ePublishing

Mediterranean Marine Science

Vol 16, No 2 (2015)

Age, Growth and Reproduction of Coryphaena hippurus (Linnaeus, 1758) in Maltese Waters, Central Mediterranean

M. GATT, M. DIMECH, P. J. SCHEMBRI

doi: 10.12681/mms.706

To cite this article:

GATT, M., DIMECH, M., & SCHEMBRI, P. J. (2015). Age, Growth and Reproduction of Coryphaena hippurus (Linnaeus, 1758) in Maltese Waters, Central Mediterranean. *Mediterranean Marine Science*, *16*(2), 334–345. https://doi.org/10.12681/mms.706

https://epublishing.ekt.gr | **e-Publisher:** EKT | **Downloaded at:** 19/04/2024 12:14:24

Research Article

Mediterranean Marine Science
Indexed in WoS (Web of Science, ISI Thomson) and SCOPUS
The journal is available on line at http://www.medit-mar-sc.net
DOI: http://dx.doi.org/10.12681/mms.706

Age, Growth and Reproduction of *Coryphaena hippurus* (Linnaeus, 1758) in Maltese Waters, Central Mediterranean

M. GATT[1], M. DIMECH[1] and P.J. SCHEMBRI[1]

[1] Department of Biology, University of Malta, Msida MSD 2080, Malta

Corresponding author: gattm1976@gmail.com

Handling Editor: Kostas Stergiou

Received: 24 November 2014; Accepted: 22 January 2015; Published on line: 27 April 2015.

Abstract

Age, growth and reproduction of the dolphinfish *Coryphaena hippurus* Linnaeus, 1758 collected from the Central Mediterranean in the period 2004-2010 by the traditional Maltese fish aggregating devices (FAD) and surface longline fisheries were studied. The *a* and *b* parameters of the length-weight relationship for fish 11-142 cm fork length (FL) (n = 4042) were determined as $a = 0.018$ and 0.022 with $b = 2.85$ and 2.79, for males and females respectively. The counting of annual increments from dorsal spines of >65 cm FL dolphinfish at X25 magnification (n = 47) permitting an age reading resolution in years, and the counting of daily increments from sagittal otoliths of <65 cm FL dolphinfish at X400 magnification (n = 583) permitting an age reading resolution in days, were estimated; the von Bertalanffy growth model applied to these fish gave the following parameters: $L\infty = 107.8$ cm FL and 120.2 cm FL, and $K = 1.9$ yr^{-1} and 1.56 yr^{-1}, for males and females respectively. The maximum age observed was 2 years. Size at 50% maturity for fish 10-131 cm FL (n = 1376) was 58.9 cm FL and 62.5 cm FL for males and females, respectively. The sex ratio for the fish sampled from the FAD fishery (10.5-131 cm FL) was 1:1.54 (M:F) and for dolphinfish sampled from the surface longline fishery (91-130 cm FL) was 1:0.76 (M:F). Back-calculated hatch dates from age-0 dolphinfish (n = 518) suggested that spawning occurs from June to September with the highest levels in June. This study is the first to use dorsal spines to determine the age of adult dolphinfish.

Keywords: *Coryphaena hippurus*, Malta, age determination, von Bertalanffy, growth model, otoliths, dorsal spines.

Introduction

Dolphinfish are members of the family Coryphaenidae which only includes one genus with two species: *Coryphaena hippurus* (Linnaeus, 1758) and *Coryphaena equiselis* (Linnaeus, 1758). Dolphinfish are found in tropical and sub-tropical surface waters of the Atlantic, Indian and Pacific oceans (Gibbs & Collette, 1959).

Coryphaena hippurus occurs in the Mediterranean from May - December, when the surface water temperatures reach >16-18°C (Massuti & Morales-Nin, 1995). In the sea around the Maltese Islands, adult dolphinfish (63-117 cm FL) are mainly caught as by-catch from the swordfish and bluefin tuna longline fisheries in spring and summer. Juvenile fish (14-70 cm FL) are exploited by surrounding net (lampara & purse seine) in Malta, Majorca, Sicily and Tunisia from late August to December. The Maltese "*kannizzati*" fish aggregating device (FAD) fishery targeting dolphinfish is a traditional one in Malta. The FADs consist of a float which is anchored by a heavy piece of limestone (minimum of 70 kg) with tied palm fronds as shown in Figure 1. The net used in the FAD fishery is a modified purse seine, in view of the absence of pursing rings. Fishermen fish these anchored FADs either during the day or the night. Fishing the floats during the night has recently become more common due to a greater yield of catch. During the day, artificial trolling lures are used to lure any fish that may be present around the FADs. Night fishing involves localisation of the shoals close to the FADs by means of powerful searchlights. If the number of fish makes the fishing operation worthwhile, the boat makes a complete circle around the shoal. Historical landings of dolphinfish in relation to the landings of two other major targeted species by the Maltese fisheries sector are shown in Figure 2.

Several dolphinfish age and growth studies have shown that these fish are short lived, fast growing species (Beardsley, 1967; Rose & Hassler, 1968) and their maximum longevity has been estimated at four years. Longevity of dolphinfish from Florida was estimated to be four years, but only 2% of the population was found to be older than two years (Beardsley, 1967), and only 4% in North Carolina (Rose & Hassler, 1968). The maximum lifespan of the Southern Caribbean dolphinfish stock does not appear to exceed 18 months, and few individuals of the North Caribbean stock live longer than two years (Oxenford & Hunte, 1999). Dolphinfish of 55cm fork length (FL) read from otoliths and caught off Majorca were reported to be 176 days old and specimens of

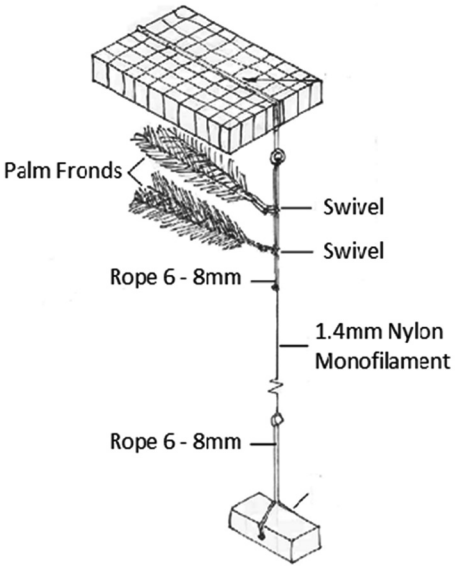

Fig. 1: FADs setup (Adapted from Farrugia Randon, 1995).

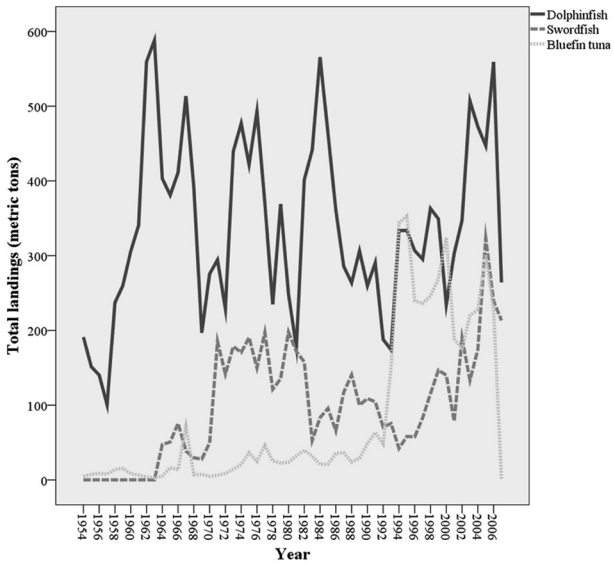

Fig. 2: Comparison of dolphinfish, swordfish and bluefin tuna landings (Data supplied by the Agriculture and Fisheries Regulation Department, MRRA)

dolphinfish caught off the Canary Islands within a range of 76 to 103 cm FL were found to be two and three years old from age reading of scales (Beardsley, 1967; Oxenford & Hunte, 1983; Uchiyama & Burch, 1986, Massuti & Morales-Nin, 1995). The maximum lifespan reported from scales for these fish in the Mediterranean was of three years, with fish at this age class ranging from 92 - 120 cm FL (Massuti *et al.,* 1999).

Age and growth rates for dolphinfish have been determined by means of scale annuli, daily growth increments in otoliths (Oxenford & Hunte, 1983; Uchiyama & Burch, 1986) and modal progression analysis (Wang, 1979; Murray, 1985). Beardsley (1967) reported that a juvenile dolphinfish specimen caught from Florida and reared in captivity grew from 450 g to 16 kg in one year and Schekter (1972) reported a growth rate of 4.3 kg (from 0.7 to about 5 kg) in 30 days. In Barbados, dolphinfish may reach lengths of over 80 cm FL in 5.5 months and over one meter in less than one year (Oxenford & Hunte, 1986). In Hawaii, they also attain a length of over one meter at the end of the first year (Uchiyama & Burch, 1986). By applying the length-weight regression of Rose & Hassler (1968) to these data, this would correspond to a mass of about 8 kg in one year. Growth rates presented by Benetti *et al.* (1994), for captive dolphinfish of 4.93 kg and 75.8 cm FL in 9.5 months were lower, yet among the fastest recorded for bony fish reared in captivity. The absolute growth rates in terms of length of wild and captive dolphinfish vary between 0.1 - 0.58 $cm.d^{-1}$ for the first year of life (Oxenford & Hunte, 1983).

From the von Bertalanffy growth functions, Schwenke & Buckel (2008), reported faster growth rates for dolphinfish from the Gulf of Mexico and the Caribbean, than those from Florida, North Carolina and the Mediterranean. Mediterranean dolphinfish were reported as having slightly smaller sizes at age 2 and 3 compared to size for these ages of Florida and North Carolina dolphinfish.

Dolphinfish, on average reach their L_∞ in a year or two and have high values of *K*. The *K* value for Mediterranean dolphinfish was estimated to be 1.9 by Massuti *et al.* (1999). This leads to steep curves in the von Bertalanffy growth curve. The asymptotic length (theoretical maximum length) of Florida dolphinfish is of 1.89 m and 1.53 m FL for males and females respectively, according to Beardsley (1967). The estimated maximum weight of 58.4 kg is however much higher than the maximum weight of 46 kg reported for this species (Florida sportsman, 1979).

There is general agreement that dolphinfish in the western central Atlantic and Mediterranean reach sexual maturity in the first year of life, and that females reach maturity at a smaller size, but at similar age to males (Massuti & Morales-Nin, 1997; Oxenford, 1999). In a study by Potoschi *et al*. (1999), it was found that the sampled dolphinfish belonging to the 0 age group had a sex ratio of 2:1 (females : males) whereas for older age groups the sex ratio was 1:1, indicating that the sex ratio varies with age class. The results obtained were in concordance with those registered by Massuti & Morales-Nin (1997) who reported a 1:1 ratio in adults sampled in the western Mediterranean Sea.

The present work provides biological information for Central Mediterranean dolphinfish, including length and weight relationships, calculation of the condition factor, sex ratios, spawning period, and length at maturity, together with growth parameters and respective growth rates from age readings of otoliths, scales and spines. Such biological information is crucial for determining the degree of exploitation that a fish stock can sustain without suffering a population decline. Full-scale stock assessments have never been carried out for this species in the Mediterranean, although a preliminary stock as-

sessment was attempted by the General Fisheries Commission for the Mediterranean (2004). More extensive and updated biological information needs to be obtained for this fish so as to better calibrate population models for future assessments.

Materials and Methods

Dolphinfish were sampled from the FAD and surface longline (SLL) fisheries. Samples of juvenile dolphinfish were collected weekly, during the FADs fishery seasons of 2004-2010 (mid-August to December) by lampara net seining operations around the FADs. Adult dolphinfish were also collected from these operations whenever available. Other adult dolphinfish were collected during the period 2007-2010 from the local longline fishery targeting swordfish and bluefin tuna. In order to collect data for the juvenile portion of the population (1-2 month old fish), which are not exploited by the fishery, a special permit for experimental fishing was granted by the Maltese authorities in 2008 and one transect of FADs was deployed one month before the official start of the FAD fishery season. These experimental FADs were visited weekly during the last week of July and the first fortnight of August, providing a fishery-independent sample of 515 juvenile dolphinfish. All the samples were processed in the laboratory and data on individual length and weight, gonad weight, sex and maturity were collected. Hard parts were extracted for age reading.

Length-weight relationships

FL was measured to the nearest millimetre and weights were recorded to the nearest gram from a sample of 4042 fish.

Age Determination and Growth

Sagittal otoliths (n = 583) were extracted from the heads of juvenile dolphinfish (<65 cm FL); these are the only structures for which daily increments have been validated from reared and wild fish from hatching to 55.4 cm FL (Uchiyama & Burch, 1986; Massuti *et al.,* 1999). Previous studies on the microstructure of sagittal otoliths of dolphinfish from the Western Mediterranean sea found that the daily ages from larger dolphinfish (> 65 cm FL) appeared to be underestimated (Massuti *et al.,* 1999). Furthermore, the daily ages of dolphinfish have been validated to a size of 55.4 cm FL (Uchiyama & Burch, 1986). Therefore, sagittal otolith analysis in this study was restricted to dolphinfish less than 65 cm FL and ages for dolphinfish more than 65 cm FL were read from spines and scales. The yearly ages read from dorsal spines (n = 47) were however used for the Von Beralanffy plot due to the difficulties encountered in detecting annuli in scales, especially at the edges and leading to potential underestimation of yearly ages from this structure.

Otoliths were removed by the frontal head section technique of Secor *et al.* (1991), and were cleaned and mounted in cold mounting resin which was then polymerised at 60°C for 24 hrs. The resulting blocks were sectioned with a Buehler Isomet low speed saw and then affixed to a labelled slide by means of thermoplastic glue and polished with 14-micron grit paper on a motorised petrographic polisher until the core was clearly visible and daily increments had sufficient contrast. Daily increments were counted from the digital image coming from a Carl Zeiss Axiophot compound microscope equipped with a Carl Zeiss Axiocam colour 1.4 MP camera. The image from the camera was transmitted to a computer and examined with the aid of Carl Zeiss Axiovision software version 4.7.2 (2006–2008). Growth increments were counted from the core to the edge of the pararostrum (Oxenford & Hunte, 1983; Massuti *et al.,* 1999). Incremental counts were made beginning at the first clearly defined mark encircling the primordium, which defined the outer edge of the nucleus (Massuti *et al.*, 1999). To determine the precision of juvenile dolphin ages, blind readings of daily growth increments for each otolith were made twice in random order. An error in reading precision greater than 10% for an individual otolith caused the otolith to be rejected. If the error in reading precision was less than or equal to 10%, then the average between the first and second readings was taken as the final age. Growth increments in otoliths from the smaller fish were enumerated along a single axis. However, as the juveniles grew older incremental intervals and resolution decreased and it was necessary to follow a circuitous path to complete a set of counts, following prominent increments laterally until an area with clear increments was found. Growth incremental marks on the otoliths were individually counted at X400 magnification to achieve an age resolution in days. Hatch dates for 518 fish were determined by subtracting the age in days (determined from otoliths) from the catch date.

Adult dolphinfish (>65 cm FL) had their entire dorsal fins removed, and the spines were prepared for reading according to the method described for swordfish by Tsimenides & Tserpes (1989). After drying, each dorsal spine was placed in a plastic mould, mounted in epoxy resin and dried in an oven at 60°C for 24 hrs. Embedded spines were removed from the mould and two sections about 0.6 mm thick were cut distally with a low speed Isomet saw and diamond wafering blades. The sections were cut at a location equivalent to half of the maximum width of the condyle base measured above the line of maximum condyle width as per Ehrhardt *et al*. (1996). Spine sections were read under a stereomicroscope at X25 magnification using transmitted light and a polariser. Images of the sections were captured using Carl Zeiss Axiovision software package version 4.7.2 (2006–2008) in combination with a Carl Zeiss MRc Moticam camera and monitor. Images of spine sections were measured in millimetres using this software, after calibration. The spine

radius was measured from the focus to the outer edge of the section with the focus being defined as the point of convergence in the vascularised core area. Broad and narrow bands could be seen very clearly radiating outwards from the central core (Figure 3). The narrow bands that were visible around the entire circumference of the spine were considered to be annuli and were assigned to age classes for a reading of age in years. Sections were read independently by two readers and identical counts were obtained in more than 90% of the cases. Samples were considered unreadable if the discrepancies between the readers could not be resolved. The pair of bands close to the core was not added to the total annular count as they were considered to have been laid down before the one-year annulus, being too close to the central core. This hypothesis was also confirmed as fish in the age-0 category with no visible annuli except the presence of a pair of bands close to the core, had FLs matching those of literature data from age-0 fish. A biological hatch date of 30th June obtained from the analysis of daily growth increments from juvenile fish was subtracted from the catch dates of Wthe adults to achieve a more realistic age

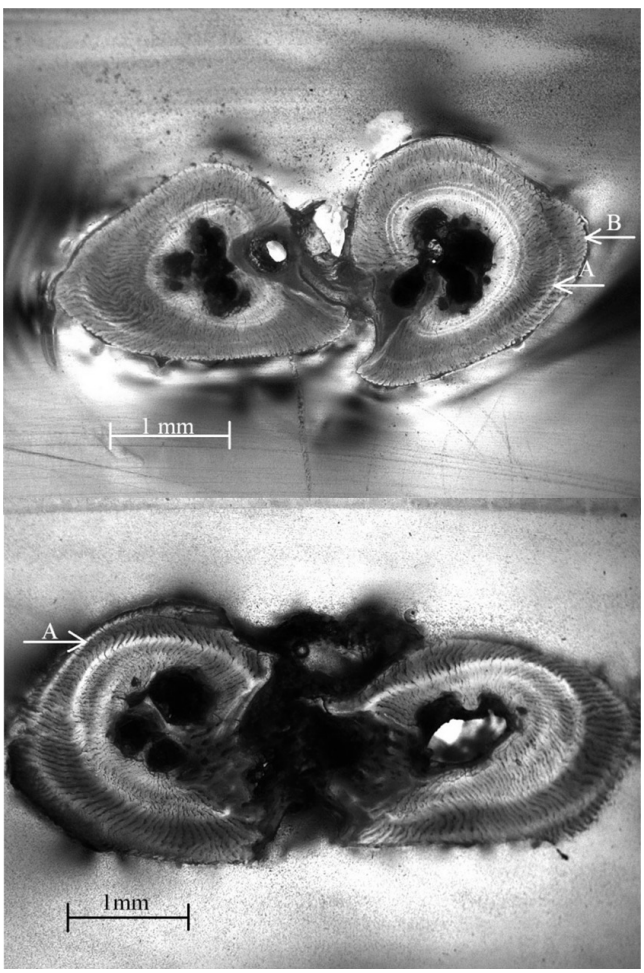

Fig. 3: Top: Two-year old dolphinfish and bottom: One-year old dolphinfish dorsal spine sections at X25 magnification. A corresponds to the 1st year annulus while B corresponds to the 2nd year annulus.

determination and provide better resolution.

The spine radii of each assigned annulus were measured for the calculation of the marginal increment ratio (MIR) according to the formula of Tsimenides & Tserpes (1989):

$$MIR = (S-R_n)/S$$

S = spine radius and R_n = radius of most recent annulus.

Scales from adult dolphinfish (>65 cm FL) were taken from an area just above the lateral line behind the tip of the pectoral fin, which provided the largest and most uniformly shaped scales considered to be best for reading. Between 15 and 20 scales from each fish were selected and left to soak for a maximum of two minutes in 10% sodium hydroxide for cleaning. The duration of immersion in this active solution was controlled to avoid damage to the scales. Any loosened organic debris obscuring the scale markings was teased off carefully using dissecting needles under low magnification. The scales were then rinsed thoroughly in distilled water and left to air dry before storing. Due to their hydrophilic nature, scales often distort under dry conservation, thus rehydration by immersion in water was necessary before further processing and mounting. Scales were mounted by fixing between two microscope slides and were examined with a stereomicroscope at X25 magnification using transmitted light and a polariser. Images of the mounted scales were captured using a Carl Zeiss Axiovision software package version 4.7.2 (2006–2008) in combination with a Carl Zeiss MRc Moticam camera and monitor. The resulting images were clear with well-defined circuli. Scale radii were measured in mm and annuli identified according to the method described by Beardsley (1967) by following three characteristic features: spacing of the circuli, broken and generally disrupted circuli, and the cutting-over in the postero-lateral field. Scales were read twice, with readings discarded when the first did not agree with the second independent reading.

Age data were fitted into the Von Bertalanffy growth function with the following form:

$$Lt = L\infty\ (1–exp\ (-k*(t – t^o))$$

Because of sexual dimorphism, separate von Bertalanffy growth parameters were calculated for males and females (Uchiyama & Burch, 1986). To determine individual dolphinfish growth rates in mm/day, the FL at capture was divided by the age in days for all age-0 fish less than 65 cm FL.

Reproduction

Sex was determined by macroscopical examination of the gonads and fish were assigned a maturity stage (n = 1376). Fish gonads were weighed to the nearest 0.1 g for the determination of the Gonadosomatic Index (GSI). For dolphinfish from the Florida Current, Beardsley (1967) described 5 maturity stages (I-immature, II-early maturing, III-late maturing, IV-ripe, V-spent) for females and 2 stages (I-immature or resting, II-mature) for males,

based on visual appearance, and his criteria were used in the present study. The GSI was calculated as:

$$GSI = [gonad\ wt/(body\ wt\text{-}gonad\ wt)]*100.$$

Results

Length-Weight Relationship

Determined ***a*** (0.018 - males, 0.022 - females,) and ***b*** parameters (2.85 - males, 2.79 - females) from the length-weight equation are shown in Table 1 and plotted L-W in Figure 4.

The Spearman's rank order correlation coefficient (r_s) was used to assess whether there is any significant correlation between the log transformed lengths and weights. The value (r_s) estimated for females was 0.984 ($P < 0.01$), for males 0.99 ($P < 0.01$), and for both sexes combined 0.987 ($P < 0.01$), which indicated that the relationship was highly significant (Table 2).

Age Determination and Growth

A total of 583 juvenile dolphinfish (<65 cm FL) sampled from the FAD fishery during 2005-2010 had their otoliths extracted and read successfully for the determination of daily increments (Table 3). A total of 47 adult dolphinfish (>65 cm FL) were successfully aged from spines (Table 4) and 73 ages were read from scales.

The irregular shape of the sectioned spines made the localisation of the focus and the measurement of the MIR extremely difficult. In fact, the intra-specimen variability of the MIR was large. This factor, together with the limited number of samples available reduces the reliability of any age validation for dorsal spines carried out by the use of the MIR. Thus, aging from dolphinfish spines cannot be considered as validated to date. Figure 5 shows the location of the spine found to be the most useful for age determination.

Aging from scales proved difficult. Direct comparisons between paired observations of spine and scale yearly ages obtained from a subsample of 29 adult individuals (Table 5) showed an underestimation in the ages read from scales.

In view of these uncertainties, readings from scales of adult dolphinfish were not used for plotting the Von Bertalanffy growth function (Figure 6), and growth parameters (Table 6) were calculated on the basis of the age-length relationships from the daily growth increments of otoliths of juvenile (<65 cm FL) fish and the annulae of the spines of adults (>65 cm FL). Determined

Table 1. The ***a*** and ***b*** parameters derived from the logarithmic form of the L-W equation for dolphinfish sampled from the Maltese longline and FAD fisheries in the period 2004-2010.

a	*b*	Sex	FL (cm)	N
0.018	2.85	Males	16-126	1468
0.022	2.79	Females	11-131	2347

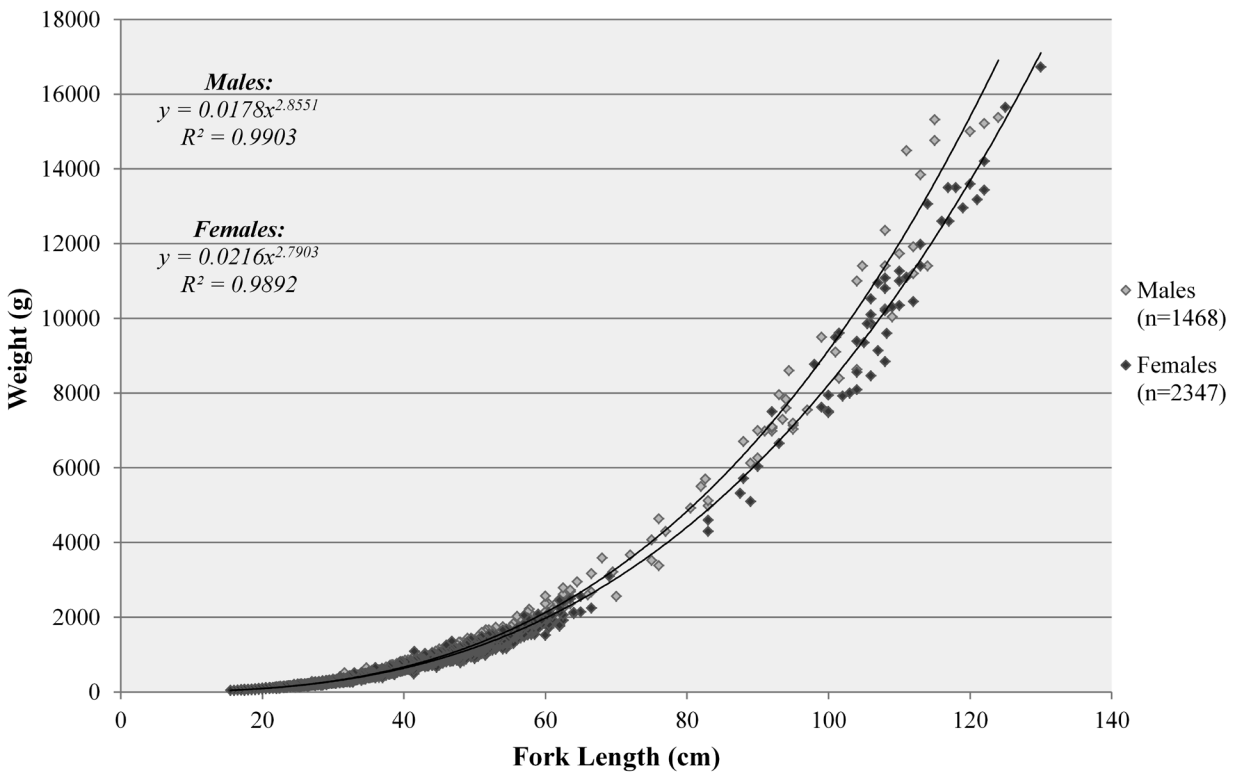

Fig. 4: L-W relationships for male and female dolphinfish sampled from the Maltese longline and FAD fisheries in the period 2004-2010.

Table 2. Spearman's rank order correlation coefficients ***(rs)*** estimated for the log linearised L-W relationship for females, males and for both sexes combined.

			Ln W
Females	**Ln FL**	Correlation Coefficient	0.984**
		Sig. (2-tailed)	< 0.001
		N	2347
Males	**Ln FL**	Correlation Coefficient	0.990**
		Sig. (2-tailed)	< 0.001
		N	1468
Sexes combined	**Ln FL**	Correlation Coefficient	0.987**
		Sig. (2-tailed)	< 0.001
		N	4042

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3. FL and daily age observations for juvenile dolphinfish (<65 cm FL) sampled from the Maltese FAD fishery during the period 2005-2010.

Sex	Measurement	N	Min.	Max.	Mean	SD
Sexes combined	Fork length (cm)	583	10	60	34	± 12
	Sagitta days	583	27	151	70	± 32

Table 4. FL and live weights for adult dolphinfish (>65 cm FL) sampled for age readings from spines. Adults sampled from the Maltese longline and FAD fisheries during 2009-2010.

Sex	Measurement	N	Minimum	Maximum	Mean	SD
Females	Fork (cm)	30	88	131	109	± 10
	Weight (g)	30	5717	19050	11010	± 2773
Males	Fork (cm)	17	72	122	96	± 14
	Weight (g)	17	3521	18450	9470	± 4598

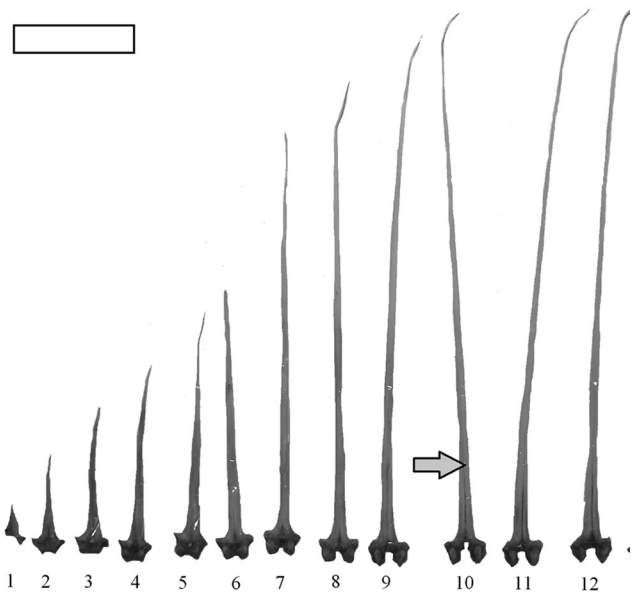

Fig. 5: Dorsal spine found to be most suitable for measurement and subsequent calculation of the MIR. This was the first of the longest spines in the dorsal fin (arrow) of dolphinfish. Spine numbers within the dorsal fin are indicated. (Scale bar: 3 cm).

$L\infty$ was 107.8 cm FL and 120.2 cm FL, with a K 1.9 yr^{-1} and 1.56 yr^{-1}, for males and females respectively. The maximum age observed was 2 years.

Mean growth rate was 5.1 mm/day (± 0.8 SD) from a sample of 566 dolphinfish aged from otoliths. The largest mean observed growth rates were for dolphinfish of FL 16 cm–35 cm (N = 298). Growth rates decreased significantly in dolphinfish of FL 36 cm–60 cm (N = 254) (Mann Whitney test: U = 11217.5, P = < 0.001) confirming that growth decreased with size.

Sex Ratio, Length at First Maturity and Reproduction

Females were more numerous than males for dolphinfish below 60 cm FL (Figure 7) and sampled from FADs. Overall, sex ratio for fish sampled from around FADs was biased towards females for all size classes (1:1.54 M:F; $X^2 = 160.2$, P < 0.0005). There was no clear trend in the relationship between the sex ratio and size distribution for dolphinfish sampled from the surface longline fishery with non-significant differences from 1:1 (1:0.76 M:F; $X^2 = 1.351$, P >0.05).

Both females (N = 730) and males (N = 583) were classified as mature when at stage II of the maturity stages table in Beardsley (1967) following Schwenke & Buckel (2008), and Perez & Sadovy (1991). The estimated sizes at sexual maturity (L_{50}) from maturity ogive plots were as follows; males: L_{50} = 58.9 cm FL, with 100% mature at 104 cm FL and females: L_{50} = 62.56 cm FL, and 100% mature at 104 cm FL (Figure 8).

For the investigation of the reproductive period in relation to GSI values, mature (Beardsley maturity II-V) dolphinfish (females N = 63 and males N = 47) read from dorsal spines as being over 1 year of age and having FL of over 65 cm, which exceeds the L_{50} for both sexes, were

Table 5. Direct comparison between paired estimates of age from spine and scale determinations from the same adult individuals.

Age structure	Age (Years)	N	Percent
Scale	0	22	75.9
	1	6	20.7
	2	1	3.4
	Total	29	100
Spine	0	1	3.4
	1	23	79.3
	2	5	17.2
	Total	29	100

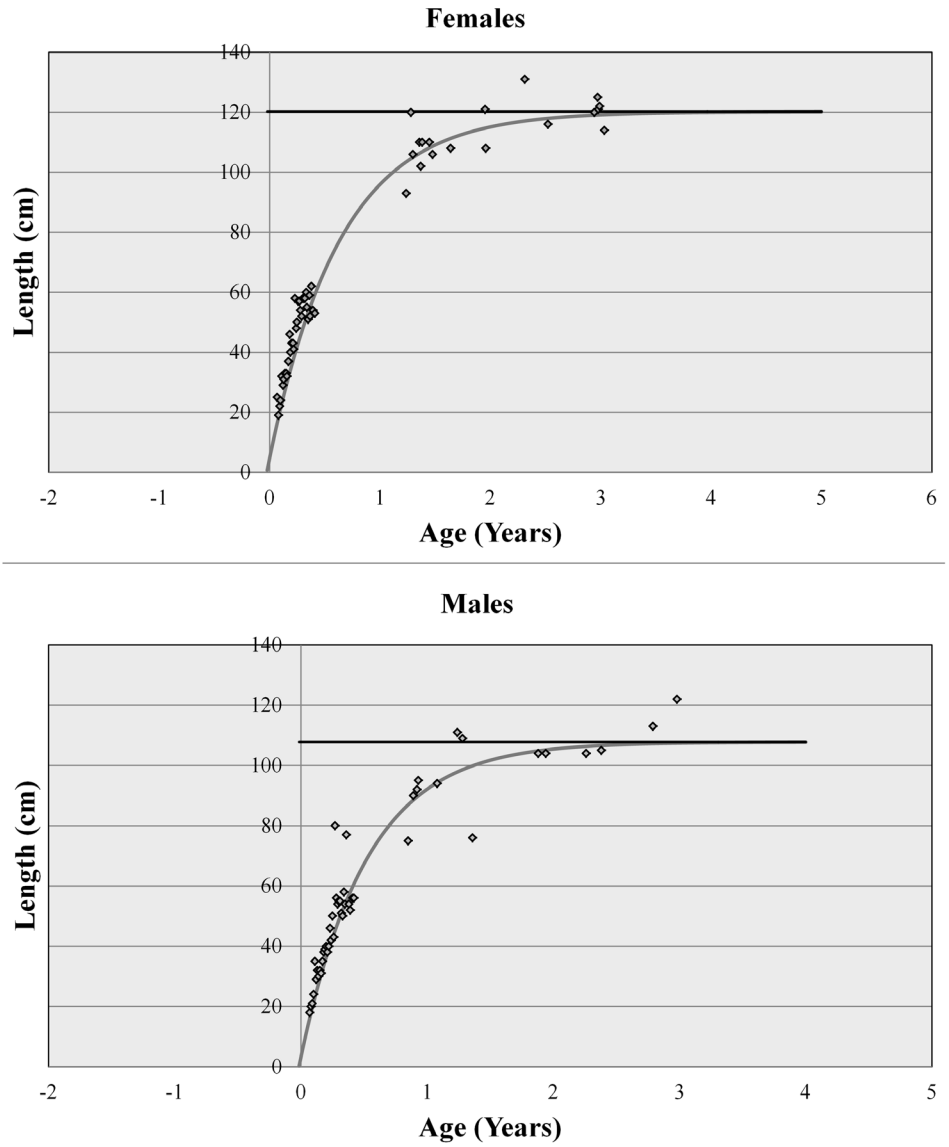

Fig. 6: Von Bertalanffy growth curve for males and females

Table 6. Dolphinfish growth parameters by sex.

Growth Parameter			
	Sexes Combined	*Females*	*Males*
Optimal K	1.54	1.56	1.9
Coeff. of determination R^2	0.945	0.968	0.939
L_∞	126.6	120.2	107.8
t_0	-0.019	-0.025	-0.016

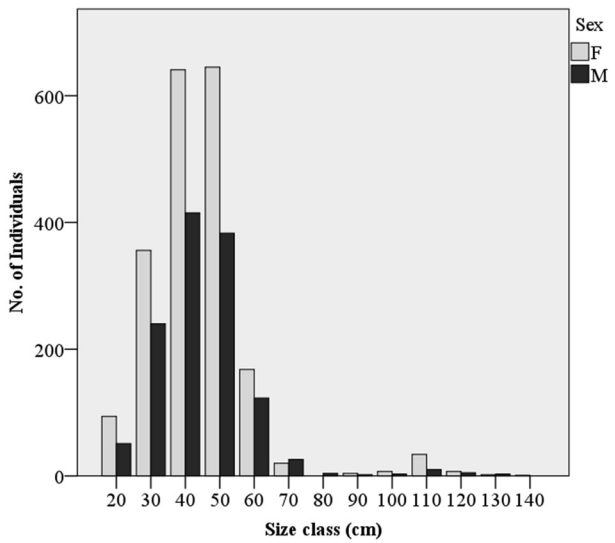

Fig. 7: Sex ratio for different size classes of dolphinfish from the Maltese FAD fishery in the period 2004–2010.

categorised as spawners. According to mean GSI values, female spawners showed peaks of intense reproductive activity from May to October. Male mean GSI values followed the same pattern but with lower values, reflecting the minimal changes in weight in male gonads throughout the reproductive period (Figure 9). The GSI values presented statistically significant differences between months for both females and males (Kruskall Wallis test: $H_{(8)}$ = 45.155, P <0.05), ($H_{(8)}$ = 40.199, P <0.05, respectively), with the highest mean rank values from May to October and markedly lower values in January, February, November and December. The combined information on the seasonal distribution of mature females in relation to GSI values indicates that dolphinfish have their reproductive period between May and October.

A sample of 518 juvenile dolphinfish aged from otoliths and collected from the FAD fishery during the period 2005-2010 was used for the investigation of birthdates. The dis-

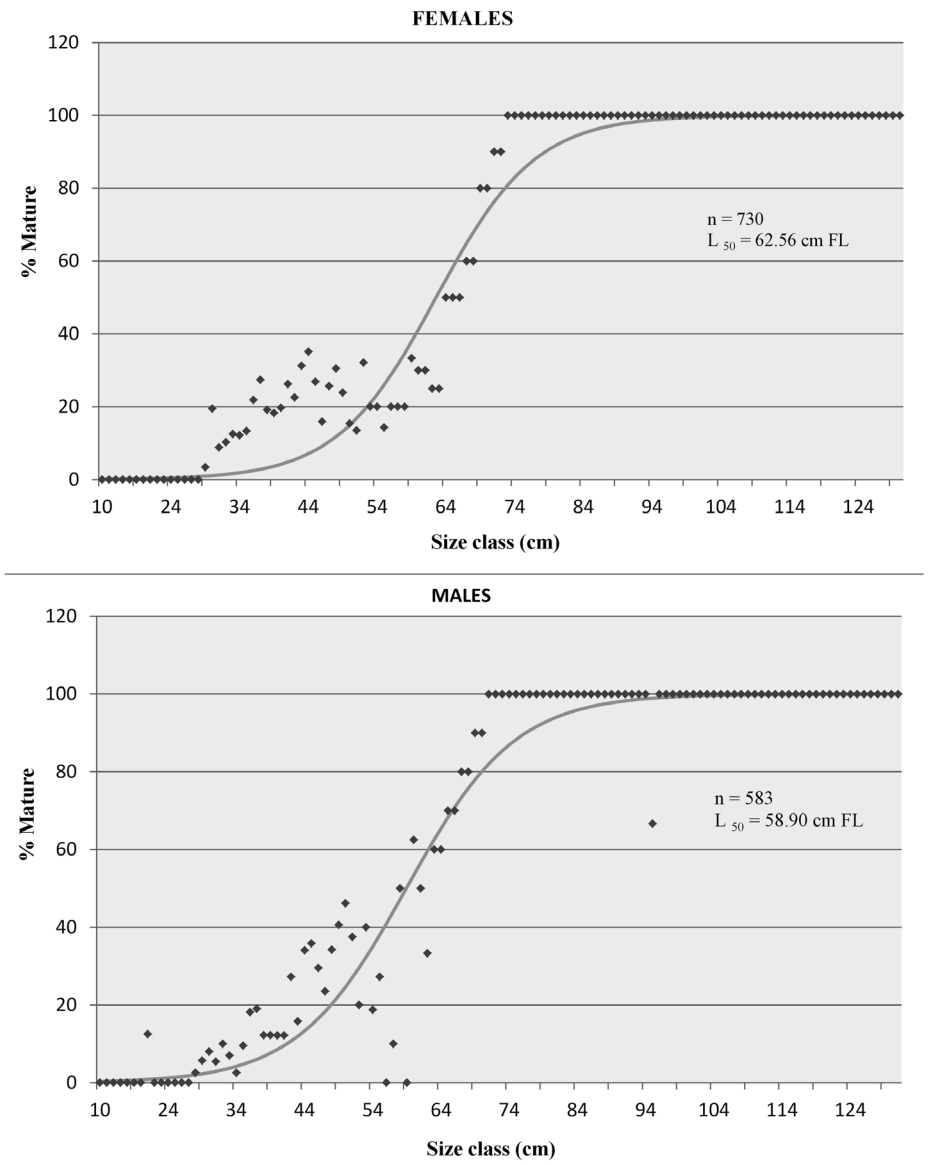

Fig. 8: Maturity ogive for male and female dolphinfish collected from Maltese longline and FAD fisheries in the period 2004–2010.

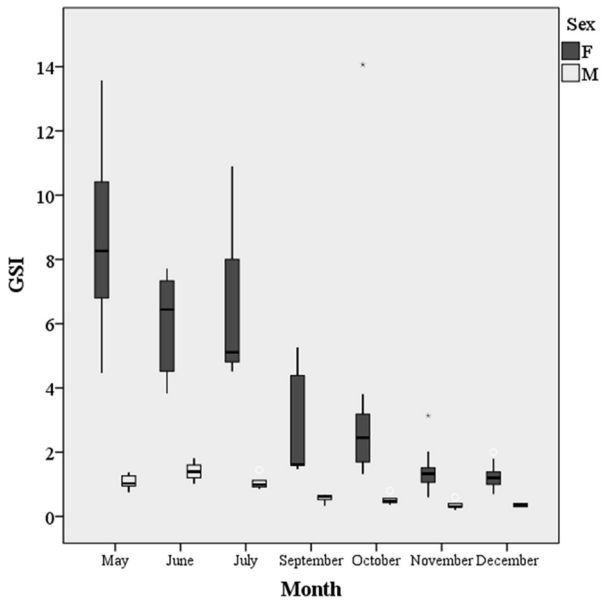

Fig. 9: Mean monthly GSI values for male and female dolphinfish categorised as spawners. Error bars represent ± 2 SE.

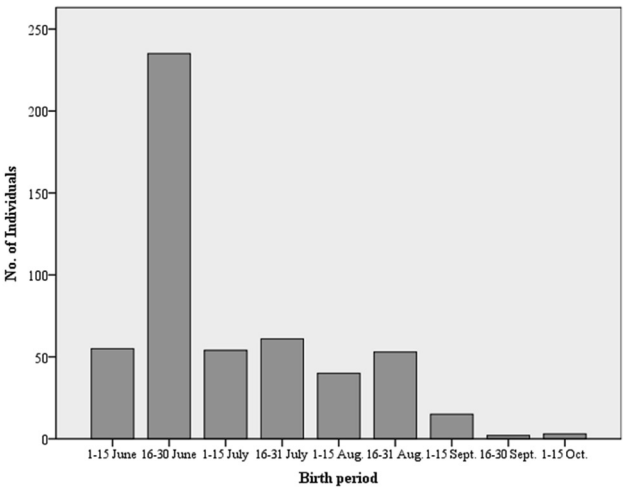

Fig. 10: Birthdate distribution for male and female juvenile dolphinfish sampled from the Maltese FAD fishery.

tribution showed a long hatching period, with a peak in the second fortnight of June and a distribution of birthdates which correlates with the reproductive season known from adult maturity data (Figure 10). Due to poor resolution from the reading of daily increments at the periphery of otoliths from fish of FL 46 cm–60 cm, there was the possibility of having final readings that were somewhat underestimated. In Figure 10 the birthdate distribution was thus plotted without the values for these fish to achieve the best resolution possible.

Discussion

The majority of individuals studied consisted of large mature fish sampled in the spring - summer spawning period, and juvenile fish sampled between summer and autumn. Some large specimens were also obtained in winter (January-February) from the surface longline fishery. These samples, coupled with surface longline fishery landings reports from the January-February period, may suggest that some adults could be choosing the Mediterranean as their wintering area and do not return to tropical areas in the Atlantic Ocean, thus forming a separate sub-population. To date no literature is available describing clear migration patterns and possible wintering areas within the Mediterranean for adult dolphinfish.

Length-Weight Relationship

Negative allometry was stronger in females (***b*** = 2.79) than in males (***b*** = 2.85), which is in agreement with other studies (Rose & Hassler, 1968; Oxenford, 1986 and Schwenke & Buckel, 2008). This characteristic is due to male dolphinfish developing a bull forehead which is fully formed at 60 cm FL (Rose & Hassler, 1968) as shown in the L-W plots for the two sexes (Figure 4) where males are heavier than females above a FL of 60-70 cm. The heaviest fish sampled in this study was in fact a male with a live weight of 25.12 kg.

Age Determination and Growth

Support for the validity of the daily ages read from dolphinfish below 65 cm FL was achieved from estimated birthdates based on otolith increments, which were found to be in good agreement with reproductive periods determined by investigations in the present study. Similarly, Massuti *et al.* (1999) were able to establish the validity of their daily age data using this methodology.

Dorsal fin spines have never been used for ageing dolphinfish. The origin and relation to the physiological stresses experienced by these fish in laying visible annuli due to a reduction in growth rate is still unknown and further investigation is required. The annuli were relatively easy to interpret and the percentage agreement was extremely high between readings performed by the same investigator, while being moderate between two readers. Previous studies on the microstructure of sagittal otoliths of dolphinfish from the Western Mediterranean have also shown that the daily ages from larger dolphinfish (>65 cm FL) appeared to be underestimated (Massuti *et al.,* 1999). The results however show that there is potential for aging dolphinfish from dorsal fin spines for these large fish. The irregular shape of dolphinfish spines and the limited number of monthly samples thwarted the validation of this new method by means of marginal increment analysis. The intra-specimen variability of the MIR was large, thus reducing the reliability of any age validation carried out by the use of the MIR. The most conclusive method to validate these ages would be the use of oxytetracycline injection in addition to conventional tagging and recapture. However, this is a resource-intensive undertaking.

To date, scales seemed to be the most used for determining the age of dolphinfish in years (Beardlsey, 1967; Rose & Hassler, 1968; Massuti *et al.,* 1999). However, reading these structures was not easy and annuli were extremely difficult to localise.

Using spine annular marks for fish over 65 cm FL with the assignment of a 30 June biological hatch date (to reduce the variability associated with length at age for +1 year fish), together with daily growth increments from otoliths for fish under 65 cm FL, an updated age-length function was determined. This age-length growth curve includes the whole size range of dolphinfish from small juveniles to large adults and is the first one for the central Mediterranean in this regard.

The growth parameters obtained from the Von Beralanffy plot were in agreement with those from the literature for similar size ranges of fish. Values obtained in this study were very close to those obtained from the western Mediterranean by Massuti *et al.* (1999). Values were also similar to the parameters obtained from North Carolina by Schwenke & Buckel (2008) and from Puerto Rico by Appeldoorn & Rivera (2000).

The determined daily growth rate of 5.1 mm/day (± 0.8 SD) was extremely fast, as in other pelagic fish. Similar growth rates have been reported for Atlantic bluefin tuna, with first year growth rates ranging from 1 to 6 mm/day (Brothers, 1981). A statistically significant decrease in growth rate with size was found, in line with the Von Bertalanffy growth model, which assumes that fish grow most quickly when young with growth slowing gradually as the individual gets older. The same trend suggesting that adult dolphinfish grow slower than juveniles was found by Oxenford & Hunte (1983). On the other hand, the present study did not find any statistically significant differences in the growth rates between sexes within the entire size range investigated.

Sex Ratio, Length at First Maturity and Reproduction

Results obtained indicate that sex ratio remains in favour of females for sizes between 20 cm and 60 cm FL, as also found in similar studies from the Mediterranean and Balearic Islands (Potoschi *et. al*, 1999; Massuti & Morales-Nin, 1997; Plata *et al.*, 2011). Larger individuals collected for the 61-140 cm size classes were poorly represented, thus a clear cut result towards a particular sex-ratio value for adult dolphinfish collected from FADs was difficult to detect. Olson & Galvan-Magana (2002) suggested that the preponderance of females below 60 cm FL sampled from the FADs fishery in the eastern Pacific Ocean could be caused by segregation because of the tendency for males to engage more in foraging behaviour away from FADs. This could make them less susceptible to be caught by lampara net operations from around these floating structures. Therefore, this female biased sex ratio from the FAD fishery is believed to result from inadvertent selection for females by fishers as a result of intersexual differences in the behaviour of the fish, rather than a real difference in sex ratio at conception or in larval and juvenile mortality rates of males and females (Nakamura, 1971; Rose & Hassler, 1968; Oxenford, 1986). The sex ratio for fish sampled from the longline fishery showed no statistically significant deviation from the 1:1 ratio in large fish (91-130 cm FL) landed by the longline fishery. In contrast to this, Oxenford (1986) suggested that large-sized males tend to spend more time in open water and thus are more common in catches from surface longlines than from around FADs.

Estimates of maturity for Mediterranean dolphinfish by Massuti & Morales-Nin (1997) gave values of L_{50} = 54.5 and 61.8 cm FL for females and males, respectively. The present results from fish sampled from the central Mediterranean were slightly different with an L_{50} = 62.6 and 58.9 cm FL for females and males, respectively**.** This analysis from the Mediterranean was derived from the macroscopic assessment of the gonads without histological verification; with the possibility of including immature individuals in the mature category and/or missing early maturing individuals. Detecting early maturing individuals by macroscopic assessment was extremely difficult, which could have led to an overestimated L_{50} for females. Histological techniques have greater precision for maturity at size estimates (De Martini *et al*., 2000) and would be necessary to fine tune any future maturity ogives for central Mediterranean dolphinfish. Another problem was due to the limited number of samples from size range 60-100 cm FL, for which there was minimal information on size at maturity, possibly affecting the maturity ogive.

Mean GSI values at each maturity stage for both sexes were provided by Oxenford (1986) for dolphinfish from Barbados. The samples collected from the present study have shown that mature female dolphinfish appear to have higher GSI values (minimum 0.08% and maximum of 14.07%) than Barbados dolphinfish (minimum 1.02% and maximum of 7.9%). Mature males from the present study (Stage II) also show higher GSI values (minimum of 0.09% and maximum of 1.8%) than those from Barbados (minimum of 0.19% and maximum of 0.48%). High GSI values are indicative of high investment in reproduction which seems to be more pronounced in the Mediterranean population sampled. The biological and environmental factors leading to this difference however require further investigation.

The determination of the reproductive period by means of GSI values suggests a more protracted reproductive season, extending from May to October, than that obtained from back-calculated birthdates; the latter suggested a less extensive spawning period from June to September. A spawning period from June to September is however more likely as the high GSI values obtained during May were from fish sampled during the last week of this month, thus most probably engaging in spawning behaviour at the start of June. In addition, GSI values alone can be an inaccurate indicator of the spawning period as the changes in GSI value are not always related to seasonality in spawning activity.

No definitive information is currently available on the location of the spawning areas and the migration pat-

terns within and out of the Mediterranean for this particular fish. Protein electrophoresis performed on dolphinfish samples collected from around the islands of Majorca, the central Mediterranean and the Canary Islands revealed no genetic differences between these locations, providing initial evidence of a single population within the area studied. Separate genetic studies were also carried on samples from Malta and Tunisia also suggesting the existence of a single group of dolphinfish individuals in the studied area (Pla & Pujolar, 1999).

Acknowledgements

We thank the staff of the Department of Fisheries and Aquaculture at the laboratory of the Malta Aquaculture Research Centre (MARC) for their help, especially Frankie Farrugia for the collection and final processing of dolphinfish hard structures, Alex Camilleri and Frans Caruana for the collection of samples from the local fish market, and Joseph Abela, captain of the vessel 'Joan of Arc' for the collection of on-board samples. We also thank Dr. B. Morales-Nin of the Mediterranean Institute for Advanced Studies (IMEDEA) in Mallorca, Spain for her guidance. This work was partially funded by the European Social Fund under the Strategic Educational Pathways Scholarship Scheme (Malta) – and is part of an on-going collaboration between the Marine Ecology Research Group (MERG) of the Department of Biology of the University of Malta and the Department of Fisheries and Aquaculture within the Ministry for Sustainable Development, the Environment and Climate Change.

References

Appeldoorn, R.S., Rivera, G.A., 2000. Age and growth of dolphinfish, *Coryphaena hippurus*, off Puerto Rico. *Fisheries Bulletin*, 98, 345-352.

Benetti, D., Iversen, S., Ostrowski, C., 1994. Growth rates of captive *Coryphaena hippurus* in Hawaii. *Fisheries Bulletin,* 93, 152-157.

Beardsley, G.L., 1967. Age, growth and reproduction of the dolphin, *Coryphaena hippurus*, in the Straits of Florida. *Copeia*, 2, 441-451.

Brothers, E.B., 1981. What can otolith microstructure tell us about daily and sub daily events in the early life history of fish? *International Council for the Exploration of the Sea,* 178, 393-394.

De Martini, E.E., Uchiyama, H., Williams, H.A., 2000. Sexual maturity, sex-ratio, and size composition of swordfish, *Xiphias gladius*, caught by the Hawaii-based pelagic longline fishery. *Fisheries Bulettin*, 98, 489-506.

Ehrhardt, N.M., Robbins, R.J., Arocha, F., 1996. Age validation and growth of swordfish, *Xiphias gladius*, in the northwest Atlantic. *International Commission for the Conservation of Atlantic Tunas, Collective Volume of Scientific Papers,* 45, 358-367.

Farrugia Randon, S., 1995. *The fishing industry in Malta. Past, present, future.* Il-Pjeta, Malta: Pubblikazzjonijiet Indipendenza, 195 pp.

Florida Sportsman, 1979. *In the wake*. FIa. Sportsman, June, p. 123.

General Fisheries Commission for the Mediterranean, Food and Agriculture Organization of the United Nations, 2004. Report of the Sixth Stock Assessment Sub-Committee Meeting (SCSA), Malaga, Spain. [ftp://ftp.fao.org/fi/document/gfcm/sac_scsa/2004/SCSA_REPORT_2004.pdf]

Gibbs Jr., R.H., Collette, B.B., 1959. On the identification, distribution, and biology of the dolphins, *Coryphaena hippurus* and *C. equiselis*. *Bulletin of Marine Science*, 9 (2), 117-152.

Massuti, E., Alemany, F., 1998. First record of larval stages of *Coryphaena hippurus* (Pisces: Coryphaenidae) in the Mediterranean Sea. *Scientia Marina*, 23 (1-2), 181-184.

Massuti, E., Morales-Nin, B., 1991. Dolphinfish fishing (*Coryphaena hippurus*) in Majorca. *Instituto Espanol de Oceanografia,* 97 (4), 891-899.

Massuti E., Morales-Nin B. 1995. Seasonality and reproduction of dolphin-fish (*Coryphaena hippurus*) in the western Mediterranean. *Scientia Marina*, 59 (3-4), 357-364.

Massuti, E., Morales-Nin, B., 1997. Reproductive biology of dolphinfish (*Coryphaena hippurus*) off the Island of Majorca (western Mediterranean). *Fisheries Research*, 30 (1-2), 57-65.

Massuti, E., Morales-Nin, B., 1999. Biology and fisheries of dolphinfish and related species, Foreword. *Scientia Marina*, 63 (3-4), 2 pp.

Massuti, E., Morales-Nin, B., Moranta, J., 1999. Otolith microstructure, age and growth patterns of dolphin (*Coryphaena hippurus*) (Pisces: Coryphaenidae) in the western Mediterranean. *Fisheries Bulletin*, 97 (4), 891-889.

Murray, P.A., 1985. Growth and mortality in the dolphinfish *Coryphaena hippurus* caught off Saint Lucia, *FAO Fishery Report*, 327, 47-153.

Nakamura, E.L., 1971. *An analysis of the catches and biology of big game fishes caught by the New Orleans big game fishing club*. East Gulf sport Fishing Marine Lab Report, 38 pp.

Olson, R.J., Galván-Magaña, F., 2002. Food habits and consumption rates of common dolphinfish (*Coryphaena hippurus*) in the eastern Pacific Ocean. *Fisheries Bulletin,* 100, 279-298.

Oxenford, H.A., 1986. A preliminary investigation of the stock structure of the dolphin, *Coryphaena hippurus*, in the western central Atlantic. *Fisheries Bulletin*, 84, (2), 451-459.

Oxenford, H.A., 1999. Biology of the dolphinfish (*Coryphaena hippurus*) in the western central Atlantic: a review. *Scientia Marina*, 63 (3-4), 277-301.

Oxenford, H.A., Hunte, W., 1983. Age and growth of dolphin, *Coryphaena hippurus* as determined by growth rings in otoliths. *Fisheries Bulletin*, 84 (4), 1-7.

Oxenford, H.A., Hunte W., 1999. W. Feeding habits of the dolphinfish (*Coryphaena hippurus*) in the Eastern Carribean. *Scientia Marina*, 63 (3-4), 303-315.

Perez, R.N., Sadovy, Y., 1991. Preliminary data on landing records and reproductive biology of *Coryphaena hippurus* in Puerto Rico. *Gulf and Caribbean Fisheries Institute,* 44, 636-650.

Plata, C.A., 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.

Pla, C., Pujolar, J.M., 1999. Genetic homogeneity of dolphinfish (*Coryphaena hippurus*) in the Western Mediterranean and the Eastern Atlantic. *Scientia Marina*, 63 (3-4), 337-341.

Potoschi, A., Renones, O., Cannizzaro, L., 1999. Sexual development, maturity and reproduction of dolphinfish (*Coryphaena hippurus*) in the western and central Mediterranean. *Scientia Marina*, 63 (3-4), 367-372.

Rose, C. D., Hassler, W. W., 1968. Age and growth of the dol-

phin, *Coryphaena hippurus* (Linnaeus), in North Carolina waters. Transactions of the American Fisheries Society, 97, 271-276.

Schekter, R.C., 1972. *Food habits of some larval and juvenile fishes from Florida current, near Miami, Florida.* Technical Report to the Environmental Protection Agency, Washington D.C., USA, 85 pp.

Schwenke, K., Buckel, J.A., 2008. Age, growth and reproduction of dolphinfish (*Coryphaena hippurus*) caught off the coast of North Carolina. *Fisheries Bulletin*, 106, 82-92.

Secor, D., Dean, J., Laban, E., 1991. *Manual for otolith removal and preparation for microstructural examination*. Belle W. Baruch Institute For Marine Biology and Coastal Research, Technical Publication Number, 1991-01, 84 pp.

Tsimenides, N., Tserpes, G., 1989. Age determination and growth of swordfish *Xiphias gladius* L., 1758 in the Aegean Sea. *Fisheries Research*, 8, 159-168.

Uchiyama, J., Burch, K., 1986. Growth of dolphins, *Coryphaena hippurus* and *C. equiselis* in Hawaiian waters as determined by daily increments in otoliths. *Fisheries Bulletin*, 84 (1), 186-191.

Wang, C.H., 1979. A study of population dynamics of dolphinfish (*Coryphaena hippurus*) in waters adjacent to Eastern Taiwan. *Acta Oceanographica Taiwan*, 10, 233-251