review of the data showed that few records have size and or weight data mistypes, problems with units, and or possible wrong codification. Thus, an outlier analysis was done with the observed size and weight records, those outside of the 97.5% bivariate non-normal percentile were excluded. **Figure 6** summarizes the reasons for the exclusion of observations. The final input data set from the ROP harvest database included a total of 236,154 observations distributed in 121,478 for large bluefin tuna (> 180 SFL cm), 84,106 for medium (100 to 180 SFL cm) size fish, and 30,570 for small fish (< 100 SFL cm) (**Table 2**).

Methods

If it is assumed that farmed bluefin tuna maintain their intrinsic growth rates of size at age, as done in previous analyses (Ortiz et al. 2014), then size at catch can be simply estimated using the invert of the growth equation (Cort *et al.,* 1991) for eastern bluefin tuna and discounting the days-at-farm. As a first approach in this study, once the size at catch was estimated, then the expected weight at catch was calculated using the current monthly conversion factors for weight-at-size (Rodriguez-Marin *et al.* 2015) or the weight-at-size for monitoring weight at catch from stereo-camera measures (Deguara *et al.,* 2017).

An initial analysis was done comparing the overall weight at size for harvest versus wild bluefin tuna. Data on weight at size of wild fish was made available from the study of Rodriguez-Marin et al. (2015). **Figure 7** shows the overall gain in weight vs days-at-farm, with an increasing trend as fish are held for longer times at the farms. However, it is noticeable the large variability in weight, and even in the initial week(s) of caging some reductions in weight were observed, likely associated with the stress induced by the catch and transfer of fish from the wild until they restore feeding behavior in the farms. Because of this large variability in weight at size it was decided to use quantile regression analysis to compare if the weight at size differs between wild and farmed fish. **Figure 8** shows the comparison of the predicted quantile regression of weight at size for the wild vs farmed bluefin tuna with corresponding 95% percentile bounds (shaded areas). It is clear that harvested bluefin has on average larger weights compared to similar size wild fish.

For eastern Atlantic bluefin tuna has been demonstrated that growth rates in farms for smaller fish (e.g. < 100 cm SFL) are higher than for wild fish (Katavic *et al.,* 2010), and further studies in the same area funded by GBYP have confirmed these higher growth rates (Anonymous, 2021). For medium and larger bluefin, GBYP funded experiments with individually tagged fish in farms have demonstrated also an increase in growth rates compared to wild fish of similar size (Lino *et al.,* 2019; Lino *et al.,* 2021). Moreover, mode-size progression analysis (MPA) by size category carried out also within GBYP program has provided similar results, showing higher growth rates in length, both in juvenile and adult fish (**Table 3**) (Alemany *et al.,* 2021). In addition, recent research studies of farmed Pacific bluefin tuna indicated also an increase in the intrinsic growth rates for medium and large-size Pacific fish at farming operations. Unfortunately, there are not sufficient observations to directly estimate a growth model for farmed Atlantic bluefin (Masuma *et al.,* 2009, Vergara-Solana 2019).

Using the results from the *in-situ* tagging experiments from the EU-Croatia and EU-Portugal farms, it was modeled the gain in size in farming operation as a function of the initial size (SFL cm) at tagging and the time in the farm (days_at_farm). Initially, 412 bluefin tuna were tagged in farms. However, due to the stress of tagging and other factors, which induced high mortality rates in medium and large fishes in the experiment carried out in Portuguese farms, only fish that were 60 or more days on the farm were included in the analyses, for a final input of 255 fish with size measurements at both tagging and harvest. A GLM mixed model was used to predict the estimated growth in size of farmed bluefin as a function of the size (bin size 10 SFL cm lower limit) of the fish at tagging event and the time in the farm in days_at_farm. Because of the non-linear pattern of growth of bluefin, for the dependent variable, it was estimated the ratio of size increase of farm-tagged fish compared to the size increase of wild fish during the same period (e.g., days in farm).

$$\frac{Size_{harv}}{\widehat{Size}_{wild}} = \beta_0 + \beta_1 * days\ farm + \beta_{i\ size10} * size\ catch_{10-cm\ bin} + \beta_{i\ month} * month_{\ tag}$$

This transformation linearized the response variable and the fitted model predicted about 73% of the observed variability from the tagging experiments.

The overall fitted model predicted, as expected, larger increases of size at farm for the smallest size (70-100 SFL cm), while for larger fish, > 110 SFL cm, size increases were predicted but at a much lower rate. In summary, *in-situ* tagging experiments show that bluefin tuna grow in size at higher rates compared to similar size wild fish. For small fish (< 100 SFL cm), on average farmed bluefin growth in size 48% cm more per month compared to wild fish, for medium size fish (100 ≤ SFL cm < 180), gain in size was on average 52%, while for larger fish was 30%. However, there is a significant variability associated with these results, particularly for medium and larger fish. Due to the logistics of the tagging experiments, most of the medium and large fish were harvested within 6 months at the farm, while all small fish were harvested at 19 months at the farm. Hence, there is limited information for extrapolating growth patterns to all sizes and at different times at farms. Nonetheless, the results are consistent with the Mode Progression Analysis (MPA) done with multiple observations of the size frequency distribution of caged bluefin tuna, corroborating the increase in growth rates in size for farmed bluefin tuna.

Based on the results of the tagging experiments and the MPA analysis, it was assumed that farming increases mainly the metabolic rates of growth (e.g., *K* parameter of the von Bertalanffy growth model), as food supply and intake are greater and regular, while energy consumption associated with migration or food searching is diminished. Hence, it was estimated a *K*-modification factor that when applied to the wild fish growth model reflected the observed size-increases from the farm tagging experiments. This was achieved by minimizing the observed vs predicted growth in size (cm) by month for each 10-cm size bin at caging by varying the *K*-modifier between 1 and 1.8. A *K*-modifier of 1 indicates the same growth as wild fish, while values greater than 1 indicate higher growth rates of farmed fish. Using this approach, it was estimated a *K*-modification factor of 1.20 (**Figure 9)**. There is, however, a transition period when the fish moves from the wild to the farm when the fish "adjust" to the new growth pattern. Of course, this shift is not instantaneous, and in this analysis, it has been assumed that on average bluefin tuna would adjust to the farming conditions and shift into the farm growth model within a period of 45 days. Under this assumption, if a fish is harvested at a farm in the first month (e.g., 30 days or less) it will have reached 50% of the farm growth model, if the fish is harvested between 30 and 45 days at farm, it will have reached 75% of the farm growth, thereafter fish harvested at farm had attained 100% of the farm growth model. This was accomplished by varying the *K*-modifier value to 1.1 (< 30 days) and 1.15 (30-45 days), respectively. The selection of 45 days as a "transition" period is based on the actual observed mean weights at harvest (**Figure 10**) by size category, where it was noticed the rather faster gain in weight for same size bin fish after 2 months at the farms, compared with the 1st month when more stable or lower gains were observed. Note, however, that for small size group, there are no observations of harvest in 1st month. **Figure 11** shows an overall size distribution by flag/farm in percent of the observed sizes at harvest (blue distributions) and the predicted size at caging (red distributions). To highlight that the Adriatic Sea farms (EU-HRV) primarily catch and farm small-size bluefin, which are kept for longer times to be harvested from 115 cm or larger sizes, after having spent around two years in the farm, and not in the first month(s) at the farm.

Once estimated the "farm growth model" it was modeled the weight at harvest as function of days at farm and the initial size at caging using the ROP harvesting data, which is substantially larger (~250 thousand observations), covers a wider size range and also larger time intervals in farms than the harvesting data from GBYP growth in farms studies. This database provides information on all farms operating in the Mediterranean and East Atlantic from 2015 to 2022. Briefly, the size at catch was estimated using the inverse of the farm growth model and discounting the days at farm, assuming that until the time of the catch/caging the fish followed the wild growth model. Then, weight at harvest was modeled as a function of the time spent at the farm (month/quarter at farm), the initial size at caging (10 cm SFL size bin lower limit), and other factors that may account for the differences among farms that are likely associated with local husbandry, biotic and environmental conditions. The initial GLM model was specified as

$$Wgt\ Harvest_{SizeGrp} = \beta_0 + \beta_1 * time\ farm + \beta_2 * size\ catch + \beta_{3i} * area_i + \cdots + \varepsilon$$

Other factors evaluated in the model included area (west, central, and east Mediterranean, and east Atlantic), flag of farm, (**Table 4**) month at harvest, the month at caging, and year of catch, ε is the error distribution assuming a $N(0, \sigma)$. The objective was to identify major factors that can explain most of the variance in weight at harvest. Initially, days at farm was included as a continuous variable, however previous analyses (Ortiz 2016) indicated that there are seasonal effects on growth, and it is not linear all year round, with higher rates in the spring-summer months, and lower growth rate in the winter. This has been corroborated by the GBYP MPA studies (Alemany *et al.*, 2021). Thus, it was decided for the 1st year-at-farm to use monthly time steps for the model and predictions, and for the 2nd and 3rd years to use quarterly time steps, indicated by the mid-month in each quarter. This was because of the low number of harvested samples and that most of the medium and large fish are harvested in less than a year, while smaller fish are kept for up to 3 years in farming facilities. Factors that were considered statistically significant in the model, other than time-step or size at catch (10 cm bin size lower limit), were set as random factors in the final model, to account for the variability associated with the factor but still be able to generate a single weight at harvest prediction matrix for the Eastern-Mediterranean bluefin tuna. In the case of small fish, the Croatian farms have clearly a different operation mode, where fish are held for longer times. Therefore, it was decided to include the factor flag/farm in the final model as a random factor, where 2 levels were estimated i) Croatia farm(s), and ii) Malta farms as a representative average of all other farms in the Mediterranean and East Atlantic. This factor only affects the estimated variance for small-size fish at caging (< 100 SFL cm) associated with the predicted weight, e.g., the 95% CI not the mean predicted weight at harvest. A table of AIC, BIC, and the adjusted *r*-Squared was estimated for models adding one factor at a time (**Table 4**).

As requested by the Commission, the updated table of farm growth should provide an estimate of the expected maximum growth of farmed bluefin tuna. This was interpreted for this study as a value with a relatively low probability of exceeding this "expected maximum". Thus, it was decided to use the upper 95% confidence interval (i.e., 2.5% low and 97.5% upper CI) of the predicted observation from the model as the maximum gain where it will be expected that only 2.5 out of 100 observations will be above this value. For comparison, the 97.5% percentile of the actual weight observations for the ROP harvest final input database was calculated to ascertain the predictability of the model.

Results and conclusions

Between 2015 – 2022, bluefin tunas have been kept in farms from 1 to 4,303 days (11+ years) but with a median of 237 days (**Table 2**, **Figure 15**), most of the fish are held for less than one year and almost all are harvested before the end of 2nd year. Only the small fish of the Croatian farms are kept in farms for longer times. For other farms in general, it appears that farms split the fish, holding bluefin into two time periods; one group is harvested at 6-12 months, while a fewer percent are held for at most 24 months. The Spanish farms show a rather distinct pattern, with more continuous harvesting of fish all year around. For the final input data, only fish up to 3 years (1096 days at farm) were included.

Figure 12 shows a scatter plot of observed weight at size for harvested bluefin. In this figure black dots show those observations from the outlier analysis that were excluded from the final input data. In size, harvested fish ranged from 85 to 285 (SFL cm) with a bimodal distribution of size, one peak at 130 SFL cm, and the second at 230 SFL cm (**Figure 13**). Similarly, the weights of harvested bluefin ranged from 16 to 464 RWT kg and showed a bimodal distribution with a first mode at about 65 kg and a second mode at 245 kg. The scatter plot (**Figure 12**) also shows the large variability of weight at size, with a mean coefficient of variance of 18%. At smaller and medium sizes (< 180 SFL cm) the variance of weight at size is much larger. Comparing the weight at harvest vs. the weight of wild fish of similar size (**Figure 8**) shows clearly that farmed bluefin do attain larger weights. **Figure 7** shows the trends of this weight gain (the *y*-axis is a gain weight (kg) in a farm compared to each initial weight at caging) vs days-at-farm, and as expected there is a positive correlation although there is substantial large variability in the data. The smoother trend in **Figure 7** suggests that in 6 months at the farm, the fish roughly increase by 30% in mass compared to wild fish and that in 2 years it will double their weight gain, also compared to wild fish. However, even for fish held for up to a year, it has been observed cases where fish at harvest weighed less than their wild counterparts. **Figure 7** also indicates by the contours of the density distribution of what sizes and at what times observations are available. Clearly, a larger percent of medium and large fish are harvested between 100 and 300 days at farm, and a second group is harvested about 600 days (20 months) at farm corresponding mainly to the small farmed fish, while a smaller percentage of small fish are kept up to 900 days in farms (**Figures 14** and **15**).

The model fits of expected weight at harvest (kg) associated with all factors evaluated are shown in **Table 4** and **Figure 16**. The full model accounts for about 94% of the variability and each factor included was statistically significant in the model, as indicated by the effect Test F-ratio and the AIC/BIC. However, the leverage plots (**Figure 16**) and the LogWorth values indicate that the main explanatory factors are the size at catch and the time at farm. Although the area, month of harvest, year, and month of catch are statistically significant, their influence on the predictions is minor, and for the purpose to produce a table of expected weight at harvest, it was decided to use only size at catch and days at farm, including the farm type as a random factor, that will likely incorporate some of the area, and local biotic and husbandry effects and being able to estimate for each month and average year the expected gain in weight. The model was applied by size categories e.g., small fish (< 100 cm SFL), medium (100 – 180 cm SFL], and large fish (> 180 cm SFL) because of the different non-linear weight-gain overall sizes, but the model in each category was exactly the same in terms of factors and random effects.

Table 5 summarizes the fit of the final GLMMs of weight at harvest as a function of time at farm and size at caging (10 cm bin size lower limit), including flag/farm as a random factor by size category. These models were used to predict weight at harvest for bluefin of size at caging between 70 to 250 SFL cm (ages 1.9 to 16 approximately) and for the corresponding months at farm of 1 to 35 (monthly 1st year, quarterly 2nd and 3rd year). **Table 6** shows the updated expected gain in weight compared to the initial weight at caging of bluefin tuna, values in parenthesis represent the upper 95% CI which should be interpreted as the maximum expected growth value. **Table 7** shows the updated expected percent weight compared to wild fish of the same size. In this table, the values are the mean predicted percent gain weight at harvest, and the values between parenthesis in each cell correspond to the estimated 95% upper confidence interval of the prediction, a value of 100% indicates a similar weight of farmed and wild fish, a value of 200% indicates that farmed fish would attained twice the weight compared to wild fish of the same age.

Overall the diagnostics and fitting results of models were satisfactory for all 3 size groups, each model accounted for 74% of the observed variability for larger fish, 87% for medium fish, and 71% for small fish, respectively (**Table 5**). Residual plots show no biased patterns, with only deviations from the expected pattern at the boundaries of the size ranges in each category, where typically a low number of samples were available (**Figure 17**). Leverage plots clearly confirmed the effects of size at catch and time in farm for each size category, while the least square means and plots of the size at catch factor indicate the positive correlation with predicted weight for all size categories (**Figure 17**). The least-square means and plot for the month at farm (Time_Farm) have also a positive correlation with predicted weight, but they also show the seasonal pattern effects in all size groups, where the gain of weight diminished during some periods of the year; for large fish, a gain of weight is higher during the first four months in the farm, slow between 5 and 8/9 month, and a slight decrease in month 14, more a less same pattern is predicted for the medium size fish, while for the small fish, the decrease of gain in weight is more prominent in months 10-11 at the farm, after an initial fast growth from 2 to 6, followed by a slower gain in weight during month 6-9 at the farm, and then a decrease in month 10 and 11, but it resumed the increase of weight after a year at farm (**Figure 17**). Considering that most of the catch and consecutive caging in farms occurs during the May-July period, the slow weight gain in month 14 for larger and medium fish, and 10-11 for small fish would coincide with the summer period of the following year, this does not seem to match with the expected slow growth during the winter months as initially proposed. It is suggested a further investigation into what may trigger the slow gain in weight in the observed and predicted data. The flag/farm factor (random) shows some variable patterns by size category, reflecting the difference in size often caged by each flag/farm. Most of these differences are not statistically significant and for some groups (e.g., small fish) the number of observations is limited, except for the Adriatic Sea farms, as can be inferred from the estimated std error in the least square means tables.

With the final models for each size category, predictions of mean weight at harvest and corresponding 95% CI were estimated for a matrix of size-at-catch SFL 10 cm bin (lower limit) from 70 to 250 cm, and for a time in farm of 1 month for 1st year (e.g. month 1 to 12) and a quarter for the 2nd and 3rd year at farm (e.g. mid-month of quarter, 14, 17, 20,…, 35) (**Table 6**). It is important to note that the models predicted weight at harvest only for those cells where there were actual observations from the farms, thus some cells are empty particularly for the first months of smaller fish. Again, the data input corresponds to a large fraction of the bluefin tuna farms, and it represents the normal operations over the period 2015-2022. If need it, interpolation can be apply to fill up the matrix table, suggesting using the average of adjacent cells on the same row.

As an overall diagnostic of the fitted results, **Table 8** presents a ratio of the observed vs predicted mean weight at harvest for bluefin tuna as a function of size at catch (rows) and time in farm (columns). In this table, values of 1 or closer to 1 indicate similar observed weight at harvest (ROP database), and the predicted by the models, the light color shade cells indicate values closer to 1, while darker blue colors indicated larger departures. All departures are associated with very low sampling in each particular cell, thus for example for fish between 90 and 120 SFL cm there were almost no harvested observations in the first two months, while a very good match of observed vs predicted values are for fish in the 150, 160, or 180 to 250 cm in the first months. Again, the limited number of observations in months 11 and 12 for almost the whole size range, which coincides with the new year's fishery catch and caging operations, as indicated in **Figure 1**, there is almost no harvesting of fish at this time, because the fishery is providing fresh bluefin tuna to the markets. **Figure 18** shows the overall trend of observed vs predicted weight at harvest for each period, while **Figure 19** shows the same information for each flag/farm. Finally, **Figure 20** shows the predicted weight at harvest as a function of size at catch and time in the farm with the predicted 95% confidence intervals.

As indicated before, the estimated upper 95% confidence intervals of the model's predictions were compared to the observed weights (ROP database) 97.5 percentile to evaluate if the model captures the observed variability associated with weight at harvest. **Figure 21** shows this comparison, indicating that for most of the time at farm the predicted CI match or is above the observed percentile of the row data. As this estimate is being suggested as a proxy for the "maximum expected" growth in the farms requested by the Commission, it is proposed for consistency with model predictions to use the model predicted upper 95% CI, which is provided in **Table 6**. It is important to note that the "maximum expected" growth value is an upper limit of a normal distribution, were the average is the mean predicted value, thus for a given harvest operation, the mean weight of harvest fish assuming that all fish were of similar size at initial caging and were hold for the same time at the farm, is given by the matrix in Table 6 mean value, and that only 2 out of 100 harvested would be expected to be close or surpass the "maximum expected weight". It will be NOT expected that 100% of the fish were close to or around the "maximum expected weight".

The 2009 SCRS estimations of expected weight at harvest were based on five research studies publications (Katavic et al 2009, Gordoa 2010, Deguara et al 2010, Deguara *et al*., 2011, Tzoumas *et al.*, 2010), that reported percent of weight increase by time at farm, and the matrix table was constructed by interpolating these percentages into the growth-at-age model of wild fish. Since then much more information has become available, including the size and weight at harvest, details of the catch and caging operations from the BCD databases (eBCD), tagging research experiments on farms with individual fish, and close monitoring of size frequency in cages using stereoscopic cameras. This new information and results indicate that farming bluefin tuna increases their intrinsic growth rates and as expected from a commercial operation, the weight of farm harvested fish is higher compared to equivalent size/age wild fish. The expected mean gain in weight of a 90 SFL cm fish in one year is about 2.6 times compared to its wild counterpart, and for a 200 SFL cm fish is 1.7 larger. It is noted, however, that the tagging experiments for the larger fish were conducted in a farm in the East Atlantic, where environmental conditions may differ from those in the Mediterranean Sea where most of the BFT farming operations are located. It is recommended that further research on growth rates be done in other areas to confirm these results.

However, there is not yet sufficient data to directly estimate growth in farms, and as indicated from the *in-situ* tagging studies the experiment with individual fish in farms is restricted and presents logistic limitations, including relative high mortality associated with the tagging event and or the potential impact of the fish manipulation on the overall growth rates. On the other hand, recent advances with non-invasive technology has shown promising results that may help to follow up individual fish in the farms without altering their normal growth and the operations of the facility. It is recommended that these new methods be explored to confirm the results presented in this study.

It is important to note that the model predictions are valid for size/month at harvest where there are sufficient observations. The updated matrix (**Tables 6** and **7**) have empty cells for those combinations of size-month where there were no observations of harvesting from the farms. This analysis started with the premise that the BFT-ROP monitoring of roughly 20% of the farming operations is representative of the overall farming activities, is unbiased, and reports random samples of harvested fish, and hence the collection of data is reliable. Otherwise, violations of these premises will invalidate the present results. Evidently, the ROP data shows differences between farms, not only in the size of the fish caged but also in the length of time that fish are kept and the overall husbandry and environmental conditions. Nonetheless, these differences were minor statistically compared with the initial size of the fish caged and the length that the fish is kept on the farm for the prediction of the expected weight at harvest. The exception was the case of farms in the Adriatic Sea, where farms in this region did show differences mainly related to the size of fish caged and the longer times that fish are kept in the farms. The variability of this exception was included in the model taking into account two levels of farms (EU-HRV, and EU-MLT, as an average of all other farms) as a random factor that modified the expected confidence intervals of the predictions.

Lastly, the current analysis provided an approach for the transition of the wild growth model to the farm growth model for bluefin tuna, discounting the initial increment in growth during the first 45 days on the farm, based on the observed ROP weight data. However, further research is recommended to address specifically how the fish adjust during the initial period at the farms, and what impacts have on the overall growth. Nonetheless, it should be pointed out that the transition approach used in this study allows a high degree of predictability of the model for the first months in those size classes where there are sufficient weight data observations (**Table 8**).

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Table 1. Summary of harvest bluefin tuna from monitored farming operations 2015 – 2022 as reported by the ROP-BFT program.

Year	Flag	N fish harvest	N fish measure	Wgt fish harvest kg
2015	EU-HRV	5,871	1,466	411,044
	EU-MLT	36,511	5,875	7,230,418
	EU-SPA	13,481	6,225	3,233,103
	MAR	1,942	543	625,510
	TUN	1,801	259	373,284
	TUR	7,248	1,158	1,252,733
2016	EU-HRV	36,736	7,460	2,484,664
	EU-MLT	59,382	8,402	11,621,822
	EU-SPA	24,487	10,649	6,117,956
	MAR	2,017	195	648,401
	TUN	1,261	141	304,409
	TUR	17,777	2,894	3,089,570
2017	EU-HRV	34,552	5,752	2,308,748
	EU-MLT	56,551	8,597	11,057,476
	EU-POR	420	418	76,600
	EU-SPA	27,529	12,550	6,857,071
	MAR	5,047	754	1,573,486
	TUR	24,342	4,869	3,844,500
2018	EU-HRV	44,663	4,612	2,860,862
	EU-MLT	59,292	6,732	11,559,431
	EU-SPA	31,388	11,930	7,603,629
	MAR	11,372	1,224	3,548,237
	TUR	41,548	4,695	4,544,165
2019	EU-HRV	41,639	5,794	2,350,466
	EU-MLT	61,049	6,759	12,448,686
	EU-POR	682	703	89,130
	EU-SPA	31,349	12,292	7,370,901
	MAR	12,609	1,892	3,980,915
	TUN	6,490	1,751	1,459,692
	TUR	52,128	5,176	6,555,275
2020	EU-HRV	56,932	11,675	3,214,006
	EU-MLT	74,726	8,674	15,194,964
	EU-POR	1,233	1,229	202,377
	EU-SPA	41,076	18,232	9,464,273
	MAR	20,248	3,656	6,537,053
	TUN	20,624	5,783	3,651,087
	TUR	40,591	4,236	5,549,870
2021	ALB	2,300	292	186,078
	EU-HRV	96,059	13,635	5,289,142
	EU-MLT	50,574	4,293	10,255,804
	EU-POR	1,370	1,067	256,807
	EU-SPA	46,612	29,945	10,402,785
	MAR	14,520	2,450	4,547,960
	TUN	30,032	5,502	4,998,159
	TUR	48,512	5,020	6,756,690
2022	ALB	1,268	150	74,479
	EU-HRV	50,774	5,630	2,660,625
	EU-MLT	12,030	1,309	1,385,426
	EU-SPA	10,090	4,695	2,113,810
	TUN	2,636	245	571,313
	TUR	19,709	2,153	3,555,032
Grand Total		**1,393,080**	**271,638**	**224,349,921**

Table 2. Summary of the number of weight observations from the ROP database input final model by size bin (10 cm SFL, rows) and month at a farm (columns). Darker colors indicate a higher number of fish harvested at that size/month period cell.

Sum of N(\	Time_Farm																			
SizeCatch_	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**17**	**20**	**23**	**26**	**29**	**32**	**35**
30																		0	0	
40															0	0	0	0	0	
50															0	0	0	0	0	0
60														0	0	0	0	0	0	0
70									4				2	167	5668	41	47	0	0	0
80				13	7	24	64	131	75	13		12	16	318	11507	24	133	585	1718	30
90		9	6	26	85	301	389	423	322	43	19	54	75	523	6485	15	25	308	817	46
100		9	17	94	358	1042	1329	1263	917	298	122	95	245	779	4273	33	21	141	183	30
110	5	8	31	141	606	1430	1944	1254	986	528	197	175	556	730	2735	62	34	73	71	21
120	9	4	62	218	700	1146	1763	1217	839	562	198	182	866	831	1583	97	65	45	65	36
130	8	6	94	290	808	1006	1079	812	620	408	176	182	1053	835	982	110	59	58	73	49
140	3	18	124	325	723	848	895	751	581	322	203	211	959	828	735	54	51	60	86	43
150	3	25	160	441	807	984	905	539	549	268	205	315	998	671	595	59	28	81	121	57
160	8	44	226	796	1187	1325	1111	715	822	455	268	379	1125	704	609	72	26	105	153	62
170	9	83	445	1355	2127	2236	1993	1267	1343	766	414	522	1553	1015	585	96	37	162	179	64
180	30	167	660	1951	3252	3683	2986	1804	1981	1123	625	676	2028	1344	574	125	39	160	175	87
190	55	245	757	2319	4271	4735	3569	2225	2554	1033	672	670	2002	1505	568	119	65	164	175	115
200	74	287	855	2566	4548	4846	3265	1905	2145	829	491	438	1390	1259	483	89	88	128	167	69
210	88	287	750	2684	3975	3662	2423	1415	1474	464	303	216	772	913	346	65	94	62	125	28
220	112	250	611	2215	2754	2455	1452	795	1005	295	131	82	387	519	222	18	54	41	70	13
230	120	183	462	1273	1621	1239	703	377	453	95	51	19	131	213	110	2	18	21	40	3
240	76	84	237	627	704	460	279	167	168	22	10	7	32	57	28		4		4	
250	16	14	67	161	134	79	36	15	16				1	2						

Table 3. Median annual growth rates (size cm increment per month) for Atlantic bluefin tuna from wild fish (Cort *et al.*, 1991) and mean growth rates estimated from Modal Progression Analyses (MPA) of length distributions obtained with stereoscopic cameras along a 12 months caging period (SCRS/2021/145) and from *in-situ* tagging experiments. Data referring to small specimens in tagging studies correspond to a farming period of 19 months, and those of medium and large individuals to farming period of around 4 months. On the other hand the size distributions were also different among the experiments. Therefore, the growth rates from tagging experiments are not strictly comparable to those from MPA analyses. Estimates are provided by size class groups.

Fish size class (SFL cm)	*Wild fish (Cort et al., 1991)*	*MPA 12-month studies*	*Tagging experiments*
Small (< 100)	1.97	3.05	3.51
Medium (100 - 180)	1.37	2.21	2.18
Large (≥ 180)	0.49	1.83	0.66

Table 4. Summary AIC corrected, BIC, and the *r*-square adjusted fit to each of the GLM models on the weight at harvest as a function of size at caging (10 cm bin size), time at farm (month), the geographical area of the farm (East, West, Central Mediterranean, and East Atlantic), and farm group (Flag2) for each group size category (large, medium, small). Model GLM column indicates the factor added to the previous model. The Flag2 represents two levels the Croatia farms and other farms, see text for further details.

Model GLM	**large**			**medium**			**small**		
	AICc	**BIC**	**Rsquare Adj**	**AICc**	**BIC**	**Rsquare Adj**	**AICc**	**BIC**	**Rsquare Adj**
+ SizeCatch_10	1216603	1216393	0.6347	782692	782776	0.7557	228830	228864	0.2687
+ Time_farm	1183583	1183854	0.7210	732069	732330	0.8662	203837	204020	0.6773
+ Area	1182403	1182704	0.7237	730482	730772	0.8687	201105	201313	0.7049
+ Flag2	1182379	1182690	0.7238	729719	730018	0.8699	201082	201298	0.7059

Table 5. Summary of the final GLMM models fit of weight at harvest of farmed bluefin tuna as a function of the month at farm, size at caging, and flag/farm as a random factor by size category (GrpSize).

Response Wgt GrpSize=large

Whole Model

Effect Summary

Source	LogWorth	PValue
SizeCatch_10	32498.80	0.00000
Time_Farm	6811.732	0.00000

Summary of Fit

RSquare	0.735623
RSquare Adj	0.735566
Root Mean Square Error	30.74669
Mean of Response	270.0776
Observations (or Sum Wgts)	121478

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
Flag	0.2393005	226.22491	121.76723	-12.43446	464.88429	0.0632	19.309
Residual		945.35895	3.8363979	937.88458	952.92344		80.691
Total		1171.5839	121.82751	965.18165	1452.4625		100.000

-2 LogLikelihood = 1177066.7366

Note: Total is the sum of the positive variance components.

Total including negative estimates = 1171.5839

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
SizeCatch_10	7	7	1e+5	42171.02	<.0001*
Time_Farm	19	19	1e+5	1893.302	<.0001*

Response Wgt GrpSize=medium

Whole Model

Effect Summary

Source	LogWorth	PValue
SizeCatch_10	31987.76	0.00000
Time_Farm	10143.26	0.00000

Summary of Fit

RSquare	0.871119
RSquare Adj	0.871079
Root Mean Square Error	18.43802
Mean of Response	120.6052
Observations (or Sum Wgts)	84106

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
Flag	0.2516859	85.563245	46.156525	-4.901881	176.02837	0.0638	20.108
Residual		339.96046	1.6581273	336.73386	343.23389		79.892
Total		425.52371	46.186098	347.74591	532.81392		100.000

-2 LogLikelihood = 728957.10249

Note: Total is the sum of the positive variance components.

Total including negative estimates = 425.52371

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
SizeCatch_10	7	7	84075	57293.23	<.0001 *
Time_Farm	19	19	84073	3300.828	<.0001 *

Whole Model

Effect Summary

Source	LogWorth	PValue
Time_Farm	5493.096	0.00000
SizeCatch_10	3900.263	0.00000

Summary of Fit

RSquare	0.708571
RSquare Adj	0.708381
Root Mean Square Error	6.450003
Mean of Response	56.15976
Observations (or Sum Wgts)	30570

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
Flag	0.9528355	39.640376	23.174952	-5.781695	85.062448	0.0872	48.792
Residual		41.602537	0.3366493	40.950522	42.270324		51.208
Total		81.242913	23.177405	49.785905	155.81724		100.000

-2 LogLikelihood = 200738.74819

Note: Total is the sum of the positive variance components.

Total including negative estimates = 81.242913

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
SizeCatch_10	2	2	30544	12224.87	<.0001 *
Time_Farm	18	18	29863	2227.326	<.0001 *

Table 6. Updated matrix table of the expected mean weight at harvest (kg) of farmed bluefin tuna as a function of size at caging (rows) and time in farms (columns, month at farm). The 1st year estimates are for each month, for the 2nd and 3rd year the estimates are for 3-month period, the value indicated correspond to the mid-month. The values in parenthesis correspond to the estimated upper 95% confidence interval (CI).

				Predicted wgt (kg) at harvest (95% upp CI) by month at farm																			
			Month at farm																				
Grp size	Start age	Size 10 bin	Wgt at cag	1	2	3	4	5	6	7	8	9	10	11	12	14	17	20	23	26	29	32	35
small	1.9	70	7			12 (32)	23 (44)	28 (50)	29 (52)	34 (56)	36 (58)	38 (60)	29 (50)	29 (50)	44 (66)	43 (65)	49 (72)	50 (73)	51 (73)	56 (79)		72 (95)	
small	2.4	80	10			19 (39)	29 (51)	35 (57)	36 (58)	40 (63)	42 (65)	44 (67)	35 (57)	36 (56)	51 (73)	50 (71)	55 (78)	57 (79)	58 (80)	63 (85)	76 (98)	79 (101)	79 (101)
small	2.8	90	14		11 (31)	29 (49)	39 (61)	45 (67)	46 (68)	50 (73)	52 (75)	54 (77)	45 (67)	46 (67)	61 (83)	60 (82)	66 (88)	67 (89)	68 (90)	73 (95)	86 (109)	89 (111)	89 (111)
medium	3.3	100	19		13 (60)	30 (79)	43 (92)	50 (99)	52 (101)	53 (102)	54 (103)	60 (110)	62 (111)	73 (122)	86 (135)	68 (117)	80 (130)	90 (139)	92 (140)	114 (162)	122 (171)		132 (180)
medium	3.8	110	25		24 (71)	41 (90)	54 (104)	61 (110)	63 (112)	64 (113)	65 (114)	71 (121)	73 (122)	84 (133)	97 (146)	79 (128)	91 (141)	101 (150)	103 (151)		133 (182)	140 (189)	143 (191)
medium	4.4	120	32	25 (69)	36 (83)	53 (102)	67 (116)	73 (123)	75 (124)	76 (126)	77 (127)	84 (133)	85 (135)	96 (145)	109 (158)	91 (141)	104 (153)	113 (162)	115 (163)	138 (185)	146 (194)	153 (202)	
medium	5.0	130	40	41 (85)	52 (99)	69 (118)	82 (132)	89 (138)	91 (140)	92 (141)	93 (143)	100 (149)	101 (150)	112 (161)	125 (174)	107 (157)	119 (169)		131 (179)	153 (201)	162 (210)	169 (217)	171 (219)
medium	5.6	140	50	59 (103)	70 (117)	87 (136)	100 (150)	107 (156)	109 (158)	110 (159)	111 (161)	118 (167)	119 (168)	130 (179)	143 (192)	125 (175)	137 (187)	147 (196)	149 (197)	171 (219)		187 (235)	189 (237)
medium	6.2	150	61	81 (124)	92 (139)	109 (158)	122 (172)	129 (178)	131 (180)	132 (181)	133 (182)	139 (189)	141 (190)	152 (201)		147 (197)	159 (209)	169 (218)	171 (219)	193 (241)	201 (250)		211 (259)
medium	6.9	160	74	106 (150)	117 (164)	134 (183)	147 (197)	154 (203)	156 (205)	157 (206)	158 (208)	165 (214)	166 (215)	177 (226)	190 (239)		185 (234)	194 (243)		218 (266)	227 (275)	234 (282)	236 (284)
medium	7.6	170	88	131 (175)	142 (189)	159 (208)		179 (229)	181 (231)	182 (232)	184 (233)	190 (239)	191 (241)	202 (252)	215 (264)	198 (247)	210 (259)	219 (268)	221 (269)	244 (292)	252 (301)	259 (308)	
large	8.4	180	104	118 (198)	142 (224)	175 (257)	196 (277)	205 (286)	207 (289)	206 (288)	206 (288)	216 (297)	216 (298)	238 (319)	239 (320)	225 (306)	239 (321)	249 (331)	267 (346)		274 (354)	279 (359)	299 (378)
large	9.2	190	121	145 (225)	170 (251)	203 (284)	223 (305)	232 (314)	234 (316)	234 (315)	234 (315)	243 (325)	244 (325)	265 (346)	266 (348)	252 (334)		277 (358)	294 (374)	282 (361)		306 (387)	326 (405)
large	10.1	200	141	175 (255)	200 (281)	233 (314)	253 (334)		264 (346)	264 (345)	263 (345)	273 (355)	273 (355)	295 (376)	296 (377)	282 (364)	296 (378)		324 (404)	312 (391)	331 (411)		
large	11.1	210	162	207 (287)	231 (313)	265 (346)	285 (366)	294 (376)		295 (377)	295 (377)	305 (386)	305 (387)	327 (408)	328 (409)	314 (395)	328 (410)	338 (420)		344 (423)	363 (443)	368 (448)	388 (467)
large	12.2	220	186	240 (320)	264 (345)	297 (379)	317 (399)	326 (408)	329 (411)			337 (419)	338 (419)	359 (441)	361 (442)	346 (428)	361 (442)	371 (452)	389 (468)		395 (475)	401 (481)	420 (499)
large	13.4	230	211	272 (352)	296 (377)	330 (411)	350 (431)	359 (440)	361 (443)	360 (442)	360 (442)				393 (474)	379 (460)	393 (475)	403 (485)	421 (500)	409 (488)			453 (532)
large	14.8	240	239	304 (384)		362 (443)	382 (464)	391 (473)	394 (475)	393 (474)	393 (474)	402 (484)	403 (484)	424 (505)				436 (517)	453 (533)	441 (520)	460 (540)	465 (546)	
large	16.3	250	269	330 (409)	355 (434)	388 (468)	408 (488)	417 (497)	420 (500)	419 (499)	419 (499)	428 (508)	429 (509)	450 (530)	451 (531)	437 (517)	451 (531)			467 (545)	486 (565)	491 (570)	511 (589)

Table 7. Matrix table of the expected percent mean weight gain at harvest of farmed bluefin tuna as a function of size at caging (rows) and time in farms (columns, month at farm) compared to wild fish weight. The values in parenthesis correspond to the estimated upper 95% confidence interval (CI). A value of 100% indicates the same weight as wild fish, and a value of 200% indicates double the weight compared to wild fish.

				Predicted percent weight increase at harvest (95% upp CI) by month at farm																			
			Month at farm																				
Grp size	Start age	Size 10 bin	Wgt at cag	1	2	3	4	5	6	7	8	9	10	11	12	14	17	20	23	26	29	32	35
small	1.9	70	7			123.% (321.%)	214.% (415.%)	250.% (443.%)	241.% (427.%)	261.% (436.%)	263.% (428.%)	262.% (418.%)	188.% (330.%)	182.% (311.%)	261.% (390.%)	230.% (346.%)	226.% (331.%)	203.% (294.%)	183.% (261.%)	179.% (250.%)		186.% (244.%)	
small	2.4	80	10			134.% (276.%)	198.% (344.%)	224.% (365.%)	217.% (353.%)	231.% (361.%)	232.% (356.%)	231.% (349.%)	175.% (283.%)	170.% (268.%)	230.% (329.%)	206.% (297.%)	203.% (286.%)	184.% (257.%)	168.% (232.%)	164.% (223.%)	180.% (234.%)	170.% (219.%)	156.% (200.%)
small	2.8	90	14		63.% (174.%)	153.% (259.%)	200.% (308.%)	217.% (324.%)	211.% (315.%)	221.% (320.%)	221.% (316.%)	220.% (311.%)	175.% (259.%)	171.% (247.%)	217.% (295.%)	197.% (269.%)	193.% (260.%)	177.% (237.%)	163.% (216.%)	159.% (208.%)	172.% (218.%)	164.% (205.%)	151.% (189.%)
medium	3.3	100	19		53.% (252.%)	121.% (319.%)	168.% (359.%)	186.% (370.%)	185.% (362.%)	182.% (351.%)	179.% (342.%)	192.% (349.%)	190.% (341.%)	216.% (361.%)	244.% (385.%)	181.% (313.%)	194.% (313.%)	197.% (305.%)	184.% (281.%)	211.% (299.%)	209.% (292.%)		194.% (265.%)
medium	3.8	110	25		78.% (232.%)	130.% (284.%)	165.% (316.%)	179.% (324.%)	178.% (318.%)	175.% (310.%)	172.% (303.%)	183.% (309.%)	181.% (303.%)	201.% (319.%)	224.% (339.%)	173.% (281.%)	182.% (281.%)	185.% (276.%)	174.% (256.%)		195.% (266.%)	192.% (258.%)	183.% (245.%)
medium	4.4	120	32	67.% (185.%)	94.% (216.%)	134.% (257.%)	162.% (282.%)	173.% (289.%)	172.% (285.%)	169.% (278.%)	167.% (273.%)	175.% (278.%)	173.% (273.%)	190.% (287.%)	209.% (303.%)	166.% (255.%)	174.% (256.%)	175.% (252.%)	166.% (236.%)	186.% (251.%)	184.% (246.%)	182.% (240.%)	
medium	5.0	130	40	88.% (183.%)	109.% (207.%)	141.% (241.%)	163.% (261.%)	171.% (266.%)	170.% (263.%)	168.% (258.%)	165.% (253.%)	172.% (257.%)	170.% (253.%)	184.% (265.%)	200.% (278.%)	163.% (239.%)	170.% (239.%)		163.% (223.%)	179.% (235.%)	178.% (232.%)	176.% (226.%)	169.% (216.%)
medium	5.6	140	50	103.% (181.%)	120.% (201.%)	146.% (228.%)	164.% (244.%)	170.% (249.%)	169.% (246.%)	167.% (241.%)	165.% (238.%)	170.% (241.%)	168.% (238.%)	180.% (247.%)	193.% (259.%)	162.% (226.%)	167.% (227.%)	168.% (224.%)	160.% (212.%)	175.% (223.%)		171.% (216.%)	166.% (207.%)
medium	6.2	150	61	117.% (181.%)	131.% (198.%)	152.% (220.%)	166.% (233.%)	172.% (237.%)	170.% (235.%)	168.% (231.%)	166.% (228.%)	170.% (231.%)	169.% (228.%)	178.% (236.%)		163.% (217.%)	166.% (218.%)	167.% (216.%)	160.% (206.%)	173.% (215.%)	172.% (213.%)		164.% (202.%)
medium	6.9	160	74	129.% (182.%)	139.% (196.%)	157.% (214.%)	169.% (226.%)	173.% (229.%)	172.% (226.%)	170.% (223.%)	168.% (220.%)	171.% (223.%)	170.% (220.%)	178.% (227.%)	187.% (236.%)		167.% (212.%)	167.% (210.%)		172.% (210.%)	171.% (208.%)	169.% (204.%)	164.% (198.%)
medium	7.6	170	88	135.% (180.%)	144.% (191.%)	158.% (207.%)		172.% (219.%)	171.% (217.%)	169.% (215.%)	167.% (212.%)	170.% (214.%)	169.% (212.%)	176.% (218.%)	184.% (226.%)	164.% (204.%)	166.% (205.%)	166.% (203.%)	161.% (196.%)	170.% (204.%)	169.% (202.%)	167.% (199.%)	
large	8.4	180	104	103.% (174.%)	123.% (193.%)	149.% (219.%)	164.% (232.%)	169.% (236.%)	168.% (235.%)	165.% (230.%)	163.% (227.%)	168.% (231.%)	166.% (228.%)	179.% (241.%)	178.% (238.%)	163.% (222.%)	166.% (223.%)	167.% (221.%)	172.% (223.%)		164.% (212.%)	162.% (209.%)	168.% (212.%)
large	9.2	190	121	110.% (170.%)	126.% (187.%)	149.% (209.%)	161.% (220.%)	166.% (224.%)	165.% (223.%)	163.% (219.%)	160.% (216.%)	165.% (220.%)	163.% (217.%)	175.% (229.%)	174.% (227.%)	160.% (212.%)		164.% (213.%)	169.% (215.%)	157.% (201.%)		160.% (202.%)	166.% (206.%)
large	10.1	200	141	114.% (167.%)	129.% (181.%)	148.% (200.%)	159.% (211.%)		163.% (213.%)	160.% (210.%)	158.% (208.%)	162.% (211.%)	161.% (209.%)	172.% (219.%)	170.% (217.%)	159.% (205.%)	162.% (206.%)		167.% (208.%)	156.% (195.%)	161.% (200.%)		
large	11.1	210	162	118.% (164.%)	131.% (176.%)	148.% (193.%)	157.% (202.%)	161.% (205.%)		158.% (202.%)	157.% (200.%)	160.% (203.%)	159.% (201.%)	168.% (210.%)	167.% (209.%)	157.% (198.%)	160.% (199.%)	160.% (199.%)		155.% (191.%)	160.% (195.%)	158.% (193.%)	163.% (196.%)
large	12.2	220	186	120.% (160.%)	131.% (171.%)	146.% (186.%)	154.% (194.%)	157.% (197.%)	157.% (196.%)			157.% (195.%)	156.% (194.%)	165.% (202.%)	164.% (201.%)	155.% (191.%)	157.% (193.%)	158.% (193.%)	162.% (195.%)		158.% (190.%)	157.% (188.%)	161.% (192.%)
large	13.4	230	211	120.% (155.%)	130.% (165.%)	143.% (179.%)	151.% (186.%)	153.% (188.%)	153.% (188.%)	152.% (186.%)	151.% (185.%)				160.% (193.%)	152.% (184.%)	154.% (186.%)	155.% (186.%)	159.% (189.%)	151.% (181.%)			159.% (187.%)
large	14.8	240	239	119.% (150.%)		140.% (171.%)	147.% (178.%)	149.% (180.%)	149.% (180.%)	148.% (179.%)	147.% (177.%)	150.% (180.%)	149.% (179.%)	156.% (186.%)				152.% (180.%)	155.% (183.%)	149.% (175.%)	153.% (179.%)	152.% (178.%)	
large	16.3	250	269	115.% (143.%)	123.% (151.%)	134.% (161.%)	140.% (168.%)	142.% (170.%)	142.% (170.%)	141.% (169.%)	141.% (168.%)	143.% (170.%)	143.% (169.%)	149.% (175.%)	149.% (175.%)	142.% (169.%)	145.% (171.%)			144.% (168.%)	148.% (172.%)	148.% (171.%)	152.% (175.%)

Table 8. The ratio of observed over predicted mean weight at harvest, dark colors indicate a higher departure from observed values.

	Time_Farm																			
SizeCatch_10	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**14**	**17**	**20**	**23**	**26**	**29**	**32**	**35**
70									0.851556				1.274163	0.898542	1.057023	1.05895	0.939734			
80				1.386042	1.150054	0.961149	1.110852	0.973508	1.005853	1.406463		1.097467	1.225517	0.947978	1.118007	1.150251	0.912437	1.025749	1.056115	1.112235
90		1.818664	1.318659	1.012778	0.910023	0.922464	0.947853	0.909538	0.969582	0.982017	1.231854	1.068169	0.960844	0.929786	1.098897	1.015747	1.147636	1.048979	1.067247	1.057096
100		2.355865	1.453966	1.051198	1.039408	0.971219	0.992365	1.015465	0.996356	0.883091	0.952273	0.809141	0.941714	0.922639	0.920286	0.985611	0.861256	0.878245	0.852714	0.788852
110	2.35667	1.676291	1.284285	1.05353	1.013018	0.970204	0.979845	0.990684	0.973042	0.883024	0.952262	0.832817	0.948433	0.929715	0.945939	0.934546	0.821118	0.992381	0.872401	0.920229
120	1.898598	1.122897	1.213406	1.058263	1.010302	0.963737	1.018042	0.963497	0.974185	0.897013	0.914242	0.90986	0.9404	0.929723	0.995873	0.896161	0.937491	1.014471	0.96548	0.931341
130	1.171404	1.118591	1.135248	1.053585	0.989987	1.030291	0.983049	0.962862	1.004596	1.035525	0.851543	0.833264	0.938173	0.936505	0.994627	0.924014	0.976289	0.990571	0.978293	0.971738
140	1.121555	1.135295	1.054918	1.025614	0.970845	0.969255	1.020883	0.989798	1.010773	0.958897	0.882576	0.890567	0.941238	0.970576	0.999762	1.021883	1.045009	1.041319	1.016389	1.053949
150	0.985491	1.107535	1.14805	1.065674	1.038386	0.94324	0.981495	0.992396	0.977106	1.000392	0.888443	0.868483	0.942864	0.966532	0.98035	1.129349	1.016402	1.031055	1.014337	1.03336
160	0.988681	0.954123	1.093816	0.997053	0.999953	1.000317	0.962838	0.961945	0.960167	0.980695	0.943318	0.886599	0.926496	0.9755	0.991544	1.145329	0.985371	0.998986	1.037497	1.038017
170	0.861244	0.957879	1.068186	0.995019	0.939242	0.976312	0.968689	0.950356	0.966124	0.974338	0.956756	0.998762	0.983822	0.976279	0.990536	1.075368	0.982996	0.997907	1.022501	1.023529
180	1.226722	1.085463	1.101613	1.016211	0.956182	0.94648	0.992173	0.950777	0.96936	0.976883	0.901434	0.868913	0.984301	0.968016	0.967114	1.038795	0.910054	1.004179	1.016206	1.020571
190	1.162039	1.129627	1.133088	1.015963	0.935405	0.986876	0.995547	0.966005	0.973798	0.968418	0.912803	1.010425	0.941601	0.971584	0.974313	1.074007	1.050362	0.993362	1.001598	0.994584
200	1.057603	1.049857	1.10233	1.06847	0.96441	0.973976	0.983174	0.963981	0.974116	0.93352	0.924687	0.948161	0.967682	0.979444	0.948526	1.022323	1.029466	0.989114	0.95687	0.989107
210	1.104345	1.026581	1.061518	1.002361	0.952977	0.965662	0.973887	0.970396	0.970051	0.984346	0.90218	0.944383	0.960759	0.973944	0.96005	0.99322	0.976935	0.982639	0.967365	1.025642
220	1.025219	0.972016	0.986129	0.985117	0.954187	0.948599	0.96569	0.980326	0.983595	0.922264	0.934237	0.911063	0.951844	0.982682	0.989725	1.018066	0.949113	0.975483	0.954009	0.937018
230	1.006185	0.974316	0.990911	0.972244	0.997481	0.971633	0.94875	0.998966	1.011477	0.940968	0.998621	0.99567	0.95596	0.955469	0.975114	0.914075	0.931662	0.973538	0.913615	0.937081
240	1.023697	0.992812	0.96216	0.988138	0.963525	0.998818	0.996626	0.989283	1.007761	0.969872	0.976685	0.9479	0.944677	0.965563	0.967107		0.903877		0.922229	
250	1.036624	1.039331	1.024435	0.990012	1.010439	0.969864	1.033034	1.00326	1.001343				0.972	0.908155						

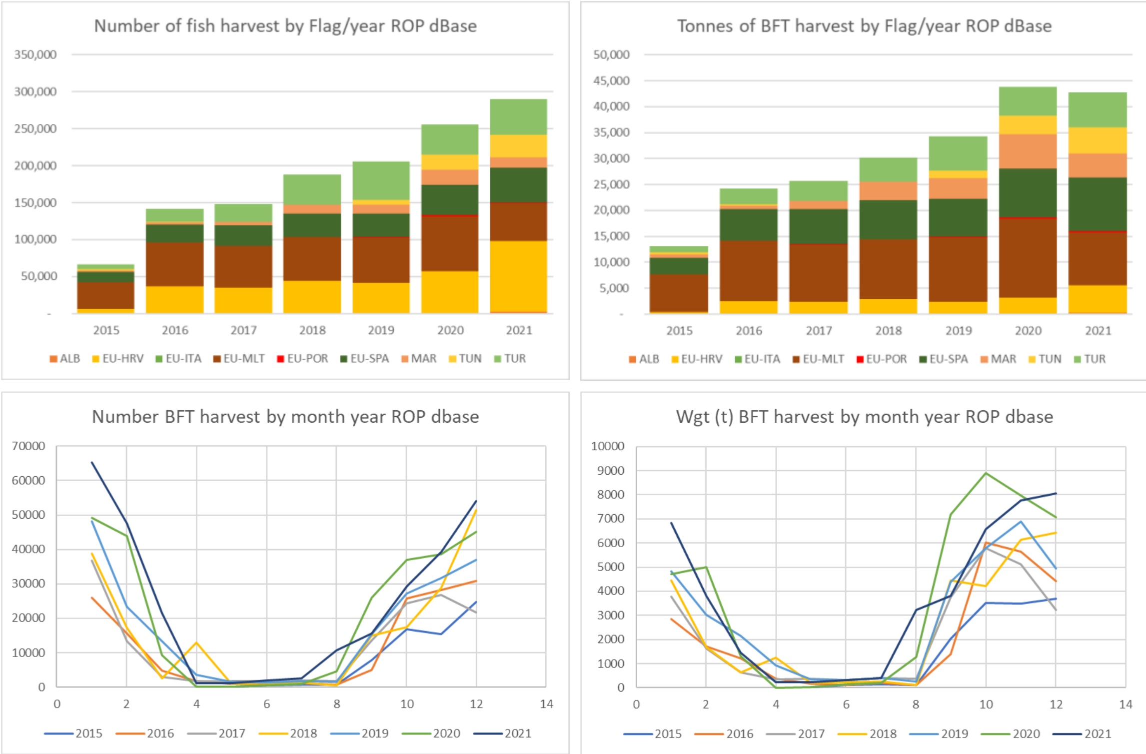


Figure 1. Summary of ROP monitored harvest operations for bluefin tuna 2015 – 2021 by CPC.

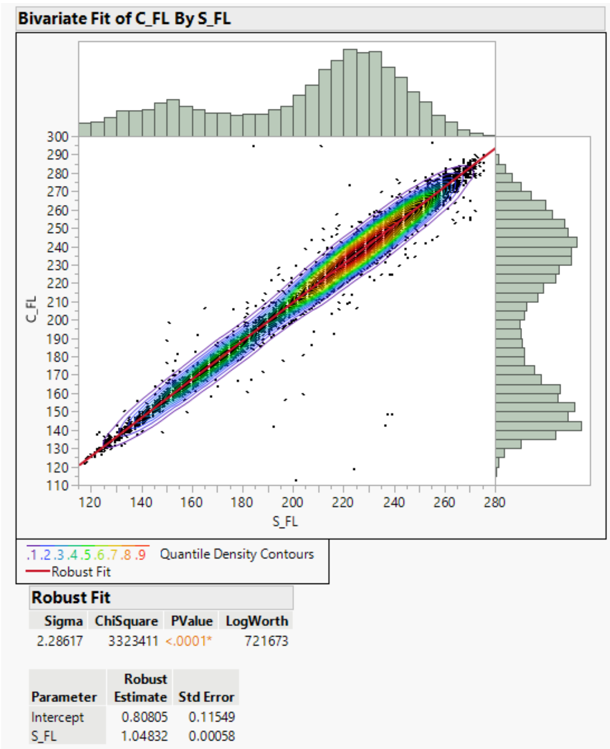


Figure 2. Scatter plot of straight fork length (cm) vs. curved fork length (cm) measures of harvested bluefin tuna 2015-2022 and estimated conversion factor.

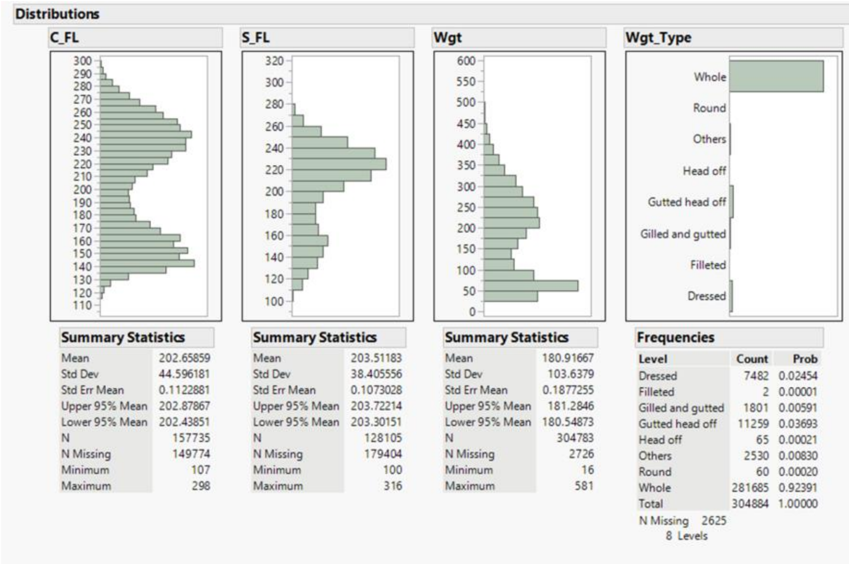


Figure 3. Harvested BFT size by type, weight and weight type measurement distributions from the ROP database 2015-2022.

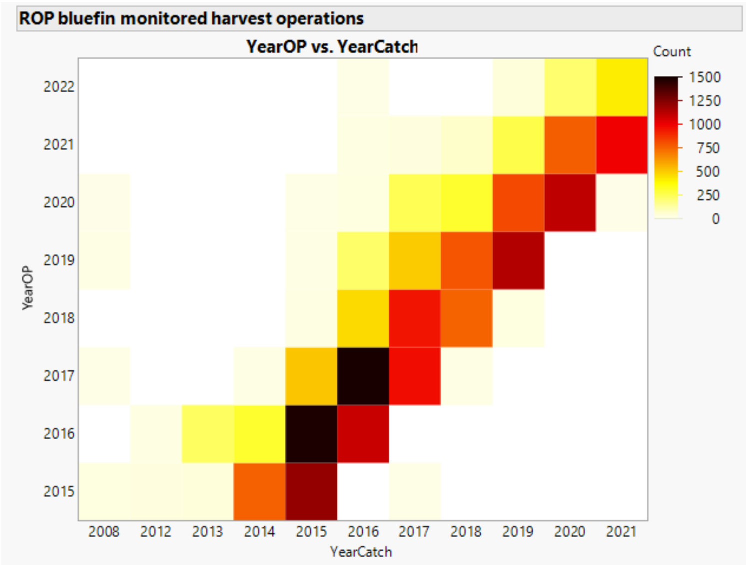


Figure 4. Heatmap of the year of catch and the year of the harvest operation (*y-axis*) from the ROP BFT monitored harvesting operations.

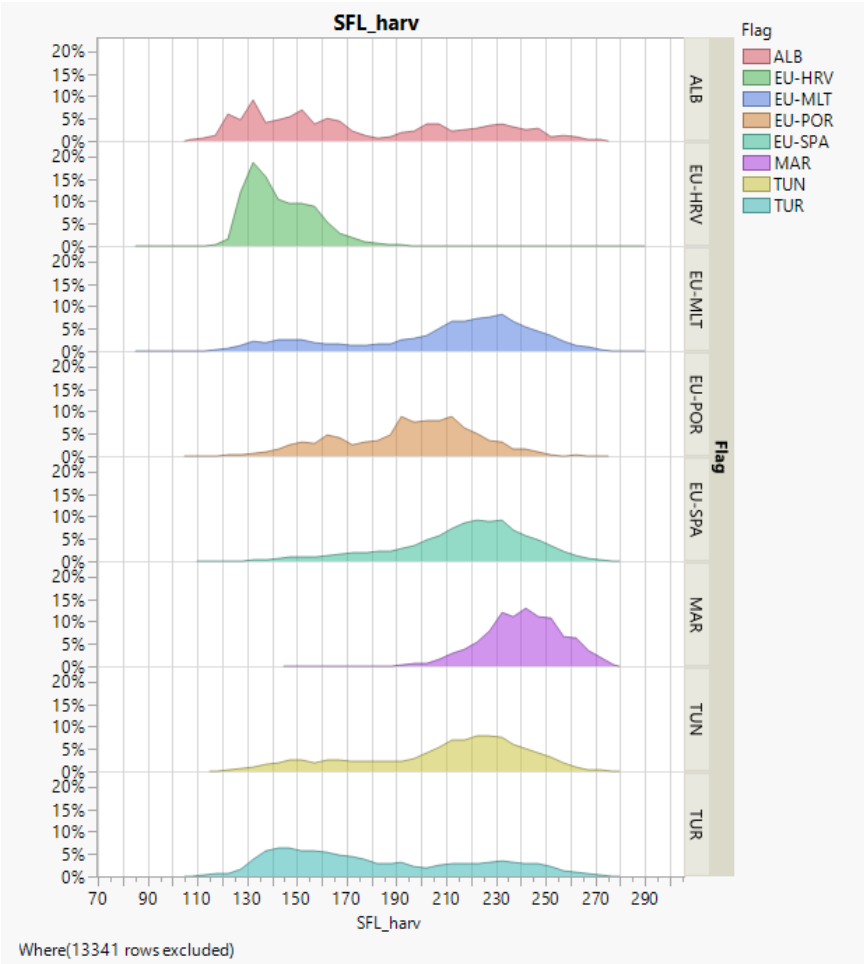
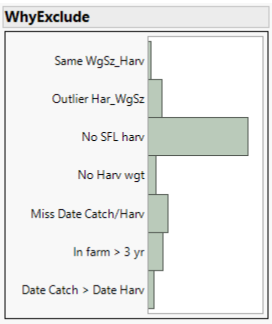


Figure 5. Distribution of size at harvest (SFL) by Flag of farms for the 2015 – 2022 period.



Frequencies

Level	Count	Prob
Date Catch > Date Harv	2235	0.03702
In farm > 3 yr	5291	0.08763
Miss Date Catch/Harv	7418	0.12286
No Harv wgt	2725	0.04513
No SFL harv	36248	0.60037
Outlier Har_WgSz	5204	0.08619
Same WgSz_Harv	1255	0.02079
Total	60376	1.00000

N Missing 249464
7 Levels

Figure 6. Preliminary quality control of ROP harvest database. The histogram shows the reasons and number of records excluded from further analysis. Input data for modeling analysis included 249,464 observations.

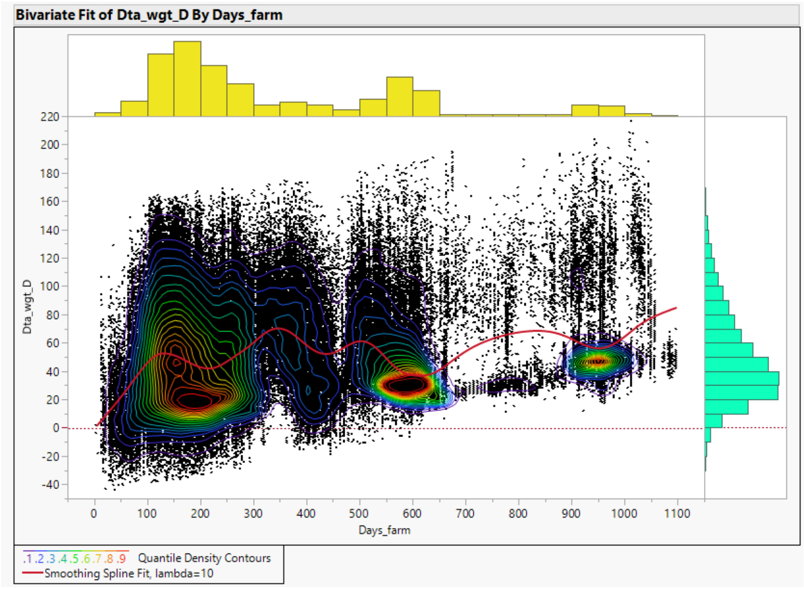


Figure 7. Scatter plot of weight gain (kg) vs. days-at-farm for harvested bluefin tuna (dots) 2015-2022 and marginal distributions. The red solid line shows the local smoother function to visualize trends, and the contours correspond to the 10th quantiles density to illustrate the distribution of samples.

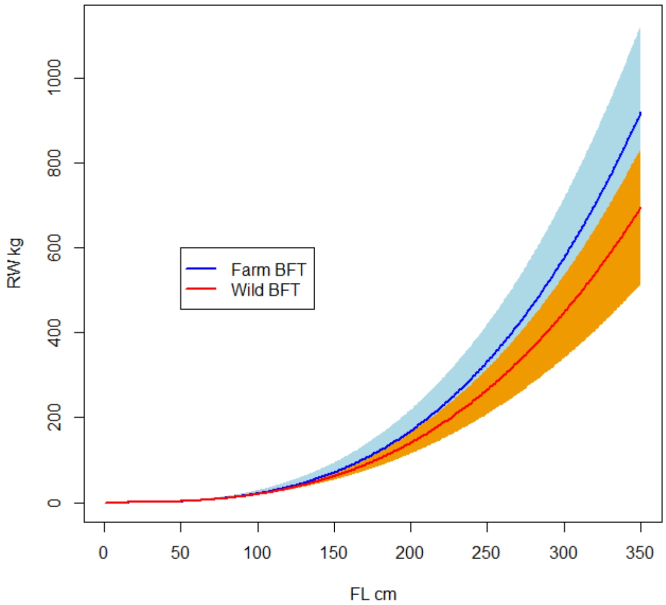


Figure 8. Estimated median weight at size (solid lines) and expected confidence bounds (95% percentiles, shade areas) for farmed vs wild bluefin tuna as estimated by quantile regression.

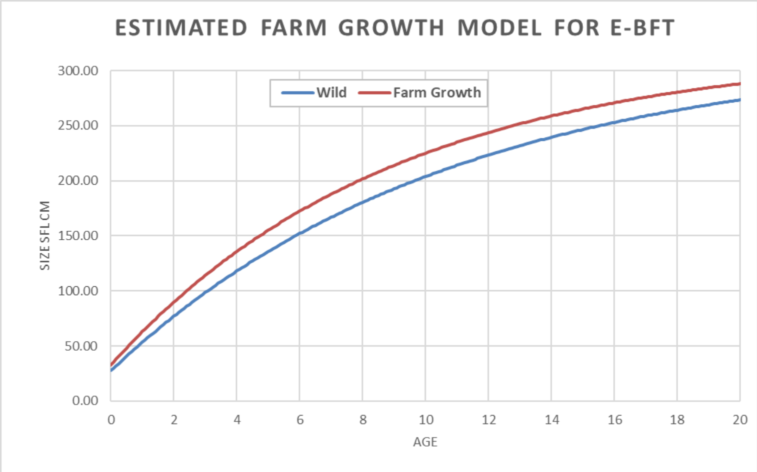


Figure 9. Estimated intrinsic growth model for farmed BFT based on the modification of the wild von Bertalanffy growth model (Cort *et al.*, 1991) by increasing the *K* such the average increase in length match the observed size increase from the *in-situ* tagging experiments by 10 SFL cm size bin intervals.

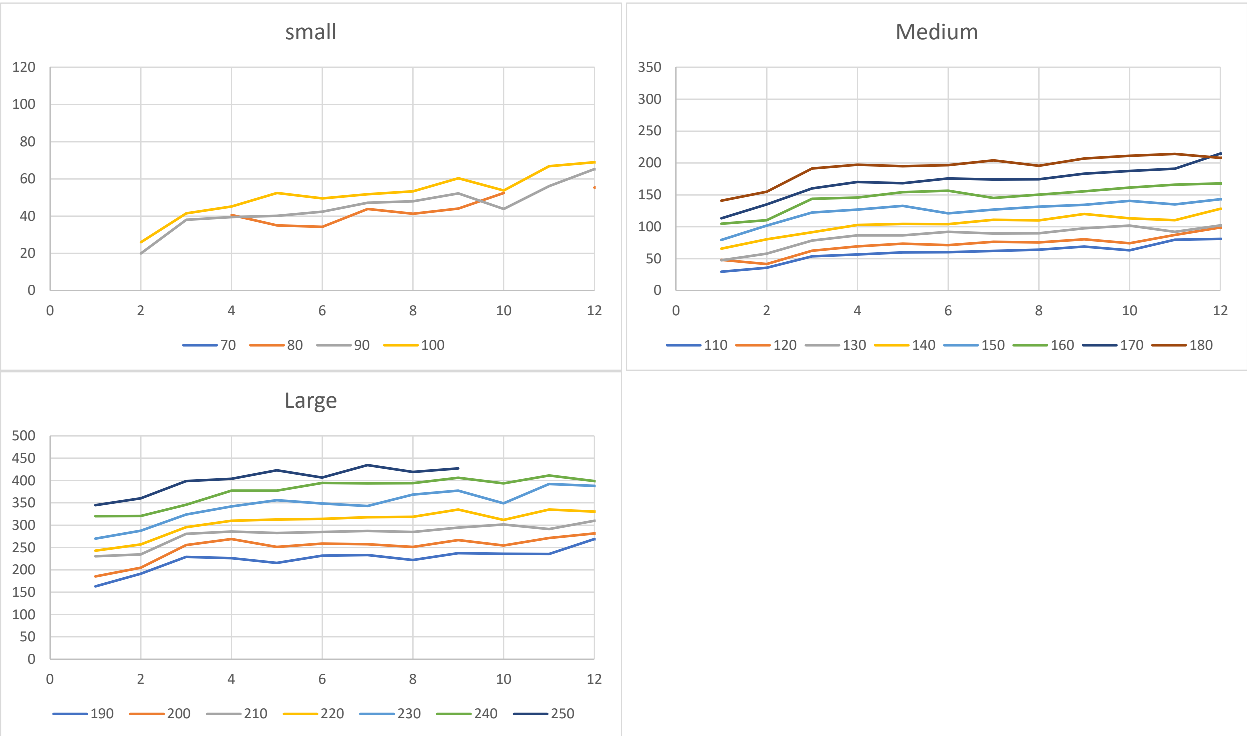


Figure 10. Observed mean weight (kg) of bluefin tuna harvest by size category (small, medium, large) and size bin (lines within each plot) by month at farm up to 12 months. Data represents the final input from the ROP harvest database.

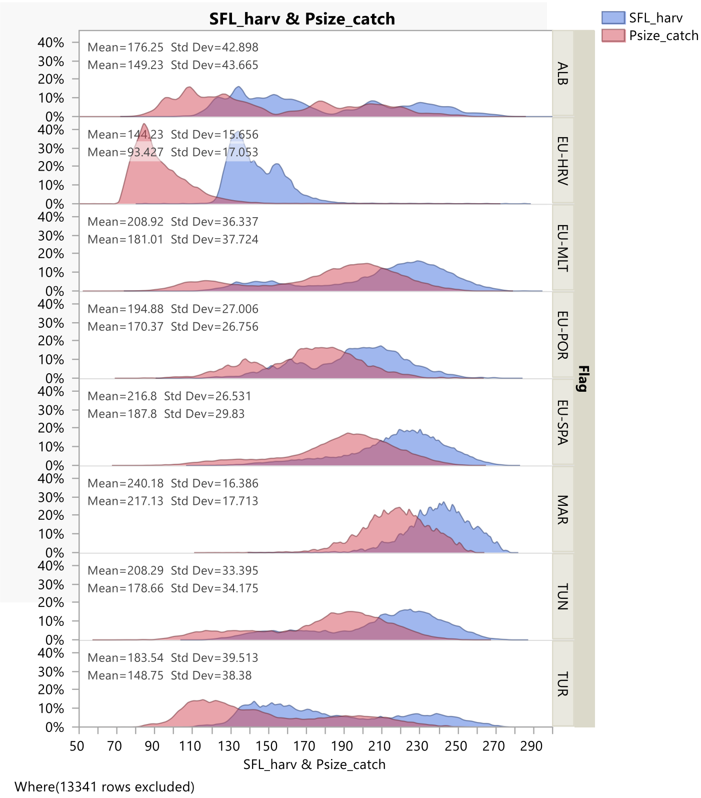


Figure 11. Estimated size-at-catch (red) and measure size-at-harvest distributions of farmed BFT harvested by the flag of farm 2015 – 2022. Estimate size-at-catch assumes a higher growth rate than wild fish.

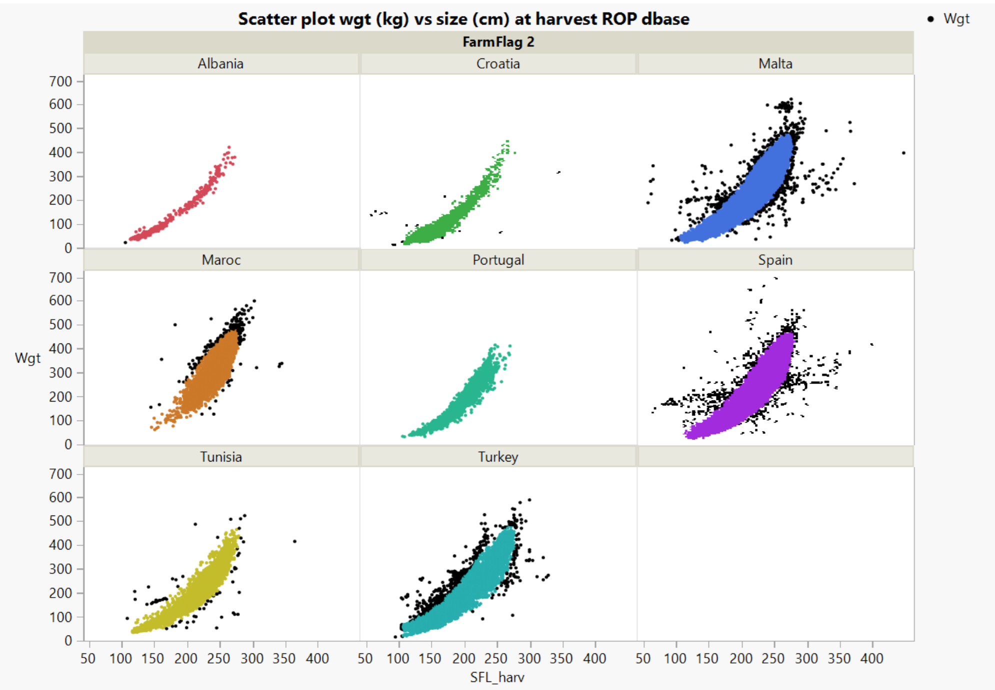
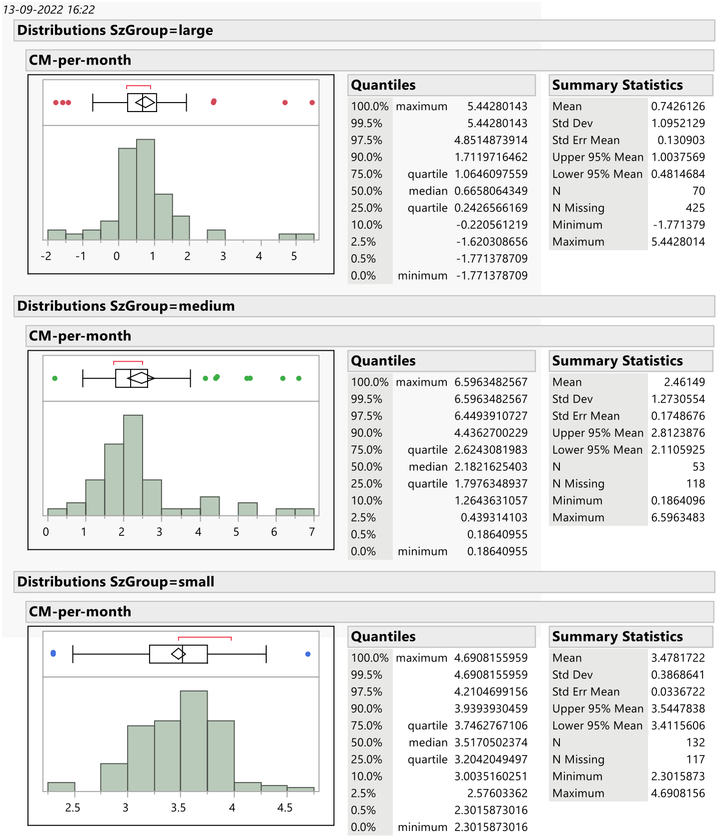


Figure 12. Scatter plot of observed weight (RWT kg) and size (SFL cm) of harvested bluefin tuna 2015 – 2022 by Flag/farm. Dark dots corresponding to values above the 97.5% quantile were considered outliers and excluded from further analysis.



Quantiles		
100.0%	maximum	5.44280143
99.5%		5.44280143
97.5%		4.8514873914
90.0%		1.7119716462
75.0%	quartile	1.0646097559
50.0%	median	0.6658064349
25.0%	quartile	0.2426566169
10.0%		-0.220561219
2.5%		-1.620308656
0.5%		-1.771378709
0.0%	minimum	-1.771378709

Summary Statistics	
Mean	0.7426126
Std Dev	1.0952129
Std Err Mean	0.130903
Upper 95% Mean	1.0037569
Lower 95% Mean	0.4814684
N	70
N Missing	425
Minimum	-1.771379
Maximum	5.4428014

Quantiles		
100.0%	maximum	6.5963482567
99.5%		6.5963482567
97.5%		6.4493910727
90.0%		4.4362700229
75.0%	quartile	2.6243081983
50.0%	median	2.1821625403
25.0%	quartile	1.7976348937
10.0%		1.2643631057
2.5%		0.439314103
0.5%		0.18640955
0.0%	minimum	0.18640955

Summary Statistics	
Mean	2.46149
Std Dev	1.2730554
Std Err Mean	0.1748676
Upper 95% Mean	2.8123876
Lower 95% Mean	2.1105925
N	53
N Missing	118
Minimum	0.1864096
Maximum	6.5963483

Quantiles		
100.0%	maximum	4.6908155959
99.5%		4.6908155959
97.5%		4.2104699156
90.0%		3.9393930459
75.0%	quartile	3.7462767106
50.0%	median	3.5170502374
25.0%	quartile	3.2042049497
10.0%		3.0035160251
2.5%		2.57603362
0.5%		2.3015873016
0.0%	minimum	2.3015873016

Summary Statistics	
Mean	3.4781722
Std Dev	0.3868641
Std Err Mean	0.0336722
Upper 95% Mean	3.5447838
Lower 95% Mean	3.4115606
N	132
N Missing	117
Minimum	2.3015873
Maximum	4.6908156

Figure 13. Distribution of the observed size increase per month of tagged BFT in farm experiments by size groups.

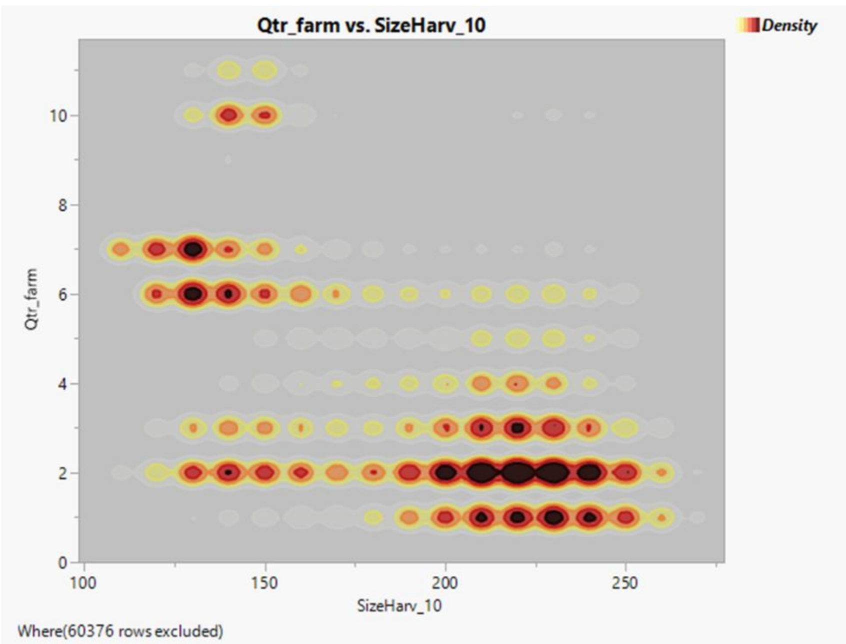


Figure 14. Density plot of the harvested BFT by size 10 bin and quarter at farm (*y*-axis), shade colors are proportional to the number of fish harvested in each cell, with darker colors indicating higher number of observations.

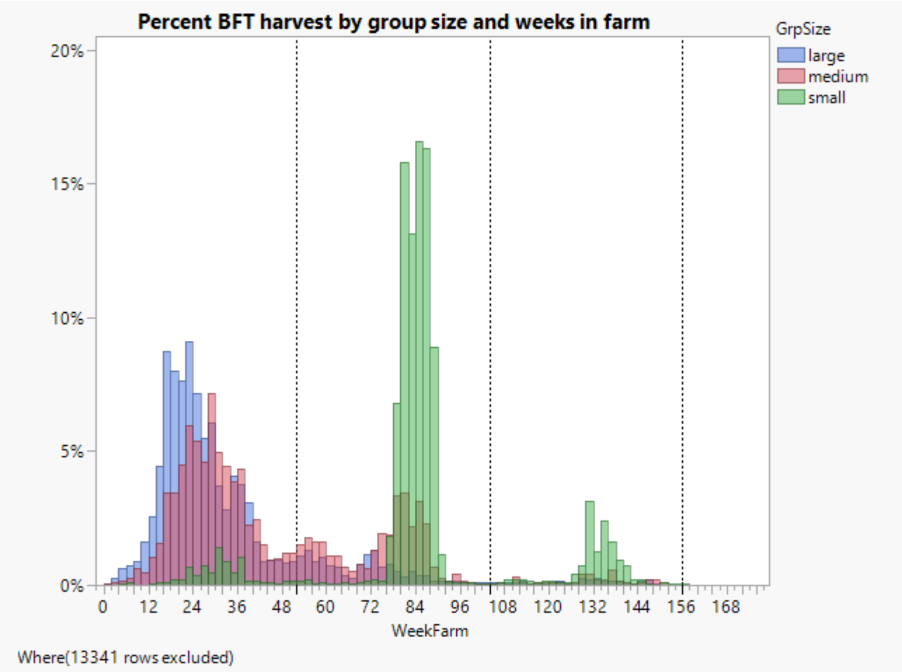


Figure 15. Percent distribution of harvested fish by weeks at farm and by size category. Data from the ROP database 2015 – 2022.

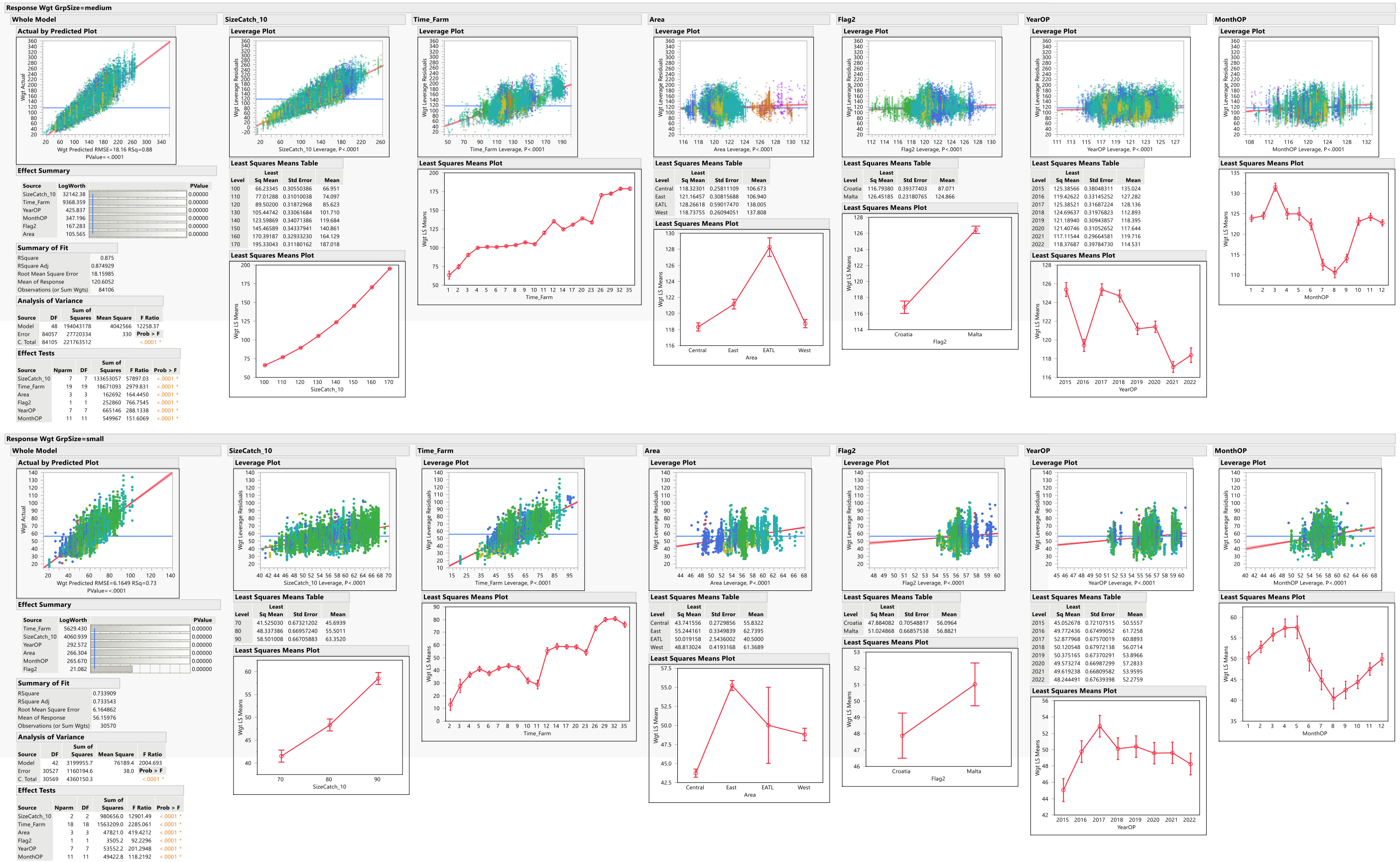
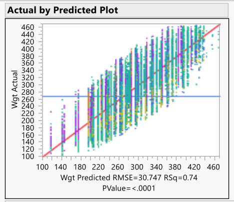


Figure 16. Summary of the GLM models fits to the observed BFT weight at harvest as a function of all evaluated factors for the medium (top) and small (bottom) size groups. Each panel shows the actual vs predicted weight at harvest values, the effect summary, the summary of fit, the analysis of variance table and effect test. For each factor evaluated is shown the leverage plot, and the least square means table and plots

Response Wgt GrpSize=large

Whole Model

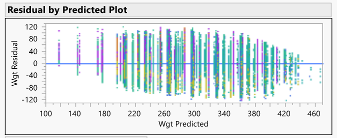
Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue
SizeCatch_10	32498.80	0.00000
Time_Farm	6811.732	0.00000

Residual by Predicted Plot



Summary of Fit

RSquare	0.735623
RSquare Adj	0.735566
Root Mean Square Error	30.74669
Mean of Response	270.0776
Observations (or Sum Wgts)	121478

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
Flag	0.2393005	226.22491	121.76723	-12.43446	464.88429	0.0632	19.309
Residual		945.35895	3.8363979	937.88458	952.92344		80.691
Total		1171.5839	121.82751	965.18165	1452.4625		100.000

-2 LogLikelihood = 1177066.7366

Note: Total is the sum of the positive variance components.

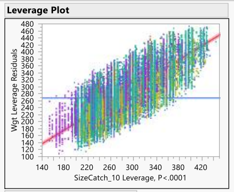
Total including negative estimates = 1171.5839

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
SizeCatch_10	7	7	1e+5	42171.02	<.0001 *
Time_Farm	19	19	1e+5	1893.302	<.0001 *

SizeCatch_10

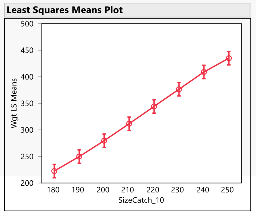
Leverage Plot



Least Squares Means Table

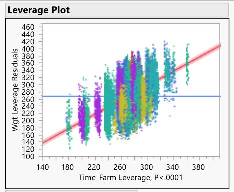
Level	Least Sq Mean	Std Error
180	222.49948	5.3484842
190	249.81201	5.3481564
200	279.65703	5.3484850
210	311.56902	5.3496286
220	344.20857	5.3519559
230	376.55017	5.3578392
240	409.07159	5.3754059
250	435.03465	5.5076623

Least Squares Means Plot



Time_Farm

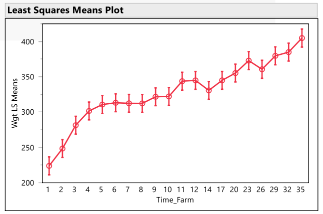
Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
1	223.97534	5.5035113
2	248.41794	5.4035015
3	281.51672	5.3650240
4	301.64635	5.3521628
5	310.74407	5.3496050
6	313.22797	5.3492120
7	312.47680	5.3514417
8	312.34473	5.3552703
9	321.71850	5.3533578
10	322.24118	5.3686426
11	343.77951	5.3855861
12	344.93040	5.3891265
14	330.75844	5.3598597
17	344.98023	5.3613297
20	355.28330	5.3863219
23	372.91738	5.5588341
26	360.63375	5.5984125
29	379.66197	5.5058182
32	384.92720	5.4720722
35	404.82457	5.6270163

Least Squares Means Plot

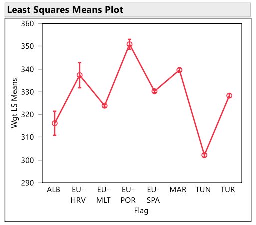


Flag

Least Squares Means Table

Level	Least Sq Mean	Std Error
ALB	316.16271	2.6986488
EU-HRV	337.27800	2.8216425
EU-MLT	323.88369	0.3430616
EU-POR	350.85183	1.1207008
EU-SPA	330.22446	0.3061023
MAR	339.54553	0.4505772
TUN	302.16175	0.4575120
TUR	328.29456	0.4373125

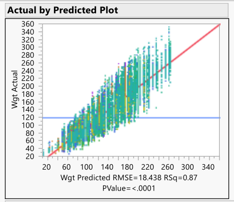
Least Squares Means Plot



Response Wgt GrpSize=medium

Whole Model

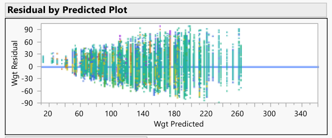
Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue
SizeCatch_10	31987.76	0.00000
Time_Farm	10143.26	0.00000

Residual by Predicted Plot



Summary of Fit

RSquare	0.871119
RSquare Adj	0.871079
Root Mean Square Error	18.43802
Mean of Response	120.6052
Observations (or Sum Wgts)	84106

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|
Intercept	125.65945	3.282719	6.976	38.28	<.0001 *
SizeCatch_10[100]	-55.46339	0.185304	84073	-299.3	<.0001 *
SizeCatch_10[110]	-44.42752	0.16761	84077	-265.1	<.0001 *
SizeCatch_10[120]	-32.1074	0.170698	84073	-188.1	<.0001 *
SizeCatch_10[130]	-16.26101	0.184132	84073	-88.31	<.0001 *
SizeCatch_10[140]	1.7848624	0.193553	84073	9.22	<.0001 *
SizeCatch_10[150]	23.662252	0.195015	84075	121.34	<.0001 *
SizeCatch_10[160]	48.794114	0.176102	84077	277.08	<.0001 *
Time_Farm[1]	-68.82036	2.621657	84079	-26.25	<.0001 *
Time_Farm[2]	-57.60338	1.263325	84076	-45.60	<.0001 *
Time_Farm[3]	-40.29385	0.562907	84070	-71.58	<.0001 *
Time_Farm[4]	-26.9738	0.369927	83926	-72.92	<.0001 *
Time_Farm[5]	-20.37126	0.286237	84079	-71.17	<.0001 *
Time_Farm[6]	-18.43807	0.26737	84072	-68.96	<.0001 *
Time_Farm[7]	-17.40633	0.255064	84079	-68.24	<.0001 *
Time_Farm[8]	-16.15429	0.277089	84077	-58.30	<.0001 *
Time_Farm[9]	-9.875275	0.289077	84079	-34.16	<.0001 *
Time_Farm[10]	-8.270842	0.348177	84077	-23.75	<.0001 *
Time_Farm[11]	2.7767594	0.456112	84076	6.09	<.0001 *
Time_Farm[12]	15.401726	0.434125	84076	35.48	<.0001 *
Time_Farm[14]	-2.085584	0.286783	84078	-7.27	<.0001 *
Time_Farm[17]	10.053023	0.29077	84079	34.57	<.0001 *
Time_Farm[20]	19.359208	0.3065	83925	63.16	<.0001 *
Time_Farm[23]	21.307823	0.749402	84073	28.43	<.0001 *
Time_Farm[26]	44.038715	0.995647	84073	44.23	<.0001 *
Time_Farm[29]	52.169505	0.681966	84077	76.50	<.0001 *
Time_Farm[32]	59.199404	0.605109	84075	97.83	<.0001 *

REML Variance Component Estimates

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
Flag	0.2516859	85.563245	46.156525	-4.901881	176.02837	0.0638	20.108
Residual		339.96046	1.6581273	336.73386	343.23389		79.892
Total		425.52371	46.186098	347.74591	532.81392		100.000

-2 LogLikelihood = 728957.10249

Note: Total is the sum of the positive variance components.

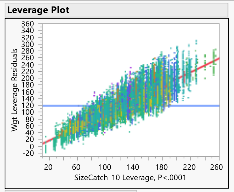
Total including negative estimates = 425.52371

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
SizeCatch_10	7	7	84075	57293.23	<.0001 *
Time_Farm	19	19	84073	3300.828	<.0001 *

SizeCatch_10

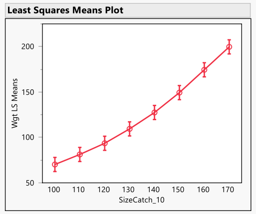
Leverage Plot



Least Squares Means Table

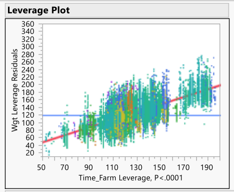
Level	Least Sq Mean	Std Error
100	70.19606	3.2877090
110	81.23194	3.2869897
120	93.55206	3.2871415
130	109.39844	3.2880218
140	127.44432	3.2888417
150	149.32171	3.2889328
160	174.45357	3.2873299
170	199.67755	3.2854926

Least Squares Means Plot

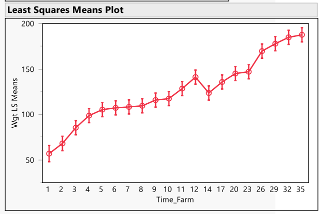


Time_Farm

Leverage Plot



Least Squares Means Plot

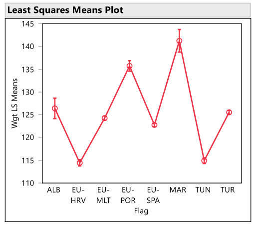


Flag

Least Squares Means Table

Level	Least Sq Mean	Std Error
ALB	126.40499	1.1453857
EU-HRV	114.44239	0.3522238
EU-MLT	124.25515	0.2438865
EU-POR	135.72229	0.5860602
EU-SPA	122.76253	0.2099957
MAR	141.23647	1.2679745
TUN	114.92267	0.3216161
TUR	125.52913	0.2254005

Least Squares Means Plot



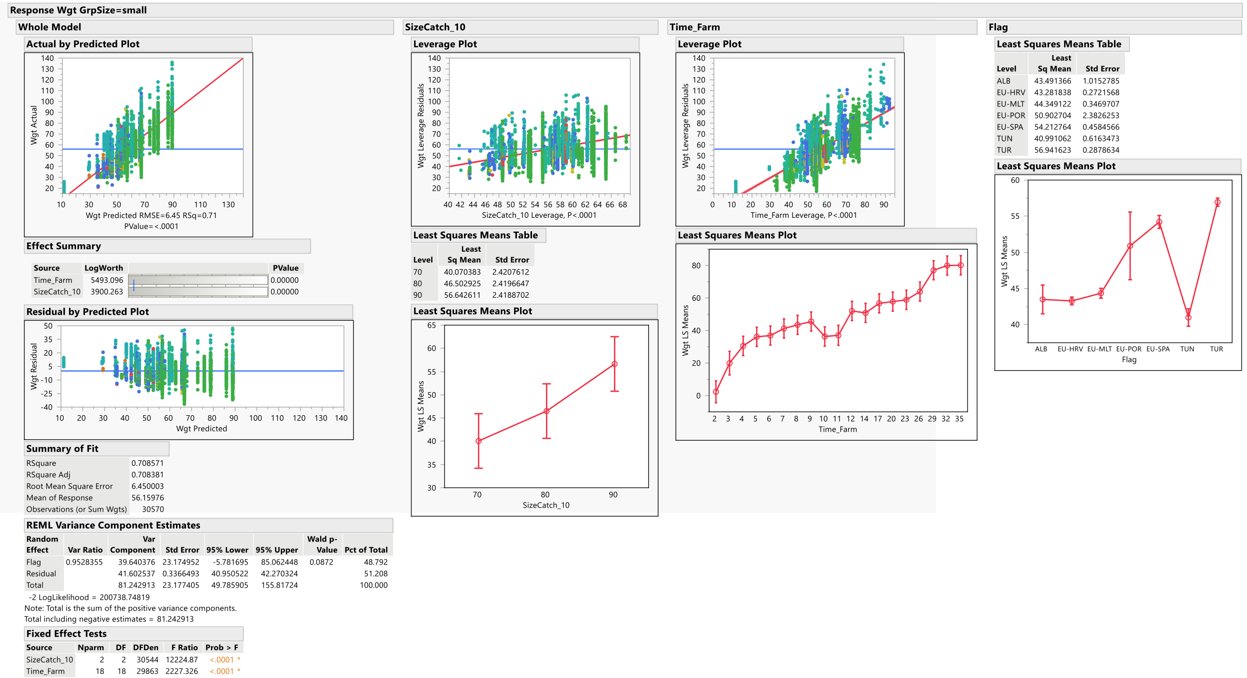


Figure 17. Expected weight at harvest GLMM final models by size category (large, medium, small) bluefin tuna whole model fit, effect summary, residual by predicted plot, REML variance component, fixed effect test, leverage plots, and least square means tables and plots.

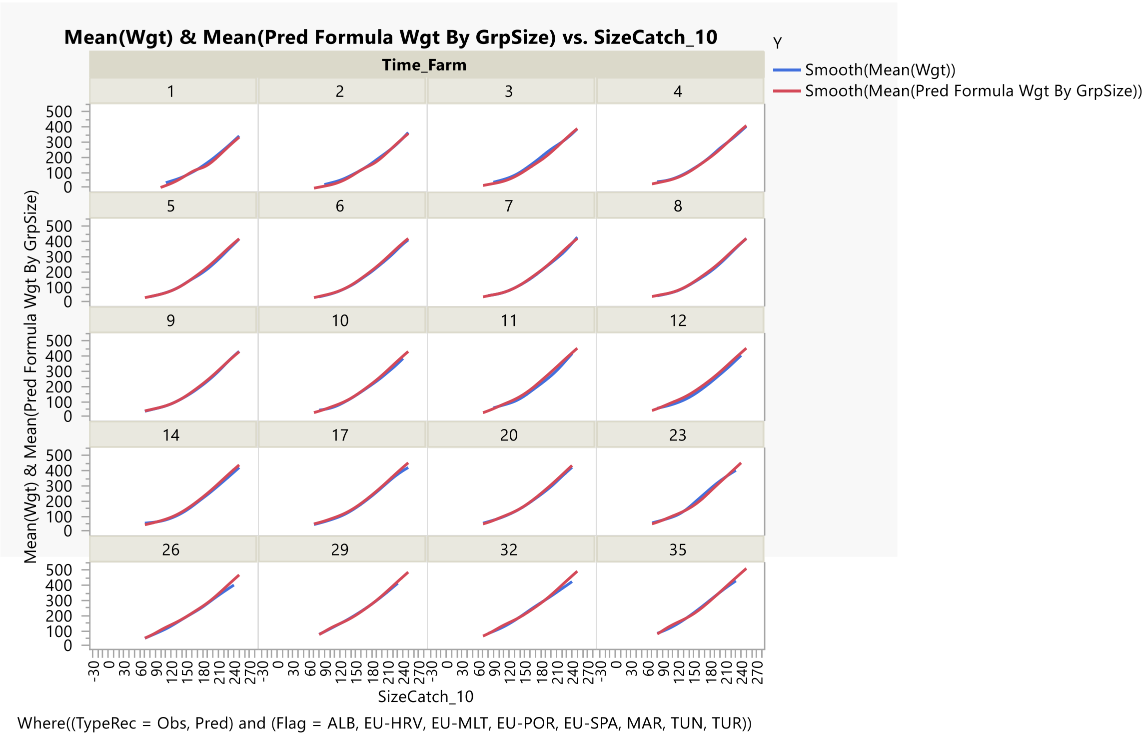


Figure 18. Diagnostic comparison of the observed mean weight (kg) at harvest (blue line) and the predicted mean weight (red line) of harvest BFT by time period (month).

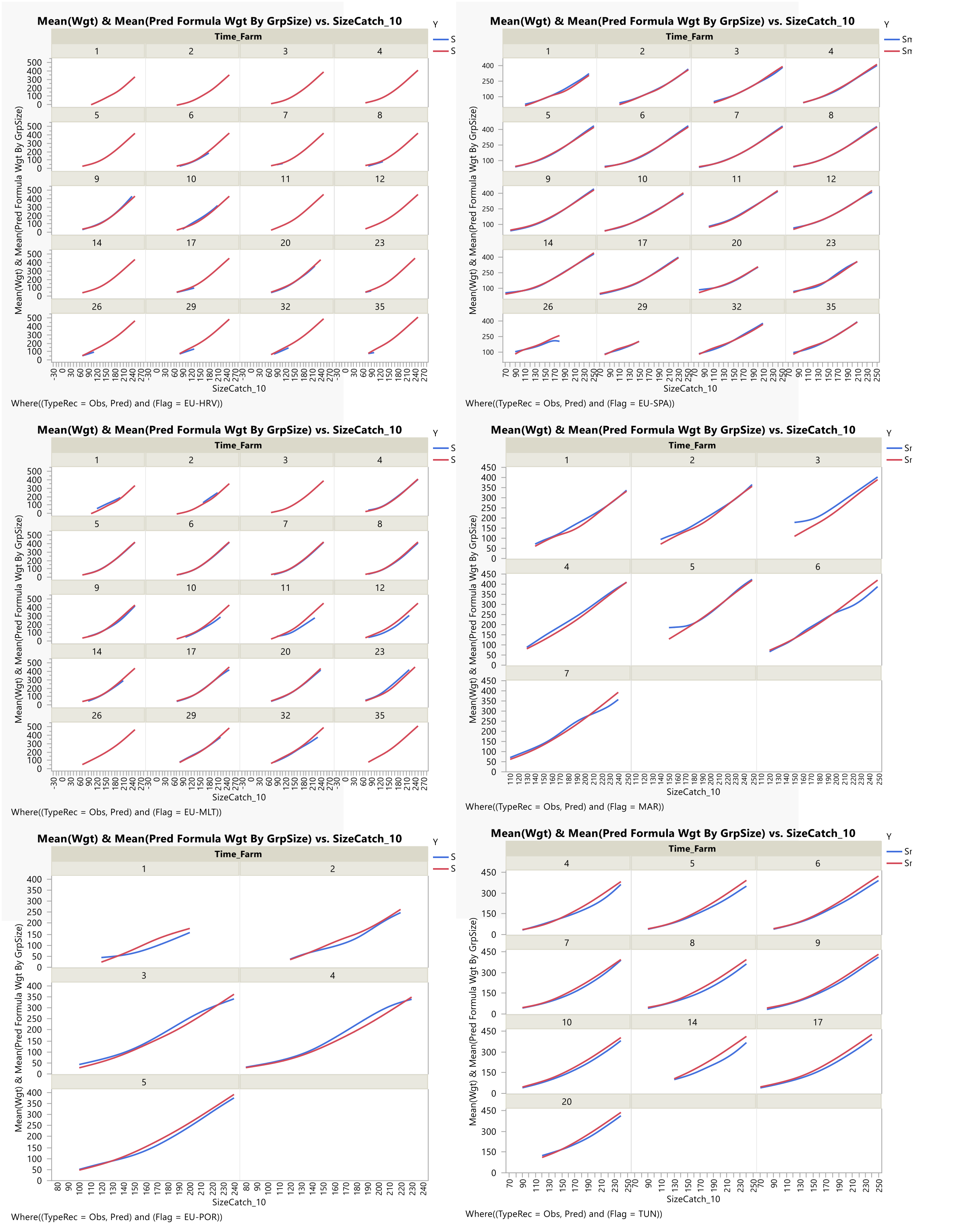


Figure 19. Diagnostic comparison of the observed mean weight (kg) at harvest (blue line) and the predicted mean weight (red line) of harvest BFT by time period (month) and by flag/farm.

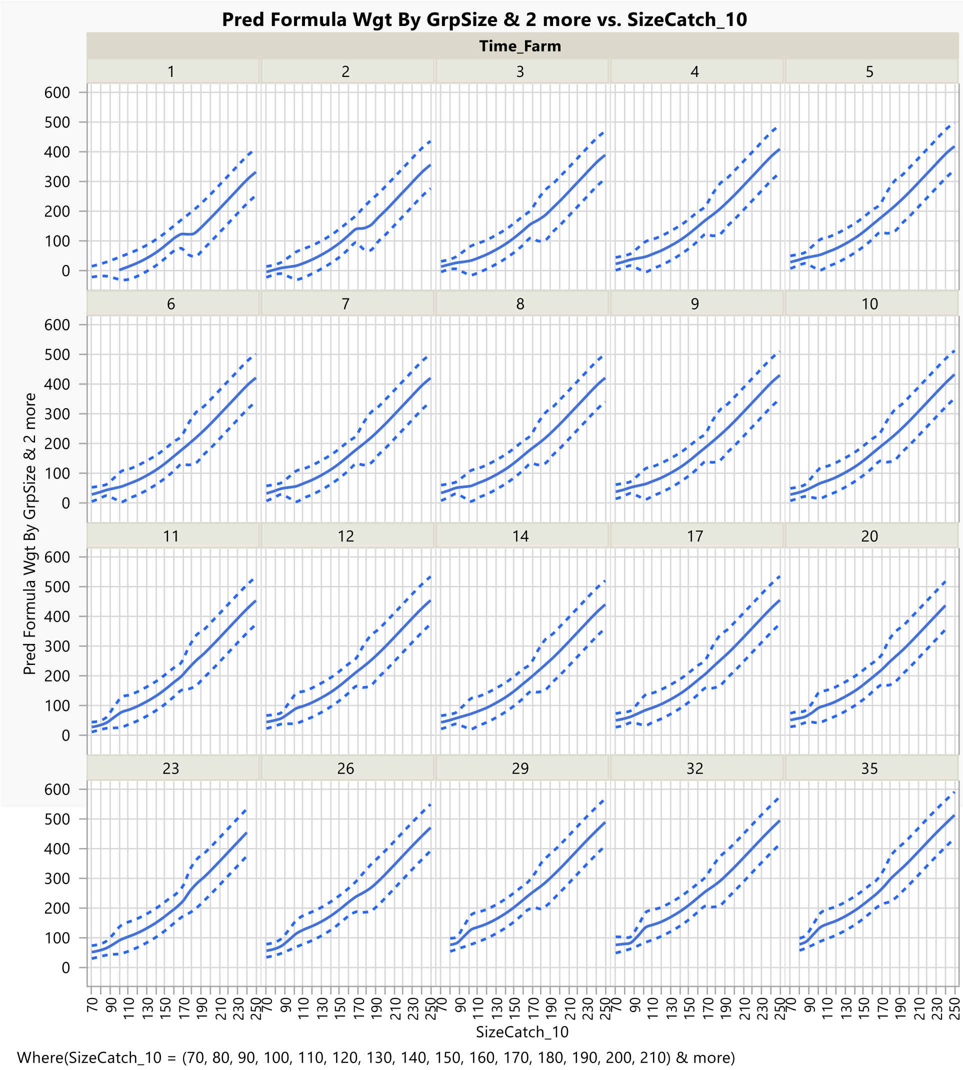


Figure 20. Predicted weight at harvest (kg, *y*-axis) for farmed BFT as a function of size at caging (SizeCatch_10, *x*-axis) and time in farm (each subplot). The solid line represents the mean value and the broken lines the 95% confidence intervals of the predictions.

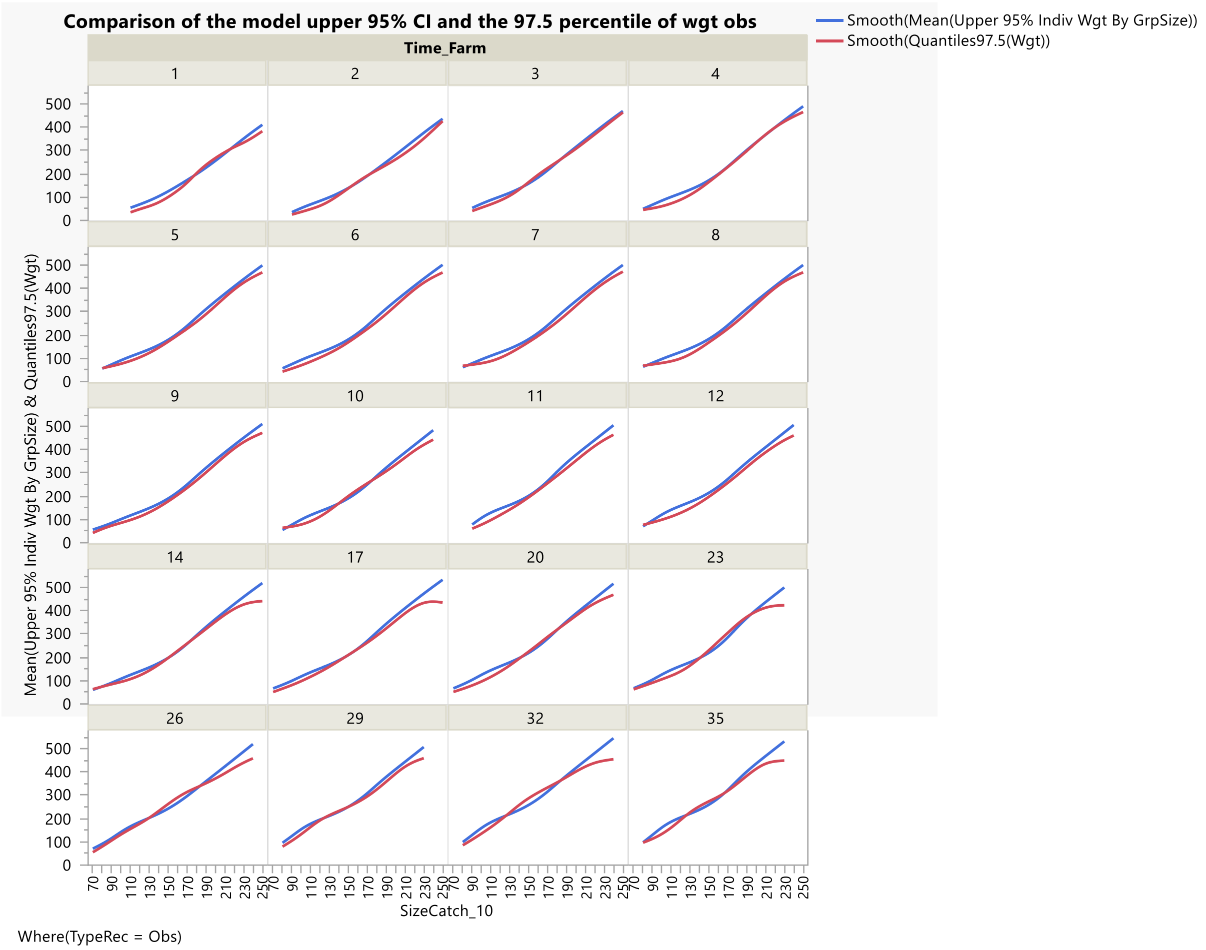


Figure 21. Comparison of the model predicted upper 95% CI (blue line) and the observed 97.5 quantile of the ROP weight (*y*-axis, kg) data (red line) by time at farm (subplot) and size at catch (10 SFL cm, *x*-axis).