ANOTHER PECULIAR SITUATION FOR YOY OF BLUEFIN TUNA (*THUNNUS THYNNUS*) IN THE MEDITERRANEAN SEA IN 2016

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SUMMARY

The possible effects of the hottest temperatures recorded in 2016 (the hottest so far) on the bluefin tuna reproductive biology have been discussed by the SCRS in the past, but the situation in 2016 was very different. After collecting some detailed samples and data about the presence of YOY in various parts of the Mediterranean Sea, an unusual situation can be observed, showing different size-at-time by area in late summer-fall 2016, possibly mirroring early, late, fractioned and continued 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 2016. This paper provides the growth curves for the many cohorts of bluefin tuna YOY which have been detected and that were born in 2016.

RÉSUMÉ

Le SCRS a discuté des effets que les températures les plus chaudes enregistrées en 2016 (les plus chaudes jusqu'à présent), et celles survenues antérieurement, pourraient avoir eu sur la biologie reproductive du thon rouge, mais la situation de 2016 était très différente. Après avoir recueilli quelques données et échantillons détaillées concernant la présence de jeunes de l'année 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 2016, ce qui refléterait des frais ayant eu lieu tôt, tard, de manière fractionnée et continue, ainsi que 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 2016. Ce document fournit les courbes de croissance de plusieurs cohortes de jeunes thons rouges de l'année (YOY) qui ont été détectés et qui sont nés en 2016.

RESUMEN

El SCRS debatió los posibles efectos de las temperaturas más cálidas registradas en 2016 (las más cálidas hasta la fecha) e incluso de las del pasado, sobre la biología reproductiva del atún rojo, pero la situación en 2016 fue muy diferente. 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 poco usual, que presenta diferentes tallas por tiempo por áreas a finales de verano-otoño de 2016, y que posiblemente refleja desoves tempranos, tardíos, fraccionados y continuos, así como 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 2016. Este documento presenta las curvas de crecimiento para varias de las cohortes de juveniles del año de atún rojo que han sido detectadas y que nacieron en 2016.

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 main spawning season. 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 the Bluefin tuna spawning behaviour, oceanography and therefore any possible effect on recruitment.

These effects are even further less known in terms of larval survival success at a basin scale and in terms of YOY recruitment, even if some local small-scale fisheries are usually good tools for monitoring the recruitment in real-time.

The complexity of the Mediterranean Sea, with its various oceanographic situations, has usually a direct effect on the spawning activity, which is partly differentiated between areas, with early spawning in the eastern part (Levantine Sea) and then quite often a prolonged spawning in the western part (Balearic Sea) or, more recently, even in the Tyrrhenian Sea. Usually, the peak of the spawning season is mid-June, with small variations from year to year, depending on the climatology and the oceanography. This peak usually implies that the Bluefin tuna young of the year (YOY) specimens have a well-known growth, at least up to December, something also well-known by several small-scale fishermen. The variability in size at time is usually quite reduced and smoothed at the end of December.

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 well-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 (Karakulak *et al.*, 2004; Oray and Karakulak, 2005; 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). Opportunistic spawning may occasionally occur in other areas when the proper oceanographic conditions are met.

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 anomalies. Spawning in the eastern Mediterranean starts usually well before all other areas, due to the early warming of the Levantine Sea. 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, 2007 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 (the so-called "pulse spawning"). 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} in average 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 in the following years. 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. Anomalies were also reported for 2015, the second hottest year so far (Di Natale *et al*., in press a).

This paper shows the very first data about the Bluefin tuna YOY collected in several Mediterranean areas in the second half of 2016.

2. Oceanographic situation in 2016

Since the beginning of February 2016 it has been clear that an unusual situation would occur again in the Mediterranean, but we were not sure if the situation will be similar to the anomaly noticed in 2015 or not. 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.

As a matter of fact, in these last years the temperature in the eastern part of the Mediterranean (Levantine Sea and area around the Nile delta) has usually started increasing in the last part of April, rapidly reaching over 21°C SST. This is the reason why the Bluefin tuna usually starts its spawning in the eastern Mediterranean, sometimes a couple of weeks before than in the other parts of the same Sea.

With the contribution of eight consecutive high monthly temperature records set from January to August, and the other months ranking among their five warmest, 2016 became the warmest year in NOAA's 137-year series (https://www.ncdc.noaa.gov/sotc/global/201613), possibly the hottest year after the XVI century. In global average, the marine and land temperature in 2016 was 0.94°C above the 20th century average, while the SST temperature was 0.75°C above the 20th century average. The SST Mediterranean temperatures at the early beginning of the year (late January and February) were quite high compared to usual average, particularly in the southern and eastern Mediterranean area.

This year the situation was different, because the sea surface temperature reached the 20°C even in the second part of February in several Mediterranean areas, quite too early compared to a "normal" SST. This very anomalous situation remained as such until about the end of February, with temperatures around 20°C in the eastern and the central-southern part of the Mediterranean (more than 1/3rd of the full Mediterranean Sea).

At the same time, the salinity showed some anomalies, being higher than usual in average, particularly at the early beginning of the year and in autumn. The detailed evolution of the oceanographic conditions is described by Di Natale *et al*. (in press b).

How all these (plus others not listed here, partly unknown) oceanographic and environmental anomalies affect the Atlantic Bluefin tuna reproductive biology and the behaviour of the YOY can be only supposed.

3. The bluefin tuna YOYs in 2016

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

These logical situations are usually very difficult to be documented or it is even difficult to find biological evidence in YOYs, either because it is not easy to obtain YOY samples from various Mediterranean areas at the same time or because of the prohibition to catch these fish (which excludes sampling from the professional fisheries).

Therefore, the only opportunity is to carry out a specific sampling, as it is usually done by ICCAT GBYP[8], or to monitor incidental catches in hand line fisheries targeting other pelagic species. In the second half of 2016 it was possible to take advantage of both opportunities.

From July to December 2016 it was possible to collect length (FL) and weight (RW) data from a total of 547 Bluefin tuna YOY. 216 specimens were collected in the Balearic Sea (from 11/09/2016 to 18/11/2016), 19 specimen were sampled in the Ionian Sea (on 25/09/2016), 36 specimen were sampled in the Levantine Sea (from 22/07/2016 to 10/09/2016), 20 specimen were sampled in the Ligurian Sea (from 02/08/2016 to 18/09/2016), 74 specimen were sampled off Southern Spain (from 02/09/2016 to 27/11/20169) and 182 specimen were sampled in the Tyrrhenian Sea (from 16/08/2016 to 17/12/2016).

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** show the distribution of samples by size and month. The difference in the number of samples by area was caused by the different availability of YOY in the fisheries, besides many efforts and fully dedication of several scientists. For details on the disappearance of YOY from the Mediterranean coasts in 2016 see Di Natale *et al.* (2018 *In press*).

According to the data analysis, it was possible to detect seven 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 YOY in July are not usual, but they can be logically found when there is the early spawning in the Eastern Mediterranean Sea; as a matter of fact, the YOY samples in July ranged from 0.047 to 0.094 gr and from 14.2 to 17.4 cm (SFL), and they were all found only in the Levantine Sea.

The most surprising sampling result was in August, when we had YOY ranging from 0.05 kg to 2.843 kg and from 14.6 cm to 52.56 cm. The samples were collected in the Levantine Sea, in the Southern Tyrrhenian Sea and in the Ligurian Sea (we have been informed that some small YOY showed-up in the second part of August also along the Catalonian coast, in Spain, but their sampling was not possible). The anomaly was related to the presence of YOY having big size and weights for this month, as it was noticed in the southern Tyrrhenian Sea, where it was possible to sample contemporary specimens of all 7 cohorts, including the first two ones, those having the highest weights and size. As a matter of fact, a Bluefin tuna YOY reaching a size of 52.6 cm and 2.843 kg in August is a clear sign of a very anomalous situation, particularly because it was together with other individuals of the same cohort. At the same time, it was noticed a second cohort where the biggest individual had a size of 41.2 cm and 1.379 kg.

The fist cohort was then sampled again in the Ionian Sea, in September, ranging from 45 to 51.8 cm and from 1.83 to 2.68 kg. The biggest individuals were respectively 51.8 cm/2.58 kg, and 51 cm/2.68 kg. This first cohort was never found later in the year in any area, possibly because it found a proper food chain quite offshore, in deeper waters.

It should be always 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).

4. Discussion

The unusual environmental and oceanographic conditions which characterized the year 2016 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."

[8] The bluefin tuna YOY that were sampled in 2016 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.

The pulse and 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 and also for the opportunistic displacements of the YOY within the Mediterranean, but it is possible that growth was partly different also in some areas.

So far, with the samples we have, it was possible to identify seven different cohorts in 2016 (**Figure 3**), but some of these cohorts include quite a large dimensional range of YOY, a possible indicator of a continuous pulse spawning in that period. Some overlapping may mask further cohorts. Furthermore, few specimens clearly had different growth (the few isolated points which are far from the line in **Figure 4**). As far as we know, this is the first time that it is possible to detect so many different cohorts in the same year.

Under these anomalous circumstances, this year it was decided not to elaborate any growth equation for the 2016 Bluefin tuna YOY, because of the difficulties for following the various cohorts over the different months.

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.

In addition, anomalously high sea surface temperatures in the first half of the year and unusually high levels of salinity were probably the trigger that affected the Atlantic bluefin tuna reproductive biology in a way to cause the anticipated spawning, at least in some areas.

As concerns the anomalous big YOY individuals sampled in the Tyrrhenian Sea and in the Ionian sea, considering that these weights and sizes can be usually attained at the end of December for YOY that were born in the first part of June (equal to at least 6 and ½ months), it is therefore logical to imagine that this first cohort sampled in August was born in February somewhere in the Mediterranean, possibly in the Levantine Sea or in the southern-central Mediterranean, originated only from Bluefin tuna adults that overwintered in the Mediterranean Sea. Can we imagine that some Bluefin tuna adults can begin their sexual maturation in late January and then spawn in February? From a physiological point of view, potentially yes, even if an event like this is very far from the normality. According to Corriero *et al*. (2003), the ovary development needs less than two months between the very initial state with the appearance of oocytes at the lipid stage and the spawning, therefore the observation concerning these anomalous YOY might reflect a very extreme but potentially possible early anomalous maturation and spawning.

If something like this happened, looking at the cohorts this happened possibly twice in early 2016, with a short delay between the first two events or with some area differentiation, because these two first cohorts had different growth rates. Always on the same line, possibly both cohorts found food chains slightly different from the usual, and this therefore possibly affected their growth, but we are not able to say if this had a positive or a negative effect. Surely, this situation was well outside the extremes reported by Piccinetti *et al*. (2013) for anticipated or delayed Bluefin tuna spawning in the Mediterranean Sea. Further analyses, including the ageing through the reading of daily ring, may contribute to better clarify the periods of these anomalous events.

These real-time observations confirm again the importance of strictly monitoring several oceanographic and environmental data (along with the YOY presence in all the Mediterranean) for possibly correlating them with the Bluefin tuna distribution and behaviour, trying to further improve our knowledge and understanding of this species, particularly in early life stages. Furthermore, the provision in real time of this information to ICCAT SCRS BFT Species Group may allow for better understanding future data sets.

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Table 1. Distribution of 2016 Bluefin tuna YOY samples by area of sampling, for 0.5 cm classes.

Area	FL (cat 2,5 cm)																		
	12,5	**15**	**17,5**	**20**	**22,5**	**25**	**27,5**	**30**	**32,5**	**35**	**37,5**	**40**	**42,5**	**45**	**47,5**	**50**	**52,5**	**55**	**total**
Balearic Sea	1	3	2	8	21	41	26	13	12	32	12	13	20	11	1				216
Ionian Sea														6	7	6			19
Levantine Sea	2	9	3	2	1	2		8	6	3									36
Ligurian Sea	1	4	3	6	2	2		2											20
Southern Spain			1	1	11	36	9	9	6	1									74
Tyrrhenian Sea			5	8	11	14	22	16	20	12	8	5	10	20	15	11	1	4	182
Total	4	16	14	25	46	95	57	48	44	48	20	18	30	37	23	17	1	4	**547**

Table 2. Distribution of 2016 Bluefin tuna YOY samples by month, for 0.5 cm classes.

Month	FL(cat2,5)																		
	12,5	**15**	**17,5**	**20**	**22,5**	**25**	**27,5**	**30**	**32,5**	**35**	**37,5**	**40**	**42,5**	**45**	**47,5**	**50**	**52,5**	**55**	**total**
July	2	7																	9
August	1	6	11	15	13	13	12	6	10	8	6	5	2	5	1	1	1		116
September	1	3	3	10	26	45	24	22	10	5	1			6	7	6			169
October					7	37	21	19	23	32	6	3							148
November								1	1	3	7	10	20	11	1				54
December													8	15	14	10		4	51
Total	4	16	14	25	46	95	57	48	44	48	20	18	30	37	23	17	1	4	**547**

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

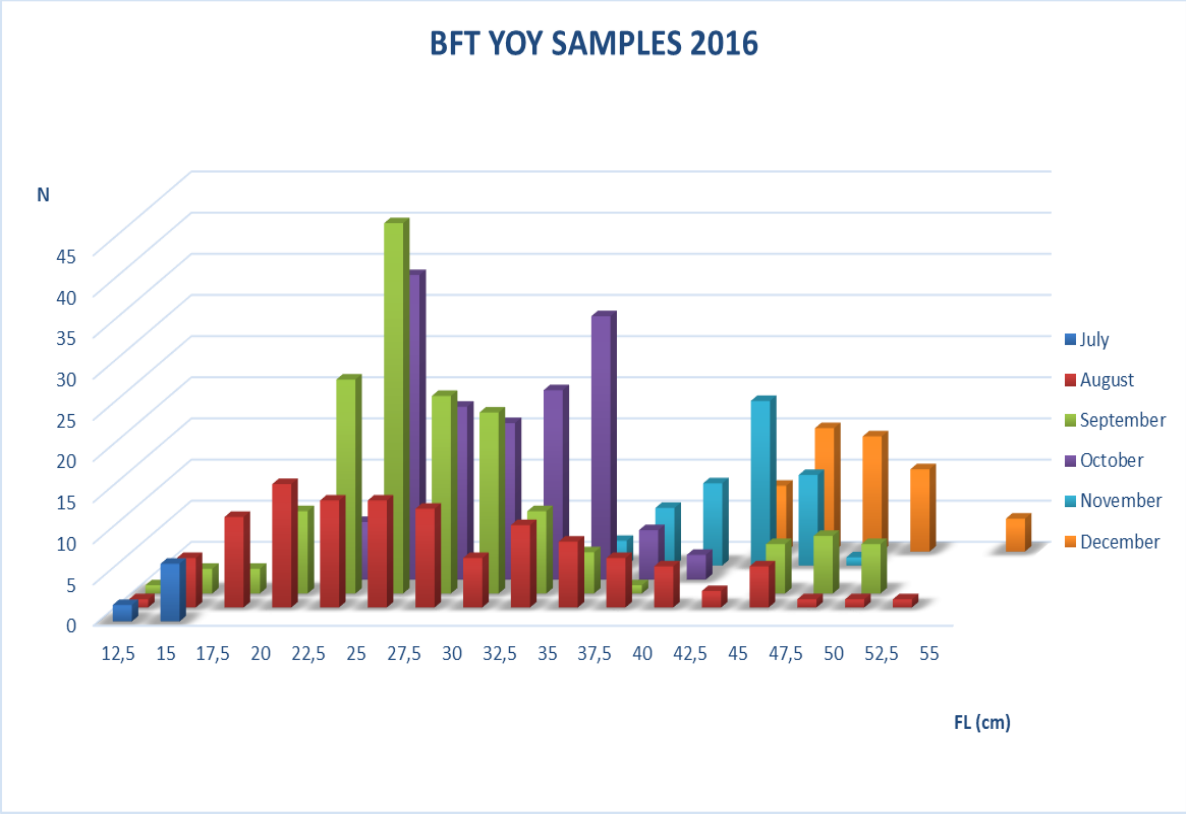
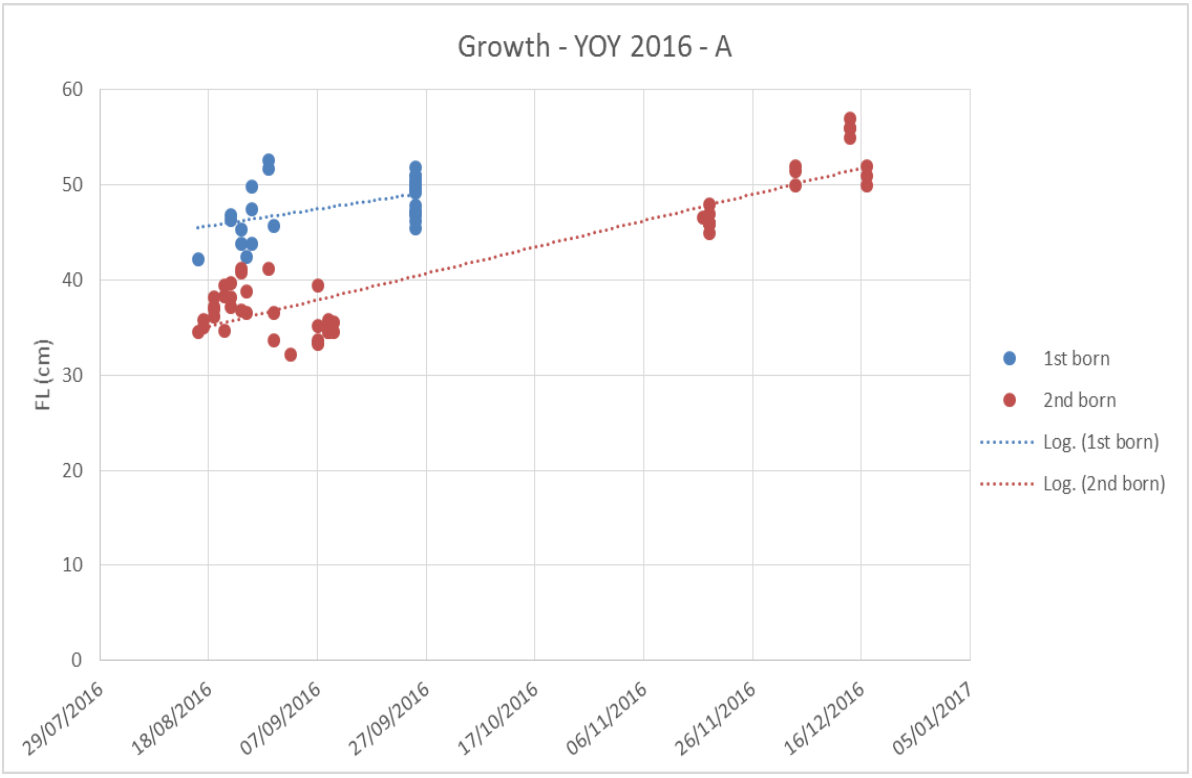


Figure 2. Distribution of 2016 bluefin tuna YOY samples collected in the various Mediterranean areas by month and size class.



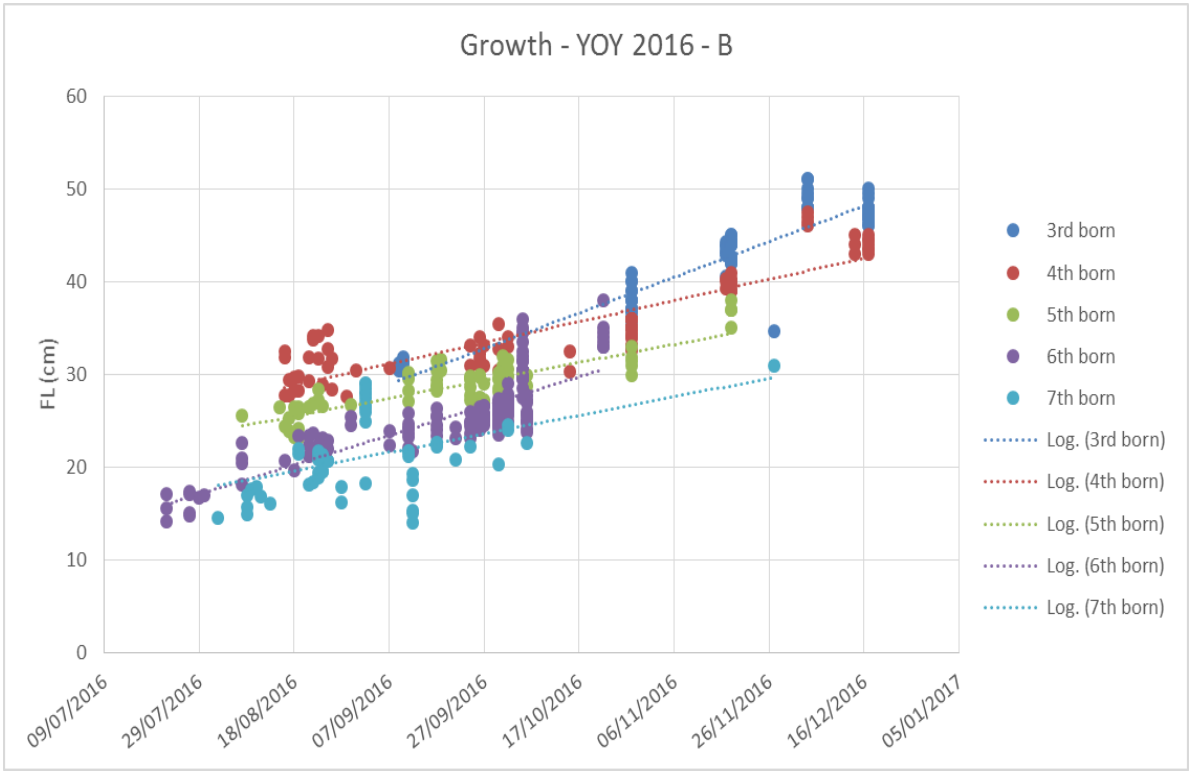
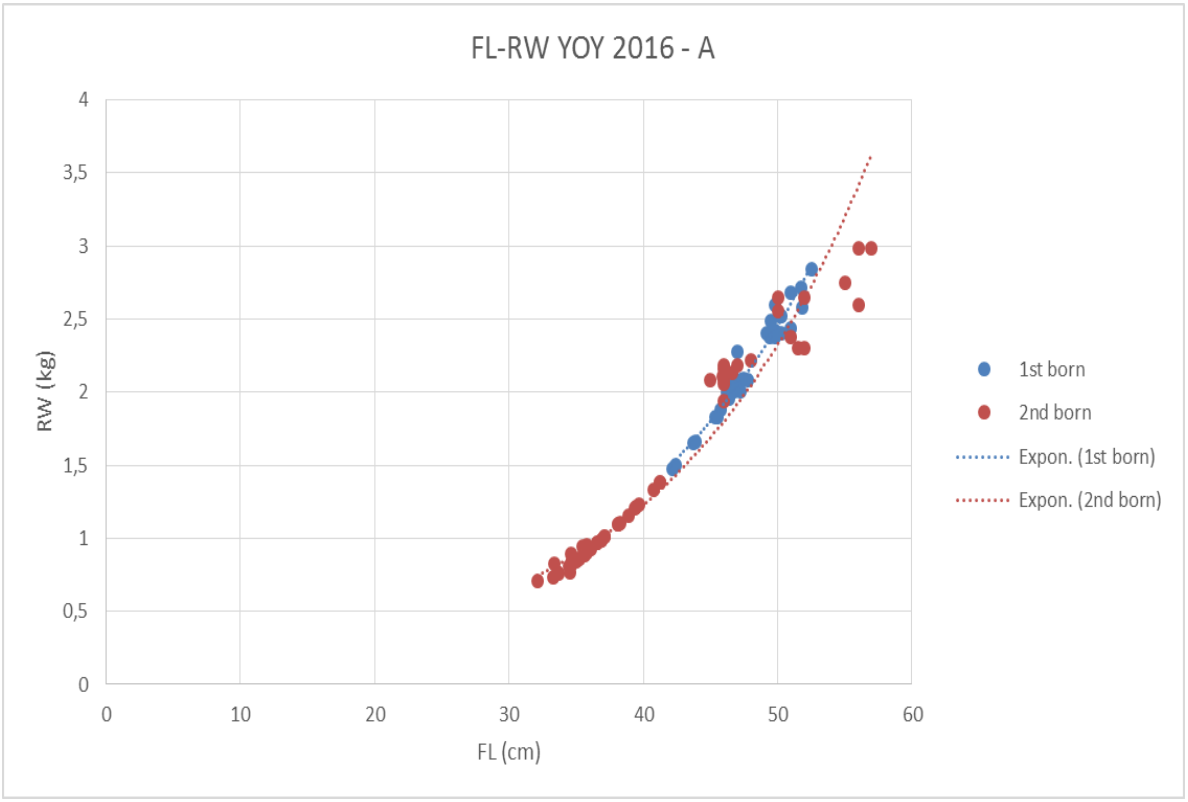


Figure 3. Growth at date of the different cohorts (above: 1st-2nd born; below: 3rd-7th born) of bluefin tuna YOYs in the Mediterranean Sea in 2016.



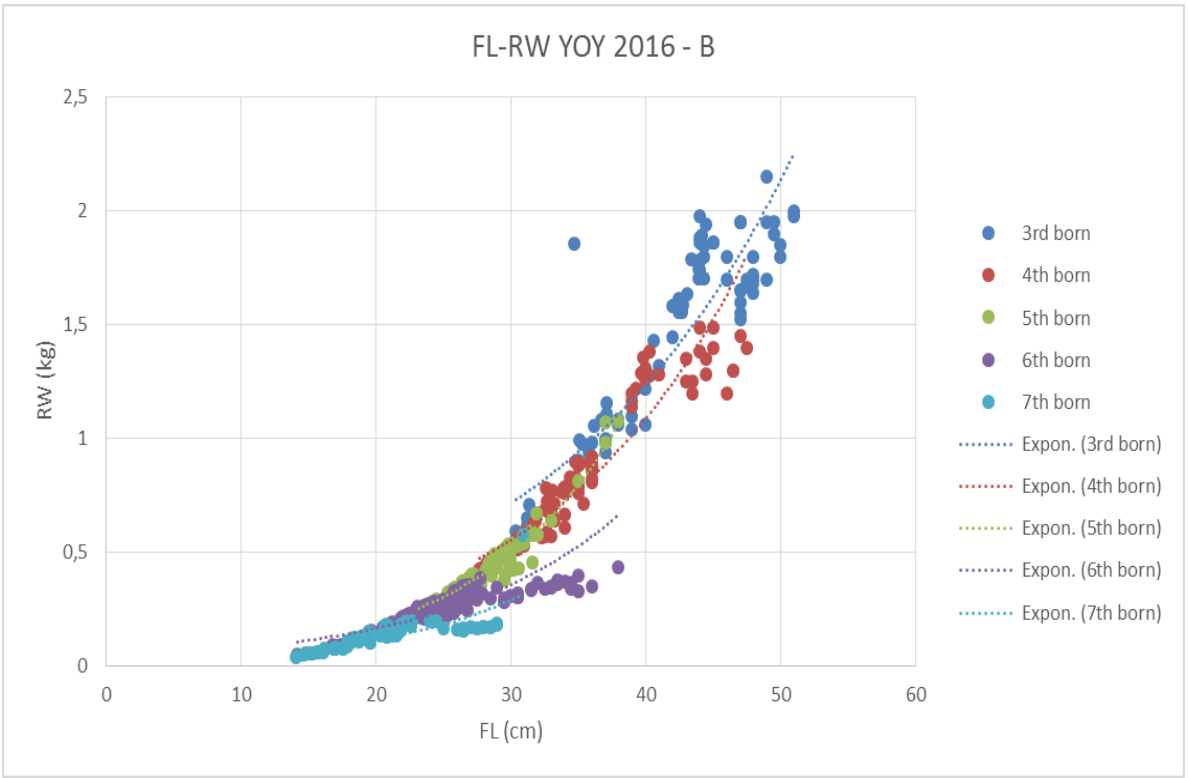


Figure 4. Length (FL)/weight (RW) correlation of the different cohorts (above: 1st-2nd born; below: 3rd-7th born) of bluefin tuna YOYs in the Mediterranean Sea in 2016.