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REVIEW AND PRELIMINARY ANALYSES OF FARM HARVESTED SIZE FREQUENCY SAMPLES OF EASTERN BLUEFIN TUNA (*THUNNUS THYNNUS*)

Mauricio Ortiz[1], Ana Justel Rubio[1], and Juan Luis Gallego[1]

SUMMARY

Size frequency data of bluefin tuna harvested at Tuna Farms was reviewed and preliminary analysis performed for its potential use within the stock evaluation models for the eastern bluefin tuna stock unit. Tuna farms had collected size and weight information from their harvesting operations, and submitted to the Secretariat since 2008. The size, weight, and sex identification data was revised and standardized. There is availability of size frequency samples at harvest since 2006, but the main uncertainty is the time at farming as it is not commonly reported due to the farming operations difficulty to track individual fish. Preliminary analyses indicated a bimodal size distribution for harvested bluefin, fist larger mode about 110-160 cm FL, and a second mode of fish over 200 cm FL. There have been variations in mean size of farmed fish by year and by flag-farm, likely representing population size trends. But the time spent in farms is quite variable, from the available data, fish can be in farms from few days up to over 1.5 year, with a median of 215 days, although the days in farm show a bimodal type distribution, with a higher proportion of the fish in cages for about 150-200 days, and a second mode at about 500 days. The weight at size analysis corroborate the gain in weight of farmed fish, increasing on overage up to the upper 95% confidence bound of the weight of wild fish at the same size.

RÉSUMÉ

Les données de fréquence des tailles du thon rouge mis à mort dans les fermes thonières ont été révisées et une analyse préliminaire a été réalisée aux fins de leur emploi potentiel dans les modèles d'évaluation des stocks pour l'unité de stock de thon rouge de l'Est. Les fermes thonières ont recueilli des informations de taille et de poids de leurs opérations de mise à mort et les soumettent au Secrétariat depuis 2008. Les données de taille, de poids et d'identification du sexe ont été révisées et standardisées. Depuis 2006, des échantillons de fréquence des tailles sont disponibles à la mise à mort, mais la principale incertitude entoure le moment de la mise en cages, étant donné qu'il n'est pas communément consigné du fait de la difficulté à suivre la trace de chaque poisson pendant les opérations d'engraissement. Les analyses préliminaires indiquaient une distribution des tailles bimodale pour le thon rouge mis à mort, d'abord un mode plus grand d'environ 110-160 cm FL et un deuxième mode de poissons supérieurs à 200 cm FL. Des variations sont apparues dans la taille moyenne des poissons d'élevage par année et par pavillon-ferme, ce qui représente vraisemblablement les tendances de taille des populations. Mais le temps passé dans les fermes est assez variable ; d'après les données disponibles, les poissons peuvent passer de quelques jours à un an et demi dans les fermes, avec une moyenne de 215 jours, même si les jours dans les fermes montrent une distribution de type bimodal, une plus grande proportion de poissons se trouvant dans les cages pendant environ 150-200 jours et un deuxième mode pendant environ 500 jours. Les analyses du poids à la taille corroborent le gain pondéral des poissons d'élevage, augmentant en moyenne jusqu'à la valeur supérieure de l'intervalle de confiance de 95% du poids du poisson sauvage de la même taille.

RESUMEN

Se revisaron los datos de frecuencia de tallas del atún rojo sacrificado en las granjas de atún y se llevaron a cabo análisis preliminares para su posible uso en los modelos de evaluación de stock para la unidad del stock de atún rojo oriental. Las granjas han recopilado información sobre talla y peso en sus operaciones de sacrificio y la han enviado a la Secretaría desde 2008. Se revisaron y estandarizaron los datos de talla, peso e identificación de sexos. Están disponibles muestras de frecuencias de tallas en el momento del sacrificio desde 2006, pero la principal incertidumbre es el momento de introducción en la granja y no se suele comunicar debido a que en las operaciones de engorde es difícil hacer un seguimiento de los peces individuales. Los análisis preliminares indicaban una distribución de tallas bimodal para los

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

peces sacrificados, siendo la primera moda entre 110-160 cm FL y la segunda de los peces de más de 200 cm FL. Se han producido variaciones en la talla media de los peces engordados por año y por pabellón-granja, lo que probablemente representa tendencias en la talla de la población. Pero, a partir de los datos disponibles, el tiempo pasado en las granjas es bastante variable ya que los peces pueden estar en la granja desde pocos días hasta más de un año y medio, con una media de 215 días. Aunque los días en la granja presentan una distribución tipo bimodal, con una mayor proporción de peces en jaulas entre 150 y 200 días y una segunda moda con aproximadamente 500 días. El análisis de peso por talla corrobora la ganancia de peces engordados, aumentando de media hasta el límite superior del intervalo de confianza del 95% del peso de los peces salvajes con la misma talla.

KEYWORDS

Mean size, Farm bluefin tuna, Size frequency

1. Introduction

In the latest decade, farming of bluefin tuna has become a major destination for most of the catches of the eastern bluefin. In average, for 2005-2011, about 60% of the catch of eastern BFT went to farms (based on catches by purse-seine fleets). Because of the logistics of the fishing operation with live fish, there is very limited information on the size and age distribution of wild bluefin caught and destined to farming. This has translated in a limited or deficient information input for recent stock assessment, greatly increasing the uncertainty of the results from recent evaluations and stock status determinations (Anon. 2012). In 2008, the ICCAT Commission requested to Bluefin tuna farms to record basic size and weight information of their harvested fish [Rec 2008/05]. Since then, data collected from harvesting operations has been submitted to ICCAT; however the formats, detailed of information and completeness of data varied substantially among reporters.

The primary objective of the analyses was to consolidate, standardized and reviewed the available harvesting information into a database. Afterwards, preliminary analyses explore the utility of the data as an input for traditional stock assessment models.

2. Data

The ICCAT bluefin tuna Farm Size data started to be reported in June 2008, following the Recommendation 08/05. Initially data was submitted with a form allowing for aggregate data reporting, later this form was update and only single fish size/weight measures were accepted. In addition, some CPCs submitted size data from their farms harvesting operations prior to 2008, however most of these data were aggregated and not information of the completeness (percent of total harvesting) were provided. A database was created identifying each harvesting operation (per day when available) by registered farm and the corresponding size/weight data for the fish harvested and measured. Due to duplicated submissions, the initial task was to remove duplicated records. A record was identified as duplicate if they have the same Farm ID, same date of harvesting, and the number and size frequency of the fish reported were similar. Most of the size measurements were reported in 1 cm size bin (114,635 records); however some were reported in 2 (59), 5 (2174) and 10 (59) cm. Reports of size in 10 cm were excluded, while reports of size in 2 and 5 cm were converted into 1 cm, by splitting the number of fish per size bin uniformly among 1 cm categories starting from the lower limit. The compiled size farm database includes 207,175 fish measured from farm harvesting operations between 2003 and 2012[2]. Of these, there were 2,535 identified individual harvest operations (e.g. having farm ID and date: dd-mm-yyyy of harvest) with corresponding 119,589 measured fish (58%), while the rest are missing the date of harvest, but it is known the year of harvest and the flag of the farm (76,507 measured fish), and or year harvest and farm ID (10,572 measured fish). Of the fish harvested and measured 189,487 (91%) have size measures, 111,877 (54%) weight measures, and 94,280 (45%) both size and weight measures for the individual fish. A small number also included sex identification (15,953). Other information requested within the farm size reports, included the total original catch (numbers and weight) and date of the catch from which the reported harvest operation originated. However, only 878 harvest operations (38%) provided the original catch and corresponding date. This information is important to estimate the time than the fish was in the farm. It has been also requested the cage(s) from which in a particular harvesting the fish were taken. Unfortunately this information is particular to each farm operation and there is not associated information at the Secretariat, thus it was possible only to identify for a given report if the fish came from a single or multiple cages harvest.

[2] Data for 2012 represents partial submissions up to the date of this analysis.

The farm size data comprise harvests from 40 registered farms corresponding to 8 CPCs; Croatia, Tunisia, Turkey, Cyprus, Spain, Greece, Italy and Malta. Some of the records prior to 2008 have no farm identifier (data were submitted as aggregated information by the CPC). For size measurements, 80% are in fork length (FL), 10% curved fork length (CFL), 5% total length (TLE), 5% in length 1st dorsal fin (LD1) and less than 0.5% had not size measurement type. All size measurements were converted to FL (cm) using the current SCRS adopted size relationships for E-BFT.

Reported Freq Type	***Conversion used***	***Reference***
CFL	FL = 0.955*CFL	PARRACK et al. (1979)
TLE	FL = TLE	NA
LD1	FL = 2.0077*LD1^1.14	Rodríguez Marin et al. (2012)

Over 95% of weight measures were reported as round weight (RD, WH), 3% as dress weight (DR), and few (<1%) in gilled and gutted (GG), and the rest blank. All were converted to round weight units using the following relationships.

Reported Product Type	***Conversion used***	***Reference***
DR	RWT = 1.25*DR	ANON. (2003)
GG	RWT = 1.16*GG	Unk
WH	RWT = WH	

For records with only weight measures, no estimation of size was done. Only about 7.6% of the records indicated sex identification. Once size and weight units were standardized to FL (cm) and RW (kg), size in 5 cm bin classes were estimated for some further analyses.

As mention above, data covered farming harvest from 2003 to 2012, however only from 2005 until 2011 there are over ten thousand reported fish measures (**Figure 1**), being 2007 and 2008 the years with the highest number of fish measured. By farm CPC, Spain and Turkey are the top two reporters accounting for 67% of size measures, follow by Malta (11%), Croatia (8%), Tunisia (6%), Italy (4%), Cyprus (2%) and Greece (1%). **Figure 2** shows the distribution of farm size samples by year and farm/flag. **Table 1** shows the number of reporting farms by Flag and year. The number of reporting farms per year as varied, being 2007-09 the year with highest number of farms active about 25, while in recent years 2010/11 were 13 and 18 respectively. By Flag, Spain reported from 10 different farms, follow by Turkey 8, Croatia 7, Malta 5, and the rest 4 or less farms.

3. Methods

Initially analyses were performed on the size and weight distributions to identify potential outliers or series non consistent with the general trend of the data. Figure 3 shows a box plot distributions of the weight at size (FL 5 cm bin size). It was noted that bluefin below 100 cm FL, show disproportionally high weights and fish over 300 cm FL show lower than expected weight distributions. Scatter plots of weight at size by farm flag (Figure 4) indicated the anomalies were from certain farm-flag however it was not possible to distinguish if the error was in the weight measure or in the reported size or size measure type. Overall, fish < 100 cm FL represent less than 2.5% of all size samples, while fish > 300 cm FL represent less than 0.10%. The size frequency distributions show variations by year (Figure 5) with the high mean average size 210 cm FL in 2006, and the lowest 158, 156 cm FL in 2007-08, respectively. However density distribution plots indicate a bimodal size distribution (Figure 6) for most years, with a large peak in the range of 100 to 160 cm FL and a second lower peak between 200 and 240 cm FL. Size distributions also varied by farm-flag (Figure 7), and among farms (Figure 8). Data reports for fish < 100 cm and > 300 cm were revised trying to identify error source. In some instances it was detected that for example same size/weight was reported, likely typing errors, in others it is unclear the source of error. It was decided to exclude for further analysis those records where fish < 100 FL cm and with weight reported > 200 kg as obvious outliers. Similarly, fish with size > 320 F cm and with weight information were excluded until further verification.

Although a limited number of observations indicating both the harvest date and the catch date of the fish samples, a review of days a caging was performed. There is information for catch date for the latest years, since 2008. For 2009 and 2010 on average 55% of the size measures has date of catch, albeit in 2011 this proportion reduced to 26% (**Table 2**). On average bluefin stay on farms for 294.4 days, but there is a wide range of caging days (**Figure 9**) from 28 to 842 (95% quantile). The maximum time in farm is over 5 years, 1846 days however this information has not been confirmed (**Figures 10 and 11**). There is also variation by CPC flag and by farm.

Similarly, sex of harvest fish was reviewed. Sex ID data is available for 2007 forwards, and from three CPC-Flags; EU-Malta, EU-Spain and EU-Cyprus (**Figure 12**). Sex at size ratios and sex at weight ratios were evaluated for the available information.

4. Results and discussion

Size and or age distribution of removals is an important input for most fisheries assessment models (Haddon 2001). It is particularly important for stocks that are highly exploited as the case for eastern bluefin tuna. Size/age information is routinely collected through sampling programs on important fisheries usually at dock or transfers of the catch to markets. However, in the case of eastern and Mediterranean bluefin, in the last decade(s) the fishery has shifted from immediate market of the catch towards bluefin farming operations where the product can reach better market quality and provide control of supply-demand (Mylonas et al 2010). As such, an increase percent of the catches of the allocated quota is realized by the purse-seine fleet which is delivered to different farms within the Mediterranean Sea. The catch operation and transfer of live fish to cages in the farms limited substantially the possibilities for obtaining reliable size measures of the catch. There have been proposals to implement visual and electronic sampling protocols, but these methodologies are still under development and testing (Burcu 2012 and 2012a, Espinosa et al. 2012, Grubisic et al. 2012), meanwhile the scientific working group has recognized the increased uncertainty of their analyses in part due to the limited size sampling of this important component of the catch. Presently, at the end of the farming, bluefin harvested is required to be sample for size, weight and biological information when possible. It has been recognized that farming operations do translate into gains in weight and size of the fish, however this increase is quite variable and the few reports show a great level of variation. These studies have further identify a wide number of potential variables that affect growth both in size and weight of bluefin inside farms, among others feeding, temperature, location, water quality, density of fish, etc. En general, it is accepted that most gain is in weight rather than in size, given in part that the fish remain for relative short time in farms (less than a year).

Since 2008 farms are oblige to submit information of their harvested fish, in size and weight at least. Some CPCs have submitted size samples for earlier years from their farms. Size frequency distribution of the farm fishes can potentially be used to infer their size at catch. For this it would require the time of caging for each fish, and a growth discount hopefully taking into consideration factors that affect farming growth as mention before. The first task of this report was to consolidate the data provided by the CPC-farms and to do a quality control of the information. Initial analyses using the weight-size relationship of harvested fish, clearly indicated some inconsistencies in the data. In particular for fish less that 100 cm FL, the reports assigned these fish unusual large weights (Figure 3). Similarly for fish over 300 cm FL, the reported associated weights were well below the expected ones, or even weight lower than those reported for fish within the 270-300 cm FL size range (Figure 3). It were also identified several records were the size and weight have the same value as reported (e.g. original size and weight measure units). What is clear was that fish < 100 cm FL or > 300 cm FL the weight units were well outside the expected values. Fortunately, the numbers of size samples within these ranges represent less than 2 % of the overall data.

An analysis of the weight at size was performed for the farm data to explore if the relationship differs from the weight-size relationship(s) currently used for wild E-bluefin by the SCRS (Ray and Cort unpublished, Arena unpublished, Rodriguez et al 2012).

Using only the weight-size information for fish within the 100 > FL > 300 cm, exponential models were estimated as:

$$RWT = alpha * FL^{\,beta}$$

for all fish, and by sex category when this information was available (Figure 13). Table 3 summarizes the estimated parameters and compare to the weight-size relationships used by the SCRS. The largest differences in expected weight at size are found between the Arena and Rey & Cort models (Figure 14). The estimates from Alot et al, from a recent published study do agree closely to the Ray & Cort predictions, while the estimates of weight at size from farmed fish are between the Arena and Rey & Cort’s model (Figure 14). However comparison of single point estimates is not sufficient informative to conclude whether or not weight at size in farms differs substantially from the wild fish, moreover when the farming period is highly variable, and even considering a relative low variance about the estimated values, for example a coefficient of variance (CV) of 15%, shows a large overlapping between the predicted weight at size values. Further analyses done with non-linear quantile regression analysis (Cade and Noon 2003, Koenker 2009) allowed comparing the quantile distributions of observed weights at a given size from farm a wild fish (data of wild fish kindly provided by IEO Scientists SCRS/2012/104). The advantage of this procedure is that breaks from assumptions of normal distribution about the predicted mean and variance of weight at a given size group.

The results of the quantile regression shows similar trend of the estimated midpoint weight at size between the nonlinear and the quantile regression models (Figure 14), however the quantile regression estimated a much higher variance of weight at size than those expected from the non-linear model, and the 95% weight quantiles extended greatly for bluefin of size 200 cm FL and larger. A comparison of the weight-size relationship from wild versus farm harvested bluefin tuna is shown in Figure 16. Both models use the quantile regression model. First, the estimated mean weight at size is greater for farmed fish, notable for fish over 200 cm FL, but more interesting is that wide confidence bounds for farmed fish which clearly overlap the wild fish estimates. This result is in part expected; as of the size-weight samples from farmed fish includes fish with wide range of time at the farms. Hence the lower bound of the expected weight at age for both farm and wild fish is very similar, while the upper bound is clearly much higher for farmed fish, and the mean weight at size of farmed fish is close to the upper bound of the wild fish. This indicates a positive gain in weight in the farming of bluefin tuna.

The information on farm harvesting by sex category showed overall an equal proportion of males and females by year and by CPC farm flag (Figure 12). Albeit, when the sex ratios were plotted by size categories, there were identified some trends: Male proportions were slightly higher for fish between 120- 190 FL cm size, and fish over 250 FL cm, consequently observed female proportions were higher for fish between 200 and 250 FL cm. However, a logistic regression of the sex ratios at size category (5 cm FL bin size) or logistic regression of sex ratios on weight category (5 kg RWT) both indicated a non-statistical significance from equal ratio at size or weight.

Finally, the sampling of farm harvest bluefin in recent years has shifted towards the regional observer program (ROP) implemented by ICCAT Commission in 20XX. Thus, explaining the low sampling in the latest year in particular. The ROP has provided recently the size database collected in 2011 and 2012, but due to time constraints comparisons with the data presented here has not been yet completed. In conclusion the size samplings at harvest of farmed bluefin provide size frequency distributions since 2006, but the main reservation is the time at farming as it is not commonly reported or due to the farming operations difficult to track for each individual fish. There is a bimodal size distribution for harvested bluefin, fist higher mode about 110-160 cm FL, and a second mode of larger fish over 200 cm FL. There have been variations in mean size of farmed fish by year and by flag-farm, likely representing population size trends. But the time spend in farms is quite variable, from the available data, fish can be in farms from few days up to over 1.5 year, with a median of 215 days, although the days in farm distribution shows a bimodal type distribution, with a higher proportions of the fish been in cages for about 150-200 days, and a second mode at about 500 days. The weight at size analysis corroborate the gain in weight of farmed fish, increasing on overage to the upper 95% confidence bound of the weight of wild fish at the same size.

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Table 1. Number of bluefin tuna harvested from farms and sampled for size and or weight by country and farm.

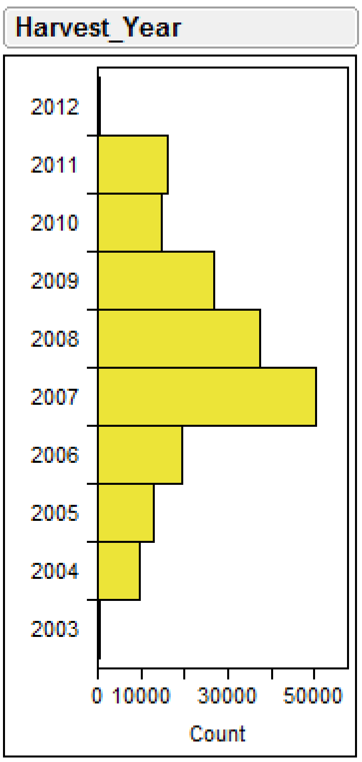
Fish measure		**YearHarvest**									
Flag farm	**FarmICCATID**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Croatia	AT001HRV00001							166			
	AT001HRV00002							393			
	AT001HRV00003							1064	955	2246	
	AT001HRV00004							484			
	AT001HRV00006							973	1001	374	
	AT001HRV00008								1072	216	
	AT001HRV00009							429		243	
	(blank)			89		3232	3034				
EU.Cyprus	ATEU1CYP00001					489					
	ATEU1CYP00002						280				
	ATEU1CYP00003					600	479				
	(blank)			1207	683						
EU.España	ATEU1ESP00001					944					
	ATEU1ESP00003					4782	4210	4185			
	ATEU1ESP00005					9385	11899	2579			
	ATEU1ESP00006					9104	1326				
	ATEU1ESP00007						4201				
	ATEU1ESP00009					258					
	ATEU1ESP00010					734					
	ATEU1ESP00011					2175	774				
	ATEU1ESP00013					589	1040	1557			
	ATEU1ESP00014					48					
	(blank)			951	12045	2795					
EU.Greece	ATEU1GRC00001				507	300			1058	212	
	(blank)					433					
EU.Italy	ATEU1ITA00001							280			
	ATEU1ITA00006									168	
	(blank)		1924	3608	3132						
EU.Malta	ATEU1MLT00001					1897	1490	1106		1130	
	ATEU1MLT00003					992	413	1007		365	
	ATEU1MLT00004					443	504	680		97	
	ATEU1MLT00007					709	888	369			
	ATEU1MLT00008					63	559	1418		634	
	(blank)			7996		1223					
Tunisie	AT001TUN00001					501	815	356	650	121	52
	AT001TUN00002					796	675	963	1021	169	293
	AT001TUN00003					745	1682	364	330		
	AT001TUN00004					196	577	476	516	121	100
Turkey	AT001TUR00004						2626	2403	1279	150	
	AT001TUR00005						1511	2086	1016	932	
	AT001TUR00006						93	567	2185	1889	
	AT001TUR00010						519	371			
	AT001TUR00011						72			5416	
	AT001TUR00012							3086			
	AT001TUR00013						1189	1569	1036	103	
	ATEU1ESP00004								1		
	(blank)	101	15760	6794	5039	6968					
Total		101	17684	20645	21406	50401	40856	28931	12120	14586	445

Table 2. Number of size measures for E-BFT from harvesting operations that have both information on date of harvest and date of corresponding catch.

		Catch Year						
Harvest_Year	No_catch	2006	2008	2009	2010	2011	2012	Total
2003	101	.	.	.	.	.	.	101
2004	9804	.	.	.	.	.	.	9804
2005	13250	.	.	.	.	.	.	13250
2006	19495	.	.	.	.	.	.	19495
2007	50371	.	.	.	.	.	.	50371
2008	35329	.	2216	.	.	.	.	37545
2009	11419	28	7848	7432	.	.	.	26727
2010	6698	135	2034	4291	1604	.	.	14762
2011	10996	165	.	72	726	2884	.	14843
2012	0	.	.	103	150	.	445	698

Table 3. Comparison of weight-size estimated relationship parameters for eastern bluefin tuna presently used by the SCRS (Arena and Rey & Cort) and from the Size farm harvested bluefin data.

Source	sex	alpha	beta	Range FL	N obs	notes
Arena	Combined	1.96E-05	3.0092			
Rey & Cort	Combined	2.95E-05	2.898958			
Alot *et al*	Combined	3.66E-05	2.8635			
	Male					
	Female					
Farm Size DB	Combined	3.91E-05	2.874385	100 - 300		
	Male	3.01E-05	2.924757	100 - 300		
	Female	6.02E-05	2.791725	100 - 300		



Frequencies

Level	Count	Prob
2003	101	0.00053
2004	9804	0.05174
2005	13250	0.06993
2006	19495	0.10288
2007	50398	0.26597
2008	37562	0.19823
2009	26847	0.14168
2010	14865	0.07845
2011	16466	0.08690
2012	698	0.00368
Total	189486	1.00000

N Missing 0

10 Levels

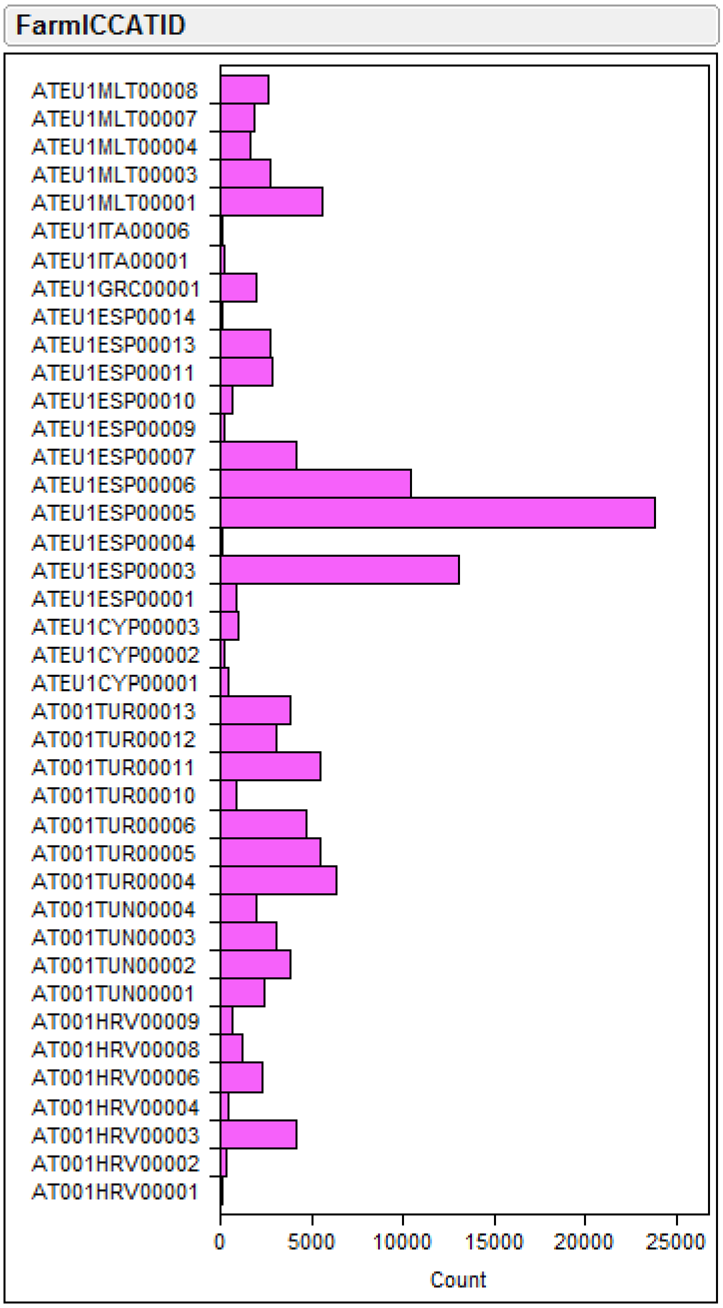


Figure 1. Distribution of Farm size samples per year and by farm ID. Values represent the number of fish harvested and size measured.

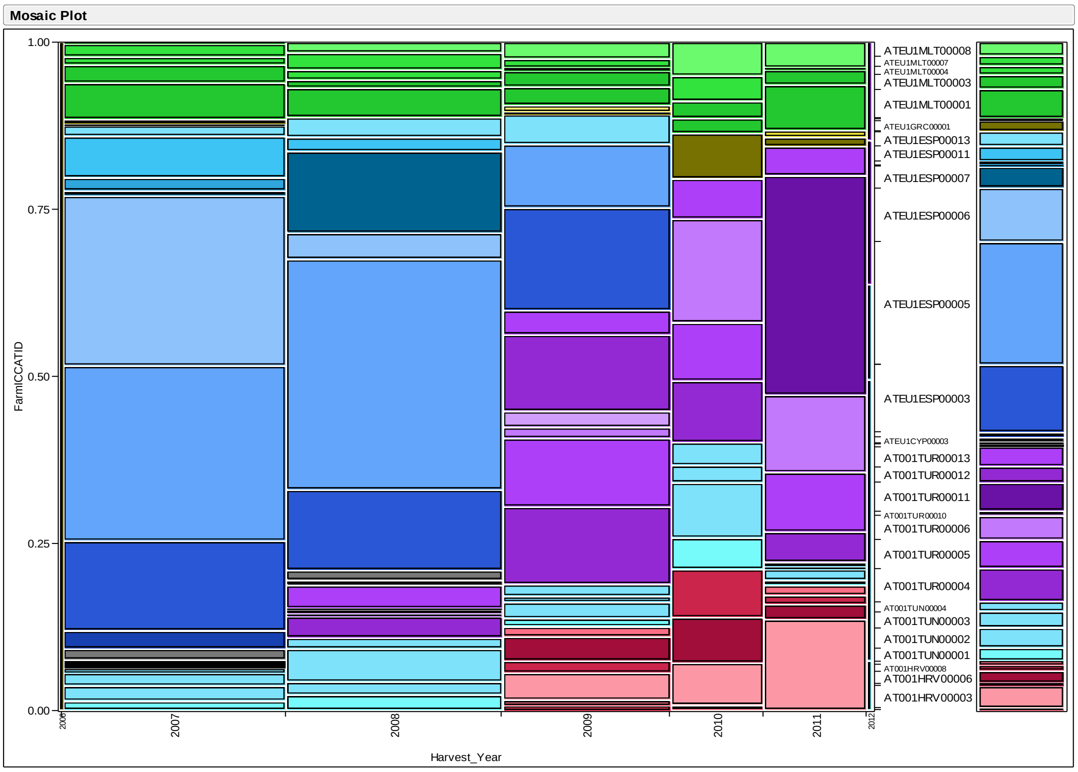


Figure 2. Mosaic plot of the number of farm size samples E-BFT by year and farm ID, color code for the same Farm Flag.

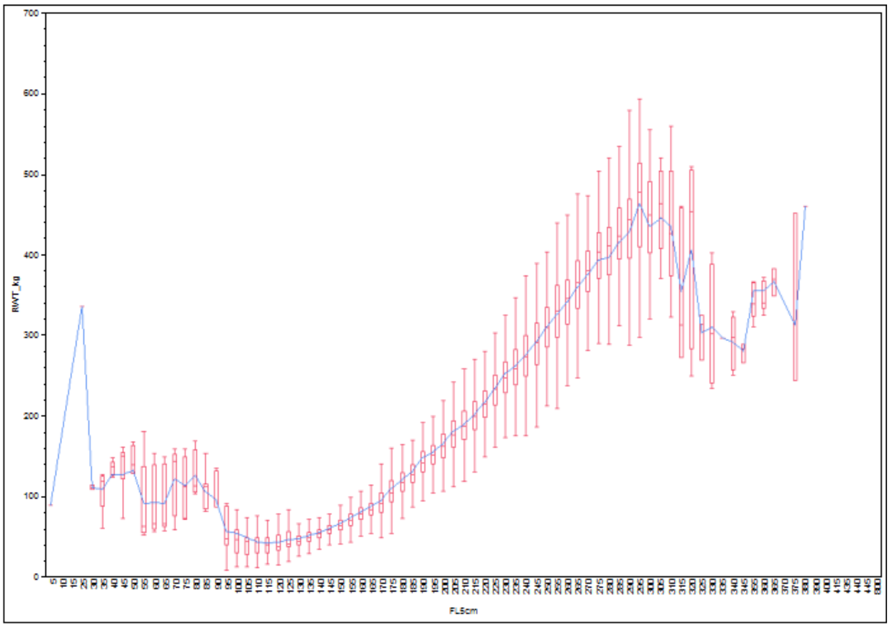


Figure 3. Box-plot distributions of weight (RW kg) at size (FL 5 cm) for farmed BFT DB.

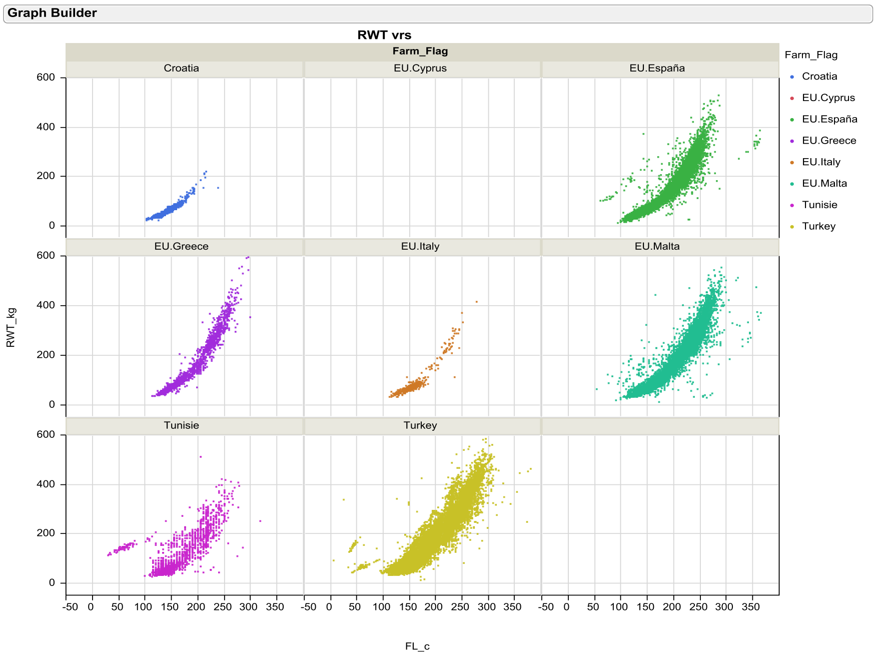


Figure 4. Scatter plot of weight (RWT kg) and size (FL cm) of E-BFT harvested at farms by CPC-Flag of farm.

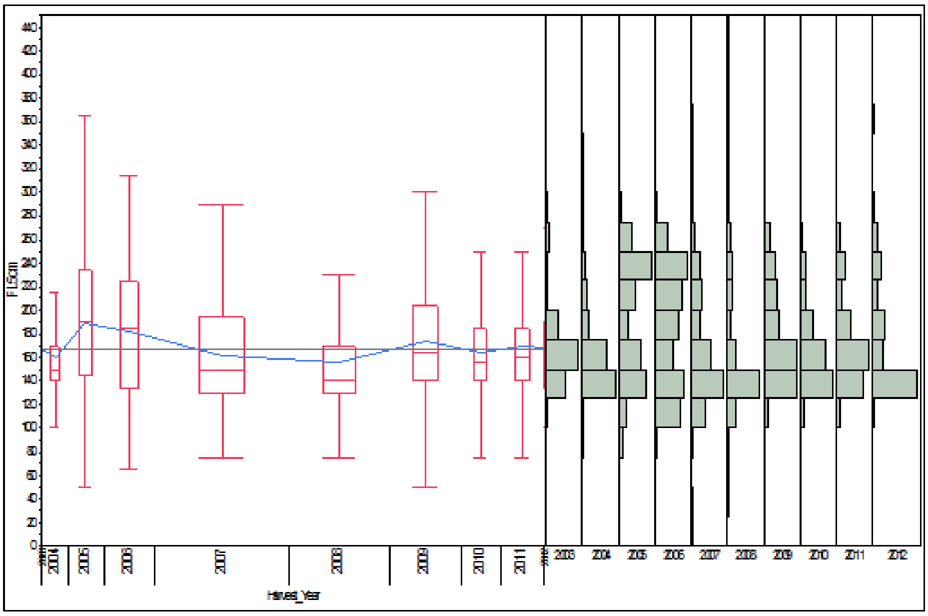


Figure 5. Size (FL cm) distribution of bluefin tuna harvested at farms by year. Width of box is proportional to number of sampled fish.

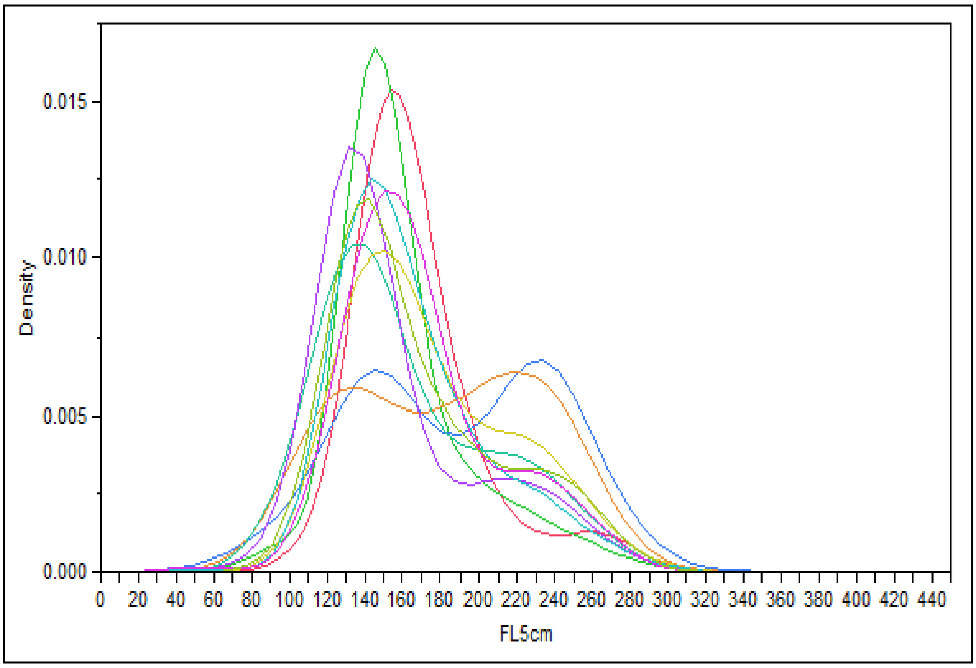


Figure 6. Frequency density of E-bluefin tuna size (FL cm) harvested at farms by year.

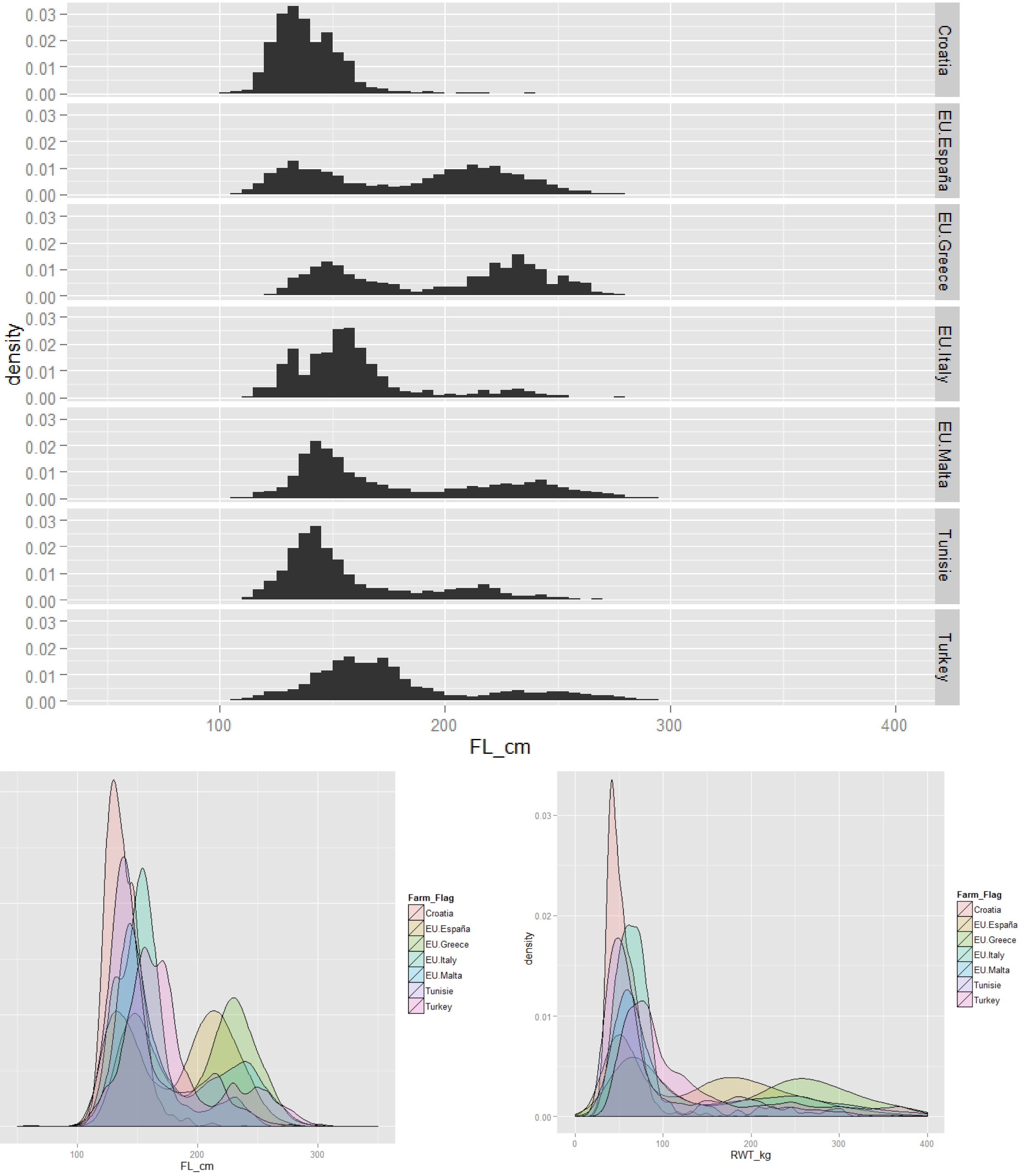


Figure 7. Size frequency distributions (top box plots, bottom density distribution) of E-BFT harvested at farms by CPC-Flag of farm.

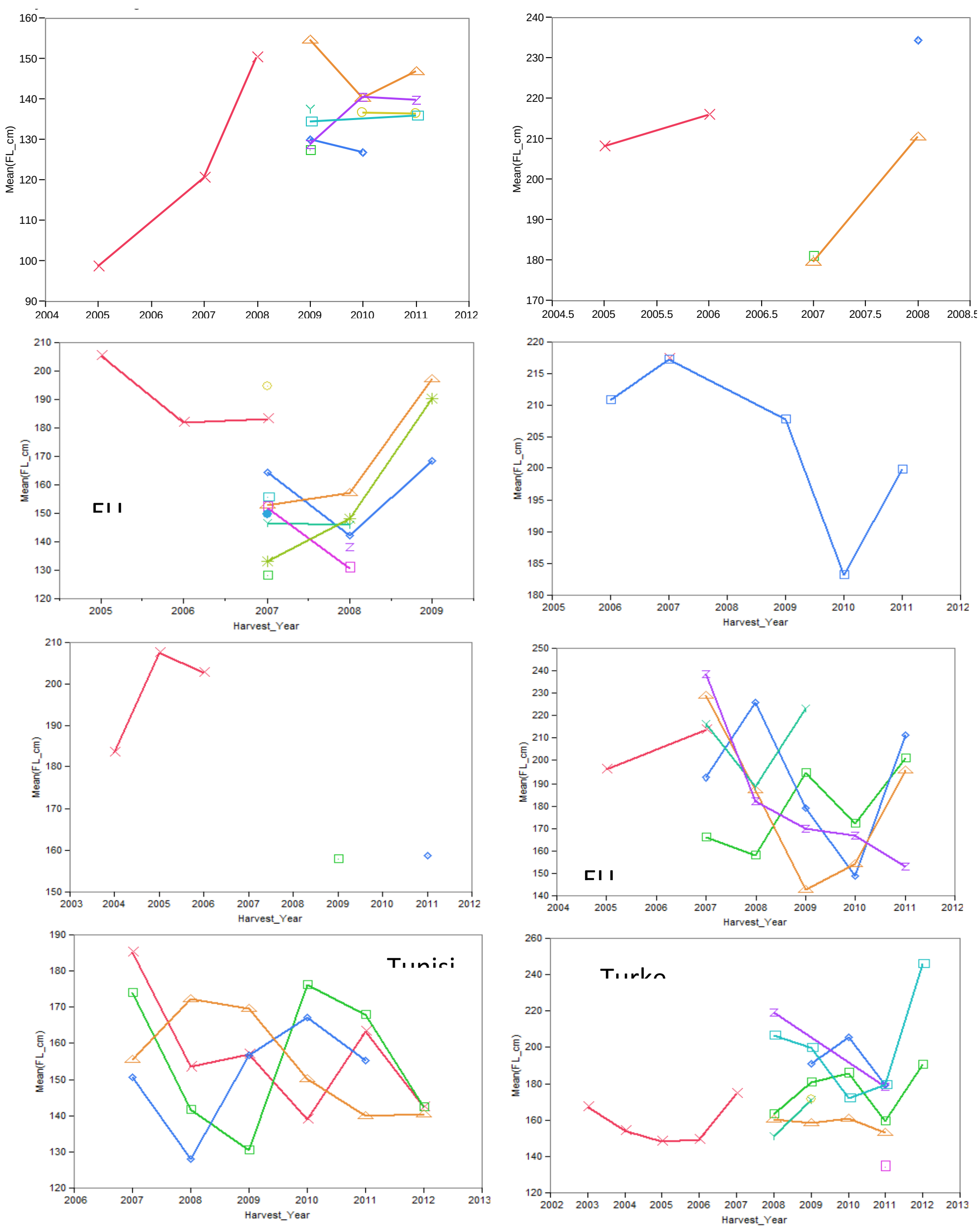
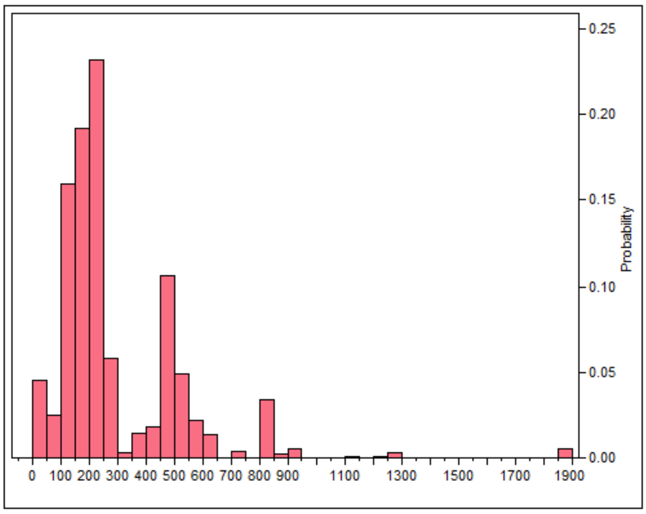


Figure 8. Mean size (FL cm) of E-BFT harvested by CPC and farms by year.



100.0%	maximum	1856.0
99.5%		1856.0
97.5%		842.0
90.0%		538.0
75.0%	quartile	451.0
50.0%	median	215.0
25.0%	quartile	155.0
10.0%		118.0
2.5%		28.0
0.5%		13.0
0.0%	minimum	0.0

Moments

Mean	294.37449
Std Dev	236.23197
Std Err Mean	1.3856261
upper 95% Mean	297.09038
lower 95% Mean	291.6586
N	29066

Figure 9. Frequency distribution of days in farms for E-BFT.

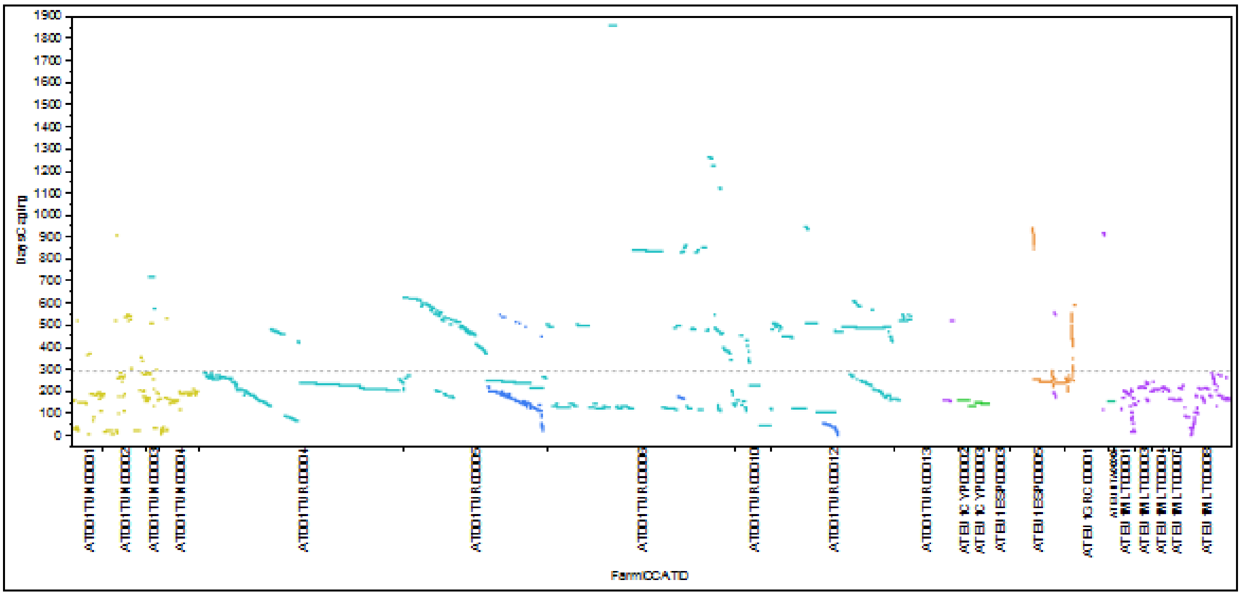


Figure 10. Days in farms (days cageing) for E-BFT by harvesting event and farm. The broken line represents the average time in farms of 294 days.

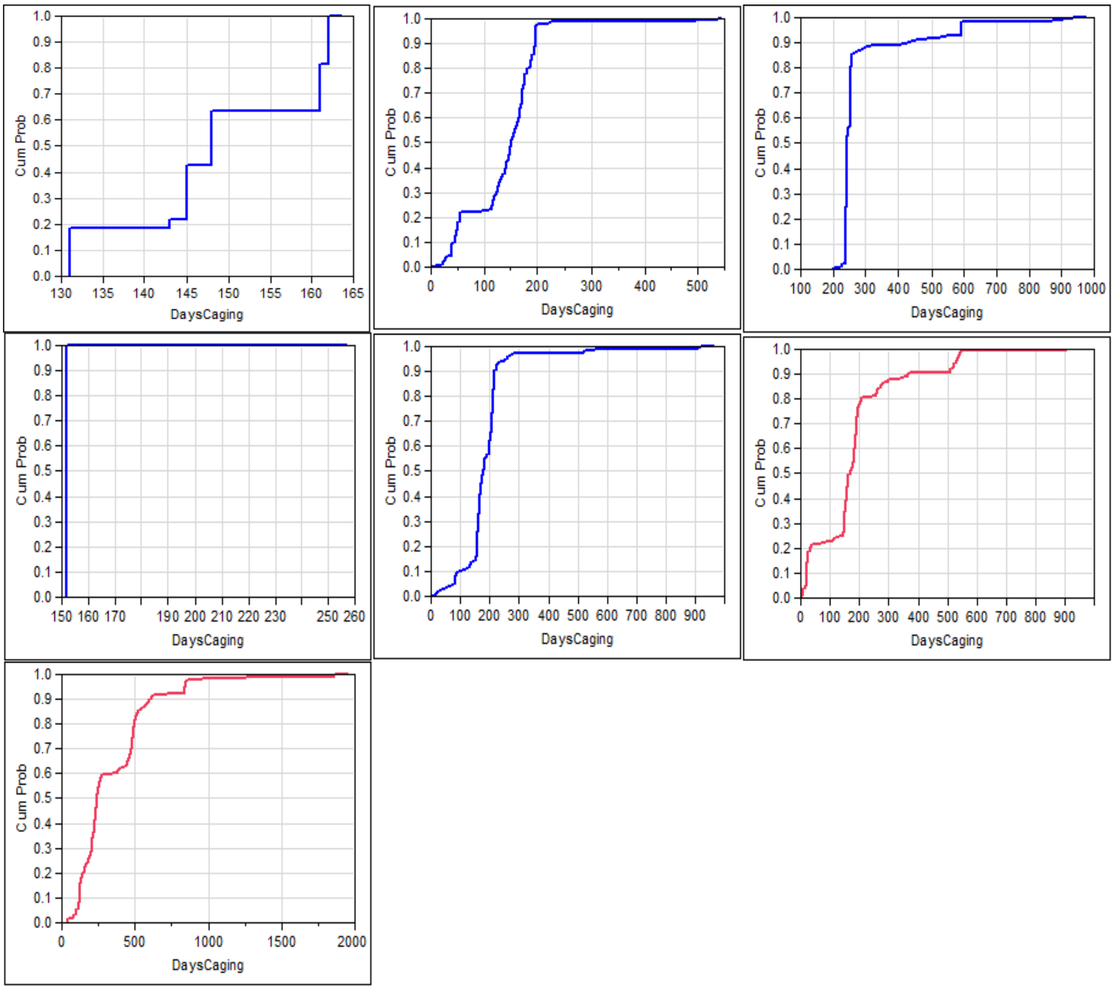


Figure 11. Cumulative plot distributions of days in farm for e-BFT by CPC Flag of farm.

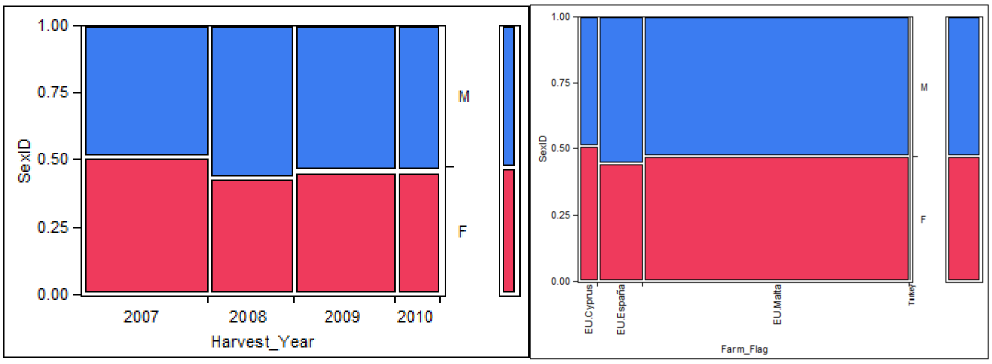
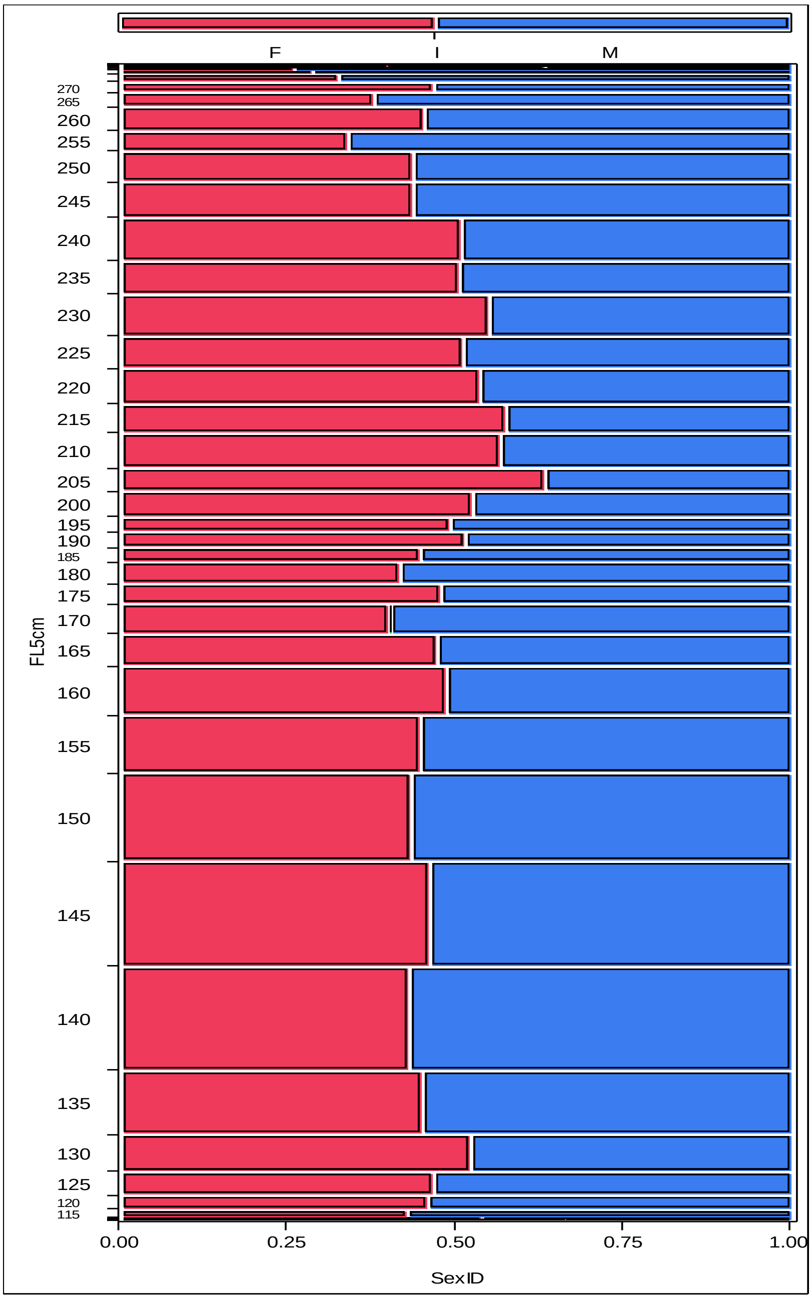


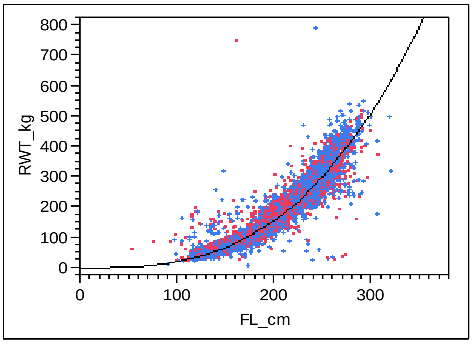
Figure 12. Mosaic plots of sex identification for E-BFT harvested at farms by year and farm flag.



Nonlinear Fit: Combined sex fit
Solution

SSE	DFE	MSE	RMSE
10343707.131	13803	749.38109	27.374826

Parameter	Estimate	ApproxStdErr	Lower CL	Upper CL
alpha	0.0000390618	2.03324e-6	3.58126e-5	0.00004259
beta	2.8743854877	0.00955829	2.85849749	2.89033061

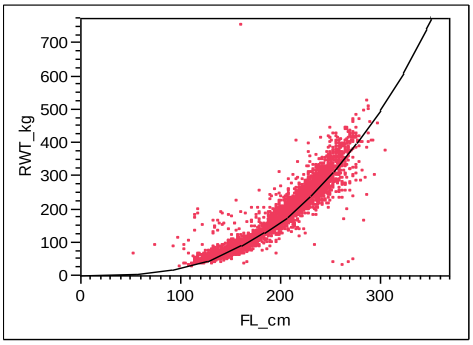


Nonlinear Fit Sex ID = Female
Solution

SSE	DFE	MSE	RMSE
4402037.0984	6373	690.73232	26.281787

Parameter	Estimate	ApproxStdErr	Lower CL	Upper CL
alpha	0.000060172	4.29087e-6	5.30059e-5	6.82617e-5
beta	2.7917249522	0.01313564	2.76848065	2.815068

Solved By:
Numerical SR1



Nonlinear Fit Sex ID = Male
Solution

SSE	DFE	MSE	RMSE
5798984.9285	7428	780.69264	27.940878

Parameter	Estimate	ApproxStdErr	Lower CL	Upper CL
alpha	0.0000300797	2.25324e-6	2.67381e-5	3.38161e-5
beta	2.9247571803	0.01372247	2.90329859	2.94632052

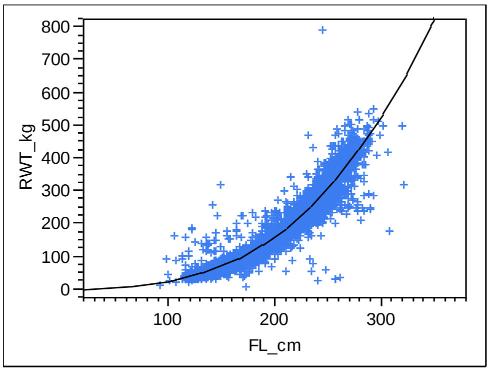


Figure 13. Nonlinear fit estimates of weight at size for farm harvest bluefin tuna by sex and combined group.

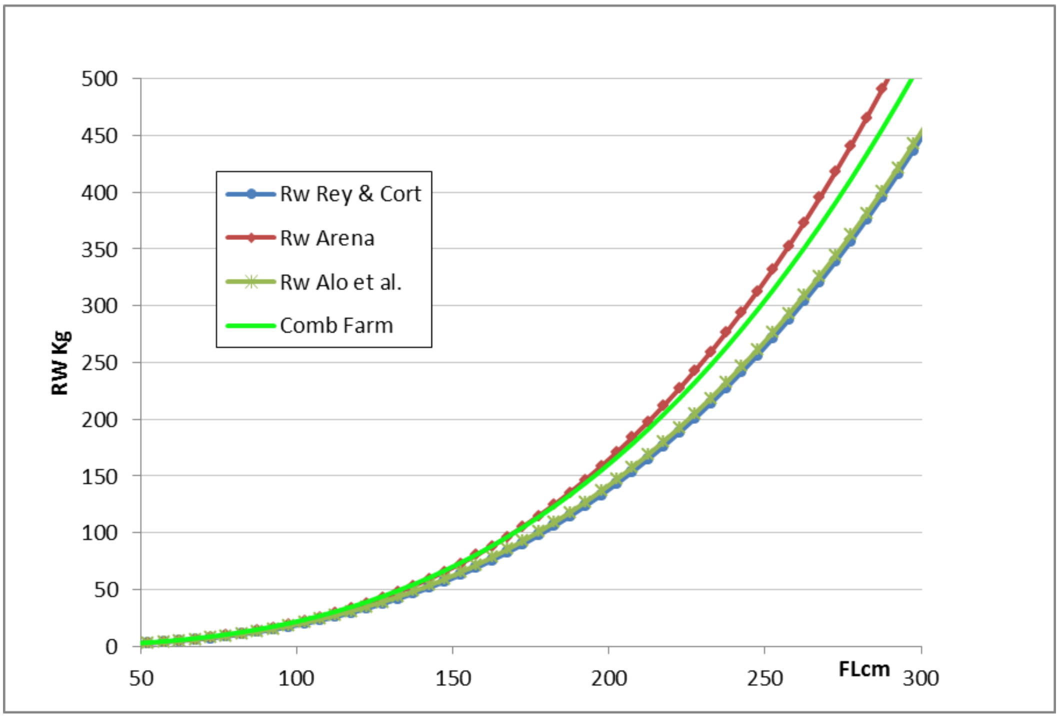


Figure 14. Comparison of estimated weight at size relationship for eastern bluefin tuna.

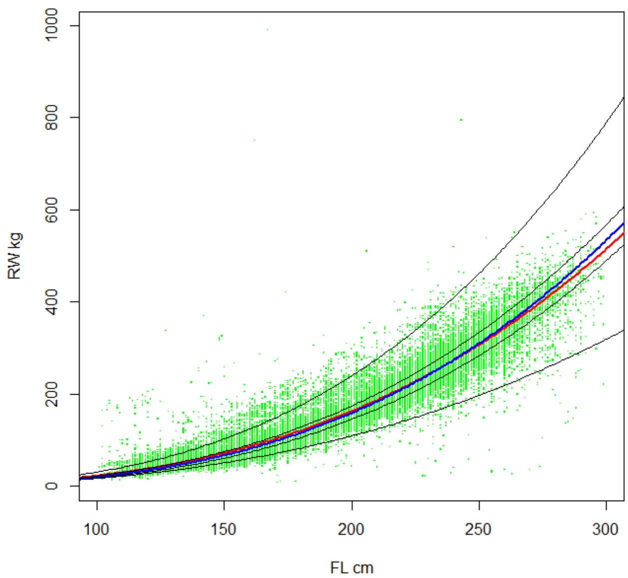


Figure 15. Comparison of Quantile regression fit (blue line) from farm harvest bluefin tuna and nonlinear power model fit (red line). Outer bands represent the 50% and 95% quantiles fits.

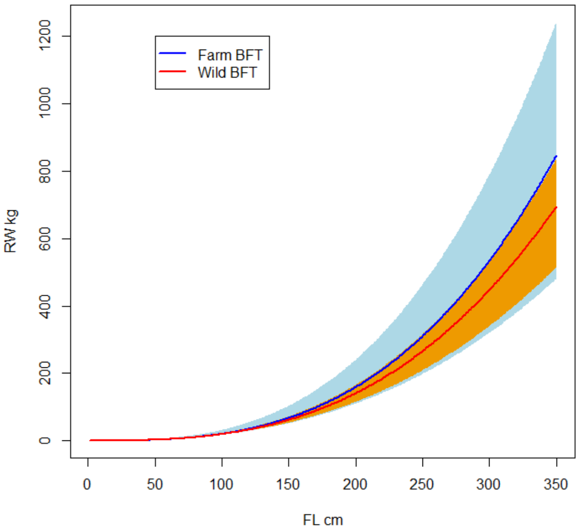


Figure 16. Comparison of the 95% quantile regression estimates for bluefin tuna weight at size from farm harvest fish (blue shade, and solid blue line) and wild fish (orange shade and red line). Data of wild fish was kindly provided by IEO scientist SCRS/2012/104.