A PECULIAR SITUATION FOR YOY OF BLUEFIN TUNA (*THUNNUS THYNNUS*) IN THE MEDITERRANEN SEA IN 2015

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SUMMARY

The year 2015 was the hottest so far in the Mediterranean Sea and the possible effects on the bluefin tuna reproductive biology were proposed to SCRS by GBYP in the same year. Now, after collecting some detailed samples and data about the presence of YOY in different parts of the Mediterranean Sea, it is possible to notice a peculiar situation, showing different size-at-time by area in late summer-fall and early winter 2015/2016, possibly mirroring fractioned spawnings and different growth rates. These fish might result in future problems for age readings and ALK at least for the juveniles of bluefin tunas born in 2015. This paper provides the growth curves and equations for the various cohorts of bluefin tuna YOY which have been detected and that were born in 2015.

RÉSUMÉ

L'année 2015 a été marquée par les températures les plus élevées observées jusqu'à présent en Méditerranée et l'ICCAT-GBYP a présenté, cette même année, au SCRS les effets que cela pourrait avoir sur la biologie reproductive du thon rouge. Actuellement, sur la base de quelques données et échantillons détaillés concernant la présence de jeunes de l'année ayant été recueillis dans différentes parties de la mer Méditerranée, il est possible d'observer une situation particulière montrant une taille à un moment donné variant selon la zone à la fin de l'été-automne et au début de l'hiver 2015/2016, ce qui refléterait des frais fractionnés et différents taux de croissance. Ces poissons pourraient engendrer des difficultés à l'avenir pour les lectures de l'âge et la clé d'identification âge-taille (ALK) au moins pour les juvéniles de thons rouges nés en 2015. Ce document fournit les courbes et les équations de croissance des différentes cohortes de jeunes thons rouges de l'année (YOY) qui ont été détectés et qui sont nés en 2015.

RESUMEN

El año 2015 ha sido el más caliente en el Mediterráneo y el GBYP presentó al SCRS en ese mismo año los posibles efectos en la biología reproductiva del atún rojo. Ahora, tras recopilar algunas muestras y datos detallados acerca de la presencia de juveniles del año en diferentes partes del Mediterráneo, es posible observar una situación peculiar, que presenta diferentes tallas por tiempo por áreas a finales de verano-otoño y principios de invierno de 2015/2016, que refleja posiblemente desoves fraccionados y diferentes tasas de crecimiento. Estos peces podrían provocar problemas futuros en relación con las lecturas de edad y ALK, al menos para los juveniles de atún rojo nacidos en 2015. Este documento presenta las curvas y las ecuaciones de crecimiento para varias de las cohortes de juveniles del año de atún rojo que han sido detectados y que nacieron en 2015.

KEYWORDS

Bluefin tuna, oceanography, climate, Mediterranean Sea, reproduction, growth rates

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1. Foreword

As reported in 2015 (Di Natale *et al*., 2016), bluefin tuna (*Thunnus thynnus*) shows immediate reactions to any environmental change like many other pelagic species, particularly when these changes occur during or close its spawning period. Some descriptions of these effects are provided by Piccinetti *et al*. (2013), a paper which includes also a summary of many other papers published in the last 150 years, but it is not so easy to have all necessary data for correlating bluefin tuna spawning behaviour, oceanography and therefore any possible effect on recruitment.

The occurrence and distribution of the main spawning areas was not very clear in the past; besides the evidence of bluefin tuna spawning in the Gulf of Mexico and in the Mediterranean Sea, the specific areas where bluefin tuna spawning regularly occurs was not well defined up to the first part of the XX century (Mather *et al*., 1995), while it was much better defined only at the very end of the XX century, when the eastern Mediterranean spawning area was finally documented. The major spawning areas in the Mediterranean Sea are around the Balearic Islands, in the southern Tyrrhenian Sea, in the central-southern Mediterranean (a large area from south of Sicily, Malta, a part of the Ionian Sea and possibly a part of the Gulf of Sirte) and in the eastern Mediterranean Sea (Di Natale, 2006; Piccinetti *et al*., 2013). These areas are consistent over the years and the aerial surveys carried out by ICCAT GBYP clearly supported this knowledge Di Natale and Tensek, 2016).

For the western Mediterranean Sea, the extensive work carried out by Rodriguez Roda (1964a, 1964b, 1967) in the Spanish traps confirmed that in May-June bluefin tuna were entering in the Mediterranean Sea with mature gonads, while they were going back after spawning, with gonads in a clear post-spawning situation, in late July-August. Several of these fish were supposed to spawn in the Balearic Sea, but not only, because many other tunas were moving also to other Mediterranean spawning grounds, as demonstrated by the history of the many Mediterranean traps (Parona, 1919; Heldt, 1930; Sarà, 1983, 1998), continuously mixing with tunas remaining in the Mediterranean for more than one year (Di Natale *et al*., 2005).

The extensive studies conducted on purse-seine fishery in the Tyrrhenian Sea (Arena, 1964, 1980, 1981, 1982a, 1982b, 1982c, 1985, 1986a, 1986b, 1988a, 1988b, 1990; Arena *et al*., 1979; Arena & Cefali, 2002), showed that the main reproductive season in this area is mostly between mid-May to mid-July, with a peak in June, usually showing a limited variability, before or after this period, each year, depending mostly on the oceanographic and environmental conditions. This period was confirmed also by De Metrio *et al*., (1988, 2003a, 2003b), Block *et al*., (2001) and Rooker *et al*. (2007) for the central Mediterranean Sea.

The central southern Mediterranean Sea is surely one of the main spawning areas for bluefin tuna in the Mediterranean Sea. Ancient trap data from Libya showed that many bluefin tunas were large mature individuals and it is supposed that most of them were spawning in the southern central Mediterranean. Apparently, the situation changed between the 80's and the '90s, when spawners were mostly concentrated in the Balearic Sea and in the southern Tyrrhenian Sea and purse-seiners exploring the Libyan waters were not able to find spawners close to the surface (Arena and Di Natale, 1987). Since 1996, after an important anomaly in the eastern Mediterranean Transient (EMT) (Di Natale, 2007), bluefin tuna spawners were again present in important quantities in these areas and most of the purse-seines catches of spawners have been reported from late May to early July in the large area around Malta, but also in the Gulf of Sirte. The situation went back to a more balanced one between the areas close to Malta and the southern Tyrrhenian Sea only since 2006, after a further change of the EMT (Di Natale, 2010b).

Spawning in the eastern Mediterranean and in the Levantine Sea usually occurs slightly earlier, starting in the first part of May (De Metrio *et al*., 2003b, Oray *et al*.,, 2005a, 2005b), when the sea temperature in this area increases well earlier than in all other parts of the Mediterranean Sea and when favourable weather situations allow the formation of an upper stratum with relatively high temperature and a stable thermocline at the proper depth. According to the earlier evolution of the hot water masses in the very last years, this situation possibly occurs also along the south-eastern part of the Mediterranean Sea, between the eastern Cyrenaica (Libya) and the eastern part of the Nile delta (Egypt).

In general, the main spawning season in the Mediterranean Sea is from the end of the second week of May to the second week of July with a clear peak around mid-June. The spawning season might have yearly variations in time, up to about 2-3 weeks on both sides, depending on the climate and oceanography, always keeping the peak in June so far. More extreme extensions might happen in few years (Piccinetti *et al*., 2013), but they are clear abnormalities. Spawning in the eastern Mediterranean starts usually before all other areas. Bluefin tuna spawning periods which have been more extended than usual were reported several times in the past (De Buen, 1923a, 1923b, 1923c; Biancalana, 1958; Scaccini, 1959; Arena, 1963, 1964; Sarà, 1983, 1998; Piccinetti *et al*., 2013), and other evidences were provided like "anomalous" size frequencies of age 0 and 1 in some spring-summer fisheries. Other evidences for prolonged spawning season were also provided by Piccinetti *et al*. (2013) for the years 2003, 2006, 2006 and 2011.

The reproduction occurs always in a fractionated manner in each bluefin tuna individual, but extended favourable oceanographc conditions for bluefin tuna spawning might increase or extend fractioned events. Marino *et al*. (2005) demonstrated that the same bluefin tuna female individual is able to release mature eggs from the ovary several times, over a certain period, with spawning having one or more days distance one from the other. In the same individual, spawning may occur during more than one month in the same season. Each bluefin tuna ovary contains various million of oocytes, recently assessed at 48 eggs g^{-1} by Aranda *et al*. (2013). A percentage of these eggs having the biggest size can be hydratated and released in a very short time following hormonal stimuli, which some predators may also captate (Suska *et al*. 2000, 2001; Schaefer, 2001; Medina *et al.* 2002; Abascal *et al.*, 2003, 2004; Corriero *et al*. 2003, 2005; Santamaria *et al*. 2003; Zupa *et al*. 2009). Logically, the same happens to male bluefin tunas, even if studies on male gonads are much more limited (Santamaria *et al.*, 2003; Abascal *et al*., 2004).

The effects of a "special" year in terms of climate and oceanographic conditions were noticed several times by ICCAT SCRS and they refer mostly to 2003, when a long and hot spring and summer had many positive effects on bluefin tuna spawning success and the consequent recruitment on both sides of the Atlantic Ocean, including the Mediterranean Sea. This specific year class was noticed in several fisheries. Bluefin tuna spawning in some recent years was more intense and/or expanded in time (and maybe also in space) in the Mediterranean Sea, resulting in a higher recruitment, particularly in 2003, 2006, 2007, 2009, 2010 and 2011. All these year classes showed-up in the same years at very small sizes (200-600 g) late in August and up to early September in many areas (Piccinetti *et al*., 2013), while the very strong 2003 class is now evident in almost all fisheries in the Atlantic Ocean and in the Mediterranean Sea, as a result of the climate anomalies in that year.

In 2015, following the usual day-by-day observations on the development of the oceanographic conditions in the Mediterranean Sea prior to and during the bluefin tuna spawning season in the Mediterranean Sea, GBYP had noticed since the beginning a very unusual situation and therefore a strict monitoring of various oceanographic parameters was established. At the same time, GBYP tried to obtain anecdotal real-time information on the fisheries in the various areas, especially on the specific behaviour of bluefin tuna in order to possibly correlate it with the particular oceanographic conditions noticed in 2015. Opportunistic spawning in marginal areas was also reported and in one case fully documented. The first observations were reported by Di Natale *et al*. (2016) to the SCRS.

This paper shows the very first data about the bluefin tuna YOYs collected in several Mediterranean areas in late summer – early fall 2015 and up to January 2016.

2. Oceanography and climate in late spring and early summer 2015

Since mid-April 2015 it has been clear that an unusual situation will occur in the Mediterranean. External temperatures were increasing almost everywhere, while sea-surface temperature (and the temperature in the upper layers) was showing various anomalous situations compared to averages in the last 20 years, and particularly compared to the recent years, since the beginning of the GBYP activities. The detailed evolution of the situation in spring-summer 2015 was described by Di Natale *et al*. (2016b).

The temperatures on land, in the last part of spring and the first part of summer 2015 in the Mediterranean Sea, were quite often over 40°C, due to a heat wave. SST in the Levantine Sea and in the Tyrrhenian Sea went over 30°C for weeks, while SST hotspots were noticed also in the Ionian Sea and in the Adriatic Sea. According to a very recent NOAA report (https://www.ncdc.noaa.gov/sotc/global/201513), 2015 was the hottest year after the XVI century.

Both the peculiar climatology and the oceanography in 2015 clearly affected the bluefin tuna spawning in the Mediterranean Sea, resulting in various fractioned spawning activities in different areas and possible different trophic chains.

3. The bluefin tuna YOYs in 2015

A fractioned bluefin tuna spawning logically results in different cohorts of young-of-the year (YOY). If spawning occurs over a very short time period, these cohorts are difficult to distinguish, because of the almost continuity of growth stages. When an undefined interval in time between one spawning even and the following occurs, then the larvae might find different environmental situation and possibly even partly different trophic chains, which are able to affect growth rates in the early life stages. Longer the interval between spawning events, greater the potential differences and longer the effects on growth rates.

These logical situation are usually very difficult to be documented or it is even difficult to find biological evidence in YOYs, either because it is difficult to obtain YOYs samples from various Mediterranean areas or because of the prohibition to catch these fish. Therefore, the only opportunity is to carry out a specific sampling, as it is usually done by ICCAT GBYP[7], or to monitor incidental catches in hand line fisheries targeting other pelagic species. In 2015 and up to January 2016 it was possible to take advantage of both opportunities.

The first information about the on-going collection of YOY samples in various Mediterranean areas was provided by Di Natale *et al*. (2016b), even if the existence of different cohorts was not clear at that time.

From August 2015 to January 2016 it was possible to collect length (FL) and weight (RW) data from a total of 363 bluefin tuna YOYs. 32 specimens were collected in the Balearic Sea (from 08/08/2015 to 13/10/2015), 39 specimens were sampled in the Ligurian Sea (from 03/08/2015 to 17/10/2015), 190 specimens were sampled in the southern Tyrrhenian Sea (from 23/08/2015 to 22/01/2016), 84 specimens were sampled in the Ionian Sea (from 25/09/2015 to 31/10/2015) and 18 specimens were sampled in the Levantine Sea (from 31/07/2015 to 29/09/2015). **Table 1** shows the distribution of samples by size and area of sampling (see map on **Figure 1** for the names of the various seas within the Mediterranean), while **Table 2** and **Figure 2** shows the distribution of samples by size and month. The difference in the number of samples by area was caused by the different availability of YOYs in the fisheries.

According to the average daily growth reported by La Mesa *et al*. (2005) and without considering at this stage any different growth rate by cohort or area and without taking into account any CV level, we can roughly estimate the following probable dates of birth for each area and cohort:

Balearic Sea: 26/04/2015 and 25/06/2015
Ligurian Sea: 27/04/2015 and 08/06/2015
Southern Tyrrhenian Sea: 26/05/2015, 01/07/2015 and 04/08/2015
Ionian Sea: 15/05/2015 and 26/06/2015
Levantine Sea: 27/04/2015and 26/05/2015

Intermediate spawning events might have been occurred as well between or near the above dates. Furthermore, it should be considered that sampling Bluefin tuna YOY in one area does not necessarily imply that these fish were born in this given area; it is the case of the Ligurian Sea, an area where spawning of bluefin tuna was never reported so far, but which is a very well-known distribution and feeding area for bluefin tuna juveniles, including YOY (Relini *et al*., 1995, 1999).

According to the data analysis, it was possible to detect three possible cohorts among the entire Mediterranean areas (**Figure 3**), each one with a different average growth and different FL/RW correlation (**Figure 4**), with some variability.

The three cohorts were analysed in detail (the various parameters are shown on **Table 3**) and they provided three different length/weight correlations as follows:

1st cohort: $W=10^{-4.99051} * L^{3.15487}$
2nd cohort: $W=10^{-5.33429} * L^{3.40862}$
3rd cohort: $W=10^{-7.0729} * L^{4.5524}$

The distribution of samples by L/W and the logarithmical correlations are shown by cohort on **Figure 5**.

[7] The bluefin tuna YOY that were sampled in 2015 for the GBYP biological studies have been all duly registered and reported by RMA certificates, according to ICCAT Rec. 11-06. These samples have been also reported to ICCAT and SCRS along with all other RMA certificates.

4. Discussion

The unusual environmental and oceanographic conditions which characterized the year 2015 were possibly the motivations for having another year with an extended bluefin tuna spawning season and more evident fractioned spawning events. This confirms what we wrote in a previous paper (Di Natale *et al*., 2016) "The unusual high temperatures, the variable thermocline, the strong winds in many areas which contributed to the mixing of the upper layer, the wide distribution of adult bluefin tuna in most of the Mediterranean areas, possibly induced it in adopting a different spawning strategy in 2015, opting for a fractioned spawning and taking advantage of appropriate oceanographic conditions and opportunities whenever they were present and moving quickly within various areas of the Mediterranean for catching them."

According to the data we had from the YOY collection, it seems that the bluefin tuna spawning season in 2015 was extended from the last part of April to the first part of August, much more than the usual variability but always within the extremes known to have been occurred so far in some previous years (Piccinetti *et al*., 2013). If this extended spawning season will result in another year of high recruitment is still uncertain, but usually strong year classes are also correlated to the events noticed in 2015.

The fractioned spawning necessarily implied that the larvae possibly found different trophic chains, some more appropriate and fitted than others, and these ecosystem variables necessarily induced differ growth rates for different cohorts. We cannot correlate the different cohorts to the various areas, because of the unbalanced opportunistic sampling, but it is possible that growth was partly different also in some areas.

The presence of various cohorts of bluefin tuna YOY is not unusual and this possibility was reported also by Orsi Relini *et al*. (2009) for the Ligurian Sea and for the year 1994, but without any further specific analysis. Various cohorts for the same year might also partly explain, along with other factors, some discrepancies in various L/W correlations described by several scientists so far.

The existence of various cohorts in bluefin tuna YOY having also different growths will certainly create problems for developing the ALK for this year class, at least for the first two years of life, increasing the uncertainties for age readings.

Again, these real-time observations confirm the importance of strictly monitoring several oceanographic and environmental factors, along the presence and distribution of juvenile bluefin tunas for possibly correlating them and for trying to further improve our knowledge and understanding of this species.

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Table 1. Distribution of 2015 bluefin tuna YOY samples by area of sampling.

Area	FL (cat 2,5 cm)																		
	12,5	**15,0**	**17,5**	**20,0**	**22,5**	**25,0**	**27,5**	**30,0**	**32,5**	**35,0**	**37,5**	**40,0**	**42,5**	**45,0**	**47,5**	**50,0**	**52,5**	**55,0**	**57,5**	total
Balearic Sea						2	9	12		2				6	1					32
Ligurian Sea	1	4	3	9	9			2	1	3	4									36
s. Tyrrhenian Sea				17	20	7	12	2	6	4	20	11	10	23	29	6	6	8	9	190
Ionian Sea							3	28	36	6	11									84
Levantine Sea			3	8	2				2	1	1	1								18
Total	1	4	6	34	31	9	24	44	45	16	39	12	10	29	30	6	6	8	9	**363**

Table 2. Distribution of 2015 bluefin tuna YOY samples by month.

Month	FL (cat 2,5 cm)																		
	12,5	**15,0**	**17,5**	**20,0**	**22,5**	**25,0**	**27,5**	**30,0**	**32,5**	**35,0**	**37,5**	**40,0**	**42,5**	**45,0**	**47,5**	**50,0**	**52,5**	**55,0**	**57,5**	total
July			1																	1
August	1	4	5	34	31	5	9	5		2										96
September						4	14	26	36	4	5	1								90
October							1	13	8	10	27	11	4	22	10					106
November													6	7	7	3				23
December											7				13	1	5	5	9	40
January									1							2	1	3		7
Total	1	4	6	34	31	9	24	44	45	16	39	12	10	29	30	6	6	8	9	**363**

Table 3. Parameters of the equation $W = a L^b$, used for predicting YOY bluefin tuna length-weight relationship for the three cohorts in 2015. Weight is in kg.

Group	Sample size	Length range (cm)	a	b	R^2
1st born	126	15.4-59	$1.022*10^{-5}$	3.15487	0.9822
2nd born	208	14.8-57	$4.631*10^{-6}$	3.40862	0.9823
3rd born	29	29-39.5	$8.455*10^{-8}$	4.5524	0.9792

Figure 1. Map of the Mediterranean Sea, showing the different internal seas.

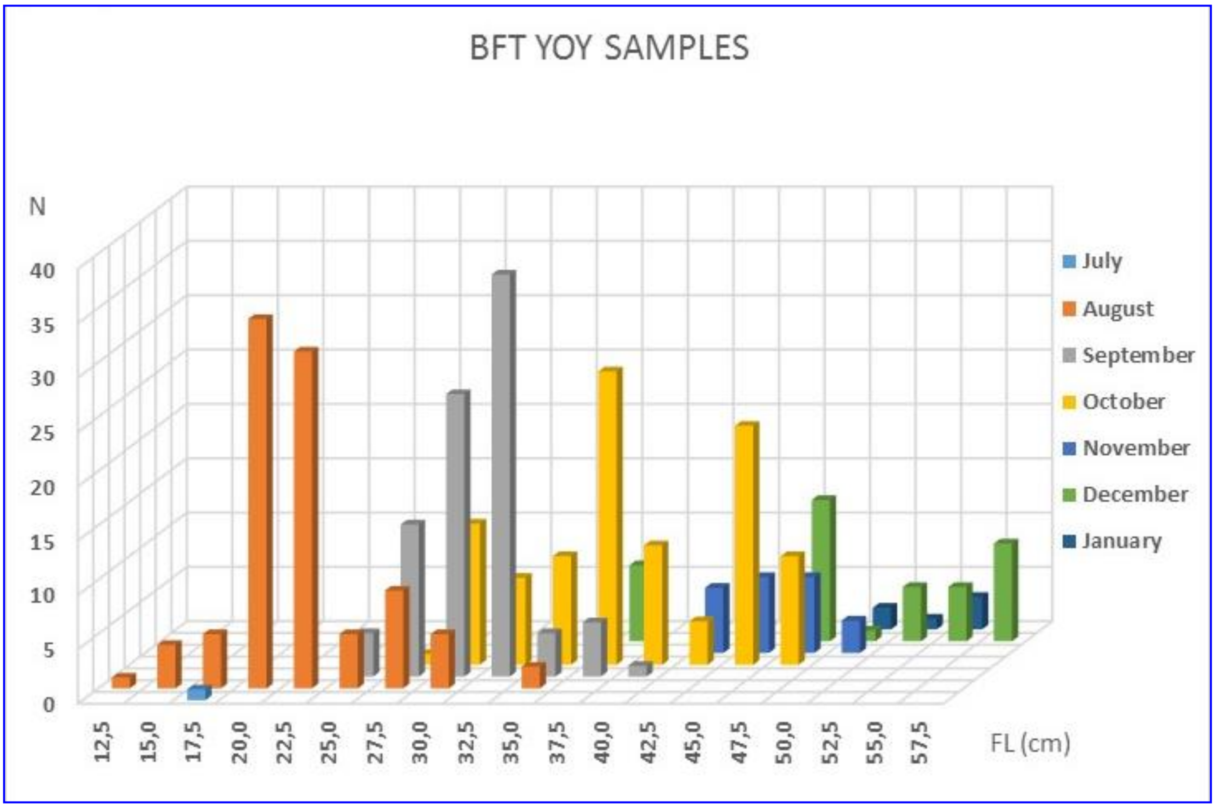


Figure 2. Distribution of 2015 bluefin tuna YOY samples collected in the various Mediterranean areas by month and size class.

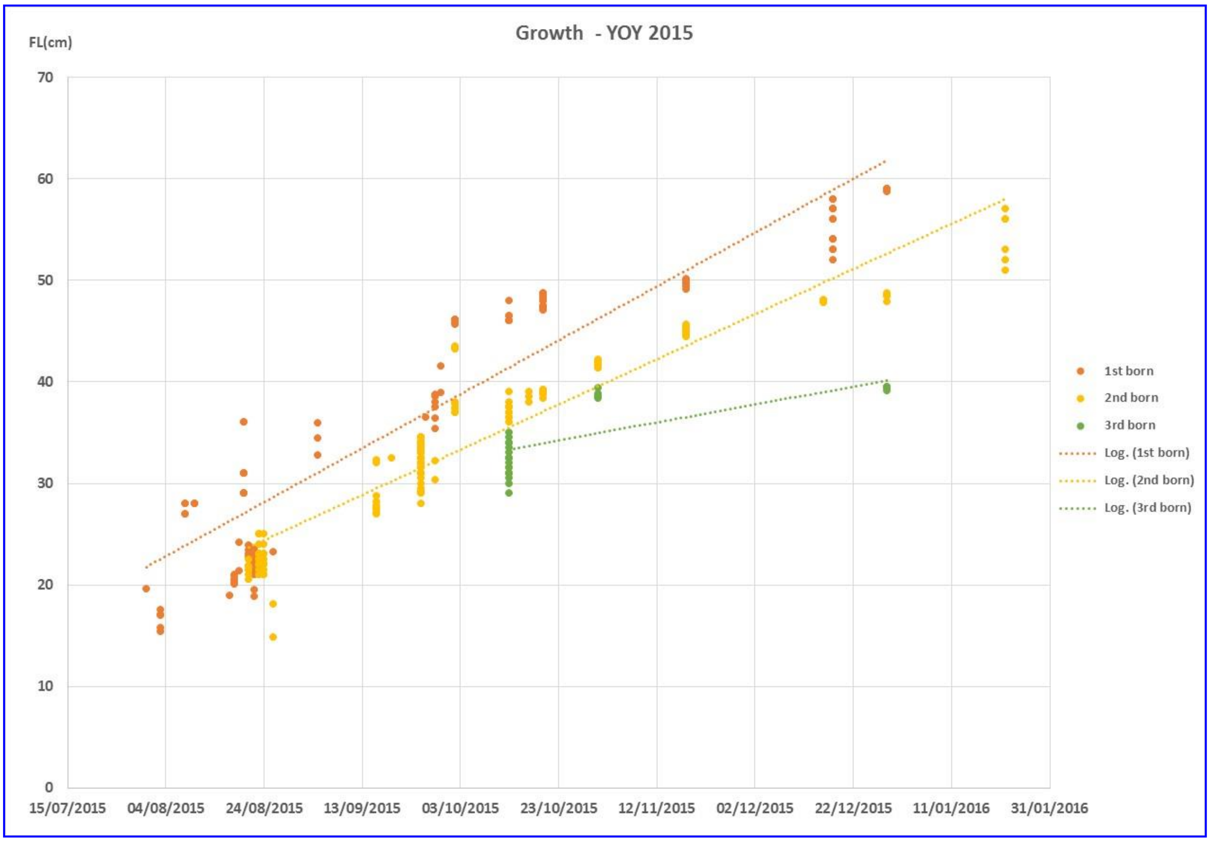


Figure 3. Growth at date of the different cohorts of bluefin tuna YOYs in the Mediterranean Sea in 2015.

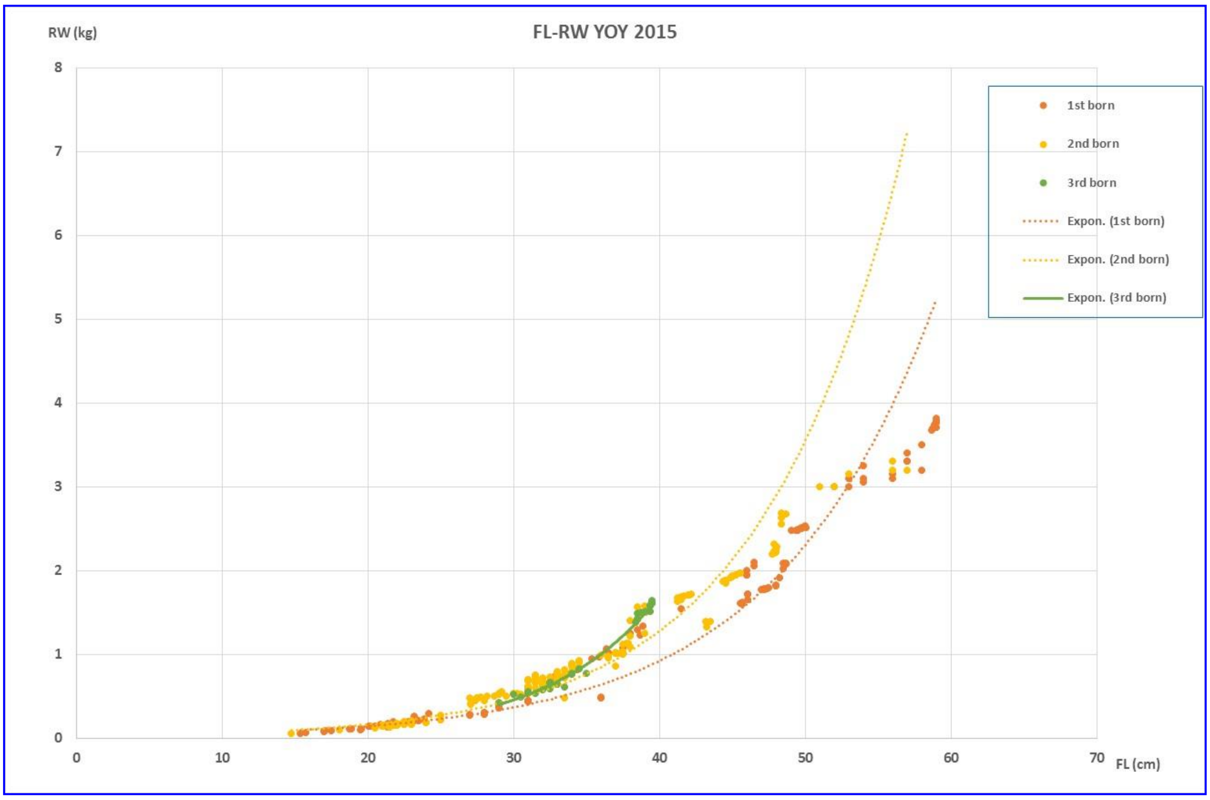
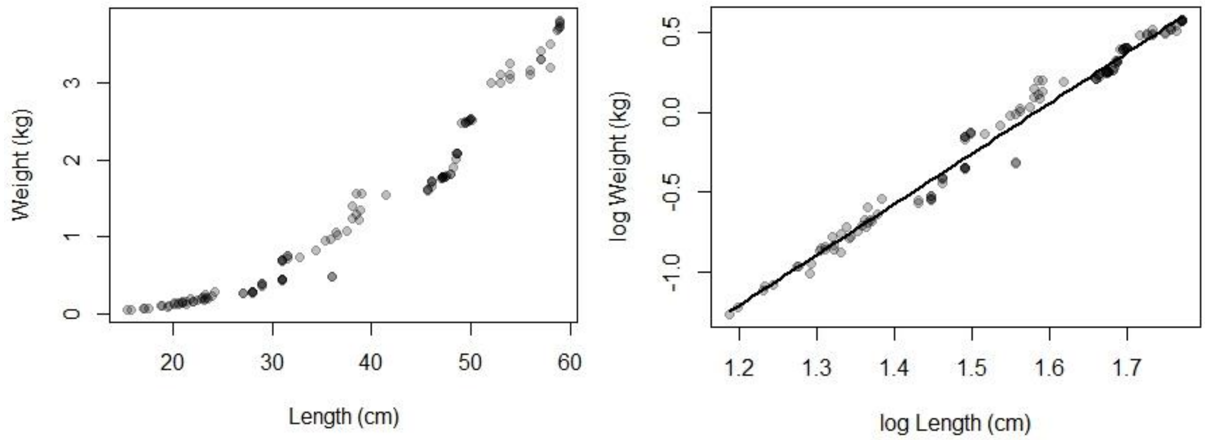
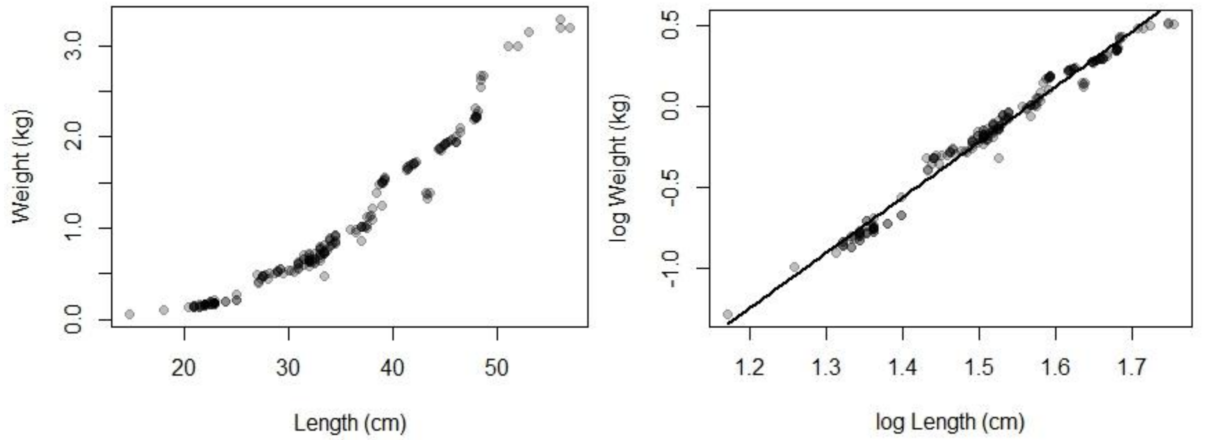


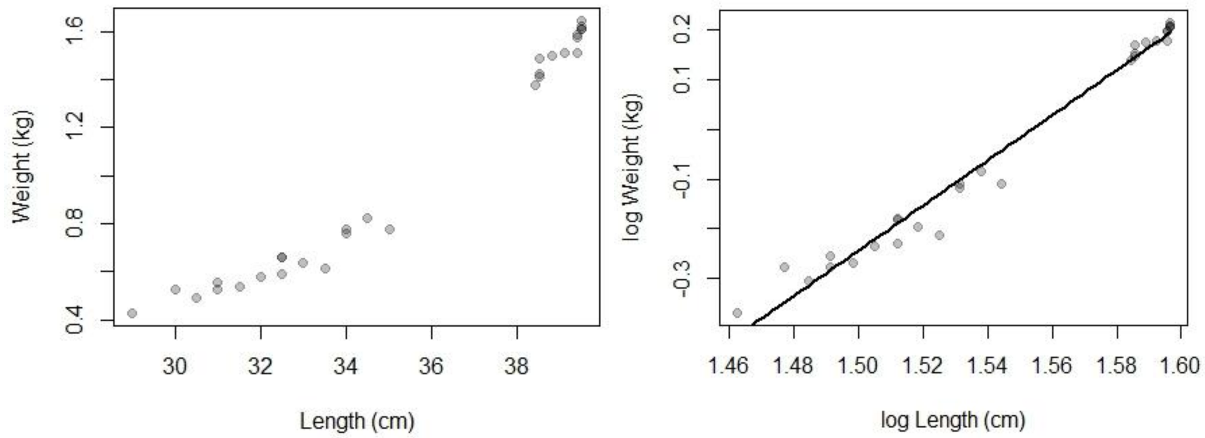
Figure 4. Length (FL)/weight (RW) correlation of the different cohorts of bluefin tuna YOYs in the Mediterranean Sea in 2015.



1st cohort



2nd cohort



3rd cohort

Figure 5. Distribution of samples by length/weight for the three cohorts (left graphs) and logarithmical correlations (log10-log10 transformed) for the same samples, showing the good fitting.