REDELVE INTERNATIONAL PUBLICATIONS

Current Trends in Fisheries and Aquaculture
Volume 2019, Issue 01
Research Article: RD-FSH-10001

Reproductive Dynamics and Fecundity of *Coryphaena Hippurus* (Linnaeus,1758) In the Eastern Tunisian Coast (Central Mediterranean)

Amina Besbes Benseddik, Raouf Besbes, Hechmi Missaoui, Soufia Ezzeddine Najaï, Othman Jarboui*

National Institute of Science and Technology of the Sea (INSTM), Tunisia

*__Corresponding author:__ *Amina Besbes Benseddik, INSTM (Centre of Monastir), Road of Khniss P.O. 59, 5000 Monastir, Tunisia. Email: amina_besbes@yahoo.fr*

Citation: Benseddik AB, Besbes R, Missaoui H, Najaï SE, Jarboui O (2019) Reproductive Dynamics and Fecundity of *Coryphaena Hippurus* (Linnaeus,1758) In the Eastern Tunisian Coast (Central Mediterranean). Curr Tren in Fish and Aqua: RD-FSH-10001.

Received Date: 01 March 2019; **Accepted Date:** 14 March 2019; **Published Date:** 22 March 2019

Abstract

In this study we investigate the reproductive dynamics of the common dolphinfish (*Coryphaena hippurus*), using gonads obtained from traditional eastern fisheries of Tunisia. From May 2013 and December 2014, a total number of 379 dolphinfish were collected (110 males and 269 females), ranging in size from 18 to 110 cm Fork Length (FL). The sampling revealed a marked seasonality in abundance with 94% of samples obtained in summer-autumn. Sex ratio (females: males) is 2 :1. At different size classes, it showed a clear dominance of females (FL< 63 cm) whereas males predominate for larger sizes (FL>63 cm). First sexual maturity is estimated at 53.5 cm (FL) for females and 60.5 cm (FL) for males. Gonado-Somatic-Index (GSI) evolution, show that the spawning period occurs between May and September. Hepato-Somatic Index (HSI) and the Condition Factor (CF)do not indicate that dolphin fish use liver and muscles reserve to develop its gonads. Ovarian development showed different kinds of oocytes, indicating that dolphinfish have asynchronous gonadal development. Mean batch fecundity (number of oocytes) estimated for 11 females was 224,347. The existence of at least two groups of distinct sizes of oocytes in mature ovaries suggests that *Coryphaena hippurus* can lay at least twice during its reproductive cycle in the study area.

Keywords: Coast East of Tunisia, Coryphaenidae *Coryphaena hippurus*, Fecundity, Reproduction Period, First maturity, Sex ratio

Introduction

The dolphinfish, *Coryphaena hippurus* (Linnaeus,1758), is a teleost, large migratory, epipelagic and oceanic fish, which are found in all tropical and subtropical waters and in the temperate regions of the world. Its distribution is limited by the isotherm of 20°C [1,2]. Its presence in the western Mediterranean (Balearic Islands), and in the central Mediterranean (Sicily, Malta and Tunisia) is seasonal. Adults usually appear in May-June [3] and juveniles are present from August to December. Adults are caught at the same time thatbluefin tuna (*Thunnus. Thynnus*) and by the same gear (purse seine and purse seine nets, long lines and fixed fisheries: traps). While the young are the subject of a small-scale fishing by means of Fish Aggregation Devices (FADs).

Much work has been devoted to the study of biology of its reproduction and gonadal development, especially in the Atlantic by [4] and [5]. Data on the Mediterranean are limited to the study gonadal development and the biology of its reproduction in the Balearic Islands [6], in Majorca [7] and in Sicily [8].

The main objective of this study is to clarify the reproductive strategy of the species and to verify if Tunisian waters constitute a spawning ground. For this purpose, gonad development, fecundity and spawning period were studied on specimens sampled in Tunisian waters between May 2013 and December 2014.This work is of great importance, since it concerns the dolphinfish of Tunisian waters considered as the main Mediterranean fishery of this species [9].

Materials and Methods

Monthly sampling was carried out on 360 individuals with fork lengths (Lf) ranging from 18 to 63 cm, caught during the fishing season and using FADs. Other samplings (n=19) were also carried out on large specimens (Lf, varies from 63 to 110 cm), caught incidentally outside the fishing season and by other gear such as long lines and purse seines.

Biological sampling is done in the laboratory, where the total length (Lt, cm), fork length (Lf, cm), total weight (Wt, d=0.1g), eviscerated weight (We, d=0.1g), gonadal weight (Wg, d=0.001g) and liver weight (Wl, d=0.001g) are measured for each specimen. Sex is determined by dissection and maturity stage by direct macroscopic observation of the gonads, according to the description of [4] and [10], which considers five stages of sexual maturity for females (I: immature, II: early maturing, III: late maturing, IV: mature and V: post-spawning) and three for males (I: immature, II: mature and III: post-spawning).

Sex ratio, which is the numerical relationship between females and males (Camarena Luhrs, 1986) is calculated and its variability as a function of time and size were analysed. Value is compared to the theoretical 1:1 sex ratio using statistical conformity test (χ^2, α=0.05).

The size at first sexual maturity is the one at which 50% of the individuals are mature. This value is derived from the joint logistic function for gear selectivity studies (King, 1995), $P(1)=1/(1+e^{-r(Lf-Lf50)})$, which relates the proportions of mature individuals to length, using software (Statsoft, 2000).[P= the proportion of mature fish per size class; Lf= average fork length corresponding to the proportion (P); r = slope of curve; L50 = fork length at 50% maturity (size at first maturity)].

Spawning period was determined through monthly observations of the macroscopic development stages, by the Gonadosomatic index's=(Wg/We) x100. The Hepatosomatic index: HSI=(Wf/We) x100 and Condition Factor ($CF= Wt/WLf^3$) were calculated to assess condition of the specimens.

To evaluate the total or absolute fecundity (Fa) we used the volumetric method proposed by [11], from oocytes collected from 11 mature females (fork length between 64 and 106 cm). Only oocytes with a diameter greater than 600 µm are considered in the calculation of fertility. Billard (1979) considers that since this size that oocyte maturation begins in teleost. Relative fecundity (Fr) is expressed as the total number of oocytes per body weight: Fr = Fa / Wt   [Fr: relative fertility, Fa = absolute fertility and Wt = total weight of fish].

For the determination of the ovarian structure at the time of egg-laying, many oocytes were measured under a binocular microscope equipped with an ocular micrometre (after dissociation of ovarian tissue in Gilson's fluid). This biometric characterization of oocytes helps to identify and explain the type of reproductive strategy (single spawning or multiple spawning).

Resultants

Sex-ratio

About 379 specimens examined on this study, we counted 168 females (71%) and 111 males (29%). The sex ratio obtained (2:1) is significantly different ($p < 0.05$) from the well-balanced sex ratio (1:1). Females predominate up to the size class of 63cm (Lf). Beyond this size, the sexes would tend to reverse (Figure 1) and the sex ratio becomes in favour of males.

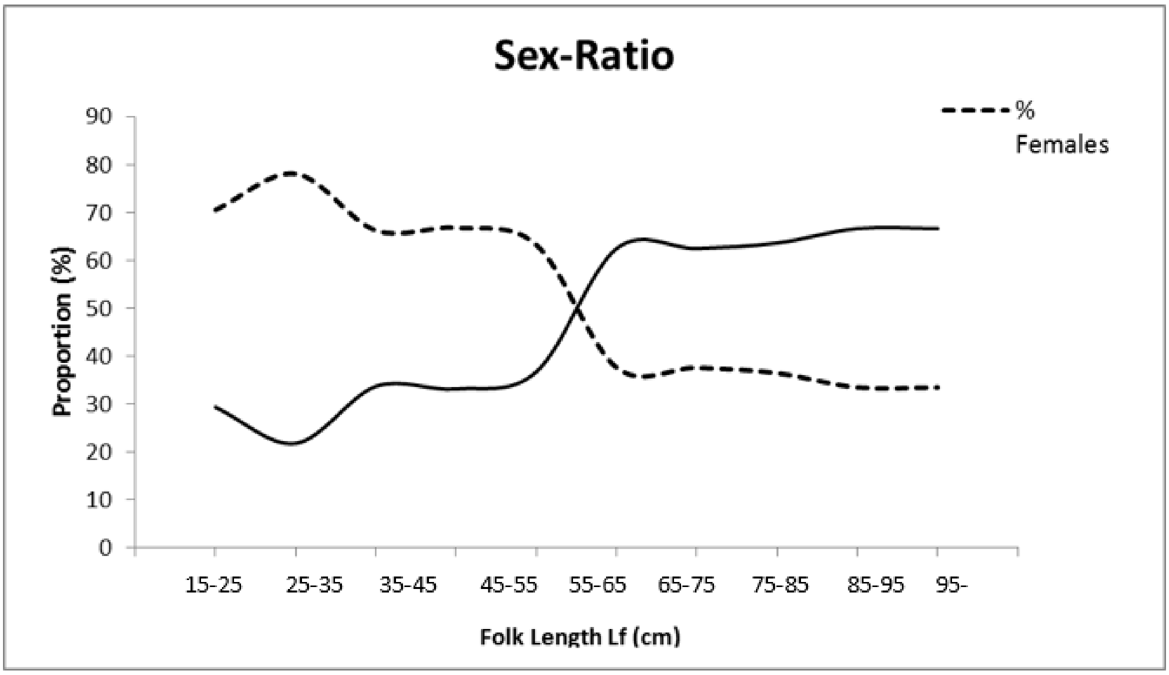

Figure 1: Variation in sex ratio (%) as function of the size (Lf) of the catches of *Coryphaena hippurus* from the East-Tunisian coasts.

The statistical test shows a significant difference for size classes smaller than 55 cm ($p < 0.05$). The difference is no longer significant beyond this size and the proportions between females and males equalize to the size of 63 cm (Lf), then the males predominate without this dominance being statistically significant ($p > 0.05$).The sex ratio is still significantly in favour of females between August and October ($p < 0.05$), then from November the proportions tend to equilibrate (Figure 2). It is inverted between May and June in favour of males, without being statistically significant ($p > 0.05$). It will then equal in July.

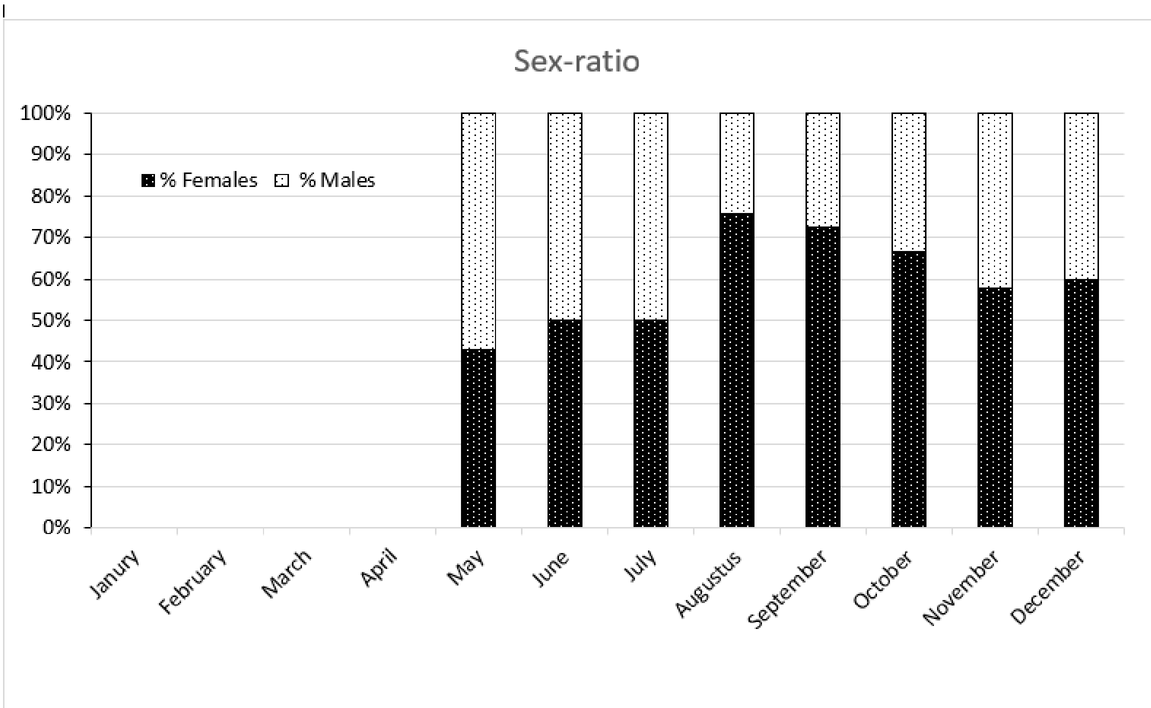

Figure 2: Variations in sex ratio (%) as function of the season(month) of capture of *Coryphaena hippurus* from the East-Tunisian coasts.

First sexual maturity

The size at first sexual maturity (Lf50) is 53.5 cm for females (Figure 3) and 60.5 cm for males (Figure 4). Maturity therefore occurs earlier in females. The length (Lf100) corresponding to the maturity of 100% of the individuals caught is 58.0 cm for females and 64.0 cm for males. While the youngest females and mature males captured were 42.0 cm and 45.0 cm (Lf), respectively.

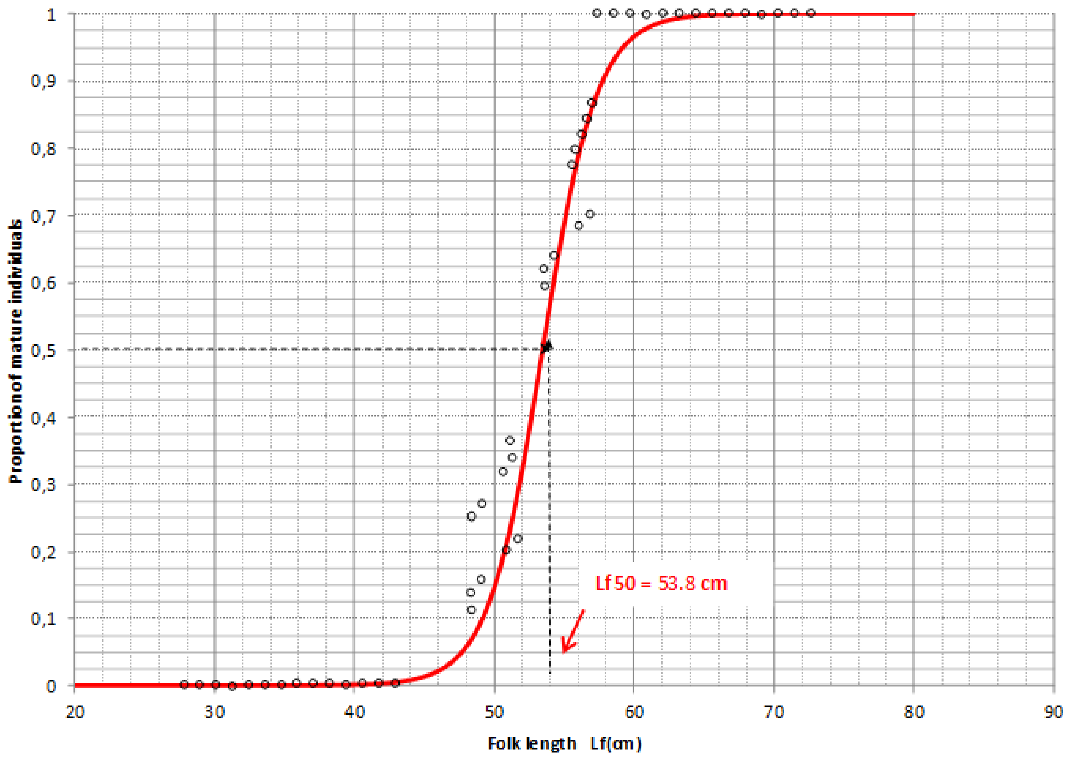

Figure 3: Sexual maturity of female *Coryphaena hippurus* from Tunisian waters [Prop. mature = 1/ (1+Exp (-(0,512) *(Lf-(53,48))))].

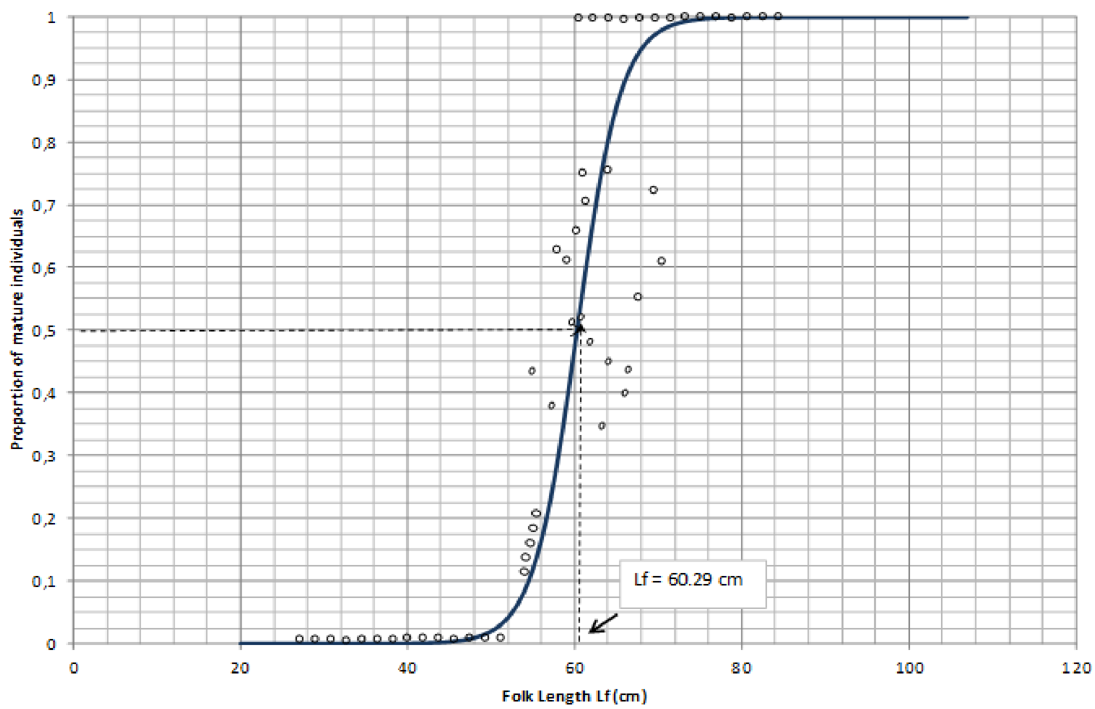

Figure 4: Sexual maturity of male *Coryphaena hippurus* from Tunisian waters [Prop. mature =1/ (1+Exp (-(0,379) *(Lf-(60,29))))].

Stages of maturity

Our sampling allowed us to have fish at all stages of maturation with varying frequencies depending on the season and fishing gear used (Table 1). Thus, in individuals caught during the campaign (August to December) by means of FADs (Figure 5), it is rather the stages I and II that are most frequent for females. Males have a large fraction of immature individuals in stage I. Maturing (mature), stage III females, and stage II males are rarer, and the first few are rare. Observed at the end of the season (November-December). Specimens captured with gear other than FADs are all mature adults (Figure 6). The proportion of stage IV females and stage II males is predominant for all available samples. Female and male post-spawning individuals were also observed in December.

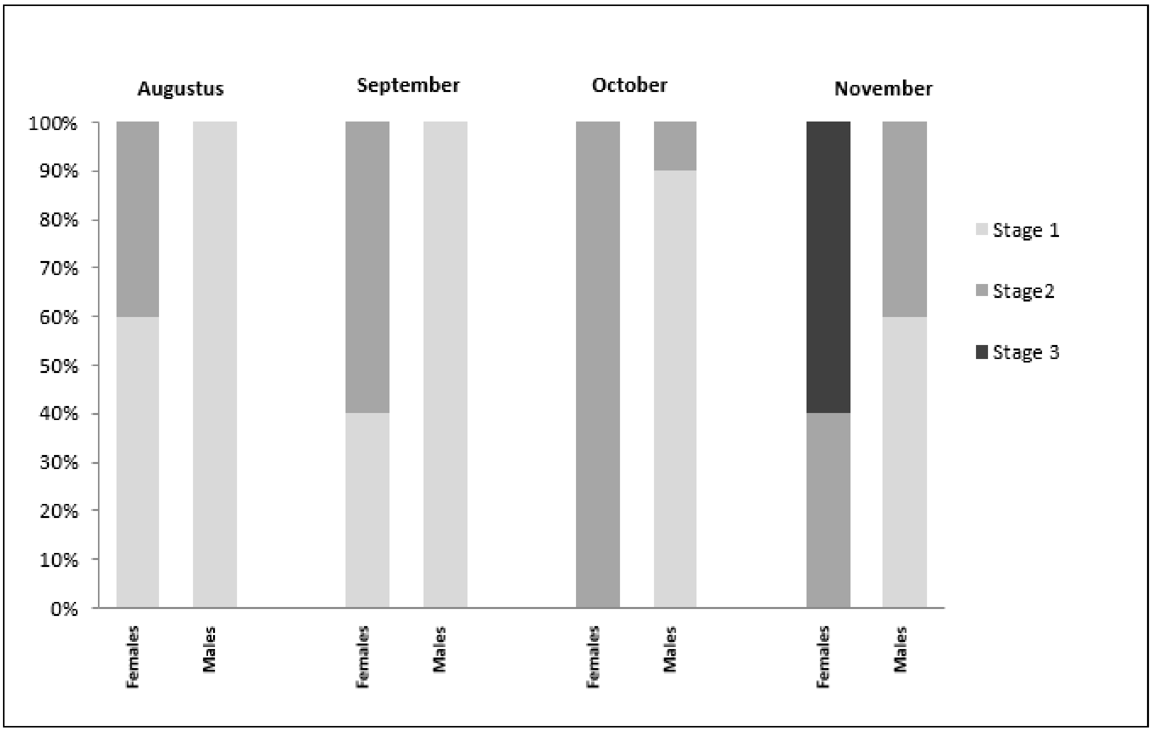

Figure 5: Monthly variation in gonadal developmental stages of *Coryphaena hippurus* caught by FADs.

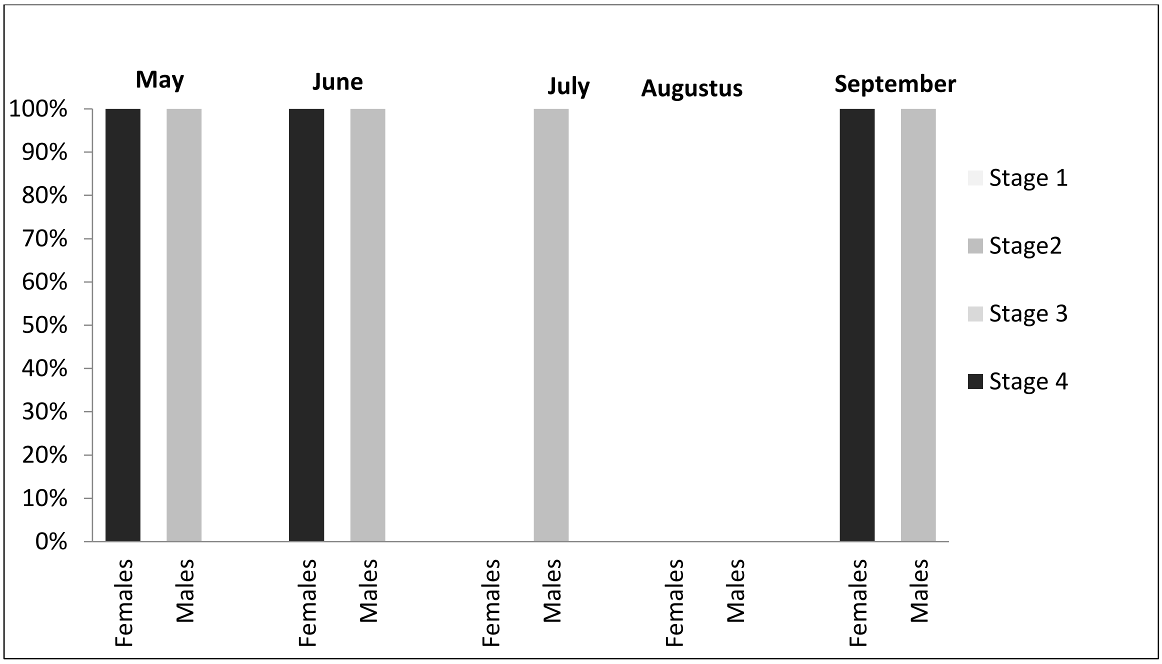

Figure 6: Monthly variation of gonadal developmental stages of *Coryphaena hippurus* caught with gear other than FADs.

Gonado-Somatic Index (GSI)

Referring to the variation of the GSI of females and males, significant differences in values ($p<0.05$) are noted between young fish caught by FADs during the fishing season (August to December) and the oldest caught occasionally by other gear outside the season (May to July / September). The lowest values are observed between August and December and the highest between May and July, and these results suggest that the reproduction of *Coryphaena hippurus* starts in May.

Indeed, from August to December, the GSI is still very low and varies on average by 0.408 ± 0.185 for females (Figure 7) and of 0.133 ± 0.066 for males (Figure 8). These low values reflect the fact that the fish from FADs (Lf<65cm) are all young individuals still immature or at the beginning of maturation. The female gonads are characterized by a pronounced vascularization and their surface becomes granular with oocytes that can be seen in individuals at advanced maturation. For males the gonads are fine and without milt.

	May	June	July	August	September	October	November	December
FADs								
Female				Stage I	Stage I - Stage II	Stage II	Stage II - Stage III	Stage III
Weight (g)				132	236 338	778	867 1072	1554
SD (g)				34	24 86	323	69 122	258
Length Lf(cm)				25	32 34	42	46 49	56
SD (cm)				3	2 3	6	2 3	3
Male				Stage I	Stage I	Stage I	Stade I - Stage II	Stage II
Weight(g)				117	316	994	1275 1579	2145
SD (g)				38	51	640	952 1129	134
Length Lf(cm)				24	33	43	46 52	62
SD (cm)				3	3	9	12 9	2
Other gear								
Female	Stage IV	Stage IV			Stage I V			Stage V
Weight (g)	4455	5013			5880			8500
SD (g)	2414	18			0			0
Length Lf (cm)	74	88			82			98
SD (cm)	13	18			0			0
Male	Stage II	Stage II	Stage II		Stage II			Stage III
Weight (g)	5600	8533	15000		17000			11285
SD (g)	4215	3443	1414		0			0
Length Lf (cm)	78	87	105		100			101
SD (cm)	21	13	7		0			0

Table 1: Weight and length of *Coryphaena hippurus* in relation to gonadal evolution and according to months and fishing techniques.

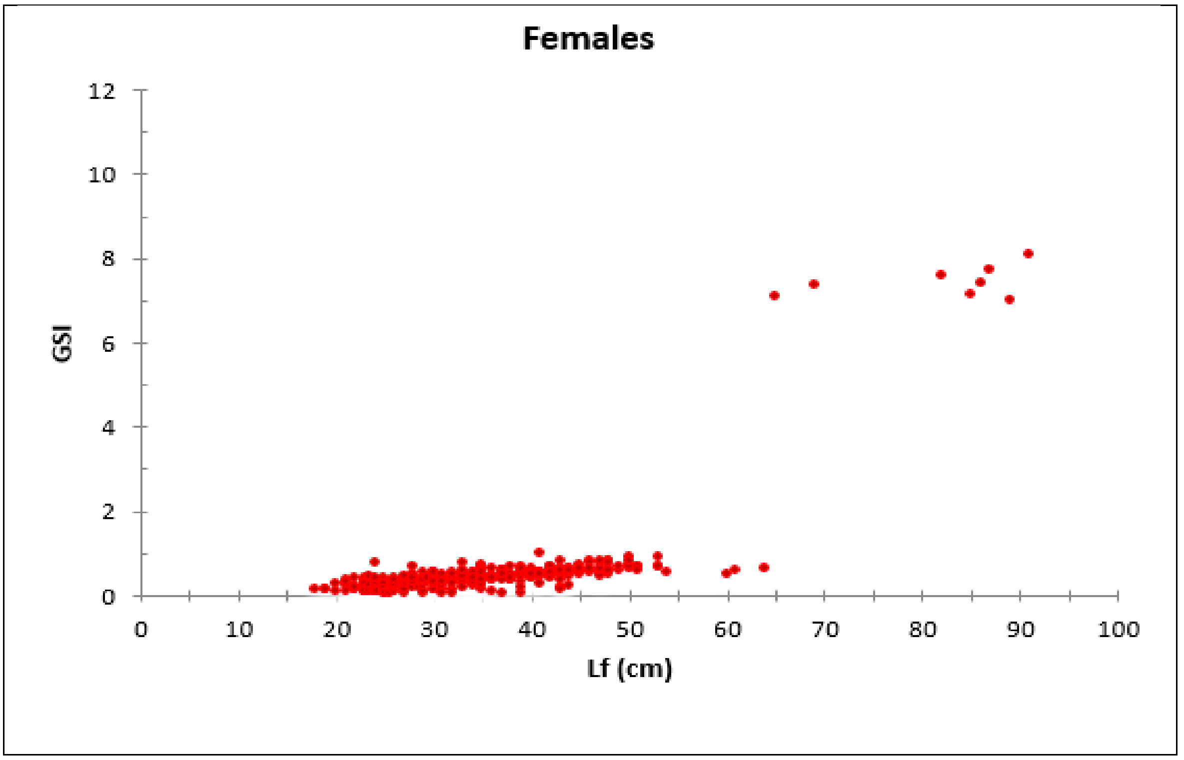

Figure 7: Variation of the Gonadosomatic Index (GSI) of females of *Coryphaena hippurus* as a function of individual length.

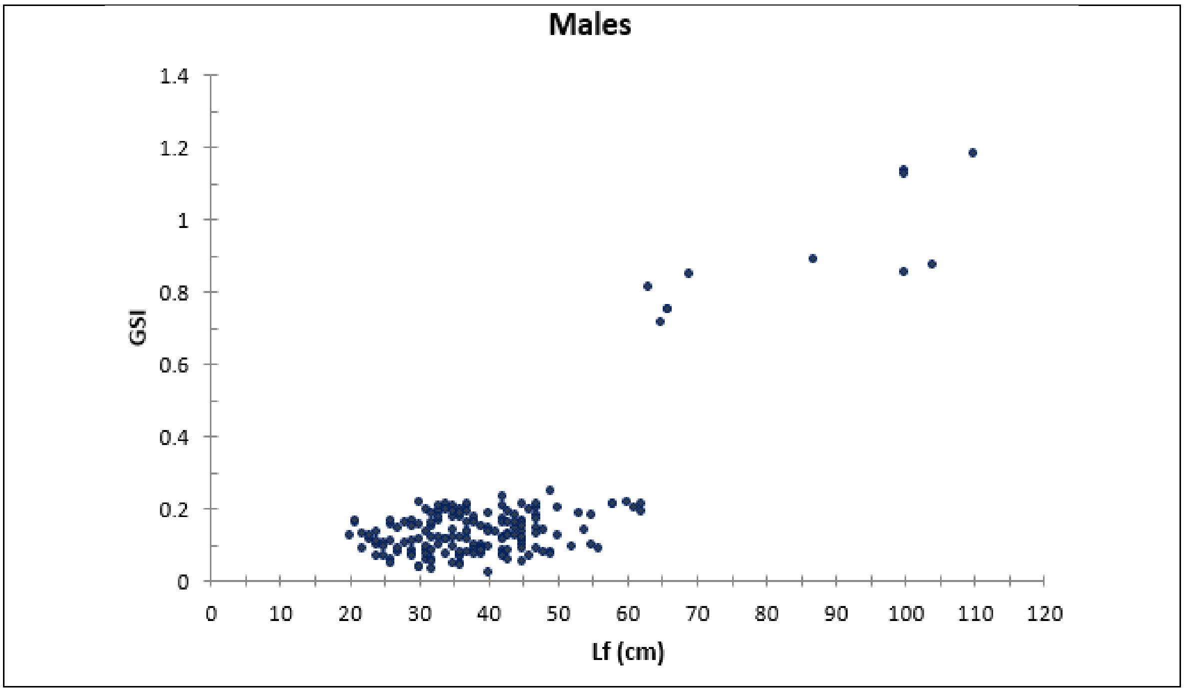

Figure 8: Variation of the Gonadotomatic Index (GSI) of males of *Coryphaena hippurus* as a function of individual length.

The GSI of the catches (LF>65cm) carried out from May to July, is at its maximum and is on average 7.423 ± 0.363 for females and 0.845 ± 0.166 for males. The females have large ovaries occupying the entire abdominal cavity, their membrane is very thin, and the oocytes are perfectly visible and ready to be expelled. The males have large testicles loaded with sperm.

Referring to the important GSI values and sexual maturity stages observed in adult specimens, the results seem to indicate and locate the main spawning period of this fish from May to September (figure 9 and figure 10).

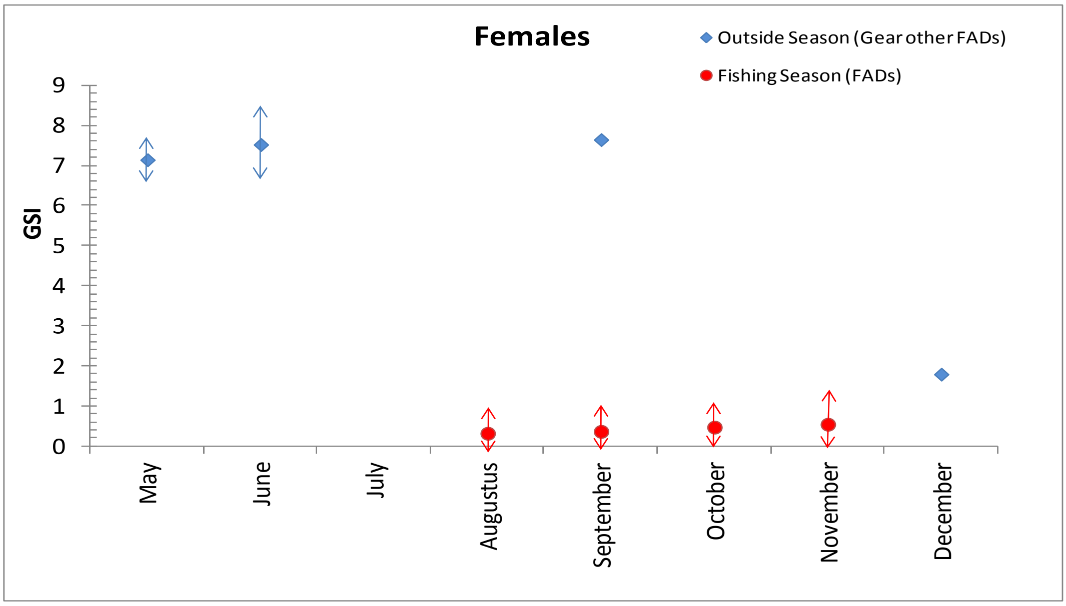

Figure 9: Monthly variation and standard deviation of the Gonado-Somatic Index (GSI) of females of *Coryphaena hippurus* (n = 260: individuals caught during the fishing season by FADs and n = 8: individuals fished outside the season by gear other than DCPs).

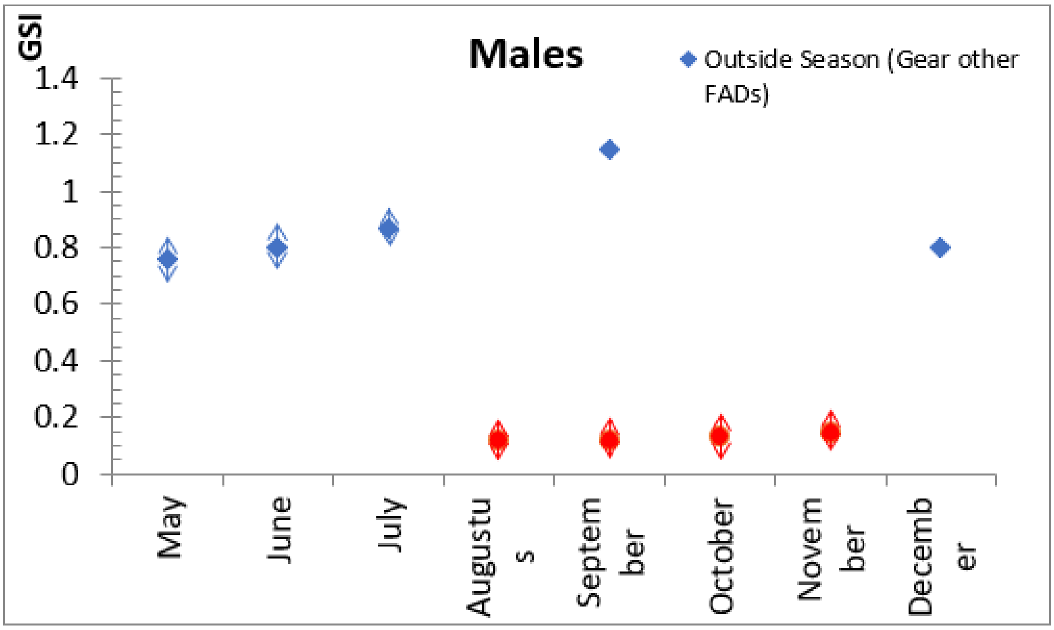

Figure 10: Monthly variation and standard deviation of the Gonado-Somatic Index (GSI) of males of *Coryphaena hippurus* (n = 100: individuals caught during the fishing season by FADs and n = 11: individuals fished outside the season by gear other than DCPs).

Hepato-Somatic Index (HSI) and Condition Factor (CF)

The evolution of this index does not show a significant difference between young and adults invidious or between the sexes ($p>0.05$). The mean values are 1.53 ± 0.690 for young females captured during the fishing season (FADs) and 2.459 ± 0.652 for adults caught outside the season (Other gear) (Figure 11). As for the HSI values of males, they are respectively 1.163 ± 0.737 and 1.540 ± 0.370 for young and adults (Figure 12). This low difference in HSI values suggests that dolphinfish does not use these lipid stores in the lever for maturation and gamete development.

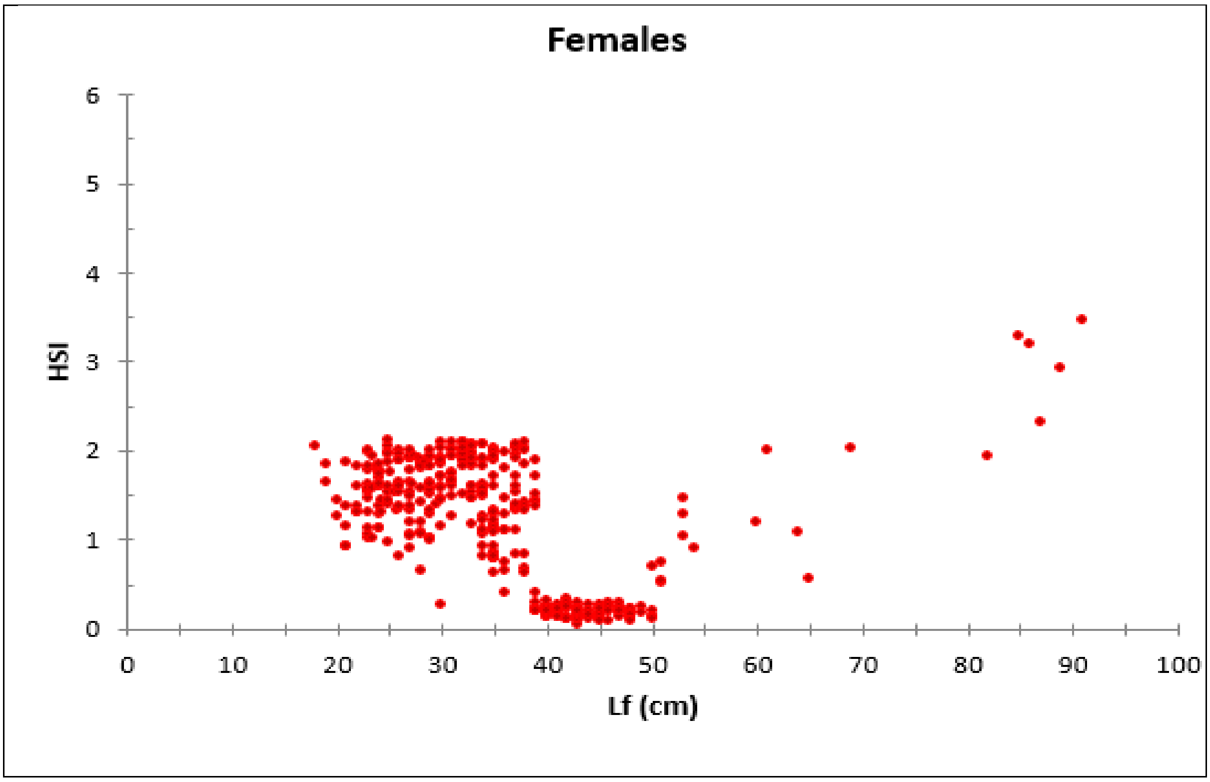

Figure 11: Variation of the Hepatosomatic index (HSI) of females of *Coryphaena hippurus* as a function of individual length.

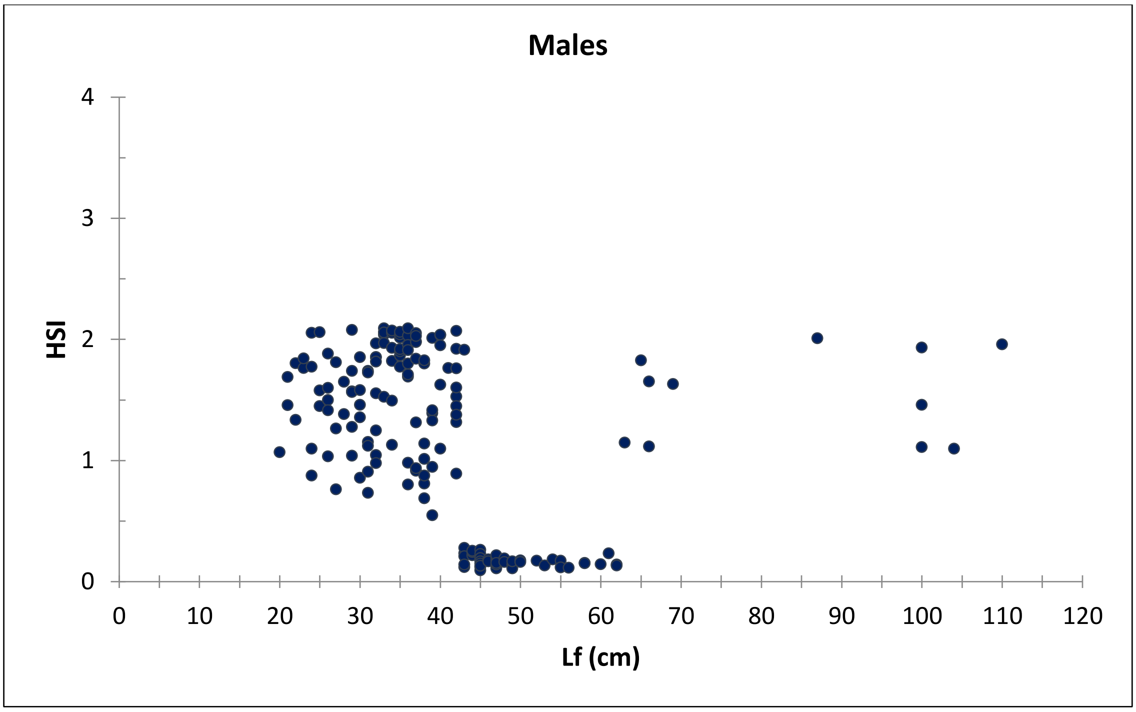

Figure 12: Variation of the Hepatosomatic index (HSI) of males of *Coryphaena hippurus* as a function of individual length.

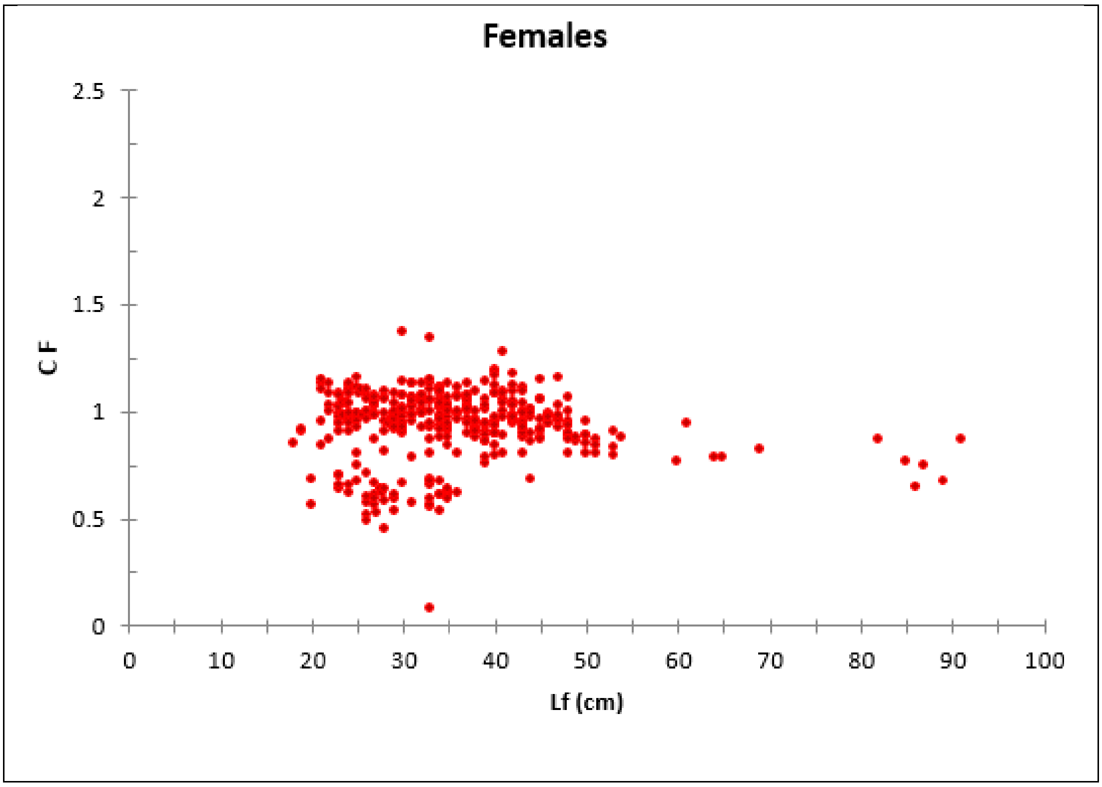

Figure 12: Variation of the Condition Factor (CF) of females of *Coryphaena hippurus* as a function of individual length.

Similarly, low amplitude in the values of CF is noted between young and adults invidious or between the sexes ($p > 0.05$).For young fishes captured during the fishing season (FADs) the mean value of CF is 0.931 ± 0.161for females and 0.980 ± 0.151 for male and it is slightly higher than that of adults caught outside the season. Values are respectively 0.771 ±0.081.for females and 1.012 ± 0.110 for males (Figure 13 and Figure 14). These low and stationary values of CF suggest also that lipid stores mobilized for gonad maturation and gamete development do not originate the muscle.

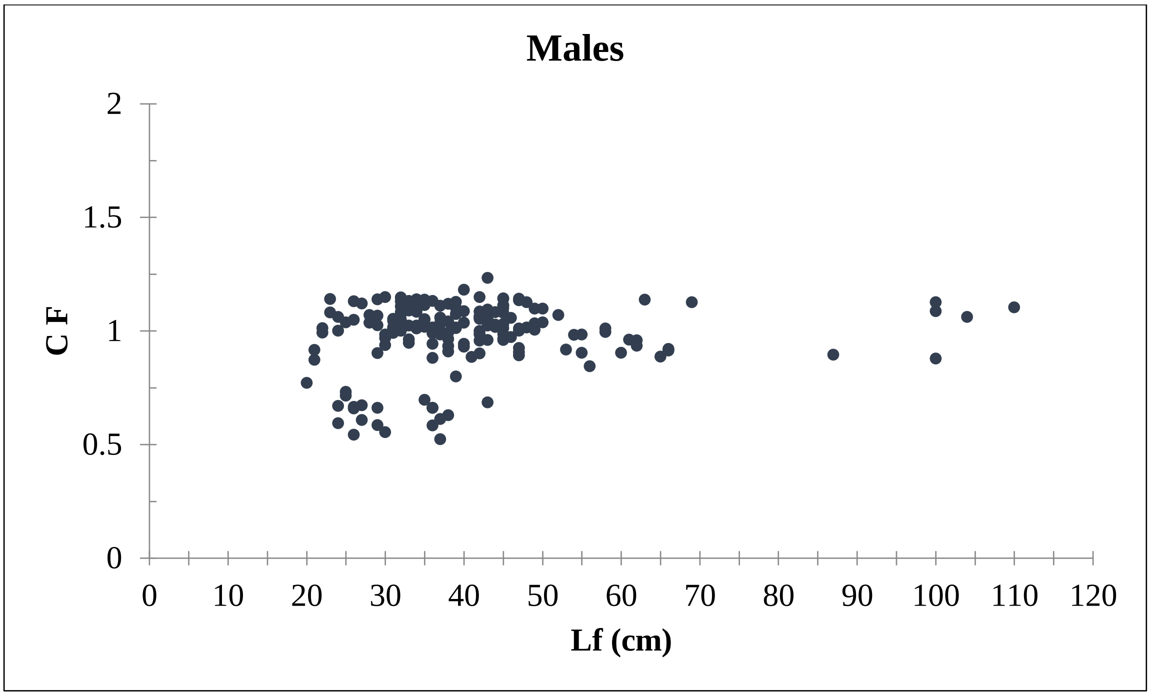

Figure 13: Variation of the Condition Factor (CF) of males of *Coryphaena hippurus* as a function of individual length.

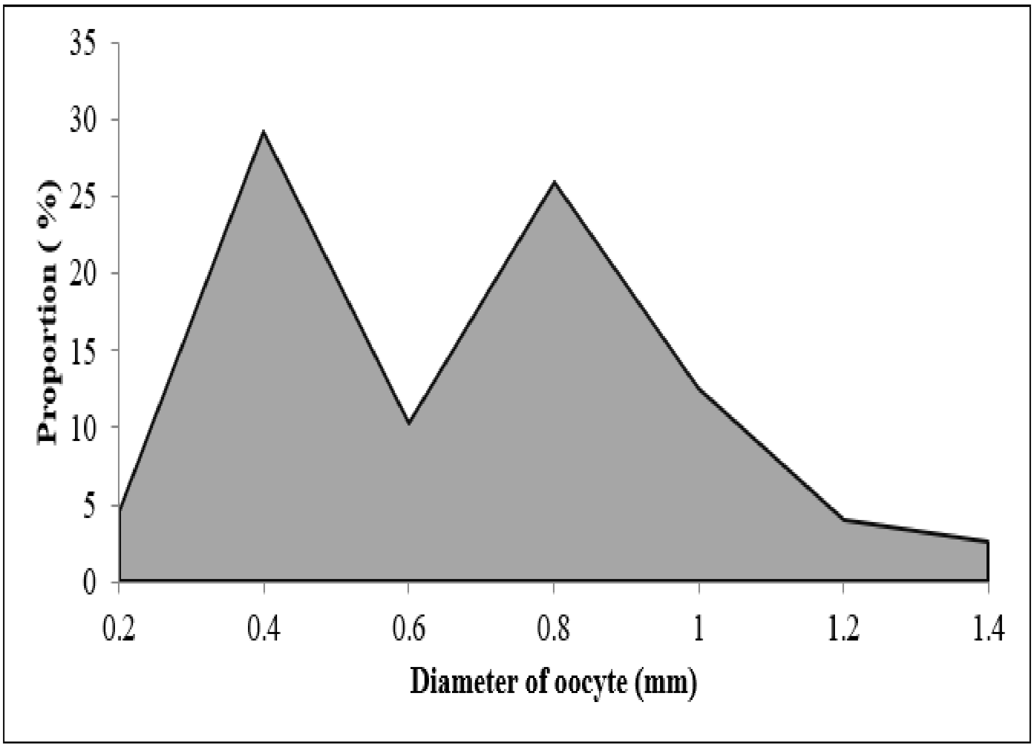

Figure 14: Frequency distribution of oocyte diameters of adult females of *Coryphaena hippurus*, used in the study of fecundity.

Fecundity and Distribution of Oocyte Size

Fecundity was assessed in 11 mature (stage IV) females captured between May and September. Females sampled have fork lengths ranging from 65 to 106 cm and a weight ranging from 2.664 g to 8.650 g (Table 2). In the same ovary, oocyte sizes are heterogeneous, and diameters range from 0.2 to 1.4 mm (Figure 15). The frequency distribution of the oocyte diameter shows the presence of a first group of immature oocytes (stage I) representing the reserve batch and whose size is 0.2 mm. From this first batch stand out three other groups of oocytes. Oocytes with diameters between 0.4 and 0.8 mm are the most abundant and represent more than 55% of all oocytes present in the ovary. The most advanced batch (0.8 mm) reflects the complete maturation and the formation of hyaline oocytes whose maximum size reached is 1.4 mm.

The absolute fecundity (Fa) of *Coryphaena hippurus* oscillates between 385,000 (Lf = 64cm, Wt = 2,664g) and 1,134,500 (Lf = 106cm, Wt = 8,650g) with an average of 660,000 ± 224,000 oocytes per female. Since the individual relative fecundity (Fr) is on average 122 ± 12 eggs per gram of mature female and 1,300 ± 245 eggs per gram of ovary.

The relationships obtained (Figure.16, 17 and 18) between the Absolute Fecundity (Fa), the total weight of the fish (Wt), the Weight of the Gonads (Wg) and the Fork Length (Lf) give respective correlation coefficients equal to 0.92; 0.78 and 0.88. Absolute individual fertility (Fa) therefore increases proportionally with the individual body weight, ovary weight and a cube of length of fish.

Date de pêche	Lf (cm)	W (g)	Wg (g)	RGS	Fa	Fr
17-mai	89	7200	740	10.28	800,400	111
22-mai	69	3500	390	11.14	460,500	132
24-mai	64	2664	320	12.01	385,000	145
26-mai	79	4500	375	8.33	450,000	100
22-juin	99	7300	860	11.78	845,300	116
26-juin	85	5025	405	8.06	653,250	130
10-juillet	106	8650	950	10.98	1,134,500	131
15-juillet	77	3660	365	9.97	445,000	122
31-juillet	91	6300	560	8.89	734,600	117
13-septembre	88	5000	380	7.6	592,800	119
13-septembre	91	6000	420	7	750,800	125
				Moyenne	659,287	122
				Ecart type	224,347	12

Table 2: Sampling data and estimation of Absolute Fecundity (Fa) and Relative Fecundity (Fr) of *Coryphaena hippurus*.

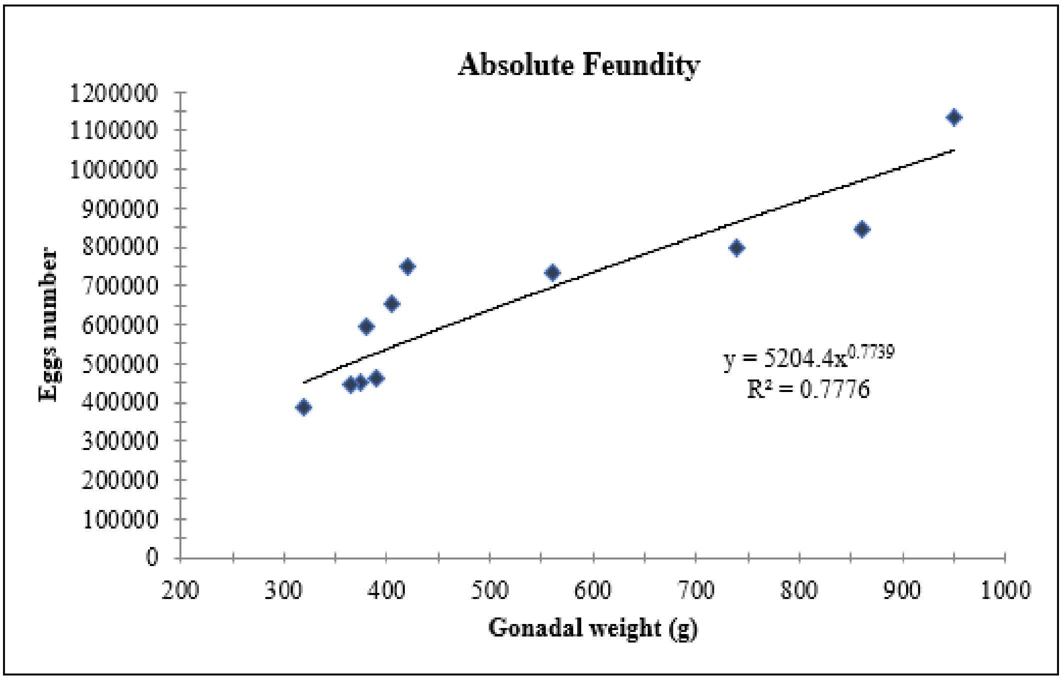

Figure 15: Correlation between fecundity and individual weight of *Coryphaena hippurus.*

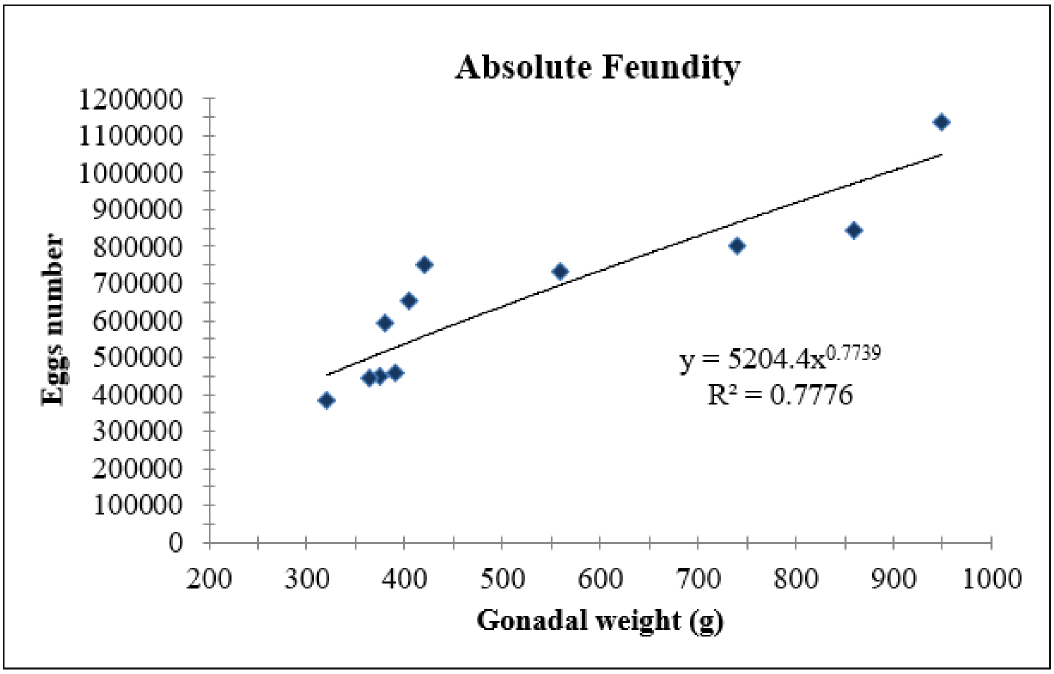

Figure 16: Correlation between fecundity and gonadal weight of *Coryphaena hippurus.*

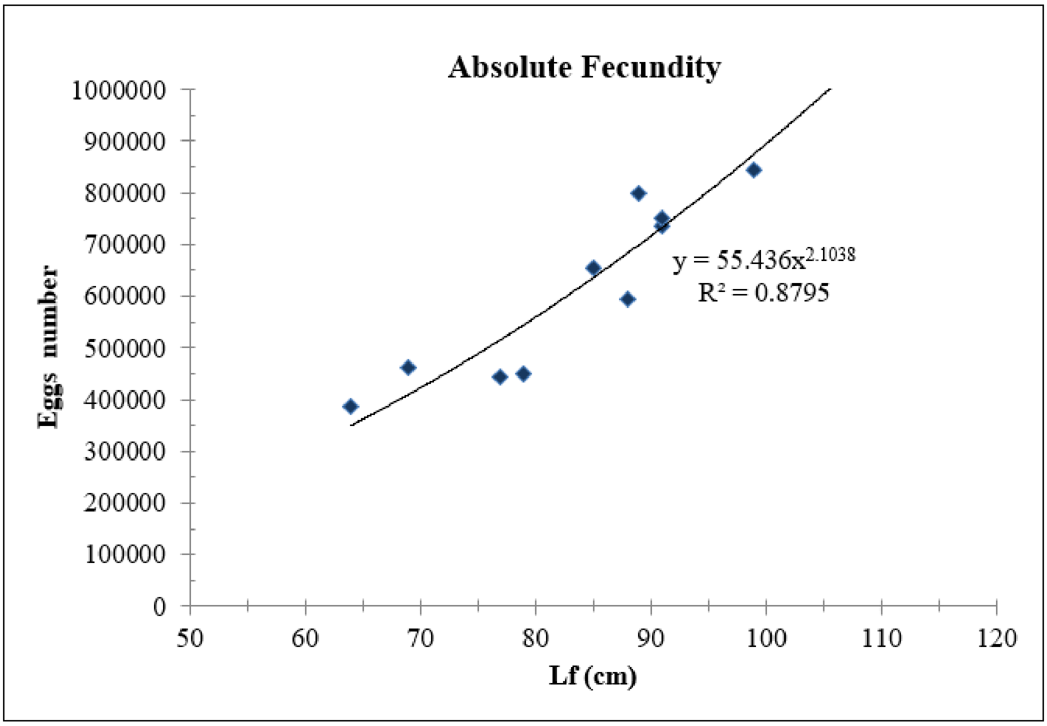

Figure 17: Correlation between fecundity and individual length of *Coryphaena hippurus.*

Discussion and Conclusion

The results obtained show that females of the dolphinfish of Tunisian waters, are globally more numerous than the males (2:1). This high proportion of females from FADs captures may be due to greater availability of females, higher natural mortality in males, or differential growth of both sexes. Rose and Hassler (1974) report that, being heavier than females, males leave concentration and fishing areas at an earlier age than females [12]. Several factors, such as trophic migration, differential growth, and sex-specific mortality rate, influence sex ratio of fish [13]. The number of males slightly higher in the months of May-June and July is the result of longlines and line catches. This predominance, however, remains insignificant with a tendency for sex to equilibrate. According to [14], females predominate at the age of 0, but at the age of 2 the sex ratio becomes in favour of the males. In addition, Kojima [15] indicates that the sex ratio changes with the fishing season. Females outnumber men at the beginning of the fishing season, but their numbers decrease to become equal to that of males during the breeding season.

This superiority of the number of females in young individuals caught by FADs between August and October, has also been mentioned in western and central Mediterranean waters by [7,8,16,17]. The authors attribute the low importance of males to the existence of a different behaviour between males and females, so females would be more willing to aggregate under FADs than males who would be freer and thus disappear from fishing zones. That is, different growth rates according to gender. The same finding has also been reported in many parts of the world [12,18,19,20]. The male's energy requirements are greater than those of females, who leave the FADs in pursuit of larger prey in order to satisfy their food needs and thus become inaccessible during fishing operations.

In this study, the use of the logistic function common to gear selectivity studies, which links the proportions of mature individuals to length and which allowed us to accurately estimate size at first sexual maturity (Lf50) which is 53.5 cm for females and 60.5 cm for males. Both sexes reach sexual maturity in their first year of life, but this occurs earlier in females (Besbes Benseddik *et al.*, 2015). The length (Lf100) corresponding to the maturity of 100% of the individuals caught is 58.0 cm for females and 64.0 cm for males. These results were confirmed by a histological study of the gonads which demonstrated that the size of first maturity is 53 cm (LF) which corresponds to stage III of maturity of female (Photo.1) and to 61 cm (LF) in the corresponding at stage II of maturity of male (Photo.2) [10,7].

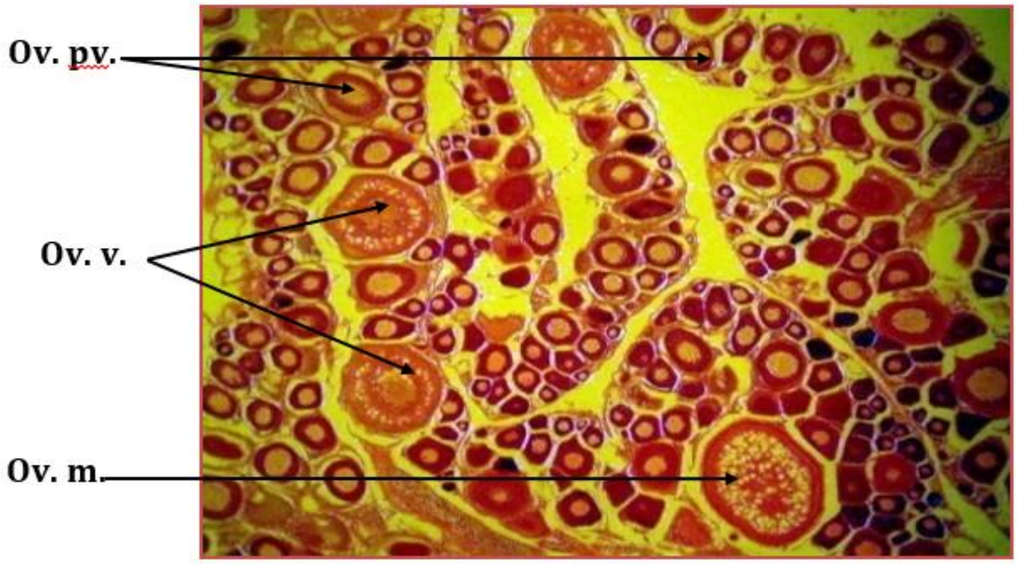

Photo 1: Photomicrograph of a histological ovarian structure of *Coryphaena hippurus* female at first sexual maturity.
Lf = 53 cm; Ov. *pv: Oocyte in previtellogenesis, Ov. v: Oocyte in vitellogenesis and Ov. m. mature Oocyte (Gx40)*

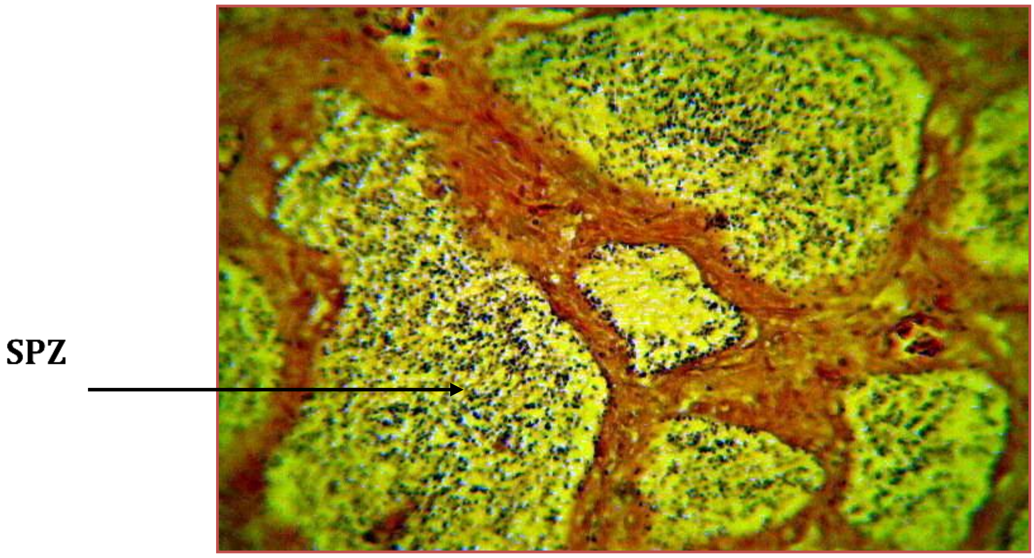

Photo 2: Photomicrograph of a histological testicular structure of *Coryphaena hippurus* male at first sexual maturity *Lf = 61 cm SPZ: Spermatozoa in the light of seminiferous tubules (Gx40).*

In the waters of Mallorca (Western Mediterranean), Massuti and Morales-Nin (1995), reach respective sizes of first sexual maturity quite close to ours, which are 54.5 cm (Lf) for females and 61.8 cm (Lf) for males [10,21]. On the island of Malta**,** Gatt *et al.* (2015) report quite different values from those in the rest of the Mediterranean with an over-estimation of the L50=62.2 cm (Lf) in females. The authors attribute this over-estimation to the difficulty of macroscopically identifying individuals with advanced maturity and that a microscopic study would have been more precise and reliable. In the Atlantic, the maturation of *Coryphaena hippurus* appears to be earlier than in the Mediterranean Sea, since in Florida, the size at first sexual maturity is according to Beardsley (1967) of 35.0 cm (Lf) for the female and 42.7 cm (Lf) for the male [4]. In the Gulf of Mexico, it is 49.0 cm (Lf) for the female and 52.8 cm (Lf) for the male [22]. While in North Carolina, [23] report that it is 45.8 cm (Lf) for females and 47.6 cm (Lf) for males. In Mexico (South Pacific), [24] estimates this size at 48.38 ± 0.84 cm (Lf) in females and 50.57 ± 2.16 cm (Lf) in males. The comparison of these results with ours remains difficult because the method of determination and the criterion of maturity adopted are different. It appears however, common to all these studies and observations.

The speed of growth of the dolphinfish confirmed by many authors [4,14,24,25,26], who reported quite significant daily growth rates in different regions of the world, especially in the Mediterranean sea with a growth rate of about 2.02mm / day in Tunisian waters [27] and 5.10 mm / day in Malta [16], suggest that in the Mediterranean, juvenile of dolphinfish from May to September can reach a stage of development and maturing of their gonads before migrating to areas where the temperature conditions are more conducive allowing them to perform their first spawning. Massuti and Morales-Nin (1995) believe that young dolphinfish born in the Mediterranean will mature and make their first egg-laying in the tropical waters of the Atlantic [3]. Monitoring and analysis of sexual maturity stages shows a difference in the percentage of mature specimens by season and fishing gear. For dolphinfish from artisanal FADs, no sampled specimens had reached full maturity. However progressive gonadal development is noted over the months, which results in an increasing rate of females maturing. This rate goes from 44% in August to 58% in September and 100% in October. In November, females are at maturity stage III. As for the males, at equal age, they seem to begin their maturity later than the females. The rate of mature males producing milt (stage II) is virtually nil from August to October. It then increases to 45% in November and mainly concerns young adults.

The highest proportion of fish at the end of gametogenesis (stage IV for females and stage II for males) is observed in long-line and gear other than FADs catches, mainly in May-June. The low percentage of individuals observed in September indicates a possible second spawning period. Monitoring the Gonado-Somatic Ratio (GSI) associated with the monthly changes in the different stages of sexual maturity shows that the values (GSI) are higher in females than in males, because of the greater development of the ovaries and the fact that the size of the juveniles caught during the fishing season are much lower than those of mature adults. The high GSI values of adult specimens that start fishing in the spring (May-June) and continue during the summer (July to September), indicate that Tunisian waters are a breeding area and that spawning is located between May and September (Besbes Benseddik *et al.*, 2015).The same results were reported in the western waters of the Mediterranean (Mallorca) and in Malta [3,16]. It is therefore more than likely that Tunisian waters constitute an important spawning ground since mature specimens of dolphins, females with substantial gonads and filled with hydrated oocytes as well as sperm males are occasionally caught from spring (May). In addition, larvae in the Central Mediterranean during a plankton survey carried out aboard the "HANNIBAL" research vessel of INSTM between 24 June and 7 July 2008 off the east coast of Tunisia since Capbonto Ras Kapoudia, [29] report the capture of two *Coryphaena hippurus* larvae, one between 50 and 100 m isobaths and one between the 100 and 200 m isobaths, corresponding to the continental shelf. These observations suggest that, as the dolphinfish approaches its breeding season, it will migrate from the Atlantic Ocean to the Mediterranean through the Strait of Gibraltar, a migration like that of the bluefin tuna (*Thunnus*. *Thynnus*) who is also very often associated with it [7,29]. However, no definitive information is currently available on the location of the spawning grounds and the migratory movements in and out of the Mediterranean that this enigmatic fish would do. Its seasonal presence in the Mediterranean therefore takes place from spring to autumn. Adults of *Coryphaena hippurus* appear from May when the temperature of the surface water exceeds 18 °C. They are observed in the open sea, whereas young invidious tend to frequent the mothers of shallow depths. A maximum of abundance and concentration of these young dolphinfish is noticed from the month of July when the temperature is 24 to 26 °C. Dolphinfish occupy this nursery for a few months only. They then leave these habitats in the fall when the water temperature drops to minus 18-20 °C [28], assume that this drop in surface temperature of Mediterranean waters from the end of autumn causes a shift of adult dolphinfish to either warmer areas of the Mediterranean, such as the Gulf of Gabes, Sardinian waters or the Balearic Islands, or a migration to the Eastern Atlantic Ocean along the West African coast where the sea surface temperature is hot all year round.

In a more recent study on the estimation of the gene flow carried out with the Migrate software, [30] reports a maximum migration rate (0.065) from the Mediterranean to the Atlantic, which supports the hypothesis of the migration of dolphinfish adults from the Mediterranean Sea to the warmer waters of the eastern Atlantic. In the tropical regions of the three oceans (Atlantic, Pacific and Indian), this reproduction period is very spread out, since wall fish are observed all year long [31]. Dolphinfish remain sexually active throughout the year in tropical waters due to the low degree of variation of the environment during an annual cycle and restrict nesting in the warmest months in subtropical regions. Although spawning may occur earlier depending on the region, the maximum intensity is always in the spring or spring-summer.

As is the case for all teleost, temperature seems to be the essential factor in triggering spawning, either by stimulating physiological mechanisms or by trophic enrichment of the medium. For *Coryphaena hippurus*, the thermal optimum for reproduction lies between 21 and 25 °C [4,6, 31,32,33]. In Tunisia, throughout the study period, the average surface water temperature was 19.13 °C in May; 22.12 °C in June; 25.39 °C in July; 26.71 °C in August and 26.71 in September. It is these favourable thermal factors that create favourable conditions for the phenomenon of reproduction and spawning. The monthly values of the Hepatosomatic Index (HSI) and the Condition Factor (CF) meanwhile, do not show any remarkable variations between the fishes caught during and out of the country. Although the energy required for spawning can come from the liver [34], elevated HSI values in adult individuals do not indicate a use of stored energy. Being a voracious, high-feeding species that does not decline during the laying period [31,35] energy required for maturation and spawning surely comes from his insatiable appetite. According to [36], the dolphinfish consumes up to 20% of its weight per day. Estimating the hatching dates of the young caught during the campaign confirms the large spawning season in Tunisia from May to September. Peak hatching appears to occur between May and July. Eggs hatching at 50-60 hours after fertilization [31], the young caught by FADs between August and December (fishing season) all came from the same eggs and are 2-8 months old for average Fork Lengths (Lf) ranging from 24 to 70 cm [27]. The same finding was reported in Mallorca, Malta, and in North Carolina, who [23] mention this concordance between breeding dates and hatching dates and confirm the age 0+ of young people.

The distribution and evolution of the oocyte size frequencies shows that the doryopterus ovary contains oocytes at different stages of maturation ranging from 0.2 to 1.4 mm with two lots individualized at 0.4 and 0.8 mm. The most advanced batch reflects the actual maturation and the formation of hyaline oocytes whose maximum size reached is 1.2 mm. This process continues until the first stock of oocytes is exhausted and thus the second batch of 0.4mm continues its vitellogenesis and evolves until ovulation (stage IV). The permanent presence of immature reserve oocytes allows repetition of the eggs. This was reported by [20], who mentions that the average interval between laying is two days. The same observation was made by Nel (1995), who states that females of captive-bred dolphins spawn naturally without hormonal injection every other day and throughout the year [37].

According to our estimates, the absolute fertility is between 385,000 and 1,345,000 with an average of 660,000 ± 224,000 for dolphin fishes of 64 to 106 cm (Lf). Our results are close to those reported in the Western Mediterranean [3,7] which estimate average fertility at 764,000 ± 343,000. In the West Central Atlantic, [4,18] report a fecundity that varies from 58,000 to 1.5 million eggs depending on the size of the females. In the coasts, Central-West Indian Ocean, Chatterji and Ansari (1982) obtain a fertility ranging from 140.000 to 550.000 eggs, for females of 55 to 80 cm (Lf). In Mexico, [20] reports a fertility rate of between 45,022 and 1,930,245 hydrated oocytes per female (49 cm <Lf <129 cm). These differences in fertility could be related, among others, to the method of estimating the number of oocytes, the number of females sampled and their size and age. According to Le Bec (1983), these differences are related to variations in abiotic factors such as temperature and salinity, or biotic (trophic) factors that therefore condition fertility and can vary it in proportions maintaining a balance between the potentials of the middle and the population. On the other hand, all the works available in literature agree that the number of eggs increases with the size and weight of the fish. This has also been shown in this study, where the relationship between absolute fertility and the various parameters (Wt, Wg and Lf) shows high correlation coefficients (0.92, 0.78 and 0.88).

These studies, which we discussed for the first time in Tunisia, on the reproductive aspects of *Coryphaena hippurus*, show that this fish has an early sexual development and that maturity is reached during its first year of life. This finding is also confirmed by many authors in many parts of the world. Our histological work on the monitoring and maturation of the females and males of the dolphinfish first discussed also in the Mediterranean [10] show that the oocyte development is of the asynchronous type and that the species is broken and intermittent. This multiple spawning strategy is also specific to tropical and subtropical species [39]. Finally, in Tunisian waters and in the Mediterranean where dolphinfish is present only seasonally, although the process of gonad maturation cannot be followed on a complete annual cycle, as it is the case in the tropical regions where it is present permanently, it remains possible in the same mature adult individual thanks to the modal ovarian structure of this species.

In conclusion, on the basis of the results of the latest genetic studies that have proven on the one hand the distinction and the genetic differences between the two Mediterranean dolphinfish populations and the Atlantic [30,40] and of On the other hand, the uniqueness of this Mediterranean stock makes it important to think about putting in place a large regional management plan involving all the countries involved in the exploitation of this important marine resource. Appropriate legislation must be put in place and applied by all these countries, and an evaluation study of this stock must be carried out in order to avoid overexploitation of the species and to guarantee its long-term survival.

References

1. Gibbs JR RH, COLLETTE BB (1959) On the identification, distribution and biology of the dolphins, *Coryphaena hippurus* and Coryphaena equiselis. Bull. Mar.Sci. Gulf Caribb 9:117-152.
2. Ditty JG, Shaw RF, Grimes CB, Cope JS (1994) Larval development, distribution and abundance of common dolphin, *Coryphaena hippurus* and pompano dolphin, Coryphaena equiselis (Family: Coryphaenidae), in the northern Gulf of Mexico. Fish. Bull 92(2): 275-291.
3. Massuti E, Morales-Nin B (1995) Seasonality and reproduction of dolphinfish (*Coryphaena hippurus*) in the Western Mediterranean. Sci. Mar 59(3-4): 357-364.
4. Beardsley GL (1967) Age, growth and reproduction of the dolphin *Coryphaena hippurus*, in the Straits of Florida. Copeia (2): 441-451.
5. Goldberg SR, Tresierra A (1985) Notes on spawning in the dolphin fish *Coryphaena hippurus* (Coryphaenidae) from Peru. Bull. Southern California Acad. Sci 84: 51-52
6. Lozano-Cabo F (1961) Biometría, Biología y pesca de la lampuga (*Coryphaena hippurus*) de la islas Baleares. Memorias de la Real Academia de Ciencias Exactas, Fisicas y Naturales de Madrid, Series de Ciencias Naturales 21: 93p.
7. Massuti E, Morales-Nin (1997) Reproductive biology of dolphinfish (*Coryphaena hippurus* L) of the island of Majorca (Western Mediterranea). Fish. Res 30: 57-65.
8. Potoschi A, Renones O, Cannizaro L (1999) Sexual development, maturity and reproductionof dolphinfish (*Coryphaena hippurus*) in the western and central Mediterranean. Sci. Mar 63(3-4): 367-372.
9. Morales-Nin B, Azevedo M, Besbes Benseddik A, Besbes R, Camilleri M, et al. (2003) Dolphinfish fishery in Mediterranean waters: Summary of recent studies. Report of the GFCM / ICCAT Meeting. Madrid 26-29 17p.
10. Besbes Benseddik A, Besbes R, Ezzeddine-Najai S, Jarboui O, Mrabet R (2015) Cycle reproductif et gamétogenèse de la dorade coryphène *Coryphaena hippurus* (Coryphaenidae) des eaux tunisiennes. Cybium, Revue Internationale d'Ichtyologie 39(1) : 47-58.
11. Kartas F, Quignard JP (1984) La fécondité des poissons Téléostéens. Coll. Biol. milieux marins. Ed. Masson Paris 121p.
12. Rose CD, Hessler WW (1974) Food habits and sex ratio of dolphin *Coryphaena hippurus* captured in the western Atlantic Ocean off Hatteras, North Carolina. Trans. Am. Fish. Soc 103 : 94-100.
13. Mellinger J (2002) Sexualité et reproduction chez les poisons. (CNRS, ed.) Paris 364p.
14. Rose CD, Hessler WW (1968) Age and growth of the dolphi *Coryphaena hippurus*(Linnaeus), in North Carolina Waters. Trans. Amer. Fish. Soc.97: 271-276.
15. Kojima S (1966) Fishery biology of the common dolphin, *Coryphaena hippurus* L., inhabiting the Pacific Ocean. Bull. Shimane Pref. Fish Exp. Stn 1: 1-108.
16. Gatt M, Dimech M, Schembri PJ (2015) Age, Growth and Reproduction of *Coryphaena hippurus* (Linnaeus, 1758) in Maltese Waters, Central Mediterranean. Medit. Mar. Sci 16(2) : 334-345.
17. Besbes Benseddik A (2017) Bio-écologie, pêche et évaluation du stock de la coryphène *Coryphaena hippurus* (Linnaeus, 1758) dans la région Est de la Tunisie. Thèse de Doctorat PhD, en Sciences Biologiques et Biotechnologie. Institut Supérieur de Biotechnologie de Monastir : (Janvier 2017), 280 pp.
18. Oxenford HA (1985) Biology of dolphin *Coryphaena hippurus* and its implications for the Barbadians fisheries. Ph. D. diss., Univ. West Indies, Cave Hill, Barbados 366 p.
19. Wu C, Su W, Kawasaki T (2002) Reproductive biology of the dolphin fish *Coryphaena hippurus* on the east coast of Taiwan. Fisheries Science 67: 784-793.
20. Plata CA, Diaz-Jaimes P, Salgado-Ugarte I (2011) Sex ratios, size at sexual maturity and spawning seasonality of dolphinfish (*Coryphaena hippurus*) captured in the Gulf of Tehuantepec, Mexico. Fisheries Research, 110: 207-216.
21. Massuti E, Morales-Nin B (1995) Seasonality and reproduction of dolphinfish (*Coryphaena hippurus*) in the Western Mediterranean. Sci. Mar 59 (3-4): 357-364.
22. Bentivoglio AA (1988) Investigations into the growth, maturity, mortality rates and occurrence of the dolphin (*Coryphaena hippurus*, Linnaeus) in the Gulf of Mexico. M.SC.Thesis, Univ.College of North Wales, Bangor, U.K 37p.
23. Kara LS, Jeffrey AB (2008) Age, growth, Nd reproduction of dolphinfish (*Coryphaena hippurus*) caught off the coast of North Carolina. Fish. Bull 106: 82-92.
24. Appeldoorn RS, Rivera GA (2000) Age and growth of dolphinfish, *Coryphaena hippurus*, Off Puerto Rico. Fisheries Bull 98: 345-352.
25. Prescod S, Hunte W (1997) A preliminary report on the feasibility of farming dolphinfish (*Coryphaena hippurus*) on the northwest coast of Barbados, W.I. (Abstract only) Proc. Gulf Caribb. Fish. Inst 49-52.
26. Schwenke K, Buckel JA (2008) Age, growth and reproduction of dolphinfish (*Coryphaena hippurus*) caught off the coast of North Carolina. Fisheries Bull 106 : 82-92.

27. Besbes Benseddik A, Besbes R, Vitale S, Ezzeddine-Najai S, Cannizaro L, et al. (2011) Détermination de l'âge et de la croissance de la coryphène, *Coryphaena hippurus*, des côtes tunisiennes par l'analyse des microstructures des otolithes. Cybium. Revue Internationale d'Ichtyologie 35(3) : 173-180.
28. Koched W, Hattour A, Said K (2011) Les larves de poissons téléostéens le long des côtes Est tunisiennes : distribution et abondance. Bull. Inst. Natn. Scien. Tech. Mer de Salammbô 38 : 29-39.
29. Sinopoli M, Andalaro F (2017) *Coryphaena hippurus*. In : P., Sartor A, Mannini R, Carlucci E, Massaro S, Queirolo A, Sabatini G, Scarcella and R, Simoni (eds), Sintesi delle conoscenze di biologia, ecologia e pesca delle specie ittiche dei mari italiani [Synthesis of the knowledge on biology, ecology and fishery of the halieutic resources of the Italian seas]. Biologia Marina Mediterranea 24(Suppl. 1) : 217-222.
30. Maggio T, Allegra A, Andaloro F, Barreiros JP, Battaglia P, et al. (2018) Historical separation and present-day structure of common dolphinfish (*Coryphaen hippurus*) populations in the Atlantic Ocean and Mediterranean Sea. ICES Journal of Marine Science 76(1): 352. doi:10.1093/icesjms/fsy174.
31. Palko BJ, Beardsley GL, Richards NJ (1982) Synopsis of the biological data on dolphinfishes, *Coryphaena hippurus* and Coryphaeana equiselis Linnaeus. FAO Fish. Synop 130, 28 p.
32. Wang CH (1979) A study of population dynamics of dolphin fish (*Coryphaena hippurus*) in water adjacent to eastern Tawan. Acta Oceanogr. Taiwan 10: 233-251.
33. Williams F, Newell BS (1957) Notes on the biology of the dorate or Dolfphinfish (*Coryphaena hippurus*) In East African waters. E. Afr. Agric. J 113-118.
34. Diana JS, Mackay (1979) Timing and magnitude of energy deposition and loss the body, lever and gonads of northern pike (Esox lucius). J. Fish Res. Board Can 36: 481-487.
35. Manooch CS, Mason DL, Nelson RS (1984) Food and gastrointestinal parasites of dolphin *Coryphaena hippurus* collected along the southestern and gulf coast of the United States. Bull. Jap. Soc. Sci. Fish 50: 1511-1525.
36. Benetti DD, Brill RW, Kraul SA JR (1995) The standard metabolic rate of dolphin fish. J. Fish Biol 46: 987-996.
37. Nel S (1995) Commercialisation of mahi-mahi. Australia. Aquaculture 9(6): 51-53.
38. Chatterji A, Ansari ZA (1982) Fecundity of dolphin-fish, *Coryphaena hippurus* L., Mahasagar 15(2): 129-133.
39. Burt A, Kramer DL, Nakatsura K, Spry C (1988) the tempo of reproduction in Hyphessobrycon pulchripinis (Characidae), with a discussion of 'multiple spawning' In: fishes. Environ. Biol. Fish 22: 15-27.
40. Sacco F, Marrone F, Lo Brutto S, Besbes A, Nfati A, et al. (2017) The Mediterranean Sea hosts endemic haplotypes and a distinct population of the dolphinfish *Coryphaena hippurus* Linnaeus, 1758 (Perciformes, Coryphaenidae). Fisheries Research 186: 151-158.
41. SchekteR RC (1982) Mari culture of dolphin (*Coryphaena hippurus*) is it feasible? Proceeding of the gulf and Caribbean fisheries. Institute, Nassau, Bahamas, November 27-32.