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Age structure and growth by otolith interpretation of *Mullus surmuletus*L. from the North-west Moroccan Mediterranean Coast

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Abstract

Age and growth of the striped red mullet (*Mullus surmuletus*) were studied by examination of growth increments within otoliths of 2033 specimens caught between March 2007 and February 2009 from the North-west Moroccan Mediterranean coast. The values of slope in length-weight relationships were calculated as 3,173 for males and 3,178 for females. Marginal increment analysis showed an annual periodicity of increment formation. The parameters of L_∞, K and $t_0$were calculated for males as 35,64 cm, 0,13 $year^{-1}$ and -2,17 year and for females as 39,40 cm, 0,19 $year^{-1}$and -1,03 year, respectively. There was significant differential growth between sexes; females attained greater length at age values than males.

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Introduction

The striped red mullet (*Mullus surmuletus,* L.) is a major target species of Mediterranean demersal fisheries and is exploited by more than one gear type (Stergiou *et al*., 1992; Renones *et al*., 1995; Demestre *et al*., 1997; Mehanna, 2009) and encountered in shallower soft bottoms, seagrass beds and rocky bottoms (Lombarte *et al*., 2000; Bautista-Vega 2008).This species occurs along the coast of Europe from the South of Norway (Wheeler, 1978) and the North of the Scotland (Gordon, 1981) to Dakar and in the Mediterranean and Black Seas too.*Mullus surmuletus*is benthic carnivores and feed on small invertebrates (Gharbi and Ktari, 1981b; Golani and Galil, 1991; N'Da, 1992b; Labropoulou and Eleftheriou, 1997; Vassilopoulou *et al*., 2001; Chérif *et al*., 2008; Mehanna, 2009; El Bakali *et al*., 2010b).

Several aspects of the striped red mullet biology have been studied, including feeding, reproduction, age and growth (Bougis, 1952;Gharbi and Ktari 1981a-1981b; Morales-Nin, 1991, Campillo;1992, , N'Da and Daniel, 1993; Renones *etal*.,1995; Labropoulou *et al*., 1997; Dorel *etal*., 1998; Jabour *etal*., 2000; Vassipoulou *etal*., 2001; Mendes *etal*., 2004; Mahé *et al*., 2005; N'Da *etal*., 2006; Chérif *etal*., 2007; Barnes, 2008; Mehanna, 2009; El Bakali *et al*., 2010a-2010b; Mukadder and İşmen, 2013; Kherraz*etal*., 2014).

Striped red mullet is among the most valuable and highly priced fish species in Morocco, though widely distributed along the entire Moroccan Mediterranean coast, their major fisheries are located in the M'diq area.

Despite its abundance, little is known about the biology of this species (El Bakali *et al*., 2010a-2010b, El Bakali *et al*., 2015)in this area.The aim of this paper is to determine age from otolith readings and to validate age estimates indirectly by means of marginal increment analysis, to estimates the growth parameters from length-at-age values and to determine length-weight relationships of *Mullus surmuletus* in the North-west Moroccan Mediterranean coast (M'diq area).

Material and methods

Collection of samples

The samples for this study were obtained twice a month from commercial trawl fishery landed in the port of M'diq (e.g. Fig.1).

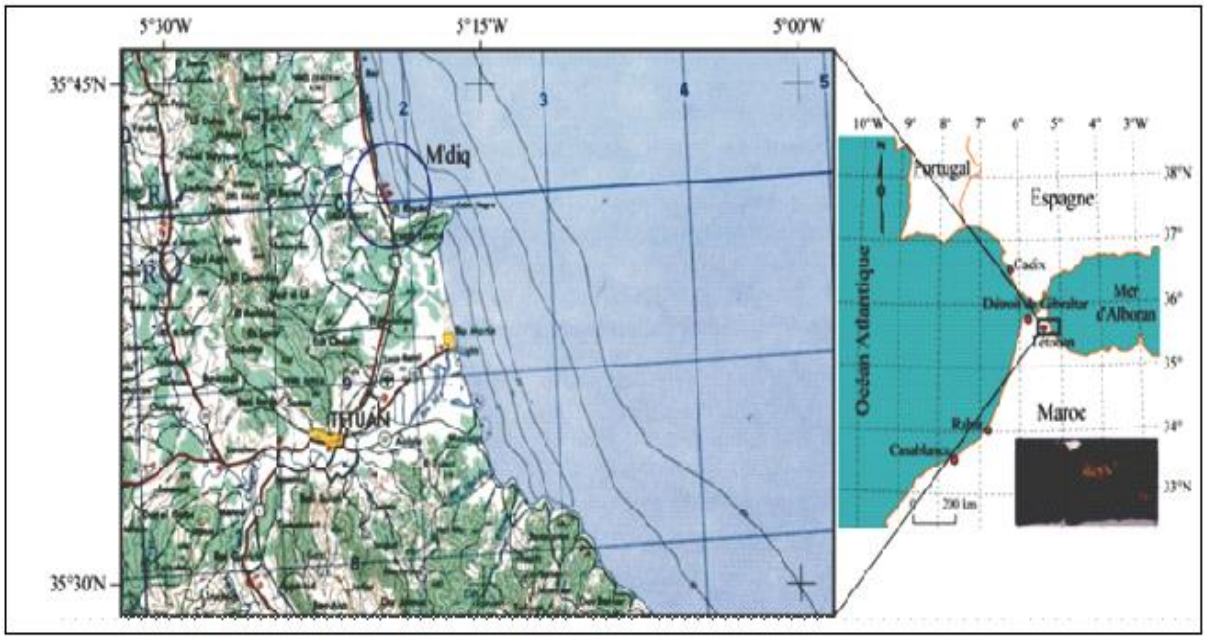

Fig. 1. Geographical situation of the study areas.

A total of 2033 striped red mullet specimens collected between March 2007 and February 2009 were individually processed in order to obtain data on the total length (TL), in centimeters, and total weight (W), in grams, sex was assigned macroscopically.

Otolith preparation and age determination

Sagittal otoliths were removed, placed in water to remove surrounding membranes, cleaned and stored dry for age determination. Ages were assigned based on counts of alternating opaque and translucent zones along the axis from core to rostral tip. Otoliths with excessive vateritic growth, deformation and indistinct annulus character were excluded from the age analysis.

To validate the periodicity of increment formation, Marginal increment (MI) analysis was carried out on otoliths by calculating monthly marginal increment according to the following formula: $MI = (R-r_n)(r_n-r_{n-1})$ where R is the otolith radius, r_n is the distance between the edge and the last growth ring and r_{n-1} is the distance between the edge and the second last growth ring.

Length-weight relationship

The relationship between weight and total length of fish, $W = a\ TL^b$ was converted into logarithmic expression: $\log W = \log a + b \log TL$. The parameters *a*and*b* were estimated by the least square method regression, as was the coefficient of determinationr^2. Significant difference of *b* values from 3, which represent isometric growth, was tested with the t-test (Pauly, 1983). Differences of *b* values between sexes were calculated by analysis of covariance (Zar, 1999)using statistica 6.0 sofware.

Growth parameters

Growth was expressed in terms of the von Bertalanffy equation (Beverton and Holy, 1957): $TL = L_\infty (1 - e^{-K(t - t_0)})$. Where $L_\infty$is the asymptotic total length, TListhe total length at age t, K the growth curvature parameter and t_0 is the theoretical age when fish would have been at zero total length. The growth performance index (Φ') was estimated to compare values of the growth parameters obtained in this study with those reportedby various studies in different geographical areas. This index was calculated as follows (Munro and Pauly, 1983): $\Phi' = 2 \ln TL_\infty + \ln K$ where TL_∞ and K are parameters of the von Bertalanffy growth equation.

Result

Length frequency distributions

Of the total fish examined (N = 2033), 904 were males, 1037 females and 92 specimens unidentified of sex. The length frequency distribution of total samples is shown in Fig. 2, the length of *M. surmuletus* ranged from 8,2 to 38,1 cm (mean 18,17±3,89 cm). Most fish were 15-26 cm TL.

Table 1. Total Length – Weight relationships ($W = aTL^b$) for female, male and both sexes combined of *Mullus surmuletus* sampled in the North-west Moroccan Mediterranean coast.

Sexes	N	Length-Weight relationships	r^2	p-value
Females	1037	$W = 0{,}0072\ (TL)^{3{,}178}$	0,98	0,000
Males	904	$W = 0{,}0068\ (TL)^{3{,}171}$	0,97	0,000
Both sexes combined	2033	$W = 0{,}0071\ (TL)^{3{,}173}$	0,98	0,000

Total lengths of males ranged from 11,2 cm to 34,5 cm (mean 17,60 ± 3,18 cm), total lengths of females ranged from 12,3 to 38,1 cm (mean 19,66±4,35 cm) (Fig. 3).

Length-weight relationships

The length-weight relationships were calculated for each sex and for sexes combined (Table 1). The values of *b* for males (*b* = 3,171, r^2 = 0,97) and females (*b* = 3,178, r^2= 0,98) indicated positive allometry growth for both sexes. There was no statistically significant slope of the length-weight regressions between sexes

(P>0,05). The length-weight relationships of males and females of *Mullus surmuletus* are represented graphically in Fig. 4.

Age and growth

Totally from 1634 examined otoliths, 114 (7,5%) specimens were rejected as they could not be evaluated due to vateritic deposition and deformations.

The age was determined by counting the annual ring marks on the surface of the otoliths, 1520 otoliths of striped red mullet were used for age study. Otoliths showed clearly the ring patterns common to teleost fishes.

Table 2. Age length key for sexes combined of *Mullus surmuletus* based on otolith readings.

Length range (cm)	Age (years)											Total
	0+	1	2	3	4	5	6	7	8	9	10	
8-9	15											15
9-10	8											8
10-11	1											1
11-12		13										13
12-13		31										31
13-14		15	10									25
14-15		3	29	19								51
15-16			61	30								91
16-17			28	44								72
17-18			9	54	4							67
18-19			23	99	49							171
19-20			9	90	54							153
20-21			1	68	47	10						126
21-22				27	49	16						92
22-23				20	112	14	1					147
23-24				15	45	13	4					77
24-25				21	25	23	4	3				76
25-26				14	17	44	14	3	3			95
26-27				24	31	10	5	7	2			79
27-28					11	10	6	6	2			35
28-29						8	3	3	4			18
29-30						10	7	4	7			28
30-31								1	2			3
31-32								4	2	3		9
32-33								1	5	1		7
33-34								2	4	2		8
34-35								3	5	1		9
35-36								4	3			7
36-37										2		2
37-38										1		1
38-39											1	1
N	24	62	170	525	444	158	44	41	39	10	1	1518
Mean (cm)	8,36	12,36	15,98	19,57	21,99	27,06	29,5	27,1	30,79	33,03	38,1	
SD	0, 33	0,33	0,20	0,11	0,12	0,39	0,40	2,16	0,41	0,12	0,00	

Table 3. Number (n), mean ± standard deviation (SD) values of total length (cm) for *Mullus surmuletus* males and females within each age class.

Age (years)	Males Mean ± SD TL min- TLmax n	Females Mean ± SD TL min- TLmax n	P
1	12,32±0,20 10,2-14,7 N=52	12,51±0,73 12-14 n=10	0,794128 P>0,05
2	15,11±0,14 13-16,8 n=110	17,57±0,30 14,5-20,3 n=60	0,000314*** P<0,001
3	17,40±0,09 14-21,5 n=215	21,07±0,13 16-26,9 n=310	0,000010*** P<0,001
4	21,07±0,12 17,1-22,9 n=154	23,01±0,14 19-27,8 n=290	0,00000*** P<0,001
5	22,31±0,19 20,0-25,2 n=60	26,25±0,23 24,0-29,3 n=98	0,00000*** P<0,001
6	24,13±0,40 22,3-26,1 n=13	28,28±0,41 25-30,9 n=31	0,00000*** P<0,001
7	25,66±0,44 24,3-28,1 n=11	30,96±0,41 26,5-30,96 n=30	0,00000*** P<0,001
8	26,57±0,46 25-33,3 n=10	32,19±0,41 28,8-32,19 n=30	0,00000*** P<0,001

The opaque zone was deposited during summer months, while hyaline rings were formed throughout winter.The annual periodicity was confirmed by the marginal increment otoliths.(Fig. 5).

Age were determined for 869 females, 625 males and 24 specimens unidentified of sex. Age-length-key of all individuals by age class and length class is presented in table 2; the maximum age of fish calculated was 10 years. As shown in table 3 mean at length-at-age values were significantly different between sexes except for age group one. Females tend to grow slightly faster in length than males (Fig 6).

Table 4. Total length- weight relationships of *Mullus surmuletus* reported by various studies.

Author	Region	N	Sex	Size range (cm)	a	b
Dorel, 1986	France	382	M+F	6-42	$7{,}410^{-3}$	3,19
Coull *et al.*, 1989	North Atlantic	49	M+F	20,5-26,5	$4{,}710^{-3}$	3,30
Morales-Nin, 1992	Majorca	1092	M+F	5-20	$1{,}610^{-3}$	2,91
Papaconstantinou *et al.*,1993	Greece	390	M+F	7,4-24,4	$1{,}510^{-3}$	3,03
Petrakis and Stergiou, 1995b	Greece	307	M+F	10,1-20,1	$1{,}2410^{-3}$	3,14
Renones *et al.*, 1995	Majorca Island	3541	M+F	10,0-32,0	$9{,}110^{-4}$	3,12
Gonçalves *et al.*, 1996	Portugal	299	M+F	21,5-38,0	$2{,}910^{-3}$	3,08
Moutopoulos and Stergiou, 1998	Aegean sea	-	M+F	14,0-32,0	$1{,}7610^{-3}$	2,89
Jabour et*al.*2000	Gabes Gulf	635	M+F	-	710^{-6}	3,12
Stergiou and Moutopoulos, 2001	Aegean sea	257	M+F	13,8-32,0	$1{,}410^{-3}$	2,95
Abdallah, 2002	Egypt	122	M+F	5,4-20,8	$1{,}110^{-3}$	3,03
Valle *et al.*, 2003	West Mediterranean	146	M+F	7,7-25,4	$9{,}710^{-4}$	3,07
Mendes *et al.*, 2004	Portugal	108	M+F	17,0-38,2	$3{,}910^{-3}$	3,36
Dulcic and Glamuzina, 2006	Adriatic	47	M+F	12,5-28,5	$3{,}910^{-4}$	3,36
Ozaidin *et al.*, 2007	Aegean sea	117	M+F	7,4-21,9	$1{,}0610^{-3}$	3,20
Ilhan *et al.*, 2009	Izmir Bay	192	M+F	6,6-22,6	$8{,}310^{-4}$	3,12
Mehanna, 2009	Egypt	1385	M+F	5,0-29,1	$1{,}0410^{-4}$	3,06
Üstün et*al.*, 2010	Edremit Bay	520	M+F	7,7-17,0	$4{,}410^{-4}$	3,53
Mukadder and Ismen, 2013	Saros Bay	556	M+F	9,6-26,8	$8{,}410^{-4}$	3,12
Mahe *et al.*, 2013	Eastern English Channel southern North Sea	1089	M+F	7,7-42,5	$3{,}2810^{-6}$	3,24
Present study	North-west Moroccan Mediterranean coast	2033	M+F	8,2-38,1	$7{,}110^{-3}$	3,17

The means lengths of individuals assigned to each age class were used to fit the von Bertalanffy growth parameters for each sexand for sexes combined. The von Bertalanffy growth parameters for *Mullus surmletus* were estimated as L_∞ = 39,40 cm, K = 0,19 $year^{-1}$ and t_0 = -1,03 year for females, and L_∞ = 35,64 cm, K = 0,13 $year^{-1}$ and t_0 = -2,17 year for males.The growth equation was found for males to be $35,64 [1 - e^{-0,13(t+2,17)}]$ and for females to be $39,40 [1 - e^{-0,19(t+1,03)}]$.

Von Bertalanffy growth curve for combined sexes (n =1518) of *Mullus surmuletus* in the North-west Moroccan Mediterranean sea from March 2007 to February 2009 is shown in Fig. 7. The calculated growth performance indexΦ' was 2,46 for females, 2,24 for males and 2,31 for both combined.

Table 5. Von Bertalanffy growth parameters and growth performance index (Φ') for males (M), females (F) and sexes combined (M+F) of *Mullus surmuletus* obtained by different authors.

Author	Region	Sexes	L_∞	K	t_0	Φ'
Gharbi andKtari, 1981b	Tunisia waters	M+F	21,5	0,5	-0,12	-
		M	19,90	0,49	-0,03	2,29
		F	21,80	0,51	-0,11	2,38
Andalora, 1982	Mediterranean sea	F	30,10	0,24	-2,68	2,34
		M	25,00	0,30	-2,39	2,27
Morales-Nin, 1986	Catalan sea	M+F	30,94	0,11	-3,85	2,21
Morales-Nin, 1992	Majorca waters	M+F	29,76	0,24	-2,06	2,19
		F	34,53	0,14	-3,82	2,32
		M	23,29	0,29	-3,33	2,18
Vassilopou and Papaconstantinou, 1992	Lion Gulf	F	33,40	0,43	-0,60	2,68
		M	28,50	0,53	-0,44	2,63
Papaconstantinou *etal.*, 1994	Greece	F	24,80	0,26	-1,58	2,21
		M	22,00	0,27	-1,46	2,11
Renones *et al.*,1995	Majorca Island	M+F	31,28	0,21	-2,35	-
Moldur, 1999	Marmara sea	M+F	32,83	0,23	-2,13	-
		F	34,48	0,21	-2,97	-
		M	27,30	0,25	-2,11	-
Jabour *et al.*,2000	Gabes Gulf	M+F	22,3	0,34	-0,79	2,23
		F	21,20	0,43	-0,65	2,29
		M	22,60	0,27	-1,07	2,14
Mahé *et al.*, 2005	North Sea	M+F	53,34	0,18	-1,23	-
N'Da *et al.*, 2006	Biscay Bay	F	42,70	0,28	-0,64	2,71
		M	35,90	0,30	-0,74	2,59
Ilhan *et al.*, 2009	Izmir Bay	M+F	27,85	0,19	-1,58	2,18
Mehanna, 2009	Egypt	M+F	31,74	0,47	-0,30	2,67
Ustun *et al.*, 2010	Edremit Bay	M+F	25,09	0,14	-2,48	-
Mukadder and Ismen, 2013	Saros Bay	M+F	27,82	0,20	-2,16	2,19
		F	28,38	0,19	-2,16	2,18
		M	26,94	0,20	-2,34	2,16
Mahe *et al.*, 2013	Eastern English Channel southern North Sea	F	51,17	0,20	-2,90	2,71
		M	36,04	0,22	-3,23	2,45
Present study	North-west Moroccan Mediterranean coast	M+F	39,20	0,13	-3,21	2,31
		M	35,64	0,13	-2,17	2,24
		F	39,40	0,19	-1,03	2,46

Discussion

Age of striped red mullet (*Mullus surmuletus*)has been the subject of a number of research in Mediterranean Sea (Gharbi, 1980; Gharbi and Ktari, 1981a; Renônes *et al*., 1995; Jabour *et al*., 2000; Abdellah, 2002) and Atlantic Ocean (Bougis, 1952; N'Da, 1992; N'Da et Déniel, 2005; N'D'a *et al*., 2006; Mahé *et al*., 2013). The ageing structure has been scales and otoliths.

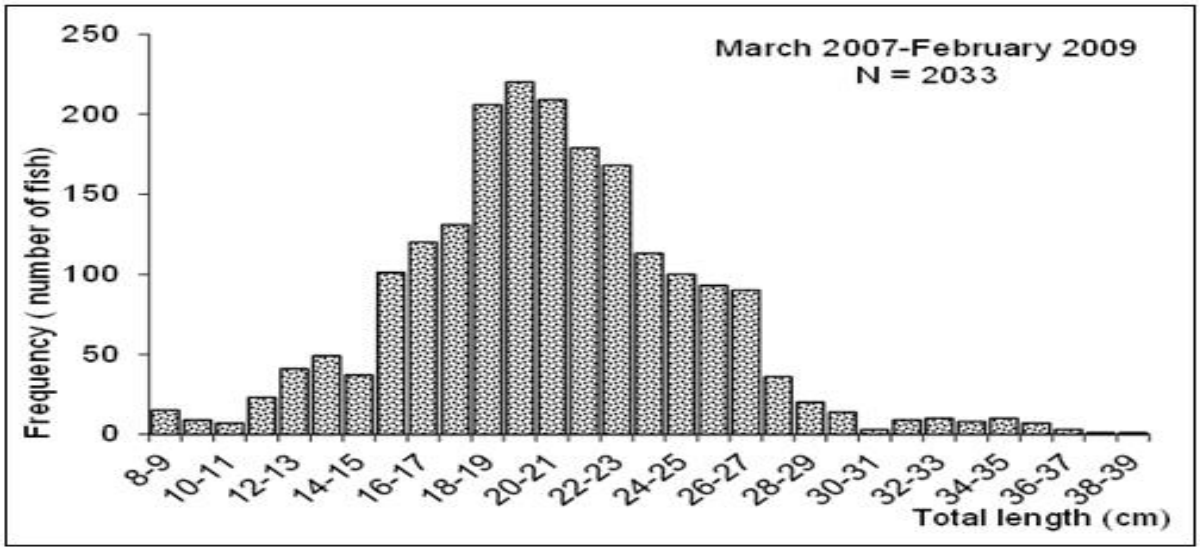

Fig. 2. Length- frequency distribution for sexes combined of *Mullus surmuletus* in theNorth-west Moroccan Mediterranean coast.

Otoliths intrepetation

Otoliths have been proven as a reliable and valid method for ageing *Mullus surmuletus* (Bougis, 1952, Morales Nin, 1991, Renones *et al*., 1995, Mahé *et al*., 2005). In this study, otolith method were used for age determination of striped red mullet collected from the North-West Moroccan Mediterranean water. Interpretation of sagittal otoliths was simple and unproblematic. Otoliths showed clearly the ring patterns common to teleost fishes.

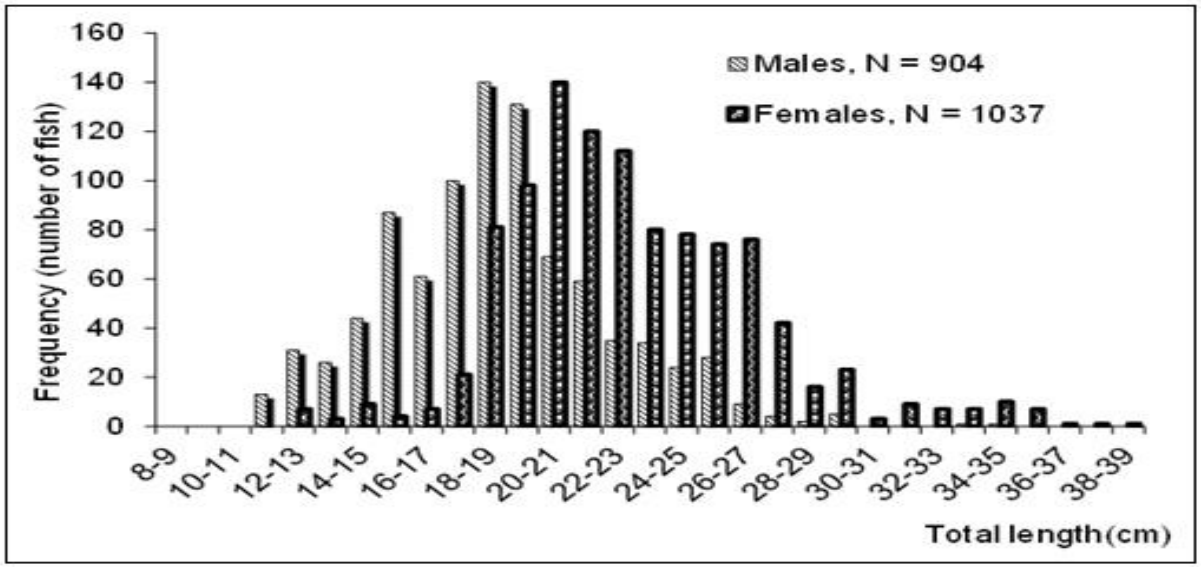

Fig. 3. Length-frequency distribution of *Mullus surmuletus* for males and females in the North-west Moroccan Mediterranean sea.

The opaque zone was deposited during summer months, while hyaline rings were formed throughout winter. Since the spawning of *Mullus surmuletus* in North-west Moroccan Mediterranean coast is taking place in April-June (El Bakali *et al*., 2010a), we can assume that the first ring is formed on otolith 6 months after spawning.The monthly variation of the marginal increment confirmed the annual periodicity of the annulus formation, suggesting that the single annulus is formed each year during autumn-winter.The same result was reported by Mahé *et al.* (2013).

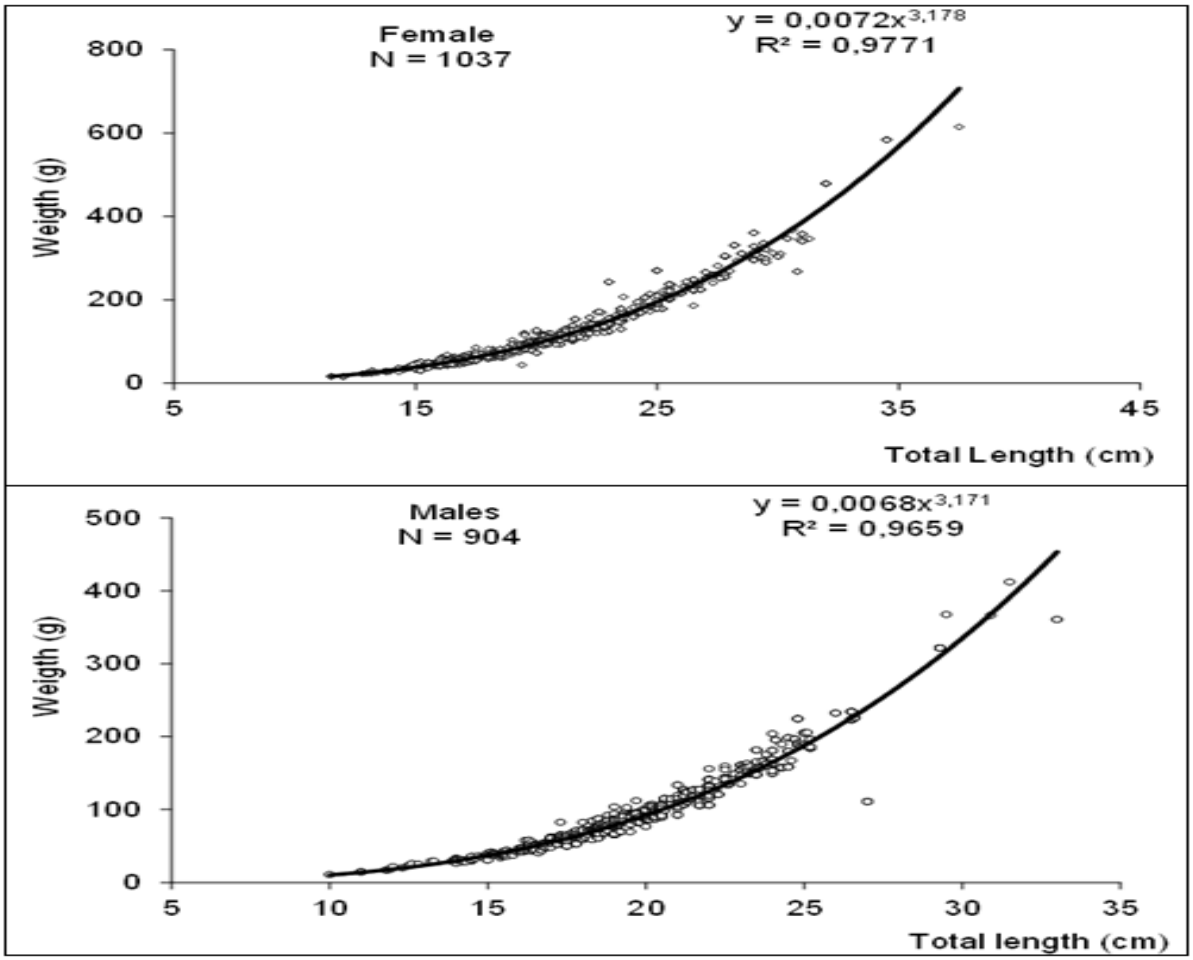

Fig. 4. Total length and weight range of *Mullus surmuletus* in the North-west Moroccan Mediterranean Sea from March 2007 to February 2009 for females and males.

Length-weight relationships

The exponents of the length-weight relationships for males (b = 3,171), females (b = 3,178) and sexes combined (b = 3,173) estimated in this study, showed that growth of *Mullus surmuletus* was positively allometric, meaning it is slightly faster in Weight than in length. Similarly positive allometric growth was noted by other authors (e.g. Tab. 4).

On the other hand, negative allometric growth was recorded of *Mullus surmuletus* in Majorca by Morales-Nin, 1992 and of striped red mullet in Agean Sea by Moutopoulos and Stergiou, 1998 and Stergiou and Moutopoulos, 2001 (e.g. Tab. 4).

These differences probably reflect the growth variations due to environmental factors such as temperature and salinity in the different areas of investigation. Level of exploitation, variations in fish shape and stomach fullness, can also affect the value of b (Mommsen, 1998).

Age and growth

The maximum age obtained in the present study, coincide with that reported by Morales-Nin, 1986 in the katalan Sea where the age composition of *Mullus surmuletus* ranged from 1 to 10 years, but it was lower than that observed by Quéro et Vayne, 1997, who found the oldest specimens from the North eastern Atlantic to be 11 years old. In addition, Jabour *et al.*, 2000, Ilhan *et al.*, 2009, Üstün, 2010 and Mahé *et al.*, 2013 reported a maximum of 5, 6, 4 and 7 years of age for *Mullus surmuletus* from the Gabes Gulf, Aegean Sea, Edremit Bay and Eastern English Channel southern North Sea respectively.

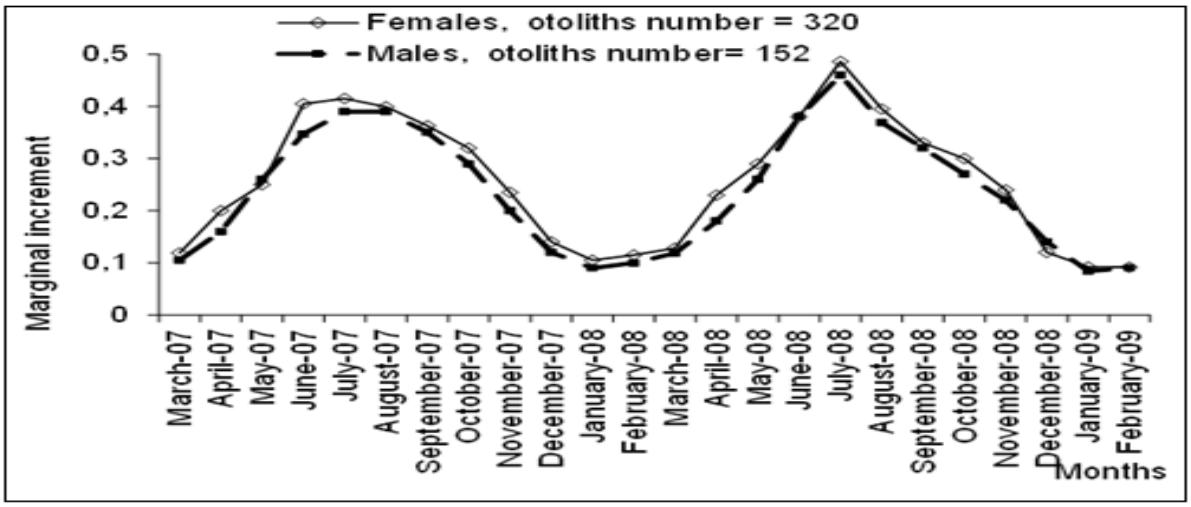

Fig. 5. Monthly trend of average marginal increments on the sagittal otolith of the*Mullus surmuletus*in the North-west Moroccan Mediterranean Sea from March 2007 to February 2009.

In this study, mean length-at-age values were significantly different between sexes of *Mullus surmuletus* except for age class group one. This difference becomes very large at the age of years old. The females exceed males by 6 cm on average at the age 8 years.This sexual dimorphism was observed by N'Da, 1992a. Thisauthorfound that from the age of 3 years, the difference in growth between males and females of the striped red mullet in the Bay of Biscay is increasing up to 5 years where it is stabilized; females were 6 cm longer than male.

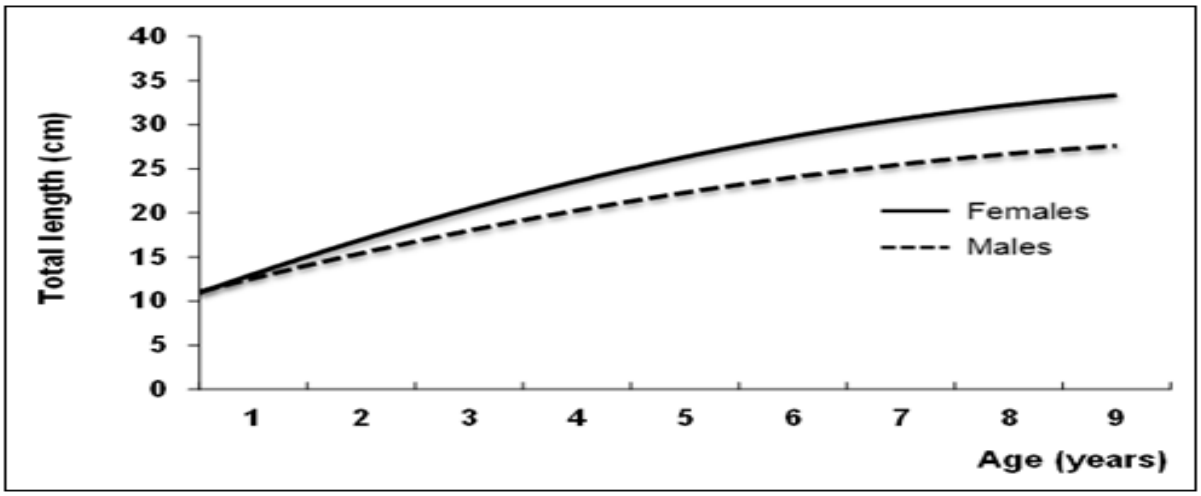

Fig. 6. Von Bertalanffy growth curves for males and females of *Mullus surmuletus* fromthe North-west Moroccan Mediterranean Sea.

The growth parameters obtained by several authors in different geographical areas are cited in Table5. When comparing these results with those of our study, some discrepancy was found, may be it is due to marine environmental changes.

According to Sparre and Venema, 1996, when we confront different parameter sets we should not compare the parameters one by one. This is why some authors urge to compare growth performance index by combining several parameters of the von Bertalanffy equation. This index turns out to be the best overall growth performance index inasmuch as it has a minimum variance (Moreau *et al.*, 1986) and is considered as a useful tool for comparing growth curves of different populations in a same species (Wootton, 1998).

In order to compare the growth of *Mullus surmuletus* populationsin different areas, all available literature data of von Bertalanffy growth parameters and Φ' values, including results from the present study are compiled in table5.Φ' values which are obtained for striped red mullet in North-West Moroccan Mediterranean water (2,46 for females and 2,24 for males) showed relatively small differences from reported in Atlantic and other areas of the Mediterranean, this index confirms the better growth potential of females compared to male.

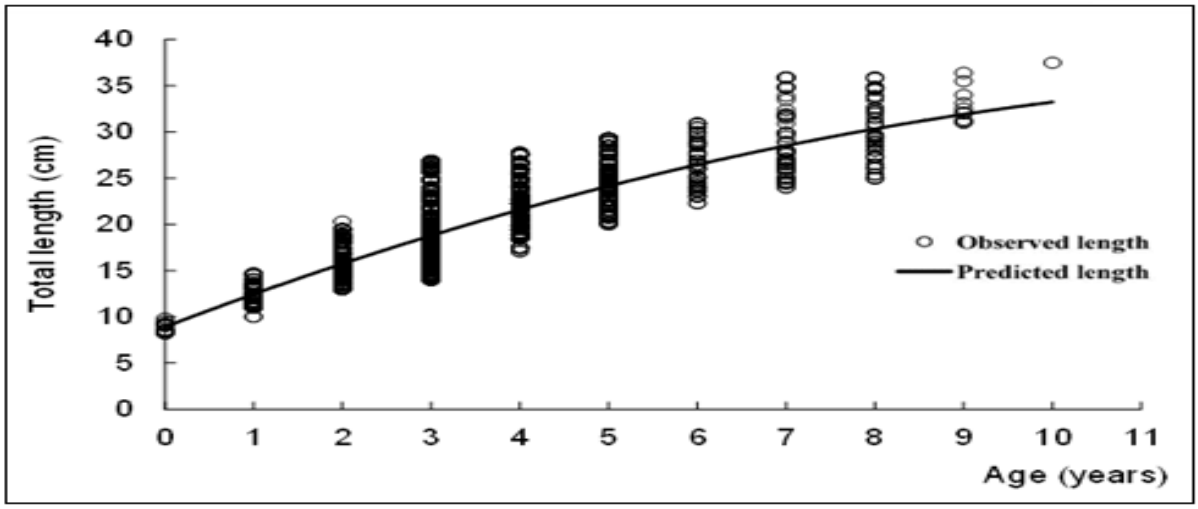

Fig. 7. Von Bertalanffy growth curve for combined sexes (n = 1518) of *Mullus surmuletus* in the North-west Moroccan Mediterranean sea from March 2007 to February 2009.

This sexual dimorphism was observed in different areas (Tab. 5).

Conclusion

The following conclusions are made from the study:

The length-weight relationship showed a significant positive allometric growth of *Mullus surmuletus*.

The monthly variation of the marginal increment confirmed the annual periodicity of the annulus formation, suggesting that the single annulus is formed each year during autumn-winter.

The maximum age was 8 years for males and 10 years for females.Age for sexes combined ranged between 0+ and 10 years.

The ven Bertalanffy growth equation was found for males to be 35,64 $[1 - e^{-0,13(t+2,17)}]$ and for females to be 39,40 $[1 - e^{-0,19(t+1,03)}]$.

The growth of striped red mullet highlighted a sexual dimorphism expressing a linear faster for the females compared the males.

The result of the present work will contribute to the knowledge on growth of *Mullus surmuletus* in North-west Moroccan Mediterranean water.

The findings of this study are important as they can be used to develop a management and protection strategy for this species in this area and will help fisheries scientists for future studies on *Mullus surmuletus* populations.

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