1

Mullidae Günther, 1859

Vernacular name: Red mullet.

Etymology: It is uncertain, from the Latin *mulleus* (red-colored like the red shoes of Roman senators) according to Walter and Avenas (2011), or from *mullus*, meaning soft according to Romero (2002, Fishbase), and also *mullus* (Latin name of the red surmullet).

Brief description: It is characterized by the presence of two mobile barbels (used to detect food). Elongated body containing 23–24 vertebrae. Two widely separated dorsal fins; the first with six to eight spines and the second with one spine and eight to nine soft rays. The anal fin has one or two short spines and five to eight soft rays. The caudal fin is forked. Maximum length 60 cm (Nelson, 2006). They are a characteristic red color only under the effect of excitation or after death. In their environment, the external markings are quite variable, generally greenish-brown on their back, silvery on the underside. They have large deciduous scales and a prominent lateral line.

Biogeography: Atlantic, Indian and Pacific Oceans and the Mediterranean Sea.

Habitat and bio-ecology: Marine, rarely found in brackish water.

Systematics and phylogeny: Based on samples from Greece and Senegal, Mamuris *et al*. (1999a) showed that genetic distances are smaller between the species *Upeneus moluccensis* and *Pseudupeneus prayensis* than between the latter and *Mullus barbatus* and *Mullus surmuletus*. Both *Mullus* species are genetically closer to *P. prayensis* than *U. moluccensis* if allozyme markers are taken into account, but the reverse is true if random amplified polymorphic DNA (RAPD) markers and mitochondrial DNA are used. The phylogenetic tree built with neighbor-joining methods and parsimony, using the three markers together, confirms this last result (Figure 1.1).

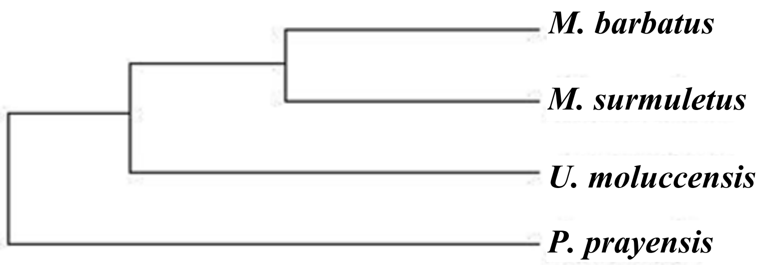


Figure 1.1. *Phylogenetic tree based on parsimony analysis using three markers together (allozymes, RAPDs, mitochondrial DNA) (based on Mamuris* et al.*, 1999a)*

Turan (2006) compared, using morphology and 12 enzymatic markers, four Mullidae species: *Mullus barbatus*, *M. surmuletus*, *U. moluccensis*, *Upeneus pori* and a subspecies, *M. barbatus ponticus*. Significant differences in allelic frequencies were revealed between *M. barbatus* and *M. b. ponticus* ($P < 0.001$). The values of the genetic distances are 0.034 between *M. barbatus* and *M. b. ponticus* and 0.341 between *M. barbatus* and *M. surmuletus*. The genetic differentiation is relatively high (D = 0.628) between *U. moluccensis* and *U. pori*. At the intergeneric level, the greatest genetic distance is between *M. surmuletus* and *U. pori* (D = 1.250) and the smallest (D = 1.056) is between *M. surmuletus* and *U. moluccensis*. *Upeneus pori* is remarkably the most genetically distinct species of the genus *Mullus* (Figure 1.2).

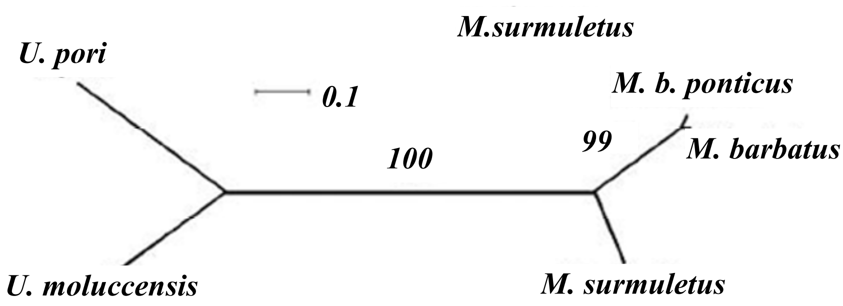


Figure 1.2. *Neighbor-joining phylogenetic tree based on Nei's genetic distances for allozymes. The lengths of the branches are proportional to the genetic distances between taxa (see scale). The numbers indicate bootstrap values for 1,000 replications (Turan, 2006)*

Morphological data, using meristic characters, lead to the same conclusions (Figure 1.3).

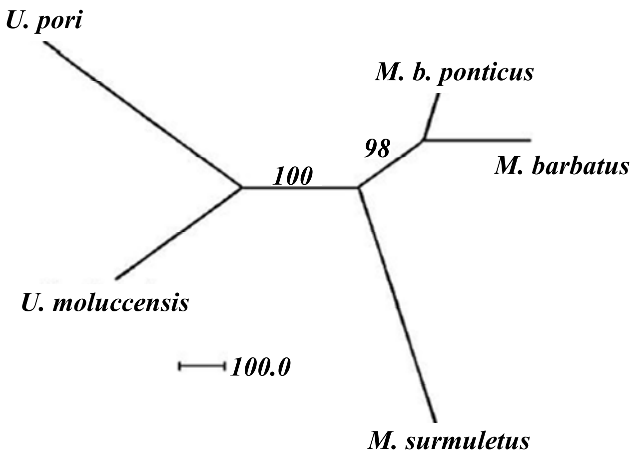


Figure 1.3. *Neighbor-joining phylogenetic tree based on Euclidean distances. The scale bar represents the length of the branch. The numbers indicate the bootstrap values (Turan, 2006)*

These same taxa were compared by Keskin and Kan (2009) who used mitochondrial markers (cytochrome b, 12S RNA, cytochrome oxidase). The phylogenetic tree, constructed from the results obtained, confirmed the existence of the two genera *Mullus* and *Upeneus*, but not that of the subspecies *M. barbatus ponticus*.

Biodiversity: There are six genera *Mulloidichthys*, *Mullus*, *Parupeneus*, *Pseudupeneus*, *Upeneichthys*, *Upeneus*, with approximately 62 species (Nelson, 2006). Three genera exist in the Mediterranean: *Mullus*, *Pseudupeneus* (Herculean immigrant), *Upeneus* (Lessepsian immigrant) (Quignard and Tomasini, 2000).

Originality: These fish are characterized by the presence of two barbels that come from the transformation of branchiostegous rays into soft and fleshy appendages, covered with sensory structures (Bougis, 1952a, 1952b; Gosline, 1984; McCormick, 1993; Lombarte and Aguirre, 1995). The ultrastructure of the taste buds of Mediterranean *Mullus* is described by Lombarte and Aguirre (1997). These taste buds have a pore from which apical endings of different chemoreceptor cells emerge.

1.1. *Mullus* Linnæus, 1758

Type: *Mullus* Linnæus, 1758, *Syst. Naturae*, 10 ed., 1: 299 (species: *M. barbatus Linnæus*, 1758, by subsequent designation by Bleeker, 1876: 334).

Etymology: From the Latin *mulleus* (red) or *mullus* (name of red surmullet).

Brief description: For this, see the “Brief description” section in the box at the beginning of the chapter. A notable characteristic of other genera is the absence of teeth in the upper jaw.

Biogeography: Atlantic and Mediterranean Oceans, Black Sea and Sea of Azov.

Habitat and bio-ecology: Demersal, marine, 5–500 m deep.

Biodiversity: This genus includes four species: *Mullus* Hubbs and Marini, 1933, *Mullus auratus* Jordan and Gilbert, 1882, *M. surmuletus* Linnæus, 1758, *M. barbatus*. The latter is represented by two subspecies: *M. barbatus barbatus* Linnæus, 1758 and *M. barbatus ponticus* Essipov, 1927. Only *M. barbatus barbatus* and *M. surmuletus* occur in the Mediterranean. Their distinctive criteria are illustrated in Figure 1.4.

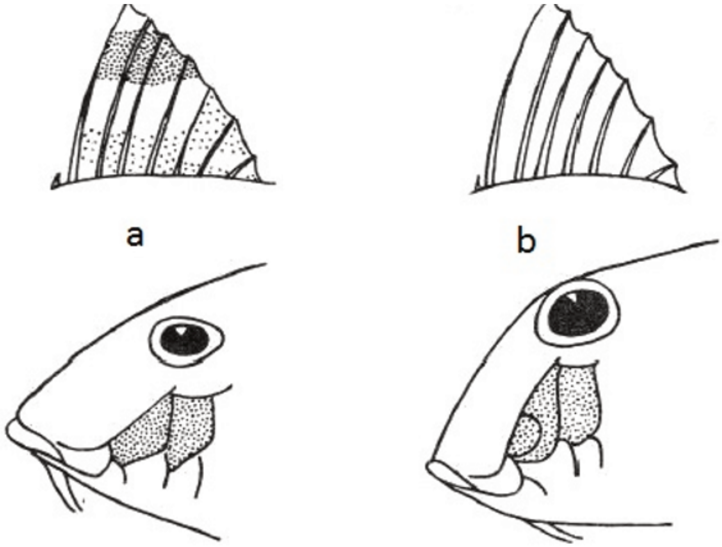
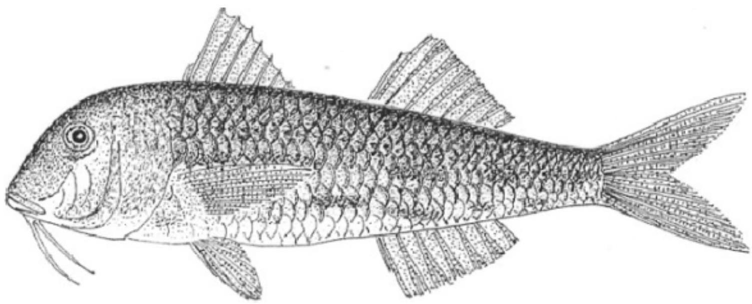


Figure 1.4. *First dorsal fin and suborbital scales: (a) Mullus surmuletus; (b) Mullus barbatus (Bauchot and Pras, 1980)*

Systematics and phylogeny: See box at the beginning of the chapter, section “Systematics and phylogeny”.

Originality: When threatened, the red mullet makes the first dorsal fin appear bigger, probably to deter any predators; the barbs are then folded into notches under the head.

1.1.1. Mullus barbatus barbatus *Linnæus, 1758*



1.1.1.1. *Nomenclature and systematics*

Holotype: *Mullus barbatus* Linnæus, 1758, Syst. Nat., Ed. X: 299 (*Habitat in M. Mediterraneo and Oceano septentrionali*). Holotype: LS no. 3.

Synonyms: *Mullus ruber* Lacepède, 1801; *M. fuscatus* Rafinesque, 1810.

Vernacular names: *Rouget de vase* (DZ), *salmonete de fango* (ES), *rouget-barbet de vase* (FR), red mullet (GB), *koutsomoura* (GR), *mulit adumma* (IS), *triglia di fango* (IT), *trillia bidha*, *rouget blanc* (TN).

Etymology: The French name, *rouget*, is due to its red color, especially as it is seen on the fishmonger’s stall. The scientific name comes from the Latin *mulleus* (reddish) or *mullus* (Roman name of this fish) and *barbatus* (bearded, because of the presence of two barbels).

Systematic problems: Two subspecies of red mullet are recognized: *Mullus barbatus barbatus* Linnæus, 1758 and *M. b. ponticus* Essipov, 1927. The first has three suborbital scales and its maxilla exceeds the anterior border of the eye in adults. The second usually has four suborbital scales and its maxilla does not reach the anterior edge of the eye. This subspecies is also smaller and more silvery and may live at shallower depths. Its geographical distribution is limited to the Black Sea and the Sea of Azov. Turan (2006) revealed significant differences in allelic frequencies between these two subspecies ($P < 0.001$), with a genetic distance value of 0.034.

1.1.1.2. *Description*

Morpho-anatomy: Elongated body with a rather flat ventral profile. The head is short, massive, with a steep profile. The muzzle is short. The chin has a pair of barbs whose length is less than or equal to that of the pectoral fins. These barbs have tactile, olfactory and taste organs, and are able to detect prey in the mud. The operculum is devoid of thorns. The lower jaw has villiform teeth; the upper jaw is edentulous, but teeth are present on the oral vault (vomer bone and palatine plates). Juveniles have teeth on the premaxilla. The cheeks have three large scales; the smallest is colorless. There are two well-separated dorsal fins: the first, colorless, has eight spines, the first of which is very small; the second fin has one spine and eight soft rays. The anal fin has two spines and six to seven soft rays. The scales are large and not very adherent, with 31–35 in the lateral line. They are between 10 and 20 cm in length (8 and 12 cm in the Black Sea), with a maximum of 30 cm. A maximum length of 29.7 cm is reported by Vassilopoulou (1992) in females in Greece.

Coloring: The coloring of this species changes according to its environment. On sand, it is beige with a dark horizontal line starting from the eye; on other substrates, it is dark and marbled, especially at the flanks. It is dull and paler at night than by day. With a pink tint, intense colors are more common on fishmonger stalls than in the water; this red hue is enhanced by descaling. The flanks have silvery highlights and the underside is white. The fry are bluish in color.

Variations: The morphology of *M. barbatus* from seven different localities, distributed in the Aegean and Ionian seas, was compared using 15 metric criteria (Mamuris *et al.*, 1998c). The mean value of the features examined differs significantly among the seven populations (analysis of variance, $P < 0.05$). Principal component analysis showed that the main features responsible for this differentiation are those related to the head and fins, accounting for 58.6% of the variance between seven groups. Sonin *et al.* (2007) report dwarfism in red mullets in the eastern Mediterranean (Israel: 14.6 cm TL in males, 17.6 cm TL in females, both aged 5 years) compared to those in the western Mediterranean (Strait of Sicily: 19.5 cm TL in males, 21.8 cm in females, aged 5 years). These authors attribute this divergence of sizes to the low productivity of the Levantine basin. In this region, the high temperature would also be responsible for this situation by inducing an intense metabolism that causes premature sexual maturity, itself causing a slowing down of growth.

Osteology, otoliths and scales: Contrary to generic descriptions, usually based on adult specimens, Aguirre (1997) indicates that juveniles of *M. barbatus* have teeth on the premaxilla. These teeth are no longer visible in specimens larger than 100 mm TL, since they are covered by a labial tissue (Figure 1.5).

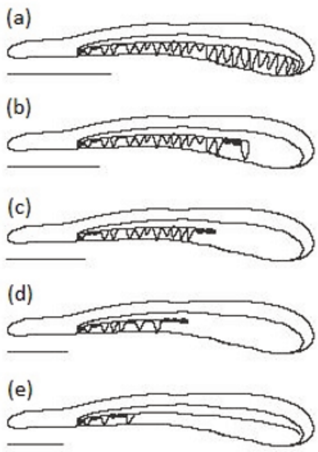


Figure 1.5. *Ventral view of dissected left premaxilla of* M. barbatus*: 45 mm (a), 50 mm (b), 60 mm (c), 70 mm (d) and 81 mm (e). The figure shows the alveoli (in black) and the teeth. Bar = 0.1 mm (Aguirre, 1997)*

Scott (1906), Sanz Echeverria (1936) and Chaine and Duvergier (1936) provide information on the sagittal otoliths of *M. barbatus*. More recently, Tuset *et al*. (2008) gave a detailed description of this otolith in the Mediterranean and north-east Atlantic. From elliptical to oval in shape, its edges are crenellated. The sulcus acusticus is heterosulcoid, ostial and medial. The ostium is funnel shaped. The cauda is tubular, curved, sharply bent from the medial region, ending near the posterior border. The anterior region is pointed. The rostrum and antirostrum are short, broad and pointed. The posterior region is rounded at irregular angles (Figure 1.6).

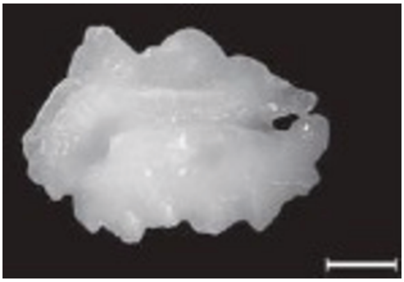


Figure 1.6. *Sagittal otolith of an individual (24.5 cm TL) of* M. barbatus *from the Western Mediterranean, scale 1 mm (Tuset* et al.*, 2008)*

This author describes the morphology of sagittal otoliths using the following ratios: otolith length/total length of fish = 1.8–2.2; otolith width/otolith length = 70.3–80.0; circularity = 16.9–17.3; rectangularity = 0.1–0.2. For north-western Mediterranean samples, Aguirre and Lombarte (1999) give the relationship between the otolith surface area (O) and the total fish length (TL) by the equation $O = 0.0097\ TL^{1.2119}$ ($r^2 = 0.9574$, n = 72), and indicate that there is no difference between the left and right otolith. Morat *et al*. (2008) describe the relationship between total fish length (mm) and sagittal otolith length (mm) using the following regression equations for those from the northwestern Mediterranean and the Aegean, respectively: TL = 73.20 Lo – 44.48 (56–235 mm, r = 0.862, $P < 0.0001$), TL = 74.11 Lo – 45.88 (120–195 mm, r = 0.849, $P < 0.0001$).

The general morphology and ultrastructure of the scales are described by Morales-Nin and Fauquet (1983). These scales are ctenoid. Their anterior field has many circulii 12 µm apart, with denticles. The latter are flattened and 2 µm wide, arranged in groups of two to four units, usually three (60%). The number of radii oscillates between four and eight, usually six (40%). The lateral fields are similar to the anterior field. The posterior field, zone of the visible scales on the body of the fish, is covered by a superficial dermis layer. This region is characterized by the presence of a series of small spines, ctenii, on the edge of the scales. Its entire surface has irregular and short ridges. The lateral line scales have a channel at the central zone whose branches split at the posterior into two branches, which in turn divide further.

Karyology: The number of chromosomes in *M. barbatus* is 2n = 44 (Vitturi *et al*., 1992; Prazdnikov, 2016). Note the absence of heteromorphic elements (sex chromosomes) in both males and females. Three pairs are metacentric or submetacentric (pair 1–3), eight are subtelocentric (pairs 4–11) and 11 are acrocentric (pairs 12–22) (Vitturi *et al*., 1992).

Protein specificity and genetic diversity: Arias and Morales (1977) compared, by electrophoresis, the soluble proteins in the muscle of *M. barbatus* and *M. surmuletus*. Electrophoregrams obtained by different methods show four protein fractions in *M. surmuletus* and two in *M. barbatus*. Mammuris *et al*. (1998a) use 20 enzymatic loci in the search for genetic differences between these two species. Electrophoretic profiles specific to each of them are highlighted in the case of the three systems PGI-2* (phosphoglucose isomerase), PGI-3* and PGM* (phosphoglucomutase). The mean value of Nei's genetic distance between the two species is 0.329. This distance is 0.068 according to Cammarata *et al*. (1991) who used seven enzymatic systems. These authors highlight profiles specific to each species in the case of the enzyme SOD and muscle proteins. Basaglia and Callegarini (1988) also find different profiles in the case of lactate dehydrogenase

(LDH) and lens proteins, while malate dehydrogenase (MDH) has the same configuration.

Using 20 allozyme markers, Mamuris *et al*. (1998a) genetically differentiated eight Mediterranean samples from *M. barbatus* (five from the Aegean Sea: Thermaikos, Allonisos, Kavala, Platania, Kymi; two from the Ionian Sea: Corfu, Amvrakikos; one from the Gulf of Lion) with a significant Fst value (Fst = 0.043; χ^2 test, $P < 0.05$). This differentiation also exists if only the eastern part of the Mediterranean (Fst = 0.041; χ^2 test, $P < 0.05$) is considered. On the other hand, the genetic distance is small, whatever the pair of samples considered (mean D = 0.0039). Mamuris *et al*. (1998b) analyzed these same samples using 29 RAPD-type molecular markers. Calculated genetic distances are positively correlated with geographic distances (Mantel t-test; r = 0.8531, t = 2.575; $P < 0.05$). Indeed, the French population of the Gulf of Lion is genetically distinct from the Greek populations and, within Greece, the populations of the Ionian Sea seem to diverge from those of the Aegean Sea. Intraspecific discrepancies are more pronounced with RAPDs than with allozymes. The results obtained on the same samples with restriction fragment length polymorphism (RFLP) markers do not show any significant genetic structuring and are more consistent with the results obtained with allozymes (Mamuris *et al*., 2001). Arculeo *et al*. (1999) examined the variability of allozymes in samples from eight Mediterranean localities (Sète, Livorno, Gulf of Castellammare, Gulf of Gela, Strait of Sicily, Venetian Lagoon, Ionian Sea, Aegean Sea). Three of the 25 loci tested were polymorphic (AAT, SDH-2, XDH-2). The observed heterozygosity was 0.043. The Nei index reveals a genetic distance of between 0.000 and 0.002. The Fst values do not show significant differences between the samples analyzed (AAT = 0.009; SDH-2 = 0.015; XDH-2 = 0.003). The average Fst value is 0.009 and the gene flow is estimated at 28 migrants per generation.

The first microsatellite markers of *M. barbatus* were developed and optimized by Garoia *et al*. (2004). Six microsatellite markers, applied to four red mullet samples from the Adriatic, give evidence that they were heterogeneous, with a low but significant Fst value (0.005, $P < 0.01$). However, there is no correlation between this genetic differentiation and geographic distance.

In a larger geographical study (Gulf of Lion, Tyrrhenian Sea, Strait of Sicily, Ionian Sea, southern and northern Adriatic), using the same microsatellite markers, Maggio *et al*. (2009) show the spatial heterogeneity of the samples (Fst = 0.003, $P < 0.001$), with the Adriatic having a certain "singularity". Ten other microsatellite loci were developed by Galarza *et al*. (2007). Their application on Mediterranean and Atlantic samples shows that the highly structured genetic distribution of muddy mullet resembles that of a metapopulation composed of independent subpopulations with autonomous recruitment, despite some connections between them (Galarza *et al*., 2009). Using the same type of markers, Félix-Hackradt *et al*. (2013) found complete homogeneity of mullet samples from 13 localities 400 km apart on the Spanish Mediterranean coast.

1.1.1.3. *Distribution*

Its distribution is common in the Mediterranean and the Black Sea, and the British Isles (occasionally in Scandinavia) and Senegal in the East Atlantic. Also present in the Canary Islands and Azores (Figure 1.7).

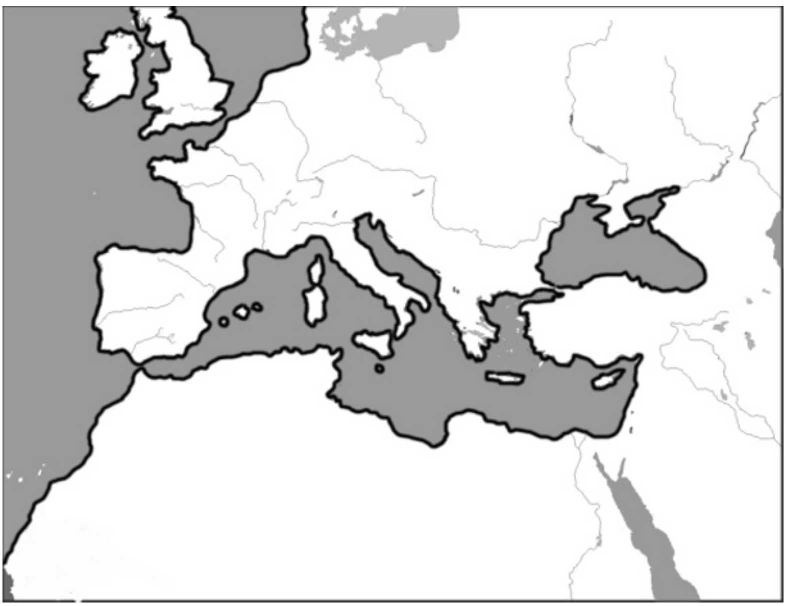


Figure 1.7. *Geographic distribution of* Mullus barbatus

1.1.1.4. *Ecology*

Habitat: Demersal and gregarious, adults of this species are found on sandy-muddy substrates, usually at depths of between 100 and 300 m, while juveniles are littoral and often live at shallower depths. In the Strait of Sicily, juveniles are recruited very close to the coast (10–30 m) in August–September and are more abundant when the surface water temperature during the early stages of development is higher than the observed average value over a long period of time (Levi *et al*., 2003). In the Aegean Sea, in the months before spawning, red mullet are more abundant in the warmer waters to the east and west than in the central region. These regions are shallower (35–60 m deep) and their temperature is 19 °C on the bed, whereas it is below 16 °C elsewhere (Maravelias *et al*., 2007). In the Heraklion Gulf, fish size increases with depth; the smaller ones prefer shallow and relatively warmer waters (Machias and Labropoulou, 2002). On the western shores of the Mediterranean, Lombarte *et al*. (2000) find that the bathymetric distribution of this species is limited and does not go beyond 200 m. It is more abundant between 51 and 200 m on mudflats (785 ind·km^{-2}), especially in sites characterized by a large continental shelf (mouth of the Ebro and Segura). This preference is more pronounced among juveniles and coincides with the distribution of their colonization areas defined by García-Rubies and Macpherson (1995). In the Gulf of Lion, this species does not exceed –200 m, but in Corsica it reaches –400 m (Campillo, 1992). In the Ionian Sea, Mytilineou *et al*. (2005) report red mullet up to 328 m. In the Aegean Sea, it is fished between 0 and 500 m, but is three to five times more abundant in the 0–100 m zone than between 200 and 500 m (Tserpes *et al*., 1999). However, Planas and Vives (1956) as well as Suau and Vives (1957) observe a higher proportion of red mullets at greater depths. Fiorentino *et al*. (2008) showed the influence of the 14-year trawling ban on increasing the mean size of mature *M. barbatus* females as a function of depth in the Gulf of Castellammare. According to García-Rodriguez *et al*. (2010), the depth itself does not affect the biomass distribution of this species, which seems to be more influenced by salinity, and to a lesser extent by water temperature. Golani (1994) studied the distribution of the two native species, *M. barbatus* and *M. surmuletus*, and two Lessepsian colonizers (*U. moluccensis* and *U. pori*) along the Mediterranean coasts of Israel. Bathymetry has been shown to be the parameter that most influences the separation of species from their respective feeding habits or spawning seasons. In fact, the colonizers occupy the shallow depths, 20–30 m for *U. pori* and 40–50 m for *U. moluccensis*; the native *M. barbatus* is dominant at depths less than 55 m and *M. surmuletus* is poorly represented at all depths.

Migrations and movement: Suau and Vives (1957) schematized the movements made by a mullet during its life. According to these authors, spawning occurs between May and July in the western Mediterranean and occurs at depths between 80 and 120 m. Eggs and larvae transported by surface currents are brought to the coast. Small red mullet (33.2–44.6 mm on average) are present between late July and early September between two isobaths (60 and 40 m). They follow their progression toward the coast (40–20 m), while acquiring the morphology of an adult. Their color changes from bluish during the pelagic stage to reddish, typical of the species. Fry live in open water and become benthic only above 5 cm in size. They reach the coast in September–October, where they finish this first trip and begin their return to initial depths, between 80 and 120 m, at a size of 6–7 cm (Larraneta and Rodriguez-Roda, 1956).

Size, lifespan and growth: Depending on the locality, the maximum age of red mullet varies between 3 years (FL = 15.38 cm, TW 57.66 g) in the Bay of Izmir (Kinacigil *et al*., 2001) and 7 years (around 21 cm) in females in Montenegro (Joksimović *et al*., 2008) and 7 years in Marseille (Campillo, 1992).

Many authors recognize the difficulty of determining the age of *M. barbatus* from scales and otoliths (Larraneta and Rodriguez-Roda, 1956; Gharbi and Ktari, 1981b) and often use indirect methods of cohort separation (Suau and Vives, 1957; Layachi *et al*., 2007; Joksimović *et al*., 2008). Indeed, due to the effect of trawling, caught red mullet are usually free of scales. As for otoliths, they pose the problem of false annual rings that probably correspond to migratory events that characterize the lifecycle of this species, as demonstrated by Larraneta and Rodriguez-Roda (1956).

Moreover, Haidar (1970) estimates that the small sizes (about 9 cm at 2 years and 15.5 cm at 4 years) given by Wirszubski (1953) in Israel are the result of a misinterpretation of stunted growth rings (annuli). On Catalan coasts, by the back-calculation of sizes using growth rings on scales from the end of growth, Larraneta and Rodriguez-Roda (1956) indicate that males measure between 11 and 11.5 cm at 1 year and 13.4 cm at 2 years, and females measure between 12–12.5 cm at 1 year and 14.4 cm at 2 years. On Tunisian coasts, the lengths observed, determined by scalimetry, reach 15.42 cm in 4-year-old males (maximum age) and 17.98 cm in 5-year-old females (Gharbi and Ktari, 1981b). Growth parameters according to the von Bertalanffy model, obtained in different regions, are presented in Table 1.1.

Some equations for length–weight relationship are given in Table 1.2. Bougis (1952a, 1952b) found growth isometry (b = 3.24) in adults in the Gulf of Lion. Haidar (1970) shows that beyond 16 cm, the allometry is greater (b = 3.26).

Sites and authors	Sex	L_∞ (cm)	K	to
Adriatic Sea (Scaccini, 1947)	M + F	27.49	0.50	–0.25
Tunisian coasts (Gharbi and Ktari, 1979)	*M	18.09	0.49	–0.17
	*F	20.46	0.50	–0.04
	*M + F	20.25	0.51	–0.01
Saranikos Bay, Aegean Sea (Papaconstantinou *et al*., 1981)	M	19.23	0.19	–2.81
	F	24.00	0.13	–2.94
Thermaikos Bay, Aegean Sea (Papaconstantinou *et al*., 1981)	M	20.91	0.13	–4.25
	F	27.54	0.09	–4.30

Catalonia (Sanchez *et al*., 1983)	M + F	29.70	0.09	–4.42
Gulf of Patraikos (Papaconstantinou *et al*., 1986)	M + F	23.31	0.04	–
Gulf of Korinthiakos (Papaconstantinou *et al*., 1986)	M + F	21.49	0.03	–
Ionian Sea (Papaconstantinou *et al*., 1986)	M + F	22.85	0.04	–
Adriatic Sea (Jukić and Piccinetti, 1988)	M + F	27.00	1.80	–
Saronikos Bay, Aegean Sea (Vrantzas *et al*., 1992)	M + F	23.50	0.51	–0.86
Gulf of Lion (Campillo, 1992)	M	22.5	0.56	–0.24
	F	24.5	0.60	–0.20
Aegean Sea (Vassilopoulou and Papaconstantinou, 1992)	M	22.71	0.21	–2.13
	F	25.49	0.21	–1.85
Adriatic Sea (Ungaro *et al*., 1994)	M + F	19.70	0.36	–1.18
Ionian Sea (Tursi *et al*., 1994)	M	22.4	0.28	–1.98
	F	24.5	0.27	–1.85
Livorno, Ligurian Sea (Voliani *et al*., 1995)	M	22.00	0.74	–
	F	29.20	0.68	–
Catalonia (Sanchez *et al*., 1995)	M + F	33.00	0.38	–0.07
Adriatic Sea (Marano, 1996)	M	27.00	0.18	–1.92
	F	34.50	0.15	–1.53
	M + F	31.50	0.18	–1.45
Santo Stefano, Ligurian Sea (Demestre *et al*., 1997)	M + F	34.50	0.34	–0.14
Adriatic Sea (Ardizzone, 1998)	M + F	27.50	0.50	–
Izmir Bay, Aegean Sea (Kinacigil *et al*., 2001)	**M + F	19.03	0.43	–0.77
Izmir Bay, Aegean Sea (Özbilgin *et al*., 2004)	M + F	24.26	0.56	–0.30
Nador Coast, Morocco (Layachi *et al*., 2007)	M + F	27.00	0.43	–0.09
Southern Adriatic (Joksimović *et al*., 2008)	M	17.81	0.28	–3.01
	F	27.47	0.14	–2.68
	M + F	30.12	0.11	–3.18

Table 1.1. *Growth parameters of the von Bertalanffy model in* Mullus barbatus barbatus *in different regions of the Mediterranean: *standard length; **length at the fork*

Sites and authors	Sex	a	b
Adriatic Sea (Zupanović, 1963)	M F	0.00655 0.00847	3.17 3.08
Eastern Adriatic (Haidar, 1970)	M + F (small) M + F (large)	0.0088 0.0051	3.05 3.26
Tunisian coasts (Gharbi and Ktari, 1979)	*M *F	– –	3.34 (3.25**) 3.11 (3.04**)
Gulf of Lion, France (Campillo, 1992)	M F	0.0074 0.01	3.14 3.05
Gulf of Korinthiakos, Greece (Papaconstantinou *et al.*, 1986)	M + F	0.000006	3.12
Gulf of Korinthiakos, Greece (Papaconstantinou *et al.*, 1986)	M + F	0.000004	3.16
Ionian Sea (Papaconstantinou *et al.*, 1986)	M + F	0.000012	3.00
Aegean Sea (Vassilopoulou and Papaconstantinou, 1992)	M + F	0.000006	3.17
Adriatic Sea (Ungaro *et al.*, 1994)	M + F	0.008	3.09
Adriatic Sea (Marano, 1996)	M + F	0.0125	2.97
Livorno, Ligurian Sea (Voliani *et al.*, 1998)	M F	0.000007 –	3.13 3.14
Izmir Bay, Aegean Sea (Kinacigil *et al.*, 2001)	***M + F	0.0071	3.29
Nador Coast, Morocco (Layachi *et al.*, 2007)	M + F	0.000009	3.03
Gulf of Tunisia (Cherif *et al.*, 2007)	M F M + F	0.0055 (0.0054**) 0.0069 (0.0059**) 0.0072 (0.0066**)	3.21 (3.19**) 3.12 (3.12**) 3.10 (3.09**)
South Adriatic (Joksimović *et al.*, 2008)	M F M + F	0.00773 0.00729 0.00767	3.09 3.11 3.10
Homa Lagoon, Turkey (Acarli *et al.*, 2014)	M + F	0.0060	3.180

Table 1.2. *Length–weight relationships ($W = aLt^b$) of* M. barbatus barbatus *in different localities in the Mediterranean: *standard length; **eviscerated weight; ***length at the fork*

Population structure and dynamics: Using data from four consecutive years, analyzed separately, Suau and Vives (1957) always find an overall sex ratio in favor of males in the north-western Mediterranean. Of the 3,966 individuals caught between the Ebro and the south of the Columbretes Islands, 53% were males, 34.2% were females and 12.8% were undetermined (Planas and Vives, 1956). On the coast of Castellón, males are numerically dominant in small sizes (up to 80% between 8 and 14 cm), females dominate at 16 cm and become exclusive beyond 19 cm (Larraneta and Rodriguez-Roda, 1956). On the other hand, in the Adriatic, females are more numerous (60.85%) (Scaccini, 1947); the same is true in the Gulf of Tunis (68%) where they dominate every month and in all size classes (Chérif *et al*., 2007) and on the Coast of Morocco, off Nador (Layachi *et al*., 2007). The difference in sampling depths may explain this discrepancy, since it is proven that males are more numerous in deeper waters.

Tserpes *et al*. (2002) conducted annual trawling surveys covering a large part of the Mediterranean (1,000 sampling points in 15 major regions) from 10 to 800 m annually from 1994 to 2000. They found spatial variations in the abundance of *M. barbatus* and attribute it to the different modes of exploitation, as well as to the biotic and abiotic conditions of each site. Although the species is under strong fishing pressure, abundance indices do not show a downward trend, suggesting good recruitment. However, the dominance of young fish makes the stock highly vulnerable to fluctuations in recruitment. The size frequency distribution by region is shown in Figure 1.8.

In the western Mediterranean, this distribution is generally unimodal and positively asymmetrical, with the exception of the Alboran Sea where three components are identified. In the eastern Mediterranean, this profile is more complex with two modal classes. The first mode corresponds to the juveniles of the year (recruits), the second corresponds to the relatively older individuals. The highest percentage of recruits is recorded in the southern Aegean, followed by the western Ionian and the southern Adriatic Sea. A remarkable profile characterizes the distribution of the northern Adriatic where two modes of the same amplitude are observed at 9 and 12 cm, respectively. Maximum lengths range from 15 (southern Aegean) to 27 cm (Sicily and southern Tyrrhenian Sea) and are generally higher in the western Mediterranean. In most cases, these values range from 20 to 24 and from 18 to 22 cm in the west and east of the Mediterranean, respectively.

Predators: Morat (2007) found, in 2006 and 2007, the remains of an individual of *M. barbatus* in the pellets of the European shag *Phalacrocorax aristotelis desmarestii* of the Riou archipelago (France), with frequencies of occurrence of 2% and 4%.

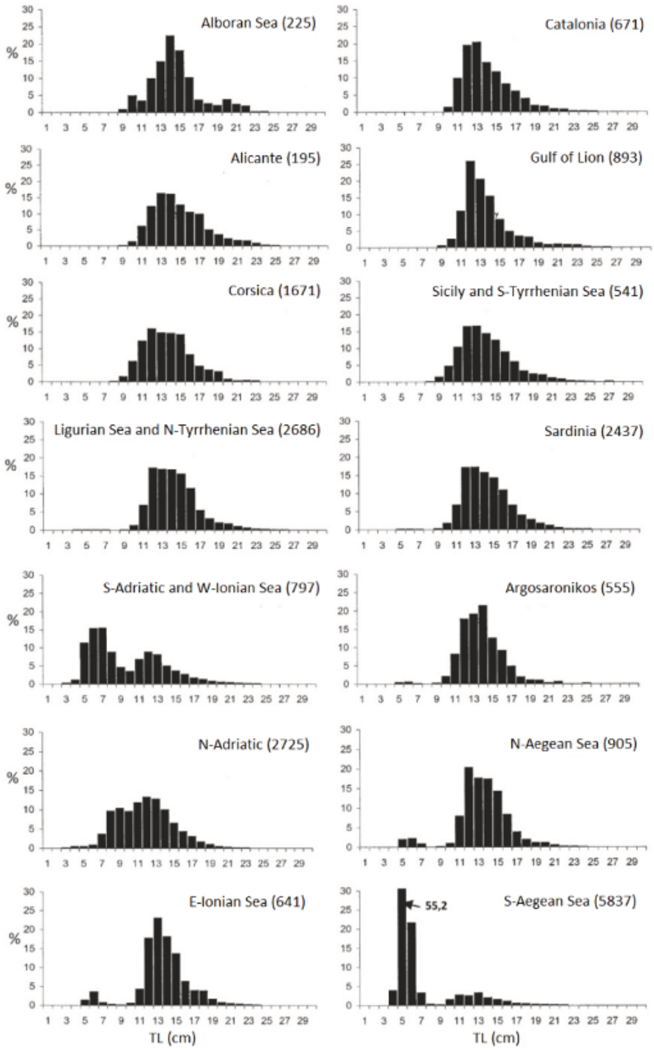


Figure 1.8. *Length frequency distribution (TL in cm) of* M. barbatus *in different areas of the Mediterranean. Numbers in parentheses indicate the average relative abundance over the sampled period, expressed as number of individuals per km*^{2} *(Tserpes* et al.*, 2002)*

1.1.1.5. *Food and feeding behavior*

Food and feeding behavior: *Mullus barbatus* is carnivorous and feeds mainly on benthic prey. Its food niche is separated from that of the congenic and sympatric species *M. surmuletus*. Their prey is different, but of the same size, allowing a good distribution of available food resources (Labropoulou and Eleftheriou, 1997). These dietary differences are related to morphological differences: for *M. barbatus,* the length of the digestive tract is greater and the height and width of the head are less than in *M. surmuletus* (Labropoulou and Eleftheriou, 1997). According to Aguirre and Sánchez (2005), these two species feed from a broad and identical prey spectrum, but the proportions are significantly different depending on the predator ontogeny, and therefore their size. According to their similarity, these are divided into six size groups:

1) the oldest adults of *M. surmuletu*s (21–31 cm TL);

2) newly recruited individuals of both species (6–8 cm TL);

3) the oldest adults of *M. barbatus* (19–21 cm TL);

4) adults of *M. barbatus* (12–18 cm TL);

5) juveniles of both species;

6) adults of *M. surmuletus* (12–20, 22 cm TL).

Similar results regarding these interspecific and ontogenetic differences were obtained by Vassilopoulou *et al*. (2001) and Bautista-Vega *et al*. (2008).

In the western Mediterranean, between the Ebro and to the south of the Columbretes Islands, 2-year-old adults prefer macrourous decapods and their larvae, followed by polychaete annelids, lamellibranch mollusks and isopods (Planas and Vives, 1956). In the Gulf of Tunis, crustaceans are the preferred prey (Fp = 77.02), whereas lamellibranch mollusks (Fp = 31.06), echinoderms (Fp = 17.39) and polychaete annelids (Fp = 15.53) are secondary prey (Gharbi and Ktari, 1979), which is confirmed by Chérif *et al*. (2011) on the northern coasts of Tunisia. In the south of the Tyrrhenian Sea, crustaceans (including gammarids) also dominate, while mollusks and polychaetes are secondary (Esposito *et al*., 2014). On the Mediterranean coasts of Morocco, their diet consists mainly of amphipods, annelids and bivalves (Layachi *et al*., 2007). In the eastern Mediterranean, polychaete annelids dominate. They represent 62.04% of the number and 51.17% of the weight of the prey ingested in Heraklion Bay (Labropoulou and Eleftheriou, 1997) and dominate in the Gulf of Amvrakikos, Greece (Vassilopoulou and Papacanstantinou, 1993), but only in large individuals (TL > 18 cm) (40.2% of weight) in the Gulf of Lion (Bautista-Vega *et al*., 2008). Caragitsou and Tsimenides (1982) found that in the Aegean Sea, the diet of individuals from 10 to 19 cm is composed mainly of mollusks and crustaceans. In this same region, according to Vassilopoulou *et al*. (2001), crustaceans, polychaetes and bivalve mollusks are the main categories of prey.

Feeding habits: Gosline (1984) suggests that the cephalic profile is an adaptation of the muscle involved in increasing the strength of the water jet used to agitate the seabed in search of prey. The use of sounds emitted by the fish could also aid their search. A form of commensalism occurs when other fish are attracted by bottom mud excavations, taking advantage of unearthed prey.

Dietary variations: On the northwestern shores of the Mediterranean, Sabatés *et al*. (2015) showed that during the oligotrophic summer season, the vertical and horizontal distribution of *M. barbatus* larvae (>8 mm standard length) corresponds to that of marine cladocerans, *Evadne* and *Penilia avirostris*. Larger sized larvae mainly consume nauplii copepods. On the North African coast, the diet does not vary with the season, size or sex of the fish (Gharbi and Ktari, 1979; Layachi *et al*., 2007). In the Gulf of Lion, small crustaceans are less frequently consumed by large individuals in favor of polychaete annelids and shrimp (Bautista-Vega *et al*., 2008). Variations, in terms of both prey diversity and size, is evident in the Gulf of Heraklion (Machias and Labropoulou, 2002). Small crustaceans and crabs are more common in small individuals, while the decapods *Alpheus glaber* and *Solenocera membranacea* dominate in the largest individuals.

In the south of the Tyrrhenian Sea, the diet composition varies with depth (surf zone, 10, 20, 30 m) in relation to the availability of benthic prey. Mysids are consumed mainly in the surf zone, whereas gammarids, decapods and copepods are the main prey in the other depths (Esposito *et al*., 2014).

Feeding rate decreases during the spawning season (April to July), as is the case on the Mediterranean coasts of Morocco (Figure 1.9) (Layachi *et al*., 2007).

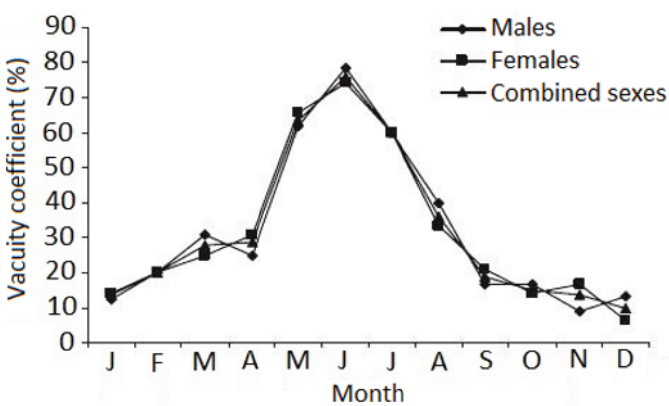


Figure 1.9. *Monthly variations in the stomach vacuity coefficient in* Mullus barbatus *from the north-east Mediterranean coast of Morocco (Layachi* et al.*, 2007)*

Jukic and Zupanovic (1965) note that the amount of food ingested is related to the temperature of the surrounding environment. This value is higher at summer temperatures (18.6–22.8 °C) and lower at winter temperatures (11.9–14.6 °C). Esposito *et al*. (2014) show that in the surf zone, their diet is composed of mysids and bivalves in summer and of cumaceans, gammarids and polychaetes in winter. At lower depths (10, 20, 30 m), seasonal variations in diet composition reflect fluctuations in gammarid abundance, confirming the opportunistic nature of *M. barbatus*. At daytime, in Hisarönü Bay (Turkey), the feeding activity of *M. barbatus* starts at dawn and peaks at noon. From midday until early evening, feeding intensity slows down and then increases slightly at sunset, before stopping almost entirely beyond that (Ünluoglu *et al*., 2002). However, the relative number of predominantly ingested prey (polychaetes, decapods, bivalves, amphipods) does not show a significant daily variation.

1.1.1.6. *Reproduction and reproductive behavior*

Sexuality: Gonochoric species.

First sexual maturity: In general, at first sexual maturity, females are larger in size than males: 13.5 cm versus 11.5 cm (Bougis, 1952a, 1952b) and 13 cm versus 12.5 cm (Campillo, 1992) in the south of France, 10.4 cm versus 9.4 cm in the Aegean Sea (Vassilopoulou and Papaconstantinou, 1992), 12.0 cm versus 10.0 cm in the Gulfs of Saronikos and Thermaikos (Papaconstantinou *et al*., 1981), 12.2 cm versus 10.1 cm in the Southern Adriatic (Carbonara *et al*., 2015). On the Tunisian coasts, adult females measure 16.0 cm (2 years) and males 14.0 cm (1 year) (Gharbi and Ktari, 1981a), but in the same zone (Gulf of Tunisia), according to Chérif *et al.* (2007), females and males reach their first maturity at the same size (13.9 cm). This size is, irrespective of sex, 9.3 cm on the Italian coasts (Voliani *et al*., 1998), 12.8 in the Gulf of Saroniko, Greece (Vrantzas *et al*., 1992) and 9 cm in Cyprus (Livadas 1988). In Izmir Bay, 1-year-old red mullet are all adults (Togulga, 1979). On Israel's Mediterranean coast, Wirszubski (1953) estimated the age of first maturity of females to be 3 years.

Spawning site and period: On Israeli coasts, spawning is reported at depths between 10 and 55 m, at temperatures of 16.5–18.5 °C, on muddy and silty sea bed (Wirszubski, 1953). Levi *et al*. (2003) found a relatively higher abundance of spawners, both at 50 m and over 200 m in two different locations in the Strait of Sicily. In the Gulf of Heraklion, abundance and biomass are relatively high in spring in waters of intermediate depths (71–150 m); this is related to the spawning season when fish travel from the coast to deep offshore waters (Machias and Labropoulou, 2002). In the central-eastern Mediterranean, Carlucci *et al*. (2009) highlight the presence of *M. barbatus* nurseries in the southern Adriatic (off the Gargano peninsula and between Molfetta and Monopoli) at a depth of 50 m.

Spawning generally occurs between April and August (Figure 1.10), with significantly higher gonadosomatic index (GSI) values in females (10% on average) than in males (less than 2% on average) (Carbonara *et al.*, 2015). It lasts from 2 to 4 months and presents some regional differences (Table 1.3).

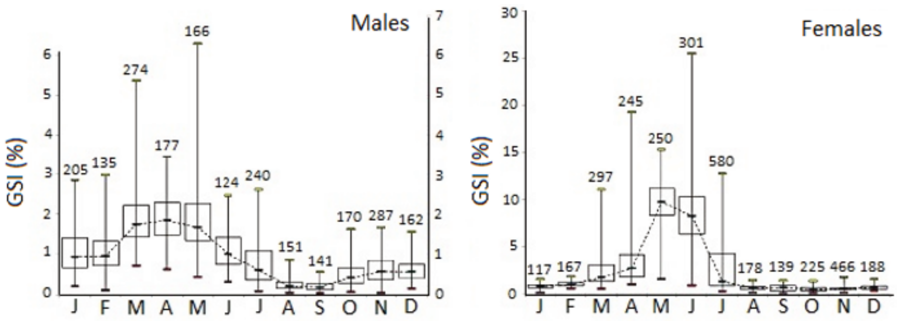


Figure 1.10. *Box plot of the monthly GSI values of* M. barbatus *females and males in the southern Adriatic. The bars indicate the low and high GSI values and the numbers above indicate the number of specimens used in the analysis (Carbonara* et al.*, 2015)*

Sites and authors	J	F	M	A	M	J	J	A	S	O	N	D
Gulf of Lion (Bougis, 1952)					■	■	■					
Israeli Coast (Wirszubski, 1953)				■	■	■	■					
Coast of Castellón (Larraneta and Rodriguez-Roda, 1956)					■	■						
Ebro-Columbretes Islands (Planas and Vives, 1956)					■	■	■					
Gulf of Iskenderun (Akyuz, 1957)				■	■	■	■					
Eastern Adriatic (Haidar, 1970)				■	■	■	■					
Algerian coasts (Lalami, 1971)				■	■	■						
Egyptian coasts (Hashem, 1973b)				■	■	■						
Tunisian coasts (Gharbi et Ktari, 1981)					■	■	■					
Gulf of Lion (Campillo, 1992)					■	■	■	■				
Ionian Sea (Tursi *et al.*, 1994)					■	■						
Nador lagoon (Layachi *et al.*, 2007)				■	■	■	■	■				
Gulf of Tunis (Cherif *et al.*, 2007)				■	■	■	■					
Northwest Mediterranean (Ferrer-Maza *et al.*, 2015)					■	■	■	■				
Southern Adriatic (Carbonara *et al.*, 2015)				■	■	■	■					

Table 1.3. *Spawning season of* M. barbatus barbatus *in the Mediterranean*

Spawning is fractionated as shown by the frequency distribution profile of oocyte diameter given by different authors (Ferrer-Maza *et al*., 2015; Carbonara *et al*., 2015).

Fecundity: For individuals between 9.4 and 22 cm in size, fished north of the Aegean Sea, Tirasin *et al*. (2007) give an average absolute fertility of 7,030 (summer 1991) and 7,960 oocytes (spring 1992). To the north-west and north-east of the Levantine Sea, they obtain 11,180 and 13,000 eggs, respectively. In all cases, absolute fecundity is positively correlated with fork length. For all the regions studied, the relative fertility is between 128 and 216 eggs/g per female. Layachi *et al*. (2007) estimated the average absolute fecundity of red mullet from Nador (Morocco) to be 36,665 ± 19,773 eggs and the relative fecundity to be 513 ± 226 eggs/g per female. On Spanish Mediterranean coasts, Ferrer-Maza *et al*. (2015) found that fertility by spawning is between 2,408 and 43,736 oocytes (18,163 ± 9,778). It is positively correlated with female size ($F = 0.33.TL^{3.627}$; $r^2 = 0.75$; n = 89) and their eviscerated mass ($F = 272.3. Me - 2554.9$; $r^2 = 0.76$; n = 89). Relative fertility by spawning is between 61 and 371 oocytes per gram of eviscerated weight. These authors also show that the most abundant helminth parasites with the highest prevalence (*Opecoeloides furcatus* and *Hysterothylacium* spp.) affect the condition of fish and their reproduction during the spawning season. The former causes a decrease in energy reserves, and the latter weakens the quality of eggs laid. There is a positive correlation between total length and fecundity by spawning for the red mullet in the southern Adriatic ($F = 0.9993.e^{0.384.}$ TL, n = 100, $r^2 = 0.6264$), which is higher in May than in June (Carbonara *et al*., 2015). The diameter of the oocytes and their lipid globule, as well as the amount of plasma vitellogenin, are also positively correlated with female size (Carbonara *et al*., 2015).

Reproductive behavior: Thresher (1984) describes the spawning behavior: males and females swim from the bottom toward the surface where they release their gametes. Spawning is nocturnal.

Eggs, larvae and ontogenesis: Raffaele (1888) indicates that there are fewer eggs and fry of *M. barbatus* than those of *M. surmuletus*. Montalenti (1937), based on Lo Bianco (1909, pl. II), gives a description and figures of the larvae and fry of *M. barbatus* measuring 4.5–45 mm; their eggs have a single oil globule. Marinaro (1971) describes eggs as pelagic, spherical, “vesicular” yolk; in the larvae, the oil globule protrudes from the anterior part of the yolk. This author found that on comparing the eggs of the two species, *M. b. barbatus* and *M. surmuletus*, in the Bay of Algiers, the eggs of *M. b. barbatus* are significantly smaller than those of *M. surmuletus* (Raffaele 1888). In both cases, egg size decreases during the spawning season (Figure 1.11).

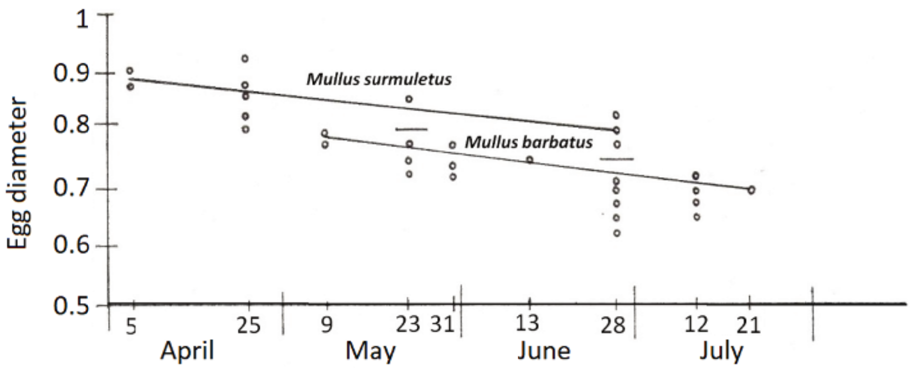


Figure 1.11. *Measurements and seasonal distribution of M. barbatus and M. surmuletus eggs in the Bay of Algiers (Marinaro, 1971)*

Metric characteristics of *M. barbatus barbatus* eggs in different regions of the Mediterranean are presented in Table 1.4.

Sites and authors	Egg diameter (mm)	Globule diameter (mm)	Spawning season
Marseille (Holt, 1899)	0.68–0.75	0.17–0.21	June–July
Israel (Wirszubski, 1953)	0.965	0.200–0.233	–
Chioggia (Varagnolo, 1964)	0.65	0.20	May–June
Algiers (Marinaro, 1971)	0.63–0.80	0.16–0.21	May–July

Table 1.4. *Metric characteristics of* M. barbatus barbatus *eggs in different regions of the Mediterranean*

1.1.1.7. *Economic importance*

Fishing is semi-industrial, artisanal and recreational. Trawling is the main method used, among others, including seine-haul fishing, gillnetting, fyke net fishing, hand line fishing and underwater fishing. Trammel nets mainly contribute to catching larger individuals, while trawling targets smaller individuals and newly recruited individuals (Martin *et al*., 1999).

Red mullet is regularly present in Mediterranean markets and occasionally in the Black Sea. It is sold fresh, chilled, frozen and salted (Fischer *et al*., 1987).

According to FAO data, all its production comes from the Mediterranean, increasing from 3,994 to 15,618 tons between 1985 and 2007. Until 2004, Turkey and Tunisia were the main producers; subsequently, Italy became the largest supplier with around 9,000 tons/year. In 2007, the main producing countries were Italy (9,463 tons), Tunisia (2,807 tons) and Turkey (2,390 tons). These three countries alone account for 93.8% of the Mediterranean produce.

Overall, *M. barbarus* is overfished in the Mediterranean, and in many areas juveniles make up the largest proportion of catches: Gulf of Gabes (Gharbi *et al*., 2004), Aegean Sea (Vassilopoulou and Papaconstantinou, 1991), Izmir Bay (Özbilgin *et al*., 2004), Gulf of Saronikos in the Aegean Sea (Napoléon *et al*., 1991), Ionian Sea (Tursi *et al*., 1994, 1996) and north-west Mediterranean (Demestre *et al*., 1997).

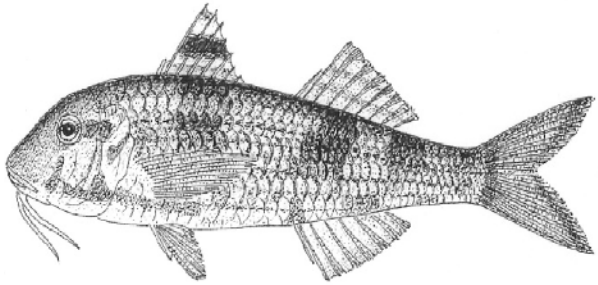
1.1.1.8. *Protection status, conservation*

According to the latest report of the European Union, dated December 21, 2006, the capture of any individual under 11 cm is prohibited, regardless of the technique used.

– Global IUCN Red List: NE.

– Mediterranean IUCN Red List: LC.

1.1.2. Mullus surmuletus *Linnæus, 1758*



1.1.2.1. *Nomenclature and classification*

Type: *Mullus surmuletus* Linnæus, 1758, Syst. Nat. Edit. X: 30 (in *M. Mediterraneo et ad Cornubiam*).

Synonym: *Mullus barbatus surmuletus* Day, 1880.

Vernacular names[1]: *Rouget* (DZ), *salmonete de roca* (ES), *rouget barbet de roche*, *surmulet* (FR), surmullet (GB), *barbouni* (GR), *mulit happassim* (IS), *triglia di scoglio* (IT), *trilja tal-qawwi* (MT), *trilia hamra*, *mallou* (TN), *tekir* (TR).

Etymology: From the Latin *mulleus* (reddish, reference to the color of the animal); *surmuletus*, from *sur* (superior to) and *mullus*, *muletus* (name of the red mullet fish).

1.1.2.2. *Description*

Morpho-anatomy: The surmullet has a fairly compressed body, a convex dorsal head and a slanted snout. Under the chin, there is a pair of barbs that are longer than the pectoral fins. The operculum is spineless. The mouth is small with a maxilla not exceeding the anterior edge of the eye. Small villiform teeth are present on the lower jaw. The upper jaw is edentulous, but teeth are present on the oral vault (vomer bone and palatine plates). The first dorsal fin is colored with contrasting bands, and seven or eight spines, the first of which is very small. The second fin has one spine and seven or eight soft rays; the anal fin has two spines and six or seven soft rays. The caudal fin has no streaks. The scales are large and slightly adherent, 33–37 on the lateral line, two on the suborbital. Maximum length is 40 cm; 25–30 cm is the average size. In the Gulf of Lion, the maximum size is 33 cm, with one exception at 38 cm (Campillo, 1992).

Coloring: The coloring is reddish, usually with a dark red longitudinal band from the eye to the caudal fin and three yellowish lines along the flanks. The color varies with age and the surrounding environment, as well as with depth and stress responses. On sandy bottoms, they are paler with a reddish-brown longitudinal line. On rocky surroundings, they are darker in color and often more mottled. The dominant red is reinforced with depth (visible only with a lamp). Tokaç *et al*. (2013) point out abnormal pigmentation in an individual 16.4 cm SL captured in Izmir Bay (Turkey).

Variations: Sabatini *et al*. (2007) studied the spinal morphology of Sardinian surmullets. Although the total number of vertebrae is constant (24), there is a difference in the number of abdominal and intermediate vertebrae with 7 + 3 in 39% and 6 + 4 in 61% in individuals studied, respectively. These differences are not influenced by size or sex, but instead are due to differences in environmental conditions affecting the early stages of ontogenesis.

1 Abbreviations: (DZ) Algeria, (EG) Egypt, (ES) Spain, (FR) France, (GB) Great-Britain, (IS) Israel, (IT) Italy, (MA) Morocco, (MT) Malta, (TN) Tunisia, (TR) Turkey.

Sexual dimorphism: The data provided by Desbrosses (1936) for the North Atlantic may be transposable to individuals in the Mediterranean. This author indicates that at a size greater than 17 cm, the female is distinguished by a more elongated muzzle in relation to the size (TL) and especially to eye diameter, and by the position of its odd fins, which are slightly further back. Males have a short muzzle and relatively bulky eyes, reminiscent of the red mullet. The interorbital space is, on average, less than the eye diameter. Fin rays, scales and vertebrae are similar in both sexes, but the variability is lower in males with less plasticity than females (Desbrosses, 1936). However, in practice, it is only possible to distinguish between sexes during the spawning season, when the female is recognized by her extended abdomen.

Osteology, otoliths and scales: Sagittal otolith data are provided by Koken (1884), Sanz Echeverria (1926, 1936) and Chaine (1938). More recently, for West-Mediterranean and East-Atlantic otoliths, Tuset *et al*. (2008) give a very detailed description, including the following characteristics: oval overall shape with crenellated irregular edges (Figure 1.12); otolith length/total length of fish = 1.4–2.0; otolith width/otolith length = 69.5–75.4; circularity = 14.0–19.3; rectangularity = 0.1–0.2.

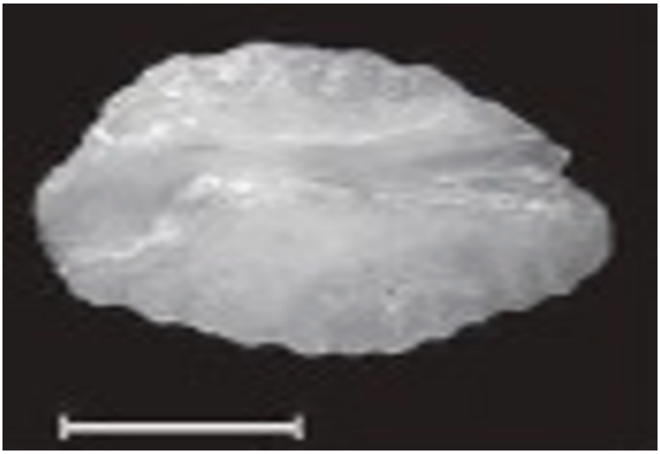


Figure 1.12. *Sagittal otolith of an individual (12.3 cm TL) of* M. surmuletus *from the Western Mediterranean, scale 1 mm (Tuset* et al.*, 2008)*

From north-western Mediterranean samples, Aguirre and Lombarte (1999) expressed the relationship between the otolith surface area (O) and the total fish length

(TL) by the equation O = 0.0159 $TL^{1.1147}$ (r^2 = 0.9750, n = 91). They also give the relationship between the surface of the sulcus acusticus (S) and the total length of the fish by the equation S = 0.0020 $TL^{1.2640}$ (r^2 = 0.9245, n = 82). The S:O ratio changes during development (t = –2.1692, P = 0.0329) increasing with the length of fish. Morat *et al*. (2008) describe the relationship between the total length (mm) and length of sagittal otoliths (mm) of *M. surmuletus* using the following regression equations for individuals in the north-western Mediterranean and the Aegean, respectively: TL = 82.33 Lo – 57.87 (79–300 mm, r = 0.870, $P < 0.0001$), TL = 79.30 Lo – 48.25 (110–205 mm, r = 0.873, $P < 0.0001$). *Mullus surmuletus*, like all mullet, has ctenoid scales (Figure 1.13) (Morales-Nin and Fauquet, 1983).

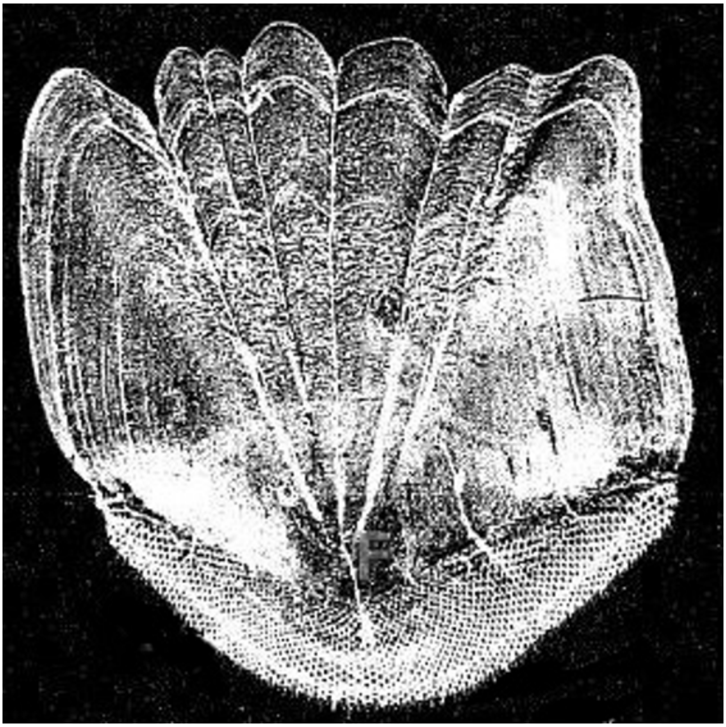


Figure 1.13. *Ctenoid scale of* M. surmuletus *(Morales-Nin and Fauquet, 1983)*

The anterior field, deeply embedded in the dermis, has circulii separated by about 11 µm. Under a scanning electron microscope, small protrusions in groups of three to five can be seen on their upper part. Circulii are regularly separated by radii. The number of radii depends on the size and age of the fish. There are between 4 and 6 radii, fewer than in *M. barbatus*, with 4 being most common. The posterior field is composed of two parts: a large central part known as the lunula and a marginal fringe. The lunula is traversed by thin ridges and is devoid of denticles. The marginal fringe has spines, known as the ctenii. The scales of the lateral line have, in their central zone, a channel that traverses them longitudinally. The inner part has a wide opening. The channel splits in the posterior part of the shell into two which, in turn, divide into secondary channels, which open by four pores.

Karyology: The number of chromosomes in *M. surmuletus* is 2n = 44. They are arranged in 22 pairs. Four pairs are metacentric or submetacentric (1–4), eight are subtelocentric (5–12) and 10 are acrocentric (13–22) (Vitturi *et al*., 1992).

Protein specificity and genetic diversity: The protein specificity of this species is discussed in the equivalent section on *M. barbatus barbatus*. Using RAPD and allozyme markers, Mamuris *et al*. (1999b) sought to evaluate genetic polymorphism in *M. surmuletus* in six Mediterranean locations, five in Greece (three in the Aegean Sea: Trikeri, Kavala, Rhodes; two in the Ionian Sea: Preveza, Corfu) and one in France (Gulf of Lion). Both methods demonstrated a high level of genetic polymorphism, with mean Fst values of 0.053 and 0.035 ($P < 0.05$) and genetic distances of 0.018 and 0.011, respectively. In both cases, the sample from the Gulf of Lion differs from those of Greece. However, only RAPDs show that there is a correlation between genetic divergences and geographical distances (Mantel t-test, r = 0.72, $P < 0.01$). On the other hand, greater heterogeneity is found in the Aegean than in the Ionian Sea. Mamuris *et al.* (2001) used two other types of molecular markers on these same six samples (RFLP and mitochondrial DNA) and came to fairly similar conclusions. They highlight that the species is structured into three distinct clades, reflecting a certain degree of isolation by distance. Two samples from the Aegean Sea (Trikeri and Kavala) form one clade, while the two populations in the Ionian Sea (Preveza and Corfu) and the Gulf of Lion form another clade: the French sample is different to those from the Ionian Sea. The third clade contains only the population from Rhodes (Aegean Sea). Galarza *et al.* (2009) analyzed the variations in allelic frequencies at 10 microsatellite loci on samples of *M. surmuletus* from nine Mediterranean sites (Cabo de Gata, Herradura, Majorca, Blanes, Italy, Porticello, Syracuse, Greece and Turkey) and two Atlantic sites (Canary Islands and Conil). There is low heterogeneity in this species in the Mediterranean, as well as a low gene flow between the Mediterranean and the Atlantic. Using 10 microsatellite markers, Félix-Hackradt *et al.* (2013) found great spatial variability in mullet samples from 13 sites 400 km apart on the Spanish Mediterranean coast. The authors indicate that larval life history traits alone do not explain the dispersal abilities of this species and suggest other mechanisms play an important role, such as small-scale movements of adults or juveniles, which are not always recognized as promoters of population connectivity.

1.1.2.3. *Distribution*

Common in the Mediterranean and the Black Sea, *M. surmuletus* is also found in the Red Sea in the Gulf of Eilat (Ben Eliahu and Golani, 1990). It lives in the eastern Atlantic, from Scotland to Senegal and the Canary Islands. Its presence in Norway, Ireland, on the northern coast of England and west of Scotland, is less frequent (Pethon, 1979; Minchin and Molloy, 1980; Davis and Edward, 1988; Gibson and Robb, 1997; Beare *et al*., 2005) (Figure 1.14).

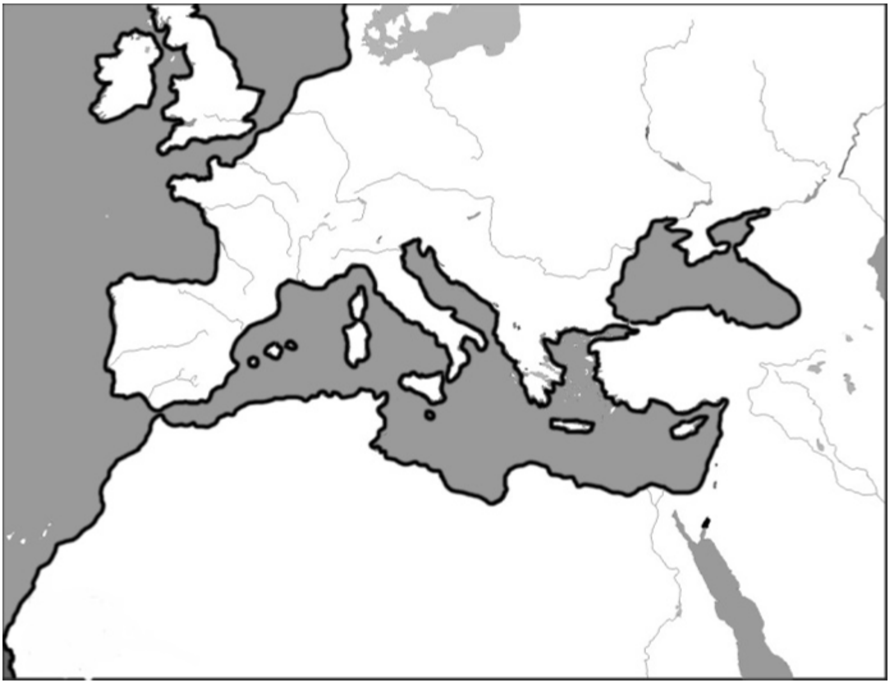


Figure 1.14. *Geographic distribution of* M. surmuletus

1.1.2.4. *Ecology*

Habitat: Its habitat is demersal and gregarious, and *M. surmuletus* is often found on loose substrates: sand, gravel, eelgrass beds or posidonia. However, it may venture close to rocks, seeking food with its two characteristic barbels. In the north-west Mediterranean (Medes Islands and along the coast between Estartit and Blanes), García-Rubies and MacPherson (1995) found red mullet juveniles (TL > 1.5 cm) mainly at the base of posidonia. Deudero (2002) showed that juveniles of *M. surmuletus* (2–6 cm) were attracted to light in the epipelagic waters of the continental shelf of Majorca. It should be noted that red mullet sometimes sleep in groups in seagrass beds and have a characteristic marbled hue.

On the Cretan coasts (Greece), *M. surmuletus* is frequently found at depths of –28 and –310 m, at temperatures between 13.6 and 23.8 °C (Machias *et al*., 1998). From 392 research trawls, conducted between 1994 and 1998 along the Spanish Mediterranean coast between 0 and 400 m, Lombarte *et al*. (2000) found that this species is more abundant on rough bottoms (gravel, sand) (116.14 ind·km^{-2}) than on loose muddy substrates (42.63 ind·km^{-2}).

Significant differences also exist depending on the depth of the rough substrate, with a maximum abundance near the coast, in shallow waters (146.46 ind·km^{-2}). A greater average size is also observed with increasing depth, especially on rough bottoms (10–50 m: 16.47 cm; 200–400 m: 26.25 cm). In addition, sea beds on a narrow continental shelf are more attractive to this species. Levi and Francour (2004) found a lower density of *M. surmuletus* on substrates colonized by the invasive alga *Caulerpa taxifolia*, limiting their access to benthic prey. A study conducted in the Gulf of Lion between 1983 and 1992 (Gaertner *et al*., 1999) shows that the bathymetric distribution of *M. surmuletus* varies. According to Hureau (1986), its presence is limited to depths less than 100 m, whereas MacPherson and Duarte (1991) find it to be between 12 and 182 m and even –409 m in the Ionian Sea (Mytilineou *et al*., 2005) and 500–800 m west of Sardinia (Tserpes *et al*., 2002). Zoubi (1994) rarely found it beyond 200 m in Morocco, with the smallest ones (6–17 cm TL) being more abundant between 0 and 100 m, the others (12–23 cm) beyond 100 m; this increase in size with depth is confirmed by Papaconstantinou *et al*. (1981). Off Majorca, the highest concentrations are observed between 30 and 70 m (Renones *et al*., 1995). Machias *et al*. (1998) studied for three consecutive years and during three seasons (summer, winter and fall), the abundance and the biomass of surmullet at different depths. They found that abundance and biomass are negatively correlated with depth during all seasons. The increase in relative abundance and biomass with depth indicates that fish, generally dominant in shallow waters, increase their presence in intermediate depths (stratum II, 71–150 m) during the spring. The authors suggest seasonal bathymetric movement in relation to recruitment. The relationship between mean total length and depth is significantly positive at all seasons ($0.645 \leq r \leq 0.833$, $P = 0.000$). Its relationship with temperature is significantly negative in summer ($r = -0.670$) and winter ($r = -0.601$), but not in spring ($r = -0.215$). Size distribution by depth indicates that individuals larger than 15.5 cm (size at first sexual maturity) are generally found in stratum II during summer and winter. The same is true for individuals over 16.5 cm in the spring.

Migrations and movement: One- to 2-month-old surmullets settle on the seabed at the end of June off the Mediterranean French coast (Bougis, 1952a, 1952b). They are 3.5–4 cm in size, but are still very elongated and have a coloring typical in open water: blue-green back and pearly white belly (Louisy, 2005). They reach 6–7 cm in August in Banyuls Bay (Bougis, 1952a, 1952b). In October, individuals approximately 4 months old were fished at depths between 0 and 40 m.

In the North Atlantic, the migration of red mullet to greater depths is not directly related to their age, but rather to their size (Desbrosses, 1935a). Due to their faster growth, females are more common than males at greater depths.

Ecological valence: Devauchelle (1980, 1983) has experimentally shown that the embryogenesis of red mullet may be affected by changes in environmental factors and degradation of water quality. Significant thermal shock (10–17 °C), short in duration (5–20 min), causes malformations of the spine, resulting in an increase in severity with increasing temperature. Chlorations at 1 ppm for 5–10 min or rapid and fleeting overpressures (2–5 bars) and depressions (0.3 bar) do not modify the eclosion rate. Eggs are more resistant to shock than the larvae.

Size, lifespan and growth: In Majorca, *M. surmuletus* reaches an age of 6 years (females of 31.6 cm TL and males of 23.0 cm TL) (Reñones *et al*., 1995). According to Quéro and Vayne (1997), the lifespan could be 11 years on the French Atlantic coast.

The age of red mullet can be determined on both scales and otoliths. Table 1.5 gives the growth parameters of the von Bertalanffy model and the length–weight relationship, obtained at different Mediterranean sites.

Compared to other fish species, *M. surmuletus* grows relatively slowly. At 3 years old, its average weight is 95 g (19.4 cm) in males and 135 g (21 cm) in females off the Tunisian coast (Gharbi and Ktari, 1981a); along the coasts of Provence in France: 145 g (22.5 cm) and 270 g (27 cm) (Bougis, 1952a, 1952b), where growth is the greatest. Male growth is always lower than that of females (Bougis, 1952a, 1952b; Gharbi and Ktari, 1981a; Renones *et al*., 1995).

Sites and authors	Sex	L_∞ (cm)	K (year^{-1})	t_0	Φ	a	b	Size interval (cm)
Tunisia (Gharbi and Ktari, 1981)	F	21.82	0.51	–0.112	2.3853	0.1403	3.351	?
	M	19.87	0.49	–0.025	2.2866	0.1443	3.283	
	F + M	21.51	0.50	–0.116	2.3643			
Tyrrhenian Sea (Andaloro, 1982)	F	30.12	0.24	–2.39	2.3379	–	–	4–28
	M	25.02	0.30	–2.68	2.2737	–	–	
	F + M	–	–	–	–	0.0067	3.2051	
Catalonia, Spain (Sánchez *et al.*, 1983)	F	–	–	–	–	0.027	2.84	5–26
	M	–	–	–	–	0.0069	3.19	
	F + M	32.52	0.1097	–3.6478	2.0632	0.0073	3.10	
Strait of Sicily (Andaloro and Giarritta, 1985)	F	29.75	0.49	–0.31	2.6370	–	–	9.8-26.7
	M	26.25	0.41	–0.25	2.4507	–	–	
	F + M	–	–	–	–	0.0093	3.070	
Majorca (Morales-Nin, 1991)	F	34.53	0.1365	–3.8210	2.2115	–	–	9.5–27
	M	23.29	0.2882	–3.3250	2.1940	–	–	
	F + M	29.76	0.2376	–2.64	2.3231	0.016003	2.91282	

Gulf of Lion, France (Campillo, 1992)	F	33.4	0.43	–0.60	–	–	–	?
	M	28.5	0.53	–0.44	–	–	–	–
	F + M	–	–	–	–	0.0182	3.00	–
Majorca (Reñones *et al.*, 1995)	F	31.90	0.205	–2.605	2.3192	0.00950	3.1090	10–32
	M	25.54	0.273	–2.450	2.2505	0.01045	3.0672	
	F + M	31.28	0.211	–2.348	2.3148	0.009101	3.12035	
Egypt (Mehanna, 2009)	F + M	31.74	0.47	–0.3	2.67	0.0104	3.0617	5–29.1
Izmir Bay, Turkey (Ilhan *et al.*, 2009)	F + M	27.85	0.193	–1.578	2.175	0.0083	3.127	6.6–22.6
Edremit Bay, Aegean Sea (Torcu-Koç *et al.*, 2015)	F + M	–	–	–	–	0.0042	3.36	7.7–17
Homa Lagoon, Turkey (Acarli *et al.*, 2014)	F + M	–	–	–	–	0.0040	3.372	4.7–10.2

Table 1.5. *Growth parameters of the von Bertalanffy model and size–weight relationship ($W = aL^b$) and growth performance index Φ of* Mullus surmuletus *in different regions of the Mediterranean*

Population structure and dynamics: In the Mediterranean, in Majorca, the majority of individuals under 13 cm are of indeterminate sex. Males are present in samples of 11–28 cm and predominate between 14 and 17 cm, while females are present between 12 and 32 cm and dominate in sizes larger than 19 cm (Figure 1.15) (Reñones *et al*., 1995).

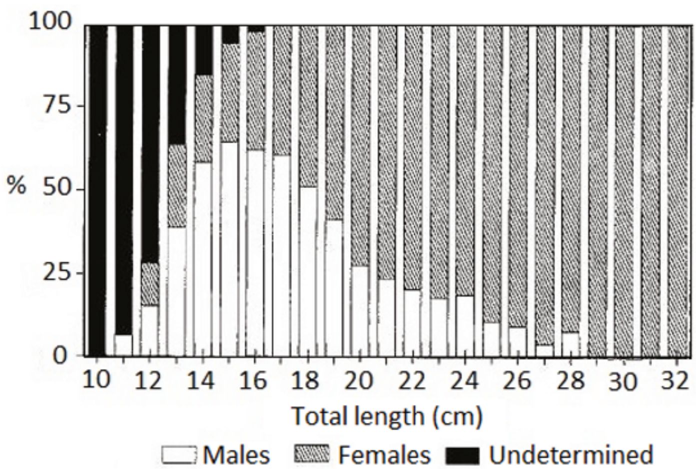


Figure 1.15. *Proportion of males, females and individuals of undetermined sexes in different size classes of* M. surmuletus *fished in Majorca between 1990 and 1992 (n = 3541) (Reñones* et al.*, 1995)*

In the Bay of Edremit in the Aegean Sea, the sex ratio is generally in favor of males with an average of 63.46% (Torcu-Koç *et al*., 2015).

Tserpes *et al*. (2002) conducted trawl surveys covering a large part of the Mediterranean (1,000 sampling points in 15 major regions) between 10 and 800 m annually from 1994 to 2000. Size frequency distribution by region is shown in Figure 1.16.

In the western Mediterranean, this distribution is polymodal. However, although the cohort of young recruits is clearly unique in the Ligurian Sea, north of the Tyrrhenian Sea and in Sardinia, only relatively older individuals are found. Similarly, in the eastern Mediterranean, the distribution is polymodal and young recruits are present in all regions except the northern Adriatic and northern Aegean. The maximum average length is greater in the western Mediterranean (22–33 cm) than in the east (15–28 cm). In the northwestern Mediterranean, *M. surmuletus* and *M. barbatus* are recruited mainly in the fall, which results in an increased number caught during this period (Lloret and Lleonart, 2002). It is also between September and November that the influx of Mullidae is the greatest in several Spanish and Italian ports (Martin *et al*., 1999).

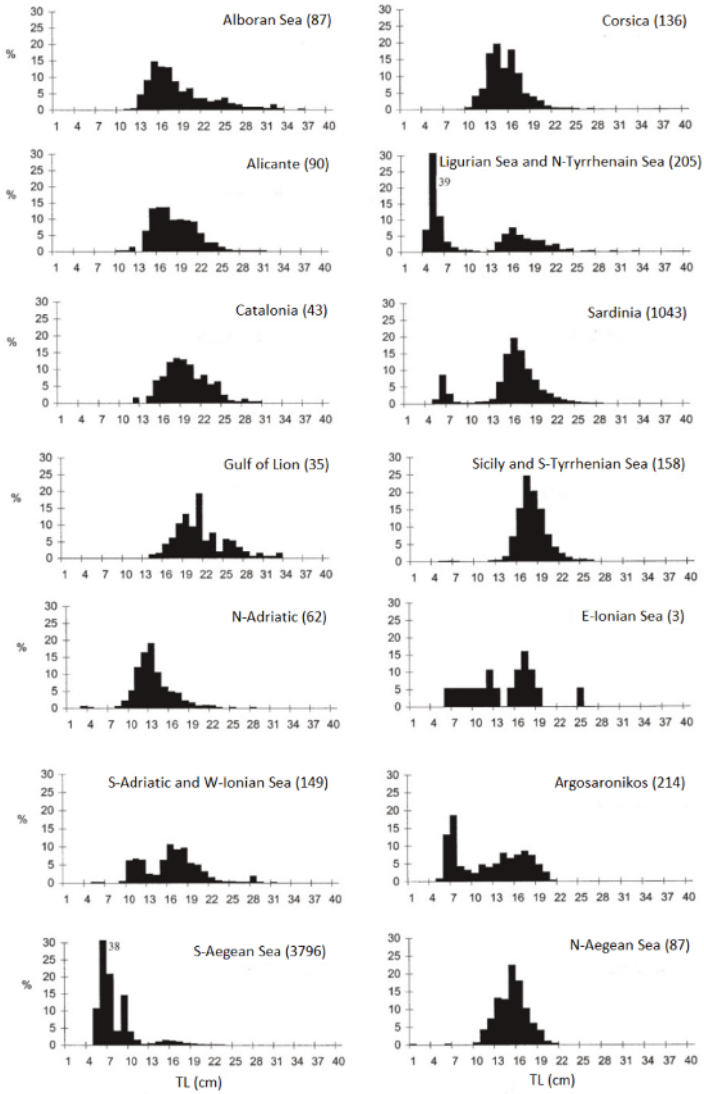


Figure 1.16. *Distribution of length frequencies (TL in cm) of* M. surmuletus *in different areas of the Mediterranean. Numbers in parentheses indicate average relative abundance over the period sampled, expressed as number of individuals per km*^{2} *(Tserpes* et al.*, 2002)*

Predators: The main predators are carnivorous fish: bass, hake, barracudas, conger, monkfish and sharks.

1.1.2.5. *Diet and feeding habits*

Diet: The red mullet is carnivorous (Labropoulou and Eleftheriou, 1997). In the Gulf of Annaba (Algeria), crustaceans (index of relative importance (IRI) = 85.19%) are preferred prey, with annelids in second place (IRI = 11%), followed by mollusks, in particular bivalves, echinoderms, cnidarians, teleosts and plants with IRI values below 2.5% (Derbal *et al*., 2010). In the Gulf of Tunis, crustaceans are the preferred prey (Cn = 71.86; F = 94.34); lamellibranches (Cn = 9.51; F = 29.63) and echinoderms (Cn = 8.1; F = 23.15) are secondary prey. Polychaete annelids (Cn = 9.72; F = 8.30) and algae (F = 2.78) are accessory prey (Gharbi and Ktari, 1979). Crustaceans, especially the mysids, are particularly common in the diet of mullet on the Tyrrhenian coasts; Nereididae and Owenidae are also quite common (De Pirro *et al*., 1999) and the species has a trophic overlap with the wrasse *Coris julis*. On the Cretan coasts, crustaceans (amphipods and decapods) also dominate (Labropoulou *et al*., 1997), as well as in the Aegean Sea (Vassilopoulou *et al*., 2001). In the Gulf of Lion, the diet consists mainly of polychaetes and different crustaceans, such as amphipods, shrimps, crabs, cumaceans, krill, mysidae and isopods (Bautista-Vega *et al*., 2008). In the Stagnone di Marsala lagoon (Sicily), juveniles are strictly benthivorous (Lombarte and Aguirre, 1997). They feed on organisms living in association with *Cymodocea nodosa* or on the sediment surface where polychaetes and harpacticoid copepods are the preferential prey. Each individual in the population of the Gulf of Annaba ingests an average of eight prey at a total weight of 0.25 g (Derbal *et al*., 2010). These values are different from those obtained in Crete (N = 6.18; P = 0.43 g) (Lapropoulou *et al*., 1997).

Feeding behavior: Surmullet detects buried prey through their barbels, and then digs the sand with large bites to unearth them. This earth-moving activity often attracts other fish (seabream, wrasse – *coris* sp. and *symphodus* sp.), ready to jump on prey that try to escape (Louisy, 2005).

The grazing behavior and activity of *M. surmuletus* are influenced by proportion of vegetation cover at the site. When this coverage (phanerogams and/or macrophyte algae *Caulerpaceae*) increases, grazing effort and distance traveled in search of prey decreases significantly (Longepierre *et al*., 2005). Similarly, the survey period increased to ensure the successful location of fish swimming above the sea bed. These changes are related to the development of a dense surface network of rhizomes and stolons and the reduction of space between fronds, which limits access to resources and increases intraspecific trophic competition. From this point of view, the role of *Caulerpa taxifolia* does not differ from that of other marine phanerogams, but it induces changes in the structure of Mullidae populations at the local level.

Feeding variations and rhythms: In the Stagnone di Marsala lagoon, juveniles feed during the day (Lombarte and Aguirre, 1997). According to Mazzola *et al.* (1999), the stomach vacuity of juveniles (SL = 48 ± 1.67 mm) varies throughout the day; it is 0% in individuals caught during the day and 100% among those captured at night. The diurnal phase (12–18 h) is characterized by the presence of isopods, ostracods, cumaceans, polychaetes and amphipods in their diet; the nocturnal phase (20–8 h) is characterized by the presence of copepods, mysidae and tanaïdacea. In this same lagoon, 5 cm individuals feed between 8 am and 11 pm, with peaking between 12 pm and 8 pm (La Rosa *et al.*, 1997). At this size, average daily consumption is close to 8% of the body's dry weight (Mazzola *et al.*, 1999). This diurnal feeding behavior is still found in adults (De Pirro *et al.*, 1999).

In the Gulf of Annaba, adults from 12.2 to 28.8 cm TL feed throughout the year, including during the period of gonad maturation (from February to June) and have an average digestive vacuity coefficient of 34.47% (Derbal *et al.*, 2010). This value is between that recorded in Crete (17.26%) (Labropoulou *et al.*, 1997) and that obtained in the Gulf of Tunis (63.8%) (Gharbi and Ktari, 1979). Karachle and Stergiou (2008) recorded a value of 58.2% for individuals with a total length of between 9.1 and 23.1 cm. The predominance of crustaceans, particularly amphipods, was observed regardless of the season and size of the fish in the Gulf of Annaba. However, Spearman's rank correlation coefficient shows the difference in spring and summer regimes ($\rho = 0.75$; $P = 0.01$), on the one hand, and fall and winter ($\rho = 0.67$; $P = 0.01$), on the other hand (Derbal *et al.*, 2010). Seasonal variations are also observed in Crete: decapods are more numerous in summer, whereas amphipods dominate in winter and spring (Labropoulou *et al.*, 1997).

The composition of the prey ingested also varies according to predator size with the occurrence of cephalopods (majority of the "various" group) exclusively in individuals over 161 mm TL. The average weight of the stomach contents increases significantly in fish larger than 171 mm (TL), whereas the average number of prey does not differ according to size (Labropoulou *et al.*, 1997). In the Gulf of Lion, a change in diet is observed only between average sized individuals (110–180 mm TL) and large individuals (>180 mm TL) (Bautista-Vega *et al.*, 2008), with an increase in the consumption of bivalve mollusks and brittle stars in large individuals. Aguirre and Sanchez (2005) also showed a regime change during the ontogenetic development of fish and a sharing of food resources with the congeneric species *M. barbatus* in the north-western Mediterranean; this is also the case in the Aegean Sea (Vassilopoulou *et al.*, 2001). In addition, the same prey are consumed by males and females in the Gulf of Tunis, but in different amounts (Gharbi and Ktari, 1979). In the Levantine Sea or Lessepsian Sea, *M. surmuletus* feeds primarily on decapods, particularly the *Pasiphaeidae* species *Leptochela pugnax*, native to the Red Sea. This species is also the main prey of the congeneric species *M. barbatus* and two colonizing species *Upeneus asymmetricus* and *U. moluccensis*. The cohabitation, in these conditions of trophic overlap, of native and colonizing species, can be explained by their spatial structuring (Golani and Galil, 1991).

1.1.2.6. *Reproduction and reproductive behavior*

Sexuality: Gonochoric species with lobular testes. Migration of spermatocytes and spermatids takes place centripetally and spermatozoa are collected in the lobule lumen from which they reach the vas deferens (Billard, 1986).

First sexual maturity: On Tunisian coasts, the smallest mature female recorded was 13.8 cm TL (10–14 months); the first maturity is at 17 cm, and at 18 cm (end of the second year of life) all individuals are mature. The smallest mature male captured measured 12.6 cm TL (10–14 months). From 14 cm, all males are sexually mature (Gharbi and Ktari, 1981b). In Majorca, sexual maturity is reached at 16.8 and 15 cm in females and males, respectively. They are all immature below 13 cm and 100% mature above 26 cm (Reñones *et al*., 1995). These values are very similar to those recorded in Provence by Bougis (1952a, 1952b): 16 and 15 cm in females and males, respectively. For the Gulf of Lion, Campillo (1992) indicates a length of 14 cm TL and an age of 2 years. Vassilopoulou and Papaconstantinou (1991) found that the first maturity of males (11.6 cm) and females (13.8 cm) is earlier in Greece.

Spawning site and period: The spawning sites of *M. surmuletus* in the Mediterranean are not documented.

In the North Atlantic, mature red mullet are reported by Desbrosses (1935a) beyond a depth of 100 m at temperatures between 9.5 and 11.9 °C and salinities of 35.1–35.6‰. In the Canary Islands, spawning is observed primarily between 19 and 22 °C (Pajuelo *et al*., 1997).

In the Mediterranean, females spawn from spring until early fall (Table 1.6).

Sites and authors	J	F	M	A	M	J	J	A	S	O	N	D
France, Mediterranean (Bougis, 1952a, 1952b)												
Algeria (Lalami, 1971)												

Egypt (Hashem, 1973b)												
Tunisia (Gharbi and Ktari, 1981)												
Gulf of Lion (Campillo, 1992)												
Majorca (Renones *et al.*, 1995)												
Bay of Edremit, Aegean sea (Torcu-Koç *et al.*, 2015)												

Table 1.6. *Spawning periods of female* M. surmuletus *in different sites in the Mediterranean*

In Majorca, the period of sexual activity is shorter in females than in males (Figure 1.17); it occurs from March to June with a maximum percentage of mature individuals in April and May.

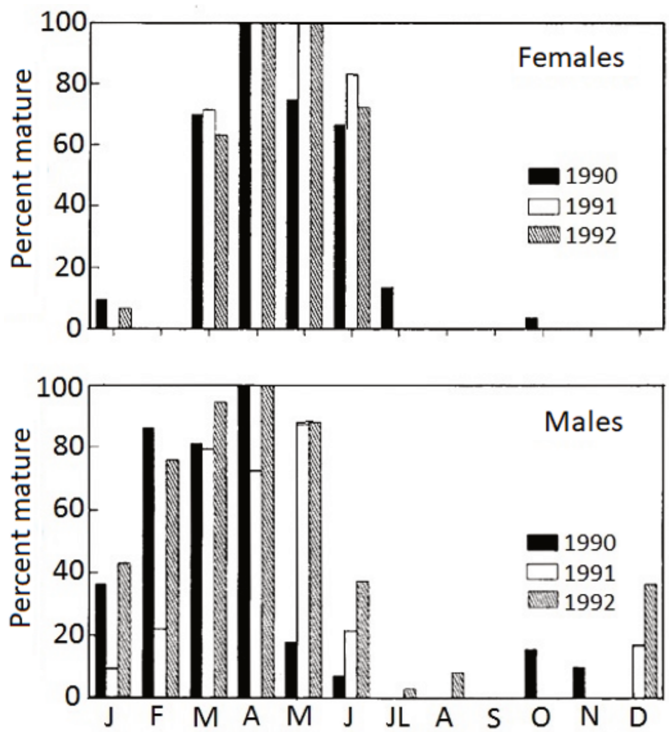


Figure 1.17. *Monthly percentage of mature females (1,868) and males (1,429) in Majorca over three consecutive years (Reñones* et al.*, 1995)*

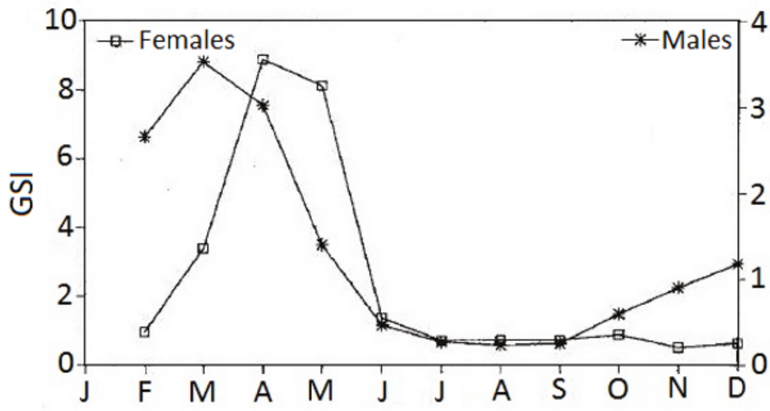


Figure 1.18. *Monthly variations in gonado-somatic index in female (547) and male (469)* M. surmuletus *in Majorca in 1992 (Reñones* et al.*, 1995)*

Although mature males are observed throughout the year, with the exception of September, male sexual activity extends from December to June, with a peak in March and April (Figure 1.18) (Reñones *et al*., 1995). Gharbi and Ktari (1981b) also found a longer spawning period in males than females in Tunisia.

In Majorca, the maximum GSI values observed are 9% in females and 3.5% in males (Reñones *et al*., 1995). They are, respectively, 5 and 2.7 in Tunisia (Gharbi and Ktari, 1981b), and about 2% in both sexes in the Bay of Edremit in Turkey (Torcu-Koç *et al*., 2015). In Provence (France), Bougis (1952) found maximum hepatosomatic index (HSI) values in May in females (3%) and in July in males (2%). These values are observed at the end or after the spawning period, which is not the case for most fish. The author attributes these unusual kinetics to the dynamic role of the liver in red mullet which transforms fats and does not only accumulate them, which is the case with other species of fish.

Fecundity: In captivity, a female weighing 400 g is likely to provide 22 consecutive spawning eggs per spawning season, with an average volume of 16,200 eggs per spawning during an observation period of four consecutive years. In captivity, fecundity can thus reach 850,000 eggs per kilogram per year (average of 4 years of spawning by a single female) (Devauchelle, 1983).

Egg, larvae and ontogenesis: We are not aware of any specific description of *M. surmuletus* eggs in their natural environment. The eggs obtained by Raffaele (1888) in an aquarium have a diameter of 0.93 mm and a lipid globule of 0.23 mm according to Montallenti (1937); a sketch of the larvae at hatching and at 6–7 days is given. The larva is characterized by an elongated yolk sac, pointed at the front, and carrying the oil globule anteriorly, which protrudes far beyond the snout. Marinaro (1971) approaches the Mullidae family from this point of view (see *M. barbatus barbatus*).

Table 1.7 provides additional information on the geographical variations on the size of eggs and their lipid globules.

Sites and authors	Egg diameter (mm)	Globule diameter (mm)	Spawning season
Naples (Raffaele, 1888)	0.93	0.23	May–August
Marseille (Holt, 1899)	0.86–0.87	0.22–0.24	April–May
Marmara (Arim, 1957)	0.82–0.85	0.22–0.23	–
Marseille (Aboussouan, 1964)	0.85–0.89	0.19–0.23	May–July
Algiers (Marinaro, 1971)	0.78–0.93	0.19–0.23	April–June

Table 1.7. *Metric characteristics of* M. surmuletus *eggs in different regions of the Mediterranean*

In aquaculture, eggs obtained have only one lipid globule and are small in size. Their average diameter is 0.88 mm with upper and lower values of 0.81–0.94 mm (Menu and Girin, 1978–1979; Devauchelle, 1983). Egg size is little affected by spawning age (Devauchelle, 1983).

1.1.2.7. *Economic importance*

According to FAO data, *M. surmuletus* is only captured in the Mediterranean where it is regularly and/or occasionally present on the market. With an irregular progression, its overall production varied from 3,994 to 15,618 tons between 1985 and 2007. Until 2004, Turkey then Tunisia were the main producers with 5,900 tons/year. Since 2005, Italian inputs have increased production to 15,300 tons/year on average by contributing 61.3% to the total production.

The fishing of red mullet is semi-industrial and artisanal. Fishing equipment used include beach seines and purse seines, trawls, gillnets, bottom longlines, fyke nets, hand lines and harpoons. Trawl catches dominate, both in number and weight, but vary greatly during the year; the largest quantities are fished in fall (Suquet and Person-Le-Ruyet, 2001). The sizes of the fish caught vary according to the type of fishing equipment used. According to Martin *et al*. (1999), in the western Mediterranean, seasonal fishing nets mainly capture adult individuals, while trawling catches newly recruited small individuals. These authors describe the overexploitation of both mullet species (*M. surmuletus* and M. *barbatus*) on the coasts of Italy and Spain, particularly the harmful effect of trawls, which catch immature individuals, while traditional methods are more selective and focus mainly on adult individuals. On the Egyptian coast, the exploitation rate E is 0.63 (M = 0.43; F = 0.73) and reflects a state of overexploitation of the stock (Mehanna, 2009). The yield per recruit and the spawning biomass values give an F_{MSY} value of 0.53 and suggest a reduction in F by 27%. This reduction must be accompanied by a 59% increase in the fertile biomass.

Surmullets breed in captivity, at least under certain conditions of shelter and feeding. Sequential data sets were obtained between early April and mid-June, corresponding to daylight conditions between 13 and 16 h 30 min and temperatures of 9.5–15 °C (Devauchelle, 1983). Ovules released and fertilized in open water are pelagic. The embryonic and larval development was described in detail by Menu and Girin (1978–1979). The temperature range compatible with embryogenesis covers a relatively wide range, 11–17 °C. Although the number of spawning attempts does not determine larval growth potential or ensure survival, the major difficulty in rearing this species is primarily due to the small size of the larvae at spawning (about 3 mm total length) and its low endogenous reserves, which are resorbed faster the higher the temperature.

1.1.2.8. *Protection status, conservation*

– In the Medes Islands (Catalonia), 44 species were sensitive to fishing bans within a marine reserve, with the exception of surmullet and species from the *Serranidae* family (García-Rubies and Zabala, 1990).

– IUCN Global Red List: NE.

– Mediterranean Red List UICN: LC.

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