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Research Article

Establishing length-at-age references in the red mullet, *Mullus barbatus* L. 1758 (Pisces, Mullidae), a case study for growth assessments in the Mediterranean Geographical Sub-Areas (GSA)

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Abstract

Length-at-age data are a fundamental tool for the assessment of exploited fish populations, their use requiring the identification of the 'unit stock'. At the present, however, the spatial reference for stock assessment in the Mediterranean Sea is based on a grid of 30 arbitrary Geographical Sub-Areas (GSA). Since older data rarely respect the GSA borders, the authors propose to reconstruct the historical data within a common frame and to assess a single reference length-at-age, together with the corresponding von Bertalanffy growth parameters, to be used as a broad benchmark for analyses inter and intra GSAs. This approach was tested using as a case study the red mullet (*Mullus barbatus* L. 1758), one of the most investigated fish of the whole Mediterranean basin. Published and grey literature was browsed, to get direct and/or indirect length-at-age estimations. To establish a common baseline and maximize the use of partial information, a vBGF (L_∞, total length in mm, and Ky^{-1}) was fitted to length-at-age data whenever possible. 56 Mediterranean sets were utilized; an overall reference growth line was estimated by sex, discussing its adequacy to the life traits of the species.

Keywords: Historical data; GSA; Red mullet; *Mullus barbatus;* Mediterranean Sea.

Introduction

Length-at-age data represent a fundamental tool for the analytical assessment of exploited fish populations (PANFILI *et al.*, 2002), especially when it is difficult to gather information suitable for production (global) or sequential (such as VPA) models, i.e. the typical situation of the Mediterranean demersal populations (FARRUGIO *et al.*, 1993; LLEONART & MAYNOU, 2003; LLEONART, 2005). At single species level, fishery theories would require the identification of the 'unit stock', i.e. a group of co-specific fishes which share location, demographic parameters and reaction pattern to fishing pressure and which might be treated as a single homogeneous entity for assessment purpose (GULLAND, 1969; FAO, 2010). Unluckily, the Mediterranean fish stocks are far from being properly identified and, in an attempt to overcome the problem of heterogeneous spatial aggregations of the data, the General Fisheries Council for the Mediterranean Sea (GFCM, 2009) has recently partitioned the Mediterranean Sea in 30 arbitrary Geographical Sub-Areas (GSA), which should become the basic spatial reference for stock assessment, implemented following a common format. Since historical data rarely reflect and respect the present GSA borders, it seems difficult to implement temporal comparisons, especially for size-at-age and growth information, a kind of data for which post-disaggregating is impossible.

In the present paper, a solution is proposed, consisting of reconstructing the historical Mediterranean data within a common frame and assessing a single reference length-at-age, together with the corresponding von Bertalanffy growth parameters, to be used as a broad benchmark for analyses inter and intra the GSAs.

In particular, the adequacy of this novel approach has been evaluated using as a case study the red mullet (*Mullus barbatus* L. 1758), a bentho-neritic species widely distributed on the muddy and sandy bottoms of the continental shelf and upper slope of the entire Mediterranean (STERGIOU *et al*., 1992; VOLIANI, 1999; FROESE & PAULY, 2010). In fact, given its economic relevance for both small- and large-scale fisheries, the high vulnerability during the recruitment period, and the present 'stable' overexploitation status (growth overfishing), the red mullet is among the most investigated fish of the Mediterranean basin (cfr. VOLIANI, 1999; TSERPES *et al*., 2002; LLEONART, 2005; CADDY, 2009).

Material and Methods

Pertinent published and grey literature was browsed, consulting the original papers whenever possible, to get both direct (i.e., based on hard-parts readings or size-structure analysis) and indirect (i.e., derived by growth models) length-at-age estimations. Speaking of the hard parts, scales and otoliths are both employed to age red mullets, but the latter have been considered the most suitable structure (GOTLIEB, 1956; PANFILI *et al*., 2002); in fact, scale reading seems to underestimate older ages. The classic 3-parameter von Bertalanffy growth function (vBGF) is the most widespread model in literature and has been maintained in the present paper, although discontinuous growth trajectories have also been proposed for this species (VOLIANI *et al*., 1998a). Given the strong sexual dimorphism in growth, sexes were maintained separated, and originally sex-pooled meta-data were discarded (but see LEVI *et al*., 1992, for a review of this kind of data). In order to set a common baseline and maximize the use of partial information (i.e., few available values), a vBGF was fit to length-at-age data when at least 3 couples of data were available; the Excel solver routine was employed to estimate the vBGF parameter by forcing the curve to the average of available t_0 estimates.

Length-at-age estimates were obtained from the original published or the *ad hoc*-derived vBGF parameters, and tabulated set by set together with an assigned uniform geographical denomination (roughly corresponding to GFCM's names, e.g., Strait of Sicily, Southern Tyrrhenian Sea, etc.). Hence, the box-plot representations of the total length-at-age by sex and year class

(L_0, L_1... L_8) were obtained to appreciate the departure from the expected symmetry and to pinpoint outliers; in fact, from the central limit theory, a normal distribution of the mean value of the parameters is expected, no matter the distribution of the original individual observation, unless these mean values were affected by geographical trends. After exclusion of the outliers, basic statistics (N, min, max, mean, s.d., C.V. and skewness) were computed. The significant correspondence between the observed length-at-age distributions by sex and year class *vs.* the expected normal distributions was checked according the non-parametric Shapiro test (SYSTAT, 2007), which is considered a suitable and robust option when a limited amount of data is available; in particular, resulting statistics lower than 0.1 are deemed sufficient to reject the null hypothesis (H_0= the mean length-at-age is normally distributed). Finally, an overall reference growth line was estimated by sex and its adequacy to the life traits of the red mullet was considered.

Results

After the extensive literature search, it was possible to collect 56 sets of length-at-age data (see Appendix for geographical locations, length-at-age data, vBGF parameters and list of references); the oldest set was that of SCACCINI (1947b), while the most recent reference was compiled by SONIN *et al.* (2007), but with data older than those collected within the SAMED program (SAMED, 2003). One further set by sex (set 24; thin-section otolith readings on 234 females and 149 males) has never been published and concerns data gathered during an experimental trawl survey carried out in 2001 in Sicily.

Data clearly reflect a non-homogeneous geographical coverage; in fact, most derive from the NW Mediterranean basin; moreover, the vBGF parameters show a wide variability even within the same geographical area, a fact that may be explained by multiple factors, (e.g., environmental changes, historical reasons, transition in effort, methodology, analysis and interpretation, etc.).

The box-plot representations displayed a general asymmetry of the mean length-at-age, stronger in males than females, and were used to pinpoint outliers in sets 39, 41, 42 and 44 (in bold and underlined in the Appendix).

The descriptive statistics by sex of the winsorized data are presented in Table 1, together with the results of the normality tests. The shape of the observed distributions was often characterized by two overlapping peaks; this feature is more evident in males (Fig. 1b) than females (Fig. 1a) and helps to explain the different results between sexes.

The parameters by sex of the three vBGFs - calculated on the mean, the minimum and the maximum values – are reported in Table 2.

The resulting reference curves, where the central line (with dots) represents the mean value of the parameters are presented in Figure 2 a missing dot indicates that the location of the mean length for that given year class could not be properly defined and would require more data. In those cases, the range of the values within the outer lines might be used to highlight unusual and/or suspicious data.

Discussion

The review and standardization of the collected references required a cumbersome treatment: beside the different methodologies of sampling (commercial or experimental, episodic or repeated), measuring

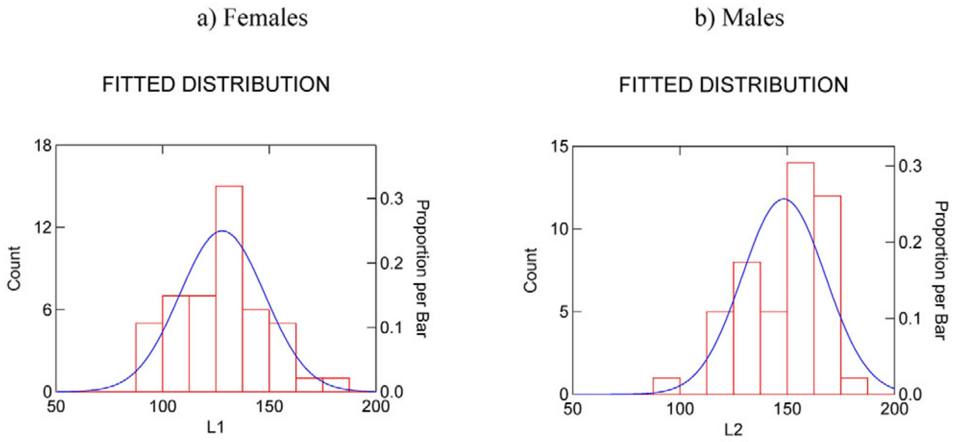

Fig. 1a, b: An example of good (a; ♀ females year class 1) and bad (b; ♂ males, year class 2) fitting of the observed length-at-age of *Mullus barbatus* to a normal distribution.

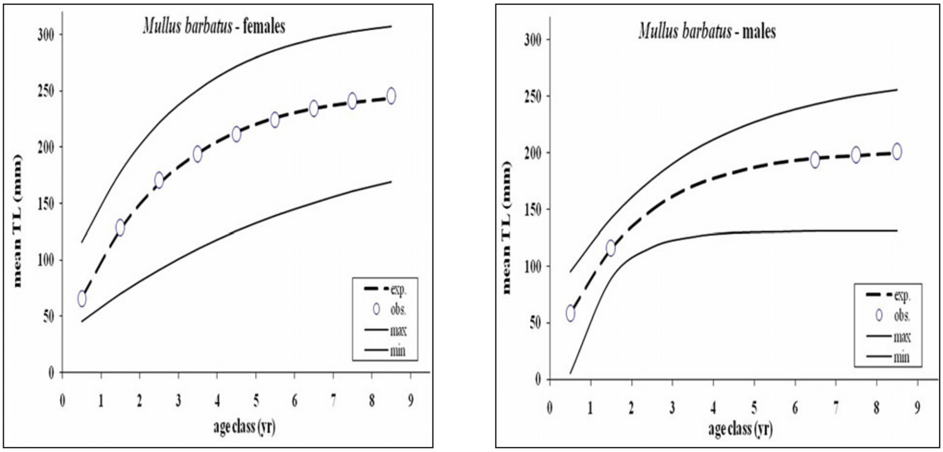

Fig. 2: Reference curves for females (♀) and males (♂) of *Mullus barbatus:* solid line denotes the vBGF from mean values, outer lines denote maximum and minimum fit.

(total or standard lengths), preparation (whole or sectioned otoliths) and elaboration (age attribution and vBGF estimation), the most relevant problems arose in the interpretation of old-fashioned references and in avoiding redundancies and circularities using already-elaborated meta-data, often computed with rearranged data. Speaking of the first difficulty, it should be possible to quantify (and correct) the evident bias in overestimating ages (WIRSZUBSKI, 1953), given the recruitment pattern recognized at that time; however, the latter cannot be avoided completely. It should be noted that the vBGF is not the unique (and maybe not even the best) approach: in fact,

Table 1a, b
Descriptive statistics (data in the Appendix), after outliers exclusion, with the result of the Shapiro normality tests for (a) females and (b) males of *Mullus barbatus*. Legend: L_0, L_1, ... L_8= great mean length-at-age; N= number of sets; min= minimum; max= maximum; mean= overall great mean; s.d.= standard deviation; C.V.= coefficient of variation; skew.= skewness; NT, p= probability level of the normality test (* and in bold those significant at p= 0.1).

a) F	L_0	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
N	46	49	49	51	51	51	51	51	51
min	26.6	89.4	121.5	89.2	111.7	131.4	148.6	163.7	176.8
max	115.9	176.4	221.9	254.0	272.8	282.3	292.9	302.7	309.8
mean	65.34	127.97	170.03	193.26	211.75	224.59	233.74	240.40	245.33
s.d.	22.26	19.97	27.34	36.07	36.11	35.15	33.99	32.92	32.08
C.V.	0.34	0.16	0.16	0.19	0.17	0.16	0.15	0.14	0.13
skew.	-0.13	0.15	0.06	-0.64	-0.57	-0.48	-0.37	-0.26	-0.17
NT, p	0.27	0.88	0.26	0.13	0.16	0.22	0.30	0.48	0.60

b) M	L_0	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
N	47	47	48	49	50	50	50	50	50
min	5.4	89.0	90.0	89.5	91.3	106.4	119.6	131.0	141.0
max	95.3	141.7	176.8	200.8	220.4	234.1	243.5	250.1	254.7
mean	58.04	115.41	148.43	166.27	178.05	187.11	193.27	197.59	200.67
s.d.	22.29	12.79	19.43	26.51	28.91	27.86	26.72	25.77	25.02
C.V.	0.38	0.11	0.13	0.16	0.16	0.15	0.14	0.13	0.12
skew.	-0.50	-0.06	-0.74	-0.99	-0.90	-0.65	-0.43	-0.26	-0.15
NT, p	0.16	0.84	**<0.01***	**<0.01***	**<0.01***	**0.049***	0.37	0.70	0.85

Table 2
vBGF parameters of the reference curve for (a) females and (b) males *Mullus barbatus* of the Mediterranean sea (MSE denotes the mean square error).

	a) Females			**b) Males**		
	minimum	**mean**	**maximum**	**minimum**	**mean**	**maximum**
L_∞ (TL; mm)	221.0	251.5	317.5	130.7	201.9	269.3
K/y	0.153	0.395	0.371	1.095	0.502	0.314
t_0 (yr)	-0.99	-0.27	-0.72	0.461	-0.18	-0.88
MSE	372.9	3.2	6.8	113.0	2.3	0.4

it has been chosen for its simplicity and its widespread diffusion, but more advanced models could be used in future studies (e.g., the Akaike Informative Criterion; KATSANEVAKIS & MARAVELIAS, 2008).

Another source of variability might be hidden in geographical variability. West-east trends, both environmental and biological, have already been hypothesized and documented in Mediterranean hydrology and species assemblages, although there is no general agreement about the most suitable bio-geographical zoning (cfr. GARIBALDI & CADDY, 1998; BIANCHI, 2007).

One of the most debated phenomenon is the so called 'Levantine nanism' (i.e., dwarf specimens achieving smaller maximum sizes, due to lower growth rates and precocious maturity) of the eastern exploited stock, which are supposed to live in warmer and saltier waters with a lower trophism than their western counterparts (cfr. AZOV, 1991). As a matter of fact, 'nanism' had already been proposed for the entire Mediterranean ichthyofauna in the past, but this 'overall' hypothesis has been considered an error by MAURIN (1970); conversely, the supposed 'Levantine nanism' of the eastern stocks has never been unambiguously demonstrated. As regards *M. barbatus*, 'nanism' was supported by SONIN *et al.* (2007) in comparing two stocks off the coasts of Southern Sicily and Israel; in fact, some geographical heterogeneity has been detected, mainly as a consequence of extension and bottom features of the continental shelf (TSERPES *et al*., 2002) and of seawater temperature fluctuations (EZZAT *et al*., 1997).

Another possibility, still to be examined in depth, is the existence of a north-south geographical gradient, synergic or contrasting the latitudinal one; in fact, the Mediterranean is oriented NW-SE, being 3800 km wide and 1800 km high, with significant difference in the superficial temperatures (TZIPERMAN & MALANOTTE-RIZZOLI, 1991) between its northern and southern coasts.

Not with standing this variability, it is interesting to verify at what point the proposed reference curve conforms to the life pattern of the red mullet, as defined in many publications from the earliest (cfr. SCACCINI, 1947A; 1947B; GOTLIEB, 1956) to the present time (TSERPES *et al*., 2002; VOLIANI, 1999; FROESE & PAULY, 2010). Gonad ripening occurs mainly in late spring and early summer (the spawning peak is in May-June) and secondarily in October-November (RELINI & ARNALDI, 1986; SABATINI *et al*., 2002). Considering the pre-eminent spawning period, the young pelagic post-larvae (19-34 mm TL), deriving from the eggs laid offshore (10-100 m), begin to recruit in shallow waters in summer at 20-50 mm (silver specimens), grow up to 60-80 mm in August (the so-called 'agostinelle') and up to 120-130 mm in November-December. Growth almost stops in late autumn and early winter, to restart in spring, but at higher rates in females than in males (200 mm *vs*. 175 mm). Maturity always occurs earlier in males than in females (1 yr *vs*. 2 yr, respectively; EZZAT *et al*., 1997), although some overlapping in size-at-maturity could be noted (males min 103-max 140 mm, females min 105-max 160 mm; from FROESE & PAULY, 2010 and/or GHARBI & KTARI, 1981); in fact, more reasoned estimates resulted in a reduced range of 100-129 mm and 120-134 mm for males and females, respectively (EZZAT *et al*., 1997). Moreover, a clear positive relationship exists between size and depth (VOLIANI, 1999).

In general, a true year ring in otoliths (hyaline ring) begins to appear in April-May, after the deposition of a 'larval' ring (the 'L' of GOTTLIEB, 1956), next to the nucleus, which reflects the transition between the larval and the demersal phase (sometimes not very clear in adult fish). Thereafter, hyaline (winter) and opaque (spring-summer) zones are laid down more or less regularly. In some fish, a second false hyaline ('O') ring occurs within the first opaque zone as a slowing growth of the otolith. Maximum age is about 10-11 yr at sizes of about 340-350 mm (SCACCINI, 1947a; 1947b); at present times, females larger than 300 mm TL are reported only in limited areas, such as the Euboean Gulf (Greece), around sites where trawling is not allowed (VASSILOPOULOU & PAPACONSTANTINOU, 1992). Fecundity does not seem to decrease with age, suggesting that longevity is higher than usual (EZZAT *et al*., 1997). Benthic and planktonic (copepods) feeders when juveniles, red mullets become opportunistic benthic feeders (worms, crustaceans, mollusks, etc.) when adult (MACHIAS & LABROPOULOU, 2002). Although well suited to feed on muddy and turbid bottoms (LOMBARTE & AGUIRRE, 1997), food availability might represent at least one of the limiting factors. Finally, theoretical and empirical evidence supports the hypothesis that a good (steep) stock-recruitment relationship for low levels of spawning stock biomass may explain the resilience of the Mediterranean demersal stocks, red mullet included (CADDY, 1993; FARRUGIO *et al*., 1993; LLEONART, 2005).

Last but not least, there is the real unitarian nature of the stocks from which parameters were derived (CADDY, 2009). A unit stock, in fact, should be defined (HALLIDAY & PINHORN, 1990) according to the genetic homogeneity and stock/fisheries distribution and structure interaction and should preferably correspond to the defined unit management areas (the GSAs in the specific case). As a matter of fact, comparison of future data with the present standard would help in highlighting the often 'non conclusive' Mediterranean genetic-based stock definition (LLEONART & MAYNOU, 2003) on the one side and the expected geographical differences on the other, due to the existence in the Mediterranean of east-west and/or north-south gradients.

Conclusions

The present approach produced Mediterranean-wide curves that are coherent with the known life pattern of *M. barbatus*; it is worth noting that the growth pattern of males seems more erratic and thus more difficult to analyze than that of females.

While waiting for a deeper examination of the degree of correspondence between GFCM's , GSAs and unit stocks (a general problem in fisheries science; cfr. HALLIDAY & PINHORN, 1990; CADDY, 2009; REISS *et al*., 2009), the present methodology, of which *M. barbatus* was a case study, could be used to derive reference curves for Mediterranean demersal resources and to compare the closeness of new estimated data with the overall, historical growth pattern of the investigated species.

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APPENDIX

Annotated vBGF parameters, corresponding estimated (*) or reported length (L, in mm) at age (year, from 0 up 8 yr) by geographical location and sex of *Mullus barbatus;* (in bold and underlined the outliers evidenced by the box-plot representation). Ly obtained from the vBGF were forced through the observed mean of t_0 (-0.95 and -0.90 for females and males, respectively). Sets with less than 3 couples of data were not considered for the vBGF fit (nc). Remarks refer to the original data. Length refers to total length if not otherwise specified (FL and SL, fork and standard length, respectively). LFDa= length frequency distribution analysis. The full reference of the consulted papers is reported in the general bibliography.

SYNOPSIS (105 sets)			*Mullus barbatus*	NB: length values in L_0 ref. t_0=0.0 were not considered; data were forced thru: F t_0=0.90												outliers in **bold underlined**	ORIGINAL LENGTH AT AGE								
set	**sex**	**geographical area**	**size (TL; mm) at age (year) from vBGF**									**VBGF parameters**			**remarks**	**from** (full references in paper bibliograpy)	**size (TL.; mm) ate age (year)**								
		age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	L_{inf}	**k**	t_0	(TL measures and/or length-at-age method when not otherwise		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	F	Alboran Sea	87.8	158.7	197.7	219.0	230.7	237.2	240.7	242.6	243.7	245.0	0.600	-0.74	LFDa	SAMED, 2003									
1	M	Alboran Sea	77.3	138.6	171.6	189.3	198.9	204.0	206.8	208.3	209.1	210.0	0. 620	-0.74	LFDa	SAMED, 2003									
2	F	Spanish coast (C. de Gata- C. Creus)	67.5	138.5	185.0	215.4	235.3	248.3	256.9	262.4	266.1	273.0	0. 424	-0.67	LFDa	SAMED, 2003									
2	M	Spanish coast (C. de Gata- C. Creus)	63.5	126.1	163.8	186.5	200.2	208.5	213.4	216.4	218.3	221.0	0.506	-0.67	LFDa	SAMED, 2003									
3	F	Spanish coast (Southern)	77.8	133.6	171.2	196.5	213.6	225.1	232.8	238.0	241.5	248.8	0.395	-0.95	LFDa	Larraneta & Rodriguez Roda, 1956	135.0	170.0	196.0	213.0	226.0				
3	M	Spanish coast (Southern)	74.7	122.2	148.7	163.4	171.5	176.0	178.6	180.0	180.7	181.7	0.588	-0.90	LFDa	Larraneta & Rodriguez Roda, 1956	124.0	147.0	162.0	172.0	177.0				
4	F	Spanish coast										nc	nc	nc	scales reading	Planas & Vives, 1956	115.5	173. 1							
4	M	Spanish coast										nc	nc	nc	scales reading	Planas & Vives, 1956	93.2	152. 1							
5	F	Spanish coasts (Catalan Sea)										nc	nc	nc	scales reading	Suau & Vives, 1957	145.0	185. 0							
5	M	Spanish coasts (Catalan Sea)										nc	nc	nc	scales reading	Suau & Vives, 1957	120.0	165. 0							
6	F	France (Gulf of Lions)	27.7	125.7	179.6	209.1	225.3	234.2	239.1	241.7	243.2	245.0	0.600	-0.20	otoliths reading	Passalaigue, 1974									
6	M	France (Gulf of Lions)	28.3	112.6	160.8	188.3	204.1	213.0	218.2	221.1	222.8	225.0	0.560	-0.24	otoliths reading	Passalaigue, 1974									
7	F	France (Gulf of Lions)	44.8	119.3	160.2	182.7	195.0	201.8	205.5	207.5	208.6	210.0	0.600	-0.40	scales reading	Passalaigue, 1974									
7	M	France (Gulf of Lions)	10.4	97.2	136.2	153.7	161.6	165.1	166.7	167.4	167.7	168.0	0. 800	-0.08	scales reading	Passalaigue, 1974									
8	F	France (South coasts)	72.3	127.6	167.4	196.0	216.6	231.4	242.1	249.8	255.3	269.5	0.329	-0.95	not reported	Bougis, 1952	120.0	175.0	200.0	212.0					
8	M	France (South coasts)	59.0	106.0	139.1	162.3	178.7	190.2	198.2	203.9	207.9	217.4	0.352	-0.90	not reported	Bougis, 1952	100.0	145.0	165.0	175.27					

(Continued)

APPENDIX (Continued)

SYNOPSIS (105 sets)			*Mutlus barbatus* NB: length values in L_0 ref. t_0=0.0 were not considered; data were forced thru: F t_0=0.90 outliers in **bold underlined**														ORIGINAL LENGTH AT AGE								
set	sex	geographical area / age	size (TL; mm) at age (year) from vBGF 0	1	2	3	4	5	6	7	8	VBGF parameters L_{inf}	k	t_0	remarks (TL measures and/or length-at-age method when not otherwise	from (full references in paper bibliograpy)	size (TL.; mm) ate age (year) 0	1	2	3	4	5	6	7	8
9	M	Corsica	49.8	117.4	157.1	180.5	194.3	202.4	207.2	210.0	211.6	214.0	0.530	-0.50	LFDa	SAMED, 2003									
10	F	Sardinia	99.2	176.4	221.9	248.7	264.5	273.7	279.2	282.4	284.3	287.0	0.530	-0.80	LFDa	SAMED, 2003									
10	M	Sardinia	24.8	115.0	167.0	197.1	214.4	224.4	230.1	233.5	235.4	238.0	0.550	-0.20	LFDa	SAMED, 2003									
11	F	Sardinia	89.4	132.6	166.9	194.1	215.8	233.0	246.7	257.6	266.2	299.6	0.230	-1.54	otoliths reading	Sabatini *et al* ., 2002									
11	M	Sardinia	76.5	141.7	176.8	195.7	205.9	211.3	214.3	215.9	216.7	217.7	0 620	-0.70	otoliths reading	Sabatini *et al*., 2002									
12	F	Ligurian Sea	72.3	127.6	167.4	196.0	216.6	231.4	242.1	249.8	255.3	269.5	0.329	-0.95	otoliths reading	Fiorentino *et al*., 1998a	136.0	166.0	188.0						
12	M	Ligurian Sea	74.2	120.1	144.8	158.0	165.1	169.0	171.0	172.1	172.7	173.4	0.621	-0.90	otoliths reading	Fiorentino *et al*., 1998a	122.0	141.0	160.0						
13	F	Ligurian Sea	26.9	152.7	209.8	235.8	247.6	252.9	255.4	256.5	257.0	257.4	0.789	-0.14	LFDa	Fiorentino *et al*., 1998a									
13	M	Ligurian Sea	44.6	121.8	165.0	189.1	202.5	210.1	214.3	216.6	217.9	219.6	0.582	-0.39	LFDa	Fiorentino *et al*., 1998a									
14	F	Tyrrhenian Sea (North)	64.3	167.5	219.0	244.6	257.3	263.7	266.9	268.4	269.2	270.0	0.697	-0.39	LFDa	Voliani *et al*., 1998a									
14	M	Tyrrhenian Sea (North)	70.3	138.4	172.3	189.2	197.6	201.8	203.9	205.0	205.5	206.0	0 696	-0.60	LFDa	Voliani *et al*., 1998a									
15	F	Tyrrhenian Sea (North)	55.9	154.7	206.9	234.3	248.8	256.5	260.5	262.6	263.8	265.0	0 640	-0.37	LFDa	Voliani *et al*., 1998a									
15	M	Tyrrhenian Sea (North)	54.9	133.1	173.1	193.5	204.0	209.4	212.1	213.5	214.2	215.0	0.670	-0.44	LFDa	Voliani *et al*., 1998a									
16	F	Tyrrhenian Sea (North)	-	144.1	217.1	254.0	272.8	282.3	287.1	289.5	290.7	292.0	0.680	nc	LFDa	Voliani *et al*., 1998b									
16	M	Tyrrhenian Sea (North)	-	115.0	169.9	196.1	208.6	214.6	217.4	218.8	219.4	220.0	0.740	nc	LFDa	Voliani *et al*., 1998b									
17	F	Tyrrhenian Sea (North)	85.9	152.2	200.4	235.5	260.9	279.4	292.9	302.7	309.8	328.7	0.319	-0.95	not reported	Voliani, 1999	153.0	199.0	236.0						
17	M	Tyrrhenian Sea (North)	69.8	124.3	161.8	187.6	205.4	217.7	226.1	231.9	235.9	244.8	0. 373	-0.90	not reported	Voliani, 1999	126.0	159.0	189.0						
18	F	Tyrrhenian Sea (down to Messina)	29.3	136.9	200.3	237.6	259.6	272.5	280.1	284.6	287.2	291.0	0.530	-0.20	LFDa	SAMED, 2003									
18	M	Tyrrhenian Sea (down to Messina)	24.9	114.4	165.1	193.7	209.9	219.1	224.3	227.2	228.8	231.0	0.570	-0.20	LFDa	SAMED, 2003									
19	F	Tyrrhenian Sea (down to Messina)	48.0	131.9	184.4	217.4	238.1	251.0	259.2	264.2	267.4	272.8	0.467	-0.41	LFDa	Spedicato et al ., 1994									

(Continued)

APPENDIX (Continued)

SYNOPSIS (105 sets)			*Mullus barbatus*	NB: length values in L_0 ref. t_0=0.0 were not considered; data were forced thru: F t_0=0.90												outliers in **bold underlined**	ORIGINAL LENGTH AT AGE								
set	sex	geographical area	size (TL; mm) at age (year) from vBGF									VBGF parameters			remarks	from (full references in paper bibliograpy)	size (TL.; mm) ate age (year)								
		age	0	1	2	3	4	5	6	7	8	L_{inf}	k	t_0	(TL measures and/or length-at-age method when not otherwise		0	1	2	3	4	5	6	7	8
19	M	Tyrrhenian Sea (down to Messina)	28.8	109.8	154.5	179.2	192.8	200.3	204.5	206.8	208.0	209.6	0.594	-0.25	LFDa	Spedicato *et al*., 1994									
20	F	Tyrrhenian Sea	27.0	152.8	209.9	235.9	247.6	253.0	255.4	256.5	257.0	257.4	0.790	-0.14	LFDa	Fiorentino *et al*., 1998b									
20	M	Tyrrhenian Sea	44.5	121.5	164.7	188.9	202.4	210.0	214.2	216.6	217.9	219.6	0.580	-0.39	LFDa	Fiorentino *et al*., 1998b									
21	F	Northern coasts of Sicily	55.2	125.9	175.3	209.8	233.9	250.8	262.6	270.8	276.6	290.0	0.358	-0.59	LFDa	SAMED, 2003									
21	M	Northern coasts of Sicily	55.4	112.3	150.6	176.5	193.9	205.7	213.6	218.9	222.5	230.0	0.394	-0.70	LFDa	SAMED, 2003									
22	F	Northern coasts of Sicily	115.9	139.3	159.0	175.7	189.9	201.8	211.9	220.4	227.6	267.0	0.168	-3.39	LFDa	Greco *et al*., 1998									
22	M	Northern coasts of Sicily	78.7	105.5	127.2	144.7	158.9	170.4	179.7	187.2	193.3	219.0	0.212	-2.10	LFDa	Greco *et al*., 1998									
23	F	Northern coasts of Sicily	91.7	110.8	127.2	141.4	153.6	164.1	173.1	180.9	187.6	228.9	0.150	-3.41	LS; otoliths reading	Potoschi *et al*., 1993									
23	M	Northern coasts of Sicily	85.6	109.6	128.2	142.5	153.5	162.0	168.6	173.7	177.6	190.7	0.260	-2.29	LS; otoliths reading	Potoschi *et al*., 1993									
24	F	Northern coasts of Sicily	79.1	117.0	147.4	171.8	191.4	207.1	219.7	229.8	237.9	270.9	0.220	-1.57	otoliths reading	Present paper									
24	M	Northern coasts of Sicily	94.0	117.6	134.8	147.5	156.7	163.5	168.5	172.1	174.7	182.0	0.312	-2.33	otoliths reading	Present paper									
25	F	Strait of Sicily	30.3	136.4	193.5	224.2	240.8	249.7	254.4	257.0	258.4	260.0	0.620	-0.20	LFDa	SAMED, 2003									
25	M	Strait of Sicily	24.3	108.3	152.6	175.9	188.3	194.8	198.2	200.0	200.9	202.0	0.640	-0.20	LFDa	SAMED, 2003									
26	F	Strait of Sicily	89.3	120.8	145.9	166.0	182.0	194.8	205.0	213.2	219.7	245.5	0.225	-2.01	otoliths reading	Andaloro & Prestipino Giarritta, 1985									
26	M	Strait of Sicily	84.6	106.4	125.0	140.9	154.5	166.1	176.0	184.5	191.7	233.9	0.158	-2.84	otoliths reading	Andaloro & Prestipino Giarritta, 1985									
27	F	Strait of Sicily	68.8	146.0	186.6	208.1	219.4	225.3	228.5	230.2	231.0	232.0	0.640	-0.55	LFDa	IRMA- CNR, 1999									
27	M	Strait of Sicily	71.1	133.6	165.5	181.9	190.2	194.5	196.7	197.8	198.4	199.0	0.670	-0.66	LFDa	IRMA- CNR, 1999									
28	F	Strait of Sicily	82.8	124.7	157.2	182.4	202.1	217.4	229.2	238.5	245.6	270.7	0.252	-0.95	otoliths reading	Sonin *et al*., 2007	85.0	124.7	154.5	183.3	201.7	218.1			
28	M	Strait of Sicily	85.1	125.3	154.0	174.5	189.1	199.5	206.9	212.1	215.9	225.2	0.339	-0.90	otoliths reading	Sonin *et al*., 2007	82.7	124.0	156.4	175.0	193.3	195.0			
29	F	Tunisian coasts	-	114.8	181.0	221.1	245.5	260.2	269.2	274.6	277.9	283.0	0.500	-0.04	LS; scales reading	Gharbi & Ktari, 1981									

(Continued)

APPENDIX (Continued)

SYNOPSIS (105 sets)			*Mullus barbatus* NB: length values in L_0 ref. t_0=0.0 were not considered; data were forced thru: F t_0=0.90 outliers in **bold underlined**														ORIGINAL LENGTH AT AGE								
set	**sex**	**geographical area**	**size (TL; mm) at age (year) from vBGF**									**VBGF parameters**			**remarks**	**from** (full references in paper bibliograpy)	**size (TL.; mm) ate age (year)**								
		age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	L_{inf}	**k**	t_0	(TL measures and/or length-at-age method when not otherwise		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
29	M	Tunisian coasts	20.9	110.6	165.2	198.4	218.6	230.9	238.4	242.9	245.7	250.0	0.497	-0.18	LS; scales reading	Gharbi & Ktari, 1981									
30	F	Tunisian coasts	71.3	128.4	171.7	204.4	229.2	247.9	262.1	272.8	280.9	306.1	0.279	-0.95	LS; scales reading	Gharbi & Ktari, 1981	130.0	167.0	207.0	231.0	246.0				
30	M	Tunisian coasts	67.7	121.4	159.0	185.3	203.8	216.7	225.7	232.1	236.5	246.9	0.356	-0.90	LS; scales reading	Gharbi & Ktari, 1981	127.0	152.0	185.0	206.0					
31	F	Ionian Sea	71.2	132.0	174.7	204.8	225.9	240.8	251.2	258.6	263.7	276.0	0.352	-0.85	LFDa	SAMED, 2003									
31	M	Ionian Sea	60.3	124.9	160.2	179.6	190.2	196.0	199.1	200.9	201.8	203.0	0.602	-0.59	LFDa	SAMED, 2003									
32	F	Ionian Sea	96.3	131.5	158.4	178.9	194.5	206.5	215.6	222.5	227.9	245.0	0.270	-1.85	otoliths reading	Tursi *et al*., 1996									
32	M	Ionian Sea	95.3	126.8	150.5	168.5	182.0	192.3	200.0	205.9	210.3	224.0	0.280	-1.98	otoliths reading	Tursi *et al*., 1996									
33	F	Ionian Sea	77.5	129.4	162.0	182.5	195.4	203.6	208.7	211.9	213.9	217.3	0.464	-0.95	otoliths reading	Tursi *et al*., 1994	133.0	158.0	184.0	190.0	208.0				
33	M	Ionian Sea										186.8	0. 585	-0.90	otoliths reading	Tursi *et al*., 1994	127.0	150.0	168.0	177.0					
34	F	Adriatic (N- Central)	71.7	136.6	180.2	209.6	229.3	242.6	251.6	257.6	261.7	270.0	0.396	-0.78	LFDa	SAMED, 2003									
34	M	Adriatic (N- Central)	66.9	123.9	161.0	185.1	200.8	211.0	217.6	222.0	224.8	230.0	0.430	-0.80	LFDa	SAMED, 2003									
35	F	Adriatic	84.4	148.8	195.0	228.3	252.1	269.2	281.5	290.4	296.7	312.9	0.331	-0.95	scales reading	Scaccini, 1947a	127.1	202.6	239.4	259.0	270.4	279.3	286.6	293.4	
35	M	Adriatic	73.9	132.1	172.6	200.8	220.4	234.1	243.5	250.1	254.7	265.2	0.363	-0.90	scales reading	Scaccini, 1947a	126.3	174.7	204.2	223.1	233.2	241.9	248.8	255.0	
36	F	Adriatic	-	92.3	147.7	181.0	201.0	213.0	220.2	224.5	227.1	231.0	0.510	-	not reported	Froese & Pauly, 2010									
36	M	Adriatic										nc	nc n	c	questionable	Froese & Pauly, 2010									
37	F	Adriatic	84.4	148.8	195.0	228.3	252.1	269.2	281.5	290.4	296.7	312.9	0.331	-0.95		Haidar, 1970	122.0	152.0	165.0	175.0	183.0				
37	M	Adriatic	60.6	102.2	127.3	142.4	151.5	157.0	160.3	162.3	163.5	165.3	0.507	-0.90		Haidar, 1970	101.0	129.0	142.0	151.0	157.0				
38	F	Hellas (Western coasts)	71.2	132.0	174.7	204.8	225.9	240.8	251.2	258.6	263.7	276.0	0.352	-0.85	LFDa	SAMED, 2003									
38	M	Hellas (Western coasts)	60.3	124.9	160.2	179.6	190.2	196.0	199.1	200.9	201.8	203.0	0.602	-0.59	LFDa	SAMED, 2003									
39	F	Hellas (Eubea and V olo Gulfs)	83.3	106.7	127.8	147.0	164.3	180.0	194.2	207.0	218.6	329.0	0.100	-2.92	FL	Froese & Pauly, 2010									

(Continued)

APPENDIX (Continued)

SYNOPSIS (105 sets)			*Mullus barbatus*	NB: length values in L_0 ref. t_0=0.0 were not considered; data were forced thru: F t_0=0.90											outliers in **bold underlined**		ORIGINAL LENGTH AT AGE								
set	**sex**	**geographical area**	**size (TL; mm) at age (year) from vBGF**									**VBGF parameters**			**remarks**	**from** (full references in paper bibliograpy)	**size (TL.; mm) ate age (year)**								
		age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	L_{inf}	**k**	t_0	(TL measures and/or length-at-age method when not otherwise		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
39	M	Hellas (Eubea and Volo Gulfs)	94.4	115.6	133.9	149.7	163.2	174.9	185.0	193.6	201.0	247.0	0.150	-3.21	FL	Froese & Pauly, 2010									
40	F	Hellas (Eubea Gulf)										nc	nc	nc	not available	Froese & Pauly, 2010									
40	M	Hellas (Eubea Gulf)	-	34.4	64.0	89.5	111.4	130.3	146.6	160.6	172.6	247.0	0.150	-	FL	Froese & Pauly, 2010									
41	F	Hellas (Athens Gulf)	56.6	99.7	130.5	152.5	168.3	179.7	187.8	193.6	197.7	208.2	0.334	-0.95	FL; otoliths reading	Papacostantinou *et al*., 1981	112.0	134.0	147.0	159.0	171.0	186.0	200.0	205.0	
41	M	Hellas (Athens Gulf)	59.5	101.9	128.5	145.1	155.5	162.1	166.2	168.7	170.3	173.0	0.468	-0.90	FL; otoliths reading	Papacostantinou *et al*., 1981	107.0	128.0	140.0	152.0	161.0	172.0			
42	F	Hellas (Athens Gulf)	-	40.3	74.9	104.7	130.3	152.2	171.1	187.4	201.3	286.6	0.152	-	LFDa	Karlou & Vrantzas, 1989									
42	M	Hellas (Athens Gulf)	-	51.1	90.0	119.7	142.4	159.6	172.8	182.8	190.5	215.0	0.271	-	LFDa	Karlou & Vrantzas, 1989									
43	F	Hellas (Athens Gulf)	-	33.8	63.3	89.2	111.7	131.4	148.6	163.7	176.8	267.7	0.135	-	suspicious data	Papacostantinou *et al*., 1981									
43	M	Hellas (Athens Gulf)	-	36.7	67.1	92.1	112.8	129.9	144.1	155.7	165.4	211.2	0.191	-	suspicious data	Papacostantinou *et al*., 1981									
44	F	Aegean Sea	45.9	111.0	159.6	195.9	223.1	243.3	258.4	269.7	278.1	303.0	0.292	-0.56	LFDa	SAMED, 2003									
44	M	Aegean Sea	46.2	110.1	152.7	181.1	200.0	212.7	221.1	226.7	230.5	238.0	0.405	-0.53	LFDa	SAMED, 2003									
45	F	Aegean Sea (Thessalonica Gulf)	3.4	27.6	49.6	69.6	87.9	104.6	119.7	133.6	146.2	275.4	nc	-0.14	suspicious data	Papacostantinou *et al*., 1981									
45	M	Aegean Sea (Thessalonica Gulf)	5.4	31.5	54.2	74.0	91.3	106.4	119.6	131.0	141.0	209.1	0.137	-0.19	suspicious data	Papacostantinou *et al*., 1981									
46	F	Aegean Sea (Central)	93.3	124.4	149.5	169.8	186.2	199.4	210.1	218.7	225.7	255.0	0.214	-2.13	FL; otoliths reading	Vassilopoulou & Papacostantinou, 1992									
46	M	Aegean Sea (Central)	84.3	115.9	140.5	159.7	174.6	186.3	195.3	202.4	207.9	227.2	0.250	-1.85	FL; otoliths reading	Vassilopoulou & Papacostantinou, 1992									
47	F	Crete	35.0	120.0	173.2	206.4	227.2	240.2	248.4	253.5	256.7	262.0	0.469	-0.31	LFDa	SAMED, 2003									
47	M	Crete	35.8	111.9	154.7	178.9	192.5	200.1	204.4	206.9	208.2	210.0	0.574	-0.33	LFDa	SAMED, 2003									

(Continued)

APPENDIX (Continued)

SYNOPSIS (105 sets)			*Mutlus barbatus* NB: length values in L_0 ref. t_0=0.0 were not considered; data were forced thru: F t_0=0.90 outliers in **bold underlined**														ORIGINAL LENGTH AT AGE								
set	**sex**	**geographical area**	**size (TL; mm) at age (year) from vBGF**									**VBGF parameters**			**remarks**	**from** (full references in paper bibliograpy)	**size (TL.; mm) ate age (year)**								
		age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	L_{inf}	**k**	t_0	(TL measures and/or length-at-age method when not otherwise		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
48	F	Marmara Sea	62.6	108.0	139.1	160.3	174.8	184.7	191.4	196.0	199.2	206.0	0.381	-0.95	not reported	Kutaygil, 1967	104.0	145.0	160.0	174.0	181.0	194.0			
48	M	Marmara Sea	58.1	98.8	123.7	139.0	148.3	154.1	157.6	159.8	161.1	163.2	0.489	-0.90	not reported	Kutaygil, 1967	100.0	128.0	134.0	145.0	150.0	165.0			
49	F	Turkey										nc	nc	nc	not reported	Akyuz, 1957	130.0	160. 0							
49	M	Turkey										nc	nc	nc	not reported	Akyuz, 1957	130.0	160. 0							
50	F	Egypt	54.8	98.9	132.3	157.6	176.8	191.4	202.4	210.8	217.1	237.0	0.277	-0.95	not reported	Hashem, 1973	104.5	130.1	153.7	175.2	195.0				
50	M	Egypt	50.5	91.5	120.9	141.9	157.0	167.8	175.6	181.1	185.1	195.2	0.333	-0.90	not reported	Hashem, 1973	97.0	118.1	138.3	155.8	171.3				
51	F	Cyprus	51.0	89.4	121.5	148.2	170.6	189.3	204.9	217.9	228.8	284.0	0.180	-1.10	otoliths+ scales reading	Livadas, 1984									
51	M	Cyprus	55.1	90.2	117.9	139.7	156.8	170.3	180.9	189.3	195.8	220.0	0.240	-1.20	otoliths+ scales reading	Livadas, 1984									
52	F	Cyprus	59.0	105.4	139.7	165.2	184.0	198.0	208.3	216.0	221.7	237.9	0.300	-0.95	otoliths reading	Livadas, 1989	115.0	130.0	162.0	189.0					
52	M	Cyprus	62.6	109.1	139.5	159.4	172.3	180.8	186.3	189.9	192.3	196.7	0.426	-0.90	otoliths reading	Livadas, 1989	115.0	132.0	159.0	175.0					
53	F	Israel	52.0	97.4	134.7	165.5	190.8	211.7	228.9	243.1	254.7	309.2	0.194	-0.95	otoliths reading	Wirszubski, 1953	107.2	130.0	159.0	192.9	214.0	229.5			
53	M	Israel	49.5	89.0	116.9	136.6	150.5	160.3	167.2	172.0	175.5	183.7	0. 349	-0.90	otoliths reading	Wirszubski, 1953	93.2	113.9	133.0	153.9					
54	F	Israel	58.7	103.8	136.5	160.2	177.3	189.7	198.7	205.2	209.9	222.2	0.323	-0.95	otoliths reading	Gottlieb, 1956	67.0	106.0	132.0	154.0	177.0	195.0			
54	M	Israel	58.1	98.8	123.8	139.0	148.4	154.2	157.7	159.9	161.2	163.3	0.489	-0.90	otoliths reading	Gottlieb, 1956	65.0	99.0	117.0	135.0	155.0				
55	F	Israel	61.9	105.6	134.5	153.6	166.3	174.7	180.3	184.0	186.4	191.2	0. 412	-0.95	otoliths reading	Gottlieb, 1956	66.0	107.0	129.0	152.0	170.0				
55	M	Israel										nc	nc	nc	not available	Gottlieb, 1956									
56	F	Israel	67.6	100.7	125.9	145.0	159.5	170.5	178.8	185.2	190.0	205.1	0.276	-0.95	otoliths reading	Sonin *et al*., 2007	90.0	82.9	126.3	141.4	158.2	176.0			
56	M	Israel	75.5	105.8	124.7	136.4	143.8	148.3	151.2	152.9	154.0	155.9	0.473	-0.95	otoliths reading	Sonin *et a* ., 2007	86.7	90.0	128.0	139.1	146.2	146.3			