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Atherinidae Risso, 1827

Vernacular names: *mirlotu*, *xugla* (ES)[1]; *athérines* (FR); silversides, sand smelt (GB); *aterinidi*, *latterini* (IT).

Etymology: from the Greek *atherina*, meaning fish, perhaps derived from *atés* (vertebral spine).

Brief description: small fish, with a total length generally less than 20 cm (except for *Odontesthes bonariensis*, Atherinopsinae: TL_{max} 72 cm). Oblong body, laterally compressed. Small superior, terminal mouth, moderately protractile jaws with very small teeth (except in *Chirostoma* sp.). Two well-separated dorsal fins: the first D1 with six to ten flexible spiny rays and the second D2 being longer, displaying one spiny ray followed by segmented rays. An anal fin with one spiny ray followed by segmented rays. Lobed caudal fin. Well-developed pectoral fins situated part-way up the body. Pelvic fins in the abdominal position with a spiny ray and segmented rays. Cycloid scales. Lateral line not marked by pores, including at least 50 scales (more than 50 in *Labidestes* sp. *Menidiinae*). Closed air bladder. Short digestive tract without pyloric ceca. Vertebrae: 31 to 60. Generally brown-silver color with a longitudinal band clearly silvered on the flanks, becoming brown or blackish in alcohol or formalin.

Biogeography: Atherinidae, Europe and America; Atherinopsinae, temperate waters in the west of North and South America; Menidiinae, Tropical Atlantic and Pacific America.

Habitat and bio-ecology: nektonic to nektobenthic fish in temperate to tropical regions. Some species of marine origin in this family tend to occupy freshwater successfully, naturally or following human intervention (transplantation). Currently, Atherinidae are present in the sea (littoral), hypersaline to brackish lagoons, freshwater estuaries, continental lakes and water courses, as well as on very varied riverbeds (sandy to muddy surroundings, hard and

1 Throughout the book, the abbreviations refer to each country as follows: ES, Spain; FR, France; GB, Great Britain; IT, Italy; TN, Tunisia.

bare or vegetated with plants or algae). Carnivorous species (from zooplanktivores to benthivores), gonochoric, ovuliparous with relatively low fertility.

Systematics and phylogeny: the Atherinidae family is not monophyletic. Some authors have identified two very distinct "groups", one from the New World (Atherinopsinae, Menidiinae) and the other from the Old World (Atherinoninae, Atherininae). The number of subfamilies recognized varies from six, according to White (1985), to four, according to Nelson (1994) and Chernoff (1986).

Biodiversity: if we allow the four subfamilies retained by Nelson (1994), the wealth of this family can be evaluated around 25 genera and 165 species. Three genera are present in the Mediterranean: *Atherina* (six species), *Atherinomorus* (one Lessepsian species) and *Odontesthes* (one species originating from America).

Paleontology: fossils have been found in some terrains from the lower European Eocene (*Rhamphognatus* sp.).

Originality: Tortonese (1985) drew researchers' attention to the benefit of research, both fundamental and applied, on Atherinidae. Sexuality can be governed by abiotic factors such as temperature for *Menidia* sp. (America). Spawning is directly related to the "moon-tide" system among *Leuresthes* sp. (America).

1.1. *Atherina* Linnæus, 1758

Type: *Atherina hepsetus* Linnæus, 1758, Syst. Nat., Ed. X: 315.

Synonym: *Hepsetia* Bonaparte, 1836, sometimes considered a sub-genus of *Atherina*.

Etymology: *atherina*, from the Greek *aterina*, meaning "fish" (Aristotle), perhaps derived from *atés* (vertebral spine). *Hepsetus, hepsetia*, from the Greek *epsétos, hepsétos* (to cook).

Brief description: scaly body and head, except at the interorbital level. Preoperculum without any "notch". Initial dorsal fin with 6 to 11 non-segmented, flexible rays. Second dorsal fin and anal fin facing one another and of the same length.

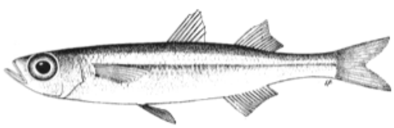
Biogeography: genus typically belonging to the temperate Mediterranean-Atlantic region.

Habitat and bio-ecology: nektobenthic, coastal, carnivorous, euryhaline fish, eggs fixed to a support, most often algae and phanerogams, by filaments.

Biodiversity: six species in the Mediterranean: four seawater, one Mediterranean brackish water and one Mediterranean freshwater species.

Systematics and phylogeny: two sub-genera are sometimes allowed, *Hepsetia* and *Atherina* (Miller, 2003), and six species. Using three mitochondrial and two nuclear markers among 318 specimens in the *A. boyeri* complex from the Atlantic, the Mediterranean and the Black Sea, Francisco *et al*. (2011) confirmed that the genus Atherina is monophyletic and highlighted two non-tropical clades, one South African (*A. breviceps*) and the other Atlantic-Mediterranean (*Atherina hepsetus, A. presbyter, A. boyeri* complex).

1.1.1. Atherina (Hepsetia) lagunae *Trabelsi* et al., *2002*



1.1.1.1. *Nomenclature*

Synonyms: *Atherina lagunae* belonging to the *Atherina boyeri* complex whose main synonyms are: *Atherina sarda* Valenciennes, Cuvier and Valenciennes, 1835 (Sardinia); *Atherina lacustris* Bonaparte, 1836 (Italy), doubtful synonym; *Atherina pontica* Eichwald, 1836 (Black Sea), doubtful synonym; *Atherina riqueti* Roule, 1902 (canal du Midi, France), *Atherina bonapartii* Boulanger, 1907 (Nile, Egypt), *Atherina (Hepsetia) boyeri*: various authors.

Vernacular names: *moixonet, pejerrey* (ES); *athérine, cabassoun, joël, siouclet* (FR); Boyer's sand smelt (GB); *Latterino capoccione*, *atherina* (IT); *gumus* (TN).

Etymology: *Atherina* is the name given to this fish by Aristotle, perhaps derived from the Greek *atès* (fish bone); *boyeri* was derived from the name of Guillaume Boyer, a naturalist and mathematician, born in Nice (France); *lagunae* was derived from the word lagoon.

Systematics issues: in their geographical distribution, Atherinidae of the *A. boyeri* complex display a mosaic of semi-isolated or isolated (continental) populations, each with their own morphological (meristic and metric), ecobiological and behavioral characteristics, depending on the constraints of the environments occupied (Kiener and Spillmann, 1969 and 1972; Bamber and Henderson, 1988;

Henderson *et al.*, 1988; Mistri, 1990; Trabelsi *et al.*, 2009). According to some authors, *Atherina boyeri* is a complex composed of new species that are in the process of emerging (Henderson and Bamber, 1987). According to Bamber and Henderson (1988) and Trabelsi *et al.* (2002a, 2002b, 2003), some populations of individuals have already reached the speciation "threshold".

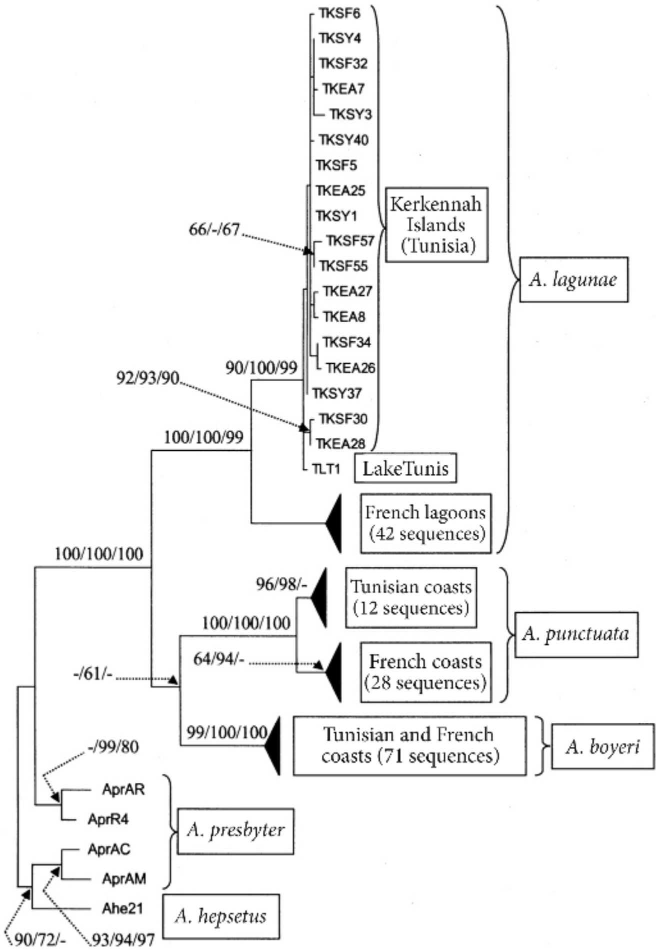


Figure 1.1. *Phylogenetic tree of the* Atherina boyeri *complex*–Atherina lagunae–Atherina punctata *(according to Trabelsi et al., 2009)*

Recent metric (Trabelsi, 2002c), meristic and genetic studies on Mediterranean populations have indicated divergences between those occupying lagoons and those living in the sea[2]. However, a genetic study (Figure 1.1) of Trabelsi *et al.* (2009) showed the presence of a population of Atherinidae with strong affinities for *A. lagunae* in the sea surrounding the Kerkennah Islands (Tunisia). Kottelat (1997) suggested that lagoon populations can be attached to the species *Atherina boyeri* Risso, 1810, and sea populations to *A. mochon* Cuvier, 1829; however, Trabelsi *et al.* (2002a, 2002b, 2003, 2004) proposed that Atherinidae living in lagoons should be included in a new species, *A. lagunae.* On the basis of electrophoretic studies of the enzyme systems of individuals from France (lagune de l'Or, Mauguio; the sea at Nice), Greece (Volos, North Aegean) and Bulgaria (Black Sea, Varna), Dobrovolov and Georgiev (1995), Dobrovolov and Ivanova (1999) and Dobrovolov *et al.* (1999, 2003) concluded that *Atherina mochon pontica* (Eichwald, 1838) is a valid species that is not synonymous with *Atherina boyeri* and should be called *A. pontica* (Eichwald, 1838). If we suppose that *A. mochon* Cuvier, 1829, is synonymous with *A. boyeri* Risso, 1810, then *A. pontica* would be endemic in the Black Sea and *A. boyeri* would be absent from it. Based on the morphology of the head bones of individuals from the Black Sea, the Caspian Sea and the Sea of Azov, Vasil'eva (1994, 1996) showed that *A. mochon* Cuvier, 1829, and *A. bonapartii* Boulanger, 1907, are conspecific, and suggested that the population in the Caspian Sea can be identified at the sub-species level as *A. boyeri caspia* Eichwald, 1838. Currently, in the Mediterranean, four atherine species can be identified: *A. boyeri*, *A. punctata*, *A. lagunae*, *A. hepsetus* and perhaps *A. presbyter.*

1.1.1.2. *Description*

Morpho-anatomy: length of the head is 4.3–5.4 times the standard length (SL), and the diameter of the eye is 2.5–3.6 times the length of the head. The relationships between the total length (TL, mm), the standard length (SL, mm) and the length of the fork (FL, mm) are as follows: for Guadalquivir (Spain), SL = 0.906FL (n = 333, r = 0.997), TL = 1.074FL (n = 333, r = 0.998)[3]; for the Balearic, SL = 0.925FL – 0.799 (n = 205, r = 0.99)[4]; for the lagoons of Méjean, Prévost and Mauguio (France): SL = 0.86TL – 1.073 (n = 2,113 females, TL = 30 – 108 mm)[5]; for the lagoons of Porto Lagos and Lake Vistonis (Greece), the relationships between TL, FLLf and SLLs are FL = 0.94 TL – 0.77, SL = 0.86TL – 1.01 and SL = 0.91FL – 0.29 (Koutrakis *et al.*, 2004); for Lake Trasimeno (Italy), SL = 0.086 + 0.872TL;

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2 Marfin, 1982c; Trabelsi and Kartas, 1989; Kartas and Trabelsi, 1990; Trabelsi *et al.*, 1992; Focant *et al.*, 1992, 1999; Trabelsi *et al.,* 1992, 1994b; Trabelsi *et al.*, 2002a, 2002b and 2003; Klossa-Kilia *et al.,* 2002, 2007; Kraitsek *et al.,* 2008; Antonucci *et al.*, 2012; Boudinar *et al.*, 2013, 2016b.

3 Fernandez-Delgado *et al.*, 1988.

4 Sintes and Gutiérrez, 2007.

5 Tomasini *et al.*, 1996 and 1999.

however, there is no difference between the sexes (Lorenzoni *et al.*, 2015). *A. lagunae*: France (Thau, Mauguio, Camargue, Biguglia) and Tunisia (Ichkeul, Bizerte, North Tunis) D1 (V) VII (X), D2 I + (9) 11 (14), A I + (11) 13 (16), P I + (12) 14 (16), Ll (39) 45 (48), Bsp (6) 7 (9) + (16) 19 (22), total (23) 26 (30), Vt (39) 44 (47) (Trabelsi *et al.*, 2002a). The relationships are as follows: SL = 0.865TL + 0.097; FL = 0.938TL + 0.145 (Alessio *et al.*, 1990).

Coloring: the body is silver colored, the back is a little browner than the belly; on the flanks, a broad, clearly silvered band extends from the head to the caudal base.

Variations: over its area of distribution, the Atherinidae display several relatively isolated populations in estuaries, lagoons and sometimes in freshwater lakes, which is certainly the origin of their subtle inter-population differences, as much at the morphological level as that of the life cycle. Therefore, this proves their high adaptive plasticity, and their absence from some sectors is not the result of abiotic conditions, but due to competition with the “specialist” and endemic species that occupy these areas (Bamber and Henderson, 1988). The variabilities of morphological and behavioral characteristics demonstrated by Kiener and Spillmann (1969, 1972) in a study on 19 populations (15 lagoons and marinas on the French Mediterranean coasts, two on the Italian (Liguria and Venice) coasts, one on the Tunisian coast and one on the Dutch coast) can be interpreted as phenotypic responses to environmental conditions and a level of genetic deviation linked to a more or less pronounced isolation of the populations. Marfin (1982c) insisted that Atherinidae had a very high polymorphism, which he believed is “linked to the characteristics of colonized environments”. He identified “two very morphologically similar types, which differ enough to be distinguished from one another”. In addition, Marfin (1982a) showed notable differences that affect the scales, the shape of the premaxilla, the vomerian and palatine tooth patches between marine and lagoon Atherinidae (Salses-Leucate, Canet, Bourdigou, canal de Port-la-Nouvelle, France). He believed that the stronger vomerian and palatine tooth, as well as the lesser development of the mouth and the branchial filter (branchiospines), in lagoon Atherinidae compared with marine Atherinidae should be linked to their feeding habits, with the first primarily feeding on benthic (crustaceans) invertebrates, while the second is more planktivorous. On this last point, this author agreed with Kiener and Spillmann (1972) who believed that the number of branchiospines is “linked to the habitat, which determines which type of food is dominant”. From the point of view of meristic characteristics, Kiener and Spillmann (1969), and Trabelsi *et al.* (2002a, 2009) gave information (extreme and average values) about 14 characteristics and focused on 19 Mediterranean lagoons. Trabelsi and Kartas (1985), Kartas and Trabelsi (1990) and Trabelsi *et al.* (2002a, 2002c) indicated the extreme and average values of nine meristic characteristics of three populations in Tunisia (Ichkeul, Bizerte, North Tunis). Populations in French lagoons can be differentiated from those in Tunisia by the number of scales on the lateral line and the number of vertebrae and rays on the pectoral fins; their averages are higher in French lagoons than those in Tunisia. Tunisian populations diverge more between one another than those on the French coast (Trabelsi *et al.*, 2002a, 2002c). Mistri and Colombo (1988) and Mistri (1990) demonstrated that at the same age, individuals in freshwater Lake Trasimeno display morphometric traits called "infantile". The 2^+ specimens in this lake are morphologically closer to 1^+ individuals than 2^+ individuals in the lagoons of Golo and Mar Piccolo (Italy). Trabelsi *et al.* (2009) studied the phylogenetic relationships of 16 marine and 19 lagoon populations based on morphological (87 biometric parameters) and genetic (cytochrome *b*) data (Figure 1.1). That study confirmed the presence of two marine (*A. punctata*, *A. boyeri*) and one lagoon (*A. lagunae*) species and showed the originality of the island population in the Kerkennah Islands (Tunisia), from all points of view closer to *A. lagunae* than to *A. boyeri* and *A. punctata*, which are typically marine. Bouriga *et al.* (2009) indicated that Atherinidae on the island of Djerba (Tunisia) are genetically of the lagoon type (*A. lagunae*), like those on the Kerkennah Islands. Note that although *A. boyeri* has been detected in the "marizined" parts of some lagoons, including Thau (France), *A. punctata* seems to avoid lagoon systems regardless of their salinity.

Boudinar *et al.* (2013, 2015) compared individuals collected from three sites on the eastern Algerian coast: in the sea (Gulf of Annaba), a lagoon (Mellah) and an estuary (Ziama wadi). That study focused on 14 metric characteristics, nine meristic characteristics and the shape of the otolith contour. These authors concluded the presence of three morphologically distinct "groups" of Atherinidae in this sector: a group in the Mellah lagoons (salinity 25–35‰), a group in the Ziama wadi estuary (maximum salinity 10‰) and a group of individuals in the sea (salinity 35–38‰). These observations were confirmed by Boudinar *et al.* (2016b) according to a study on the analysis of the otolith shape (Fourier) and the results obtained in genetics from three mitochondrial markers (CR, cyt b, 16S) and one nuclear marker (2nd intron S7).

Sexual dimorphism: females reach a maximum size clearly higher than that of males. For the lagoons at Roussillon (France), Marfin (1982a) obtained the following values: M = 69 mm, F = 75 mm (Leucate); M = 62 mm, F = 71 mm (Canet); M = 75 mm, F = 82 mm (Bourdigou) . In the Greek lagoons at Messolonghi and Etolikon, the sizes of these species were respectively 103 mm TL for females and 83.1 mm TL for males (Leonardos and Sinis, 2000). In the Caspian Sea, females reach 128 mm TL (11.69 g TW) and males reach 120 mm TL (9.01 g TW) (Paimar *et al.*, 2009).

Osteology, otoliths, scales: Marfin (1982c) gave a detailed description of the scales depending on the age of individuals, as well as some bones in the skull and the splanchnocranium. Vasil'eva (1994, 1996) studied bones in the head of Atherinidae (*Atherina* sp.) in the Black Sea, Caspian Sea, the Sea of Azov and the Aral Sea. Hamrouni *et al*. (2005) and Bouriga *et al*. (2005) found notable differences between the premaxilla, maxilla and dental bones in lagoon Atherinidae (*A. lagunae*) in Lake Ichkeul and marine Atherinidae (*A. boyeri*) in Tunisia. Boudinar *et al.* (2015) showed remarkable divergences affecting the morphology of sagitta (Figure 1.2) of specimens from three very different habitats in Algeria: Mellah lagoon (S‰: 25.4–34.8), Ziama wadi estuary (S‰ ≤ 10) and the sea (S‰: 35–37.9). The sagittal otolith was described by Chaine (1958, pl. 5, fig. 200–203 and 206–209). Tuset *et al*. (2008) showed images of the sagitta of three specimens from the north-east Atlantic, whose body size was TL= 6.0–9.5 and 13.7 cm. The scales were of cycloid type.

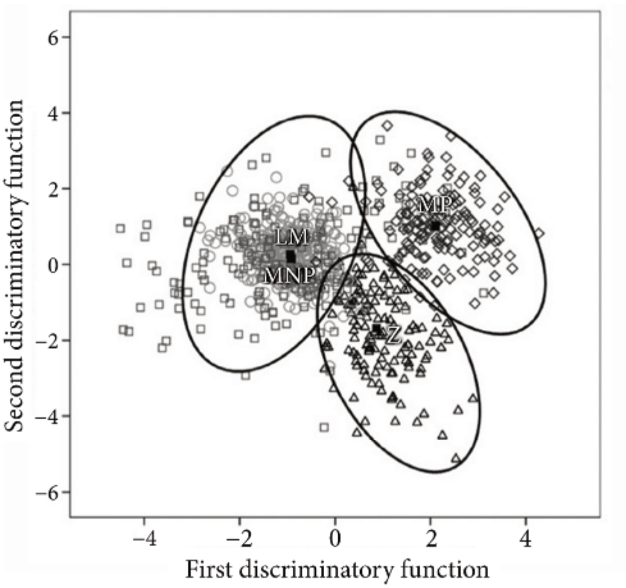

Figure 1.2. *Discriminatory analysis of somato-morphological parameters of four populations of* Atherina boyeri *from the Algerian coast. Mellah lagoons (LM, blank circles), Ziama wadi estuary (Z, blank triangles), both Atherinidae without black spots, Gulf of Annaba (sea) without black spots (NMP, blank squares) and Gulf of Annaba (sea) with black spots (MP, blank lozenge) (from Boudinar* et al.*, 2015)*

Karyology: 2n = 48 (Vasil'ev, 1980; Klinkhardt *et al*., 1995).

Protein specificity and genetic diversity: morpho-anatomical studies (Kiener and Spillmann, 1969; Mistri and Colombo, 1988) and parasite studies (Berrebi and Britton-Davidian, 1980) have demonstrated the presence of distinct populations in the distribution area of *A. boyeri*. Since the 1990s, genetic studies (Focant *et al*., 1992, 1993, 1996, 1999; Cammarata *et al*., 1996) have confirmed the population complexity of this species by distinguishing a laguno-estuarian set from a marine set. Based on morpho-anatomical and genetic data (mtDNA, cytochrome *b*), Trabelsi *et al*. (2002a, 2002b) confirmed these results and believed that in the Mediterranean, Boyer's three "groups" of Atherinidae could be identified and ranked as species: two typically marine (*A. punctata*, *A. boyeri)* and one inhabiting lagoon (*A. lagunae*). The results obtained by Congiu *et al.* (2002), Klossa-Kilia *et al.* (2002 and 2007), Astolfi *et al.* (2005), Mauro *et al.* (2007) and Milana *et al.* (2008) confirm this point of view.

The geographical sites from which these specimens were collected have been considered by geneticists to cover a large section of the Mediterranean. In France, Focant *et al.* (1992, 1993) demonstrated biochemical divergences (electrophoresis of muscle parvalbumins) between marine and lagoon populations in the Gulf of Lion (Mauguio, the lagoons of Thau and Or) and Corsica (Urbino). Using the same technique, Focant *et al.* (1999) demonstrated some "genetic homogeneity" in populations in the Camargue but detected divergences between sites close to the sea (six) and those more distant from it (three).

In Italy, Creech (1991) studied four populations and found evidence (electrophoresis) of similarities between those of the Italian Lake Trasimeno and those of lagoons in the Gulf of Lion (France). Using RAPD, Congiu *et al*. (1997) demonstrated some similarity between populations on the Italian coasts, but indicated that those of the lagoons of Sardinia and Sicily are remarkably different. Congiu *et al.* (2002) studied the populations of 11 Adriatic and Tyrrhenian lagoons and two freshwater lakes (Bolsena, Trasimeno). These authors indicated that there were no markers specific to these lagoons, but there was a strong correlation between genetic and geographical distances. On the other hand, they emphasized that the population of the lagoon of Marsala (Sicily) was genetically different from other Italian lagoons, and that it could have affinities with Tunisian populations; the same was demonstrated for the Cyprinodontidae *Aphanius fasciatus* (Maltagliati, 1999). The study of iso-enzymatic polymorphism indicated differences between the lagoon population of Marsala and the coastal marine population of Trappeto in Sicily (Cammarata *et al.*, 1996). Mauro *et al.* (2007) highlighted significant differences in enzymatic systems between river estuaries Birgi and San Bartolomo (Sicily) and marine sites at Chioggia, Catania and Gaeta. Milana *et al.* (2008) studied (mtDNA, tRNA, cytochrome *b*) 17 populations of *A. boyeri*: six marine, five Italian lagoons (Muravera, Fogliano, Marsala, Verano, Lesina), three Italian lacustrine (Trasimeno, Bolsena, Bracciano), one in the Black Sea, one lagoon in Portugal, one in Thau, France. Along with Trabelsi *et al*. (2002a, 2002b, 2004), they identified the presence of three cryptic species in the Mediterranean.

In a study conducted in Greece, Klossa-Kilia *et al.* (2007) indicated divergences between the Lakes Trichonida and Kaiafas, the Aitoliko lagoon (north-western Greece) and seven marine sites (eastern and western Greece, 12s rRNA, 16s rRNA and mtDNA analyses). The study carried out by Kraitsek *et al*. (2008 – mtDNA, 12s, 16s rRNA) on 15 marine populations (Kymi, Evionari, Kalymnos), lagoon populations (Kefalonia, Amvrakikos, Kourna and one Turkish lagoon) and lacustrine population (Vistonida, Kourna, Iznik) has also indicated significant genetic divergence between populations in the Aegean and Ionian seas and those in lakes and lagoons bordering the sea. Astolfi *et al.* (2005) studied genetic variability (mtDNA) across seven lagoons in the western Mediterranean, three in the Adriatic, one in the Tage estuary and one in the Danube. These authors demonstrated high structuration and clear interlagoon fragmentation, which they link to the geographical distances between the sampled zones. The groups identified are 1) the Siculo-Tunisian Straight (Sicily and Tunis), 2) Black Sea (Danube), 3) Adriatic, 4) Tyrrhenian Sea and 5) north-west Mediterranean, with Mauguio (France) and the Tejo (Portugal).

Francisco *et al.* (2011) used three mitochondrial markers and two nuclear markers among 318 specimens of the *A. boyeri* complex from the Atlantic, the Mediterranean and the Black Sea and confirmed the results from Trabelsi *et al.* (2002a, 2002b) and Francisco *et al.* (2008), showing the presence of three very distinct bodies: lagoon Atherinidae without black spots, marine Atherinidae with black spots and marine Atherinidae without black spots. Heras and Roldàn (2011) confirmed the genetic divergences (125 rRNA, cyt b, COI), already mentioned by several authors, between lagoon populations (Mar Menor) and common and occasional marine populations of the Spanish coasts. Similarly, these divergences were also confirmed by Kraitsek *et al.* (2012): genetic divergences (mtADN, cytochromes cyt b and COI) between lagoon and marine populations on the Greek coasts of the Ionian Sea and the Aegean Sea (23 sites) and the Turkish coasts (one site, Lake Iznik); divergences between common and occasional marine Atherinidae; and the discovery of a genetically common population similar to the rare ones. Moreover, these observations were confirmed by Boudinar *et al*. (2016b) who, using three mitochondrial markers (CR, cyt b, 16S) and one nuclear marker (intron S7), showed in the western Mediterranean the presence of three groups of Atherinidae within the *A. boyeri* complex: one without black spots in brackish and freshwater habitats and two (one with black spots and the other without) in sea water. More locally, these authors showed the peculiarity of individuals in the Ziama wadi and the convergence that exists between the population of the Mellah lagoon (Algeria) and the Mauguio lagoon (France).

1.1.1.3. *Distribution*

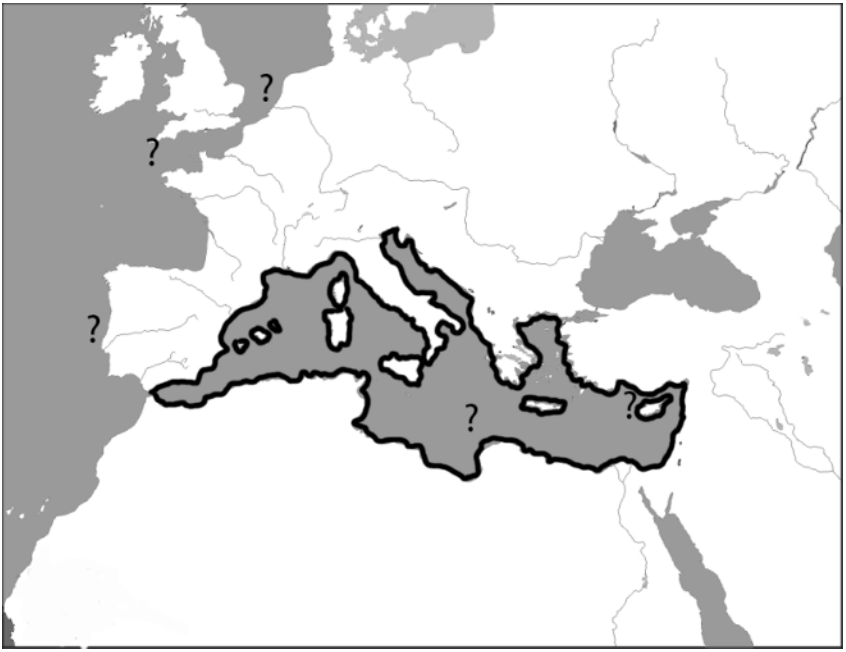

Figure 1.3. *Geographical distribution of* Atherinae lagunae *(question marks indicate unconfirmed presence on the Atlantic coasts and in some parts of the Mediterranean)*

This species (*A. boyeri/lagunae* complex) that is typical of temperate waters is undergoing expansion in the northern zones of the Atlantic Ocean (Figure 1.3). Currently, it has been recorded on the coasts of north-west Scotland (isolated populations), the Dutch (Van der Velde, 1976) and English coasts (Bowers and Naylor, 1964), and as far as Morocco, Madeira and the Azores.

In the Mediterranean, this species is present in all coastal waters. Its presence in the Black Sea is doubtful although valid for the species *A. pontica*; this species was introduced into the Caspian Sea (Patimar *et al.*, 2009), and from there to the Aral Sea in 1953 and 1954 (currently extinct). *A. boyeri/lagunae* is naturally present or, indeed, after introduction into some continental lakes in Italy (Trasimeno, Bracciano, Bolsena, Albano, Nemi, Carinola, Fondi, Omodeo, Coghina)[6], Greece (Trichonis, Ozeros, Tavropos[7], where settlement of the population in Lake Trikonis results from the construction of a dam on the River Acheloos in 1969)[8], Turkey (Trabzon, Iznik, Sapanca)[9] and Egypt (Lake Karoun (El-Zarka, 1968), the Suez Canal, Lakes Amer and Menzalah (under the name *Atherina pontica* by Chabanaud, 1937)). It was recorded in the Canal du Midi (France) by Depéret (1833) and Roule (1902, 1903), under the name *Atherina riqueti*; however, this has not been confirmed.

1.1.1.4. *Ecology*

Habitat: gregarious species, nektonic to nekto-demersal, willingly inhabits vegetation and algae in marine, brackish and freshwater habitats. It is sometimes considered to be pelagic in freshwater lakes (Kottelat, 2007).

Migration and movements: although they reproduce in lagoons, some individuals move greater or lesser distances between these and the nearby sea, so much so that *Atherina* can be called “semi-sedentary” (Quignard *et al.*, 1993). Kiener and Spillmann (1972) indicated that the sudden departure of Atherinidae from lagoons in winter is a common phenomenon. In addition, Clavero *et al.* (2005) demonstrated regular movements of Atherinidae (12 to 70 mm TL) between the bottom and the surface of the water, in a small river in southern Spain. These fish engage primarily in diurnal activity, which is more accentuated in larger individuals than in smaller ones. The arrival of small individuals at the surface is linked to their planktonophagous diet. Large, more opportunistic individuals (Vizzini and Mazzola, 2002) also feed on benthic animals and thus remain on the bottom, thereby limiting their predation by diurnal piscivorous birds such as *Bubulcus*, *Egretta* and *Alcedo*. Rosecchi and Crivelli (1992, 1995) described migrations of adults from the Vaccarès salt lagoon (mean 20.3 $g.l^{-1}$) to two temporary freshwater ponds (0.2 to 3.0 $g.l^{-1}$) (South Relongues and North Relongues), during the autumn and winter (mainly

6 Bonaparte, 1836; Moretti *et al.*, 1959; Minervini *et al.*, 1990; Gandolfi *et al.*, 1991; Bianco, 1998; Lorenzoni *et al.*, 2015.

7 Economidis *et al.*, 2000; Vasileiou *et al.*, 2000.

8 Daoulas *et al.*, 1997; Vasileiou *et al.*, 2000.

9 Kutrup, 1996; Özulug *et al.*, 2005.

November to March) from 1987 to 1989, via the Fumemorte Canal (salinity 0.2 to 3.5 $g.l^{-1}$). These migrants, whose size ranges from 31 to 63 mm FL, with a majority from 34 to 43 mm FL (1^+), lay in these ponds from March until the end of June. Spawners and fry (FL mean of alevins was 18.5 mm at South Ralongues and 23.5 mm at North Ralongues in May 1989) leave these ponds before they dry up to rejoin the Vaccarès at the beginning of July. Mortality between hatching and departure ranges from 97.5 to 99.9%, depending on the year. From July to October, the majority of Atherinidae live in the Vaccarès. Marion (1894) indicated that Atherinidae travel from the "lower Camargue" to small water courses in April to May. As for the Camargue lagoons, Poizat and Crivelli (1997) gave a demographic balance between the "arrival and departure" of nine species (three periods of occupation: 1986–87, 1987–88 and 1988–89), including *A. boyeri/lagunae.* For the latter, the balance was positive except in 1988–89. The year 1989 was particularly dry. According to Bardin and Pont (2002), the alternation between day and night is the main factor governing the arrival in the Impérial lagoon (Camargue, France) during three months (between March and May). The reported occurrence of Atherinidae in surveys has in fact been 13 times higher during the day than at night. The authors accepted that Atherinidae, as with the majority of "ocean pelagic" fishes, see their way visually and thus move during the day (Manteifel *et al.*, 1978). In this sector, the direction of currents does not seem to determine the movement of Atherinidae between the sea and the lagoon and vice versa, given their speed and swimming ability (Bardin and Pons, 2002). In the northern zone of the Adriatic (Boscolo, 1970) and in the Ponto-Caspian region (Yusufova, 1970; Savenkova and Asanov, 1991), Atherinidae migrate in the autumn into the waters whose temperature exceeds 8°C; they return to coastal waters, lagoons and estuaries when the temperature exceeds 8°C, especially when it reaches 14 C to 20°C. In Greece, communication between the sea and Lake Trichonis was possible via the River Achelloos and Lake Lysimacia; however, since 1961, a dam has prevented the movement of organisms between the two lakes and thus between the sea and Lake Trichonis (Leonardos, 2001).

Ecological valence: *A. lagunae* is a very euryvalent species. In the lagoons of Salses-Leucate and Bourdigou (France), Atherinidae live in waters whose salinity ranges between 0 and 40‰ (Marfin, 1982a, 1982b, 1982c). Specimens from Thau experimentally support salinities between 2-5 and 56 (71)‰ (Paris and Quignard, 1971). This species also lives in freshwater (Trasimeno Albano in Italy, Trichonis in Greece, Sapanca and Iznik in Turkey) as well as in hypersaline waters (77‰ in some Corsican lagoons, 45–70‰ in the lagoons of Bardawil and Timsah and in Lakes Amer in Egypt); however, reproduction is only possible in waters with a salinity of 2–42‰ (Quignard and Pras, 1986). According to Kiener and Spillmann (1969), a high calcium ion content promotes survival and the development of eggs in freshwater. This species also tolerates temperatures between 0–1°C and above 30°C. According to Markevich (1977), in the Aral Sea, Atherinidae tolerate temperatures below 8°C for 6 months only if their lipid reserves represent at least 4% of their body weight. Kiener and Spillmann (1972) indicated that Atherinidae flee lagoons in winter, especially when a change in temperature is sudden and substantial, as happened in 1972 in the Olivier pond near Berre (France), where the air temperature dropped to -4.2°C. In addition, Atherinidae can occupy very confined and barely structured spaces with very low biodiversity (Baudin 1980), such as the Citis pond (France).

Size, lifespan and growth: in the Guadalquivir estuary, Atherinidae do not live longer than 2 years (2^+) and 60% of maximum size (10 cm FL) is reached in the first year of life (Fernandez-Delgado *et al.*, 1998). These authors provided "weight/size" equations according to sex and time. In the estuary of the River Segura (south-eastern Spain), the parameters of the weight (TWg)/size (FL, cm) relationships are as follows: log a = $5.58.10^{-3}$, b = 3.26 (n = 1936, FL_{min} = 3.9 cm, FL_{max} = 9.4 cm, r^2 = 0.971) (Andreu-Soler *et al.*, 2006a). For Lake Zonar (Spain, Cordoba), Fernandez-Delgado and Hernando-Casal (1982) obtained the following values: size TL_{max} = 73.5 mm, TW = $10.4 \times 10^{-6}TL^{2,9}$ for males; TL_{max} = 90 mm, TW = $7.3.10^{-6}TL^{3,01}$ for females. For an estimated age of 3 years (scalimetry and FL frequency), individuals at Mar Menor (Andreu-Soler *et al.,* 2003a, 2003b, 2006b) have a maximum size of FL = 87 mm for males, and FL = 94 mm for females. The parameters of the von Bertalanffy equation are FL_∞ = 83.56 mm, k = 0.86 year^{-1}, t_0 = - 0.13 year, and those of the size (SL, mm)/weight (g) (gutted fish) relationships are a = $6.25.10^{-6}$, b = 3.113 (n = 856, r^2 = 0.97) for males and a = $8.29.10^{-6}$, b = 3.043 (n = 1080, r^2 = 0.97) for females. In this case, 56.2% of the maximum size is reached by first sexual maturity (Andreu-Soler *et al*., 2003b).

For the lagoons of Leucate, Canet and the Bourdigou estuary (France), Marfin (1981, 1982a) indicated an age of 2 years, in exceptional cases 3 years and a maximum size (SL) of 82 mm (TL about 9 cm). The lifespan of the males (expressed in months) is slightly less than that of females. In these sites, the females have a maximum size (SL) greater than that of males (Leucate: M = 69 mm, F = 75 mm; Canet: M = 62 mm, F = 71 mm; Bourdigou: M = 75 mm, F = 82 mm). This author described the growth per month of cohorts from 1976, 1977 and 1978. According to these data, the growth of the males did not differ from that of females, and ceased in winter except in the Bourdigou estuary where it was merely slowed down. Size (SL) at 1 and 2 years ranged from 49 mm/64–66 mm in Leucate, 44–48 mm/58 mm in Canet and 54–57 mm/66–68 mm at Bourdigou. For these same lagoons, the sizes obtained by Hervé (1978) (scalimetric back-calculation) were clearly lower: 37.5 mm/54.0 mm in Leucate and 39.4 mm/51.5 mm in Canet. The size/weight relationship for individuals preserved in formaldehyde from Prévost (France) was $TW = 0.48TL^{3,20}$ (Kohler, 1976). In a study conducted in Thau, Bach (1985) indicated a maximum age of 4 years. In the lagoon of Mauguio (France), the maximum size was 98 mm FL for a weight (TW) of 6.7 g; the lifespan was 4 years (Quignard *et al.*, 1993). In the lagoons of Méjean, Prévost and Mauguio (France), TL_{max} for females was 108 mm and TL_{max} for males was 92 mm (Tomasini *et al.*, 1999; Tomasini and Laugier, 2002). According to Kohler (1976), in Prévost, TW (g) = $0.48TL^{3,2}$ cm (individuals in formaldehyde), and the growth of juveniles was greatest from April to June. In the brackish lagoon at Tampan in the Camargue, Crivelli (1981) distinguished three groups by age, including mean lengths of 39, 54 and 76 mm. Nevertheless, in the Camargue (Fumemorte canal and Ralongues pools), maximum sizes were respectively 94 mm FL and 63 mm FL, with the maximum age of 4^+ (scalimetry and distribution of size frequencies). At a given age, even though females have a size greater than that of males, the differences are not statistically significant (Rosecchi and Crivelli, 1992). As for size (FL)/weight relationships for the body (We), Rosecchi and Crivelli (1992) showed that there was no difference between males and females. In the Imperial lagoon in the Camargue, the maximum size between March and May 1994 was 93 mm TL (TL mean 59.1 mm for males and 61.6 mm for females) (Bardin and Pont, 2002).

According to Alessio *et al.* (1990), in the Massaciuccoli lagoon and its backwaters (the Burlamacca canal and the port of Viarregio, Italy), the maximum size was 90 mm TL, the lifespan was 4 years (4^+ scalimetry) and the size (TL mm) in the first winter of life was 39.3 mm, in the second 55.6 mm, in the third 71.3 mm and in the fourth 84.0 mm (otolithometry and operculometry). The size/weight relationship was Log W (mg) = 3.099 Log TL (mm) + 2.340. These authors also obtained growth curves for weight and length per trimester. In the Venice lagoon, the maximum size was 120 mm TL (Boscolo, 1970), and the size at 1 year was 73 mm and at 2 years was about 100 mm. In the lagoon of Lesina (Adriatic), the maximum size of males ranges from 7 to 8 cm SL and that of females from 9 to 10 cm SL. The size (SL, cm)/weight (TW, g) relationships for males without parasites were ln TW = –5.445 + 3.210 ln SL and for males with parasites (isopod *Mothocia epimerica*) were ln TW = –5.532 + 3.240 ln SL. Those for females without parasites were ln TW = –5.576 + 3.249 ln SL and for those infected with parasites (*M. epimerica*) were ln TW = –5.869 + 3.328 ln SL (differences were not significant) (Bello *et al.*, 1997). In the Aquatina lagoon (Adriatic), the maximum length (SL) was 90 mm at 2 years (Maci and Basset, 2010); these authors provided monthly size/weight relationships and the following size/weight relationship: ln TW = –11.45 + 2.956. ln SL (n = 41 576 individuals, SL = 20–90 mm, r^2 = 0.94). According to Pallaoro *et al.* (2002), Atherinidae in the Pantana lagoon (Croatia) reached the age of 4 years (scalimetry), a maximum size of 11.8 cm TL (females). Linear growth for both sexes was L_∞ = 17.21 (1 - $e^{-0,201\ [t\ +\ 1,0285]}$), with k = 0.347 among females and k = 0.506 among males. The size/weight relationship did not differ according to sex and was isometric. The parameters of the mass (TW, g)/size (TL, cm) relationship in the estuary of the river Mirna (Croatia) were as follows: a = 0.0075, b = 2.975, r^2 = 0.980, TL = 4.5–15.7 cm, n = 710 (Dulčić and Glamuzina, 2006).

In the estuary of the river Mala Neretva (Croatia), males and females reached a length (TL) of 9.8 cm and 11.6 cm respectively (Bartulovic *et al.*, 2004b). The maximum age was 4 years for both sexes (scalimetry), but females showed better growth than males. The parameters of the von Bertalanffy equation were as follows: TL_∞ = 9.914 cm, k = –0.973 $year^{-1}$, t_0 = + 0.191 year (TL = 4.5–9.8 cm) for males; TL_∞ = 10.577 cm, k = –1.19 $year^{-1}$, t_0 = –0.006 year for females; TL_∞ = 13.503 cm, k = –0.368 year $^{-1}$, t_0 = + 0.972 year for both sexes. For the same estuary, the weight (TW, g)/size (TL or SL, cm) relationships were as follows: a = 0.00343, b = 3.243 (TL, cm) and a = 0.00682, b = 3.181 (SL, cm) (n = 1200) for both sexes; a = 0.00452, b = 3,100 (TL, cm) and a = 0.00694, b = 3.166 (SL, cm) (n = 462) for males; a = 0.00327, b = 3.268 (TL, cm) and a = 0.00666, b = 3.194 (SL, cm) (n = 606) for females.

In the lagoons of Messolonghi and Etolikon (Greece), the maximum (TL_{max}) length of males was 83.1 mm and that of females was 103 mm for a maximum age of 3 years (scalimetry) (Leonardos and Sinis, 2000). The weight (EW)/size (TL) relationship of males and females were not significantly different: EW = $4.168.10^{-3}TL^{3,15}$ (n = 426, TL = 13.8–103 mm, r^2 = 0.95). The parameters of the von Bertalanffy model were as follows: TL_∞ = 74.97 mm, k = 0.67 and t_0 = 0.46 year for males; TL_∞ = 119.94 mm, k = 0.23 and t_0 = 1.37 year for females. In this case, 66.67% of maximum size was reached in the first year. According to Leonardos (2001), in the freshwater Lake Trikonis in the same region, the maximum age was 4 years, the maximum size (TL) was 109.53 mm (135 mm according to Economou *et al.* 1994 and 112 mm according to Chrisafi *et al.* 2007) and the maximum somatic weight (EW) was 10.64 g. The weight/size relationship was EW = $3.6.10^{-3}TL^{3,18}$ (n = 503, TL = 44–109 mm). The parameters of the von Bertalanffy equation were as follows: TL_∞ = 112.4 mm, k = 0.42 $year^{-1}$, t_0 = + 0.40 year. In this case, 52.86% of maximum size was reached during the first year of life. In the northern zone of the

Aegean Sea, Lamprakis *et al.* (2003) obtained the following values: a = 0.004, b = 3.189, r^2 = 0.942, TL = 6.2–11.4 cm, n = 149. For the Strymon estuary (Greece), Koutrakis and Tsikliras (2003) indicated the following values: a = 0.0075, b = 3.023, r^2 = 0.986, TL = 1.1–11.5 cm, n = 706. For the Rihios estuary (Greece), the values obtained were a = 0.0096, b = 2.891, r^2 = 0.981, TL = 2.5–10.7 cm, n = 158. For the Porto-Lagos lagoon, the values obtained were a = 0.0074, b = 2.975, r^2 = 0.978, TL = 3.6–9.7 cm, n = 86. In the Vistonis, Lake Vistonis and the Porto Lagos lagoon (Koutrakis *et al.*, 2004), the maximum age calculated by scalimetry was 4 years (TL = 100 mm) and the maximum size was TL = 105 mm (3 years). The size/weight relationship was TWg = $2.10^{-6}TL^{3.22}$ mm (n = 1056, r^2 = 0.98); the difference between sexes was not significant. In these environments, 61.78% of maximum size was reached during the first year. The parameters of the von Bertalanffy equation were as follows: L_∞ = 128.1 mm, k = 0.26 $year^{-1}$, t_0 = –1.64 year for males; L_∞ = 166.54 mm, k = 0.16 $year^{-1}$, t_0 =–1,90 year for females; L_∞ = 116.97, k = 0.35 $year^{-1}$, t_0 = –0.99 year for both sexes.

In Turkey (Tarkan *et al.*, 2007), whether it is in freshwater zones, brackish or marine lagoons, the maximum age was 3 years (otolithometry), but linear growth differed depending on the biotope. It was clearly higher in the Ömerli reservoir (TL_{max} = 12.9 cm) than in the Homa lagoon and in the Bay of Izmir. In the freshwater Lake Iznik (Turkey), the maximum age for both males and females was 5 years (four age groups 0–IV); the maximum size was 110 mm (TW = 9 g) for males and 115 mm (TW = 11 g) for females. The size/weight relationship was TW = $0.002TL^{3,485}$ for males and TW = $0.004TL^{3,062}$ for females. The parameters of the von Bertalanffy equation were as follows: TL_∞ = 141.11 mm, K = 0.27 $year^{-1}$, t_0 = –0.49 year for both sexes; TL_∞ = 121.11 mm, k = 0.33 $year^{-1}$, t_0 = –0.28 year for males; TL_∞ = 155.31 mm, K = 0.21 $year^{-1}$, t_0 = –0.73 year for females. In Lake Kouma in Crete, the maximum size was TL = 9 cm (Tingilis, 2001).

According to Gon and Ben-Tuvia (1983), the population of the Bardawil lagoon (Egypt) was mainly composed of individuals aged at least one year (0^+), and some 1^+ (otolithometry) did not exceed a size of 63 mm SL (9,705 individuals examined). In this lagoon, Ben-Tuvia and Golani (1993) only collected small individuals from the "aged 0 group" and in the sea, they collected 1^+ individuals ranging from 60 to 80 mm TL (TL_{max} = 95 mm), which confirms Gon and Ben-Tuvia's (1983) hypothesis that individuals longer than 60 mm leave this lagoon. In the Bardawil lagoon (Egypt), the TW (individuals in formaldehyde)/SL relationship was TW g = $13.7.10^{-6}SL^{2.93}$ mm (Gon and Ben-Tuvia, 1983). In the Karoun lagoon (Egypt), the maximum size was TL = 95 mm (El-Zarka, 1968).

In the Ichkeul lagoon (Tunisia), the maximum size was TL = 108 mm (Trabelsi *et al.*, 1994a). In the Bizerte lagoon, for sizes between 21 and 60 mm TL (TW = 0.22–1.73 g), the parameters for the ratio $TW = aTL^{b}$ were as follows: a = 0.0079, b = 3.275 for males; a = 0.0087, b = 3.369 for females; $TW = 0.0086TL^{3,092}$ for both sexes (Bouriga *et al.*, 2014). In the Mellah lagoon (Algeria), TL_{max} = 8.3 cm and in the Ziama estuary, TL_{max} = 20.2 cm (Boudinar *et al.*, 2015). For the same Algerian lagoon, Boudinar *et al.* (2016a) indicated that the maximum size of females was slightly higher than that of males because they did not exceed the size class 8.0–8.4 cm TL, while females fit into the size class 8.4–8.7 cm TL. As with females in this lagoon, males reached the age of 3 years (scalimetric and otolithometric observations), and the "total length (cm)/raw weight (g)" relationships were as follows: $TW = 0.0054TL^{3,077}$ for males; $TW = 0.0047\ TW^{3,176}$ for females; $TW = 0.0046TL^{3,179}$ for both sexes. In addition, according to a scalimetric evaluation of age, the parameters of the von Bertalanffy equation were as follows: L_{∞} = 9.49 cm, k = 0.316, t_0 = –0.998 year for males and L_{∞} = 11.67 cm, k = 0.179, t_0 = –1.514 year for females. According to an otolithometric evaluation of age, these parameters were as follows: L_{∞} = 9.68 cm, k = 0.3, t_0 = –1.02 year for males; L_{∞} = 11.93, k = 0.171; t_0 = –1.55 year for females. According to Munro and Pauly's index, growth performances were the same for both males (3.24) and females (3.19) in the Mellah lagoon (Boudinar *et al.*, 2016a). In an estuary near the Mediterranean (the Guadalquivir estuary (Spain)), growth was continuous during the whole year, with slowing in March–April, the spawning period and the formation of a growth cessation ring between April and July. In this case, 60% of maximum size was reached in the first year of life; age did not exceed 2 years (group 2^{+}) (Fernandez-Delgado *et al.*, 1988).

In the freshwater Lake Trasimeno (Italy), the maximum size reached was 10.10 cm TL and the maximum weight was 8.20 g. Although sex was not recorded, the authors indicated that females were larger and heavier and had a longer lifespan than males (maximum age 4^{+}, sex not indicated). The equation parameters described the relationship between weight (W raw of ungutted fish) and size (TL) which was significantly different from those of females ($\log_{10}W = -2.326 + 3.139 \log_{10} TL$) and males ($\log_{10}W = -2.366 + 3.168 \log_{10} TL$). The parameters of the von Bertalanffy equation (for both sexes) were as follows: TL_{∞} = 10.03 cm, k = 0.18 $year^{-1}$, t_0= –0.443 year (scalimetry).

Population structure and dynamics: in the Zonar lagoon (Spain), the M/F sex ratio was 0.8. This value changed according to size; above 71.5 mm TL, only the females were represented (Fernandez-Delgado and Hernando Casal, 1982). In Mar Menor, between February and December 1997, 1.3% of ichthyoplankton comprised Atherinidae larvae (6.0–19.2 mm TL) with a density of 7.8 ± 1.0 larvae for 1,000 m^3 (Pérez-Ruzafa *et al.*, 2004). In this lagoon (November 1997, September 1998), the sex ratio generally favored females (1,978 males/2,263 females), but males dominated the age class 1^+. In the Leucate, Canet and the Bourdigou estuaries (France) in 1978, Atherinidae populations comprised 95% individuals below 2 years (Marfin, 1982a). Kohler (1976) described the recruitment dynamic in the Prévost lagoon (France): from January to March, the size distribution was unimodal (mode 7.5–6.5 cm TL); in April, there was a massive recruitment of small-sized individuals (mode 4.5 cm TL), larger than that found in December with a group of individuals whose mode was about 7.5 cm TL; finally, small-sized individuals disappeared in January. In this lagoon, the overall sex ratio was balanced, but with changes depending on size: M/F = 1.35 for TL = 4–7 cm and 0.71 for TL = 7–10 cm. Mouillot *et al.* (2007) placed Atherinidae in the general context of the functional organization of 17 species of fish in the lagoons of Salse-Leucate and Saint-Nazaire (France) according to morpho-anatomical characteristics and physicochemical factors in the environment, including salinity. In the backwaters of the Vaccarès pool (Fumemorte canal and Relongues ponds) in the Camargue, catches made in November 1988 (18,878) and July 1989 (117,423 individuals) indicated the great numerical abundance of Atherinidae, respectively 79.44% and 31.54%, followed by *Liza ramada* and *Mugil cephalus* (8.11% and 0.21%), *Lepomis gibbosus* (5.55% and 0.20%) and *Ameiurus melas* (2.54% and 0.09%); the percentage of other species was less than 1% except for *Gambusia affinis* and *Gasterosteus aculeatus* which reached 59.80% and 7.21% in Relongues (Poizat and Crivelli, 1997). In the Imperial lagoon in the Camargue, the structure of the population was very homogeneous (TL = 35–93 mm and M/F sex ratio = 1.04 from March to May) (Bardin and Pont, 2002). Of the 9,779 fish caught (15 species), Atherinidae was placed third (19.3%) after gobies, *Pomatoschistus microps* (44.9%) and mullets (28.0%), followed by eels, mosquito fish, sticklebacks, sole, bass and sardine (Bardin and Pont, 2002).

The Mar Piccolo (southern Italy) is rich in 28 species from 16 families (Prato and Prato, 2010). In 2007–2008, of the species caught, *A. boyeri* represented 32.1%, *Liza aurata* 28.3%, *Symphodus cinereus* 7.2% and *Zosterisessor ophiocephalus* 7.1%. In the lagoon of Venice, the sex ratio was balanced (M/F = 1.01), and the maximum sizes of males and females differed slightly (Boscolo, 1970). In the lagoon of Lesina, the global M/F sex-ratio was 0.6 (n = 1816). It was balanced between 2 and 4 cm SL and appeared to favor females with sizes between 4 and 7 cm SL (M/F = 0.7–0.1); no males were found to be larger than 7–8 cm SL (Bello *et al.,* 1997). In the Pantana lagoon (Croatia), during the spawning season from March to July 2000, the sex ratio was M/F = 1/1.03; males dominated in the small size ranges, while individuals larger than 10.9 cm TL were females (Pallaoro *et al*., 2002). In the estuary of the river Pantan (Adriatic), of the 9,434 individuals caught (42 species) over the four seasons, *A. boyeri* represented 33.2%, *Pomatoschistus marmoratus* 28.1%, *Liza aurata* 8.3% and *Liza ramada* 7.1% (Matic-Skoko *et al*., 2005). In the estuary of the river Zrmanja (Adriatic), of the 10,035 specimens collected over the four seasons belonging to 17 families, Atherinidae represented 60.3%, followed by *Symphodus ocellatus* (14.4%) and *Pomatoschistus marmoratus*

(7.5%) (Matic-Skoko *et al.*, 2007). In the Mala estuary Neretva (Croatia), five age classes (0, 1, 2, 3, 4) were identified, in which 4^+ individuals represented up to 2% of samples collected in March–April. The global sex ratio favored females (M/F = 0.76). Males that dominated from April to June (spawning period) were in the class size 6.5–7 cm TL (Bartulovic *et al.*, 2004b). Recruitment of juveniles (0^+) began in June and stopped in October, with a variable average size at recruitment: 3.9 cm TL in June, 4.3 cm in July and 4.1 cm in August 2001 (Bartulovic *et al.*, 2006). In the estuaries of the Neretva and Mala Neretva (Croatia), Dulčić *et al.* (2007) indicated that young specimens of the year (Y-O-Y) were very abundant. The Bay of Maliston, an estuary of a pre-lagoon zone influenced by the river Neretva (Croatia), is rich in 28 species. In 2003, *A. boyeri* represented 81.87% of catches, followed by *A. hepsetus* (6.31%). In the lagoon of Porto-Lagos (Greece, Aegean Sea), of over 35 listed species, *Atherina boyeri* was the most abundant (46.6%) in drag-net fishing catches, followed by *Pomatoschistus marmoratus* (28%) and *Aphanius fasciatus* (9.1%) (Koutrakis *et al.*, 2005). In the Vistonis Lake system and the Porto Lagos lagoon, five age classes (0, 1, 2, 3, 4) coexisted with an M/F sex ratio of 1/2.5 (n = 246) (Koutrakis *et al.*, 2004); males that dominated from August to November and females were always more abundant in size classes above 60 mm TL. Catches in the Drana lagoon (Greece, Aegean Sea), which was reconnected to the sea in 2004 with salinity reaching 41‰, were numerically dominated by *A. boyeri* (37.6%) and *Pomatoschistus marmoratus* (31.7%); mullet represented only 5.2% (Koutrakis, 2009). In the Messolonghi and Etolikon lagoons (Leonardos and Sinis, 2000), four age classes (0, 1, 2, 3) were identified, with individuals dominating the first two age classes. The recruitment of 0^+ fishes took place from May to October. In these lagoons, the global M/F sex ratio was 1/1.2 with substantial seasonal variations: males dominated in February–March and females from April. In Lake Trichonis (Greece), in April 1992, the Atherinidae population was classified into five age classes (0, 1, 2, 3, 4); the percentages with which they occurred were 36, 30, 21, 12, and 0.2% respectively (Leonardos *et al.*, 1993; Leonardos, 2001). In the small Italian lagoon Aquatina (0.45 km^2, 2 m deep), *A. boyeri* was the most abundant species (95% of fish captured); the structure of this population showed modifications over time linked to the biological cycle and seasons, as well as spatial variations depending on local conditions (Maci and Basset, 2009, 2010). These authors noted that the smallest individuals were primarily found in confined zones and that the condition of large specimens was better than that of small specimens, especially when they occupied sites with optimal temperature and well-oxygenated water. They emphasized that small-scale environmental gradients could cause movement and determine preferential locations and differential physiological states (conditions) within a population, as important on the scale of seas or continents. In the Ösmerli reservoir (Turkey), the Atherinidae population included more than four age groups (0, 1, 2, 3 years) (Tarkan *et al.*, 2007) and the M/F sex ratio was 1/1.25, ranging from 1/1.28 in the Homa lagoon and 1/1.96 in the Bay of Izmir. According to Ozeren (2009), four or five age classes could coexist in the freshwater Lake Iznik where the M/F sex ratio was 1/1.7. The sampled population in the hypersaline Bardawil lagoon (Egypt) was mainly composed of small individuals (12–30 mm SL) belonging to “age group 0” and some larger individuals (maximum 63 mm SL) from “age group 1” (otolithometry) (Gon and Ben-Tuvia, 1983). In this same lagoon, Ben-Tuvia and Golani (1993) detected only the presence of 0^+ individuals (otolithometry), and collected older “age group 1” specimens in the sea. According to Gon and Ben-Tuvia (1983), the sex ratio of the population of the Bardawil lagoon varied according to size: F/M = 1/1 for less than 34 mm SL; 1.8/1 for 35–50 mm SL; 25/1 for SL > 50 mm; and F/M = 1.7 for 10–60 mm SL. In the lagoon of Bizerte, the sex ratio favors females regardless of the month (M/F= 1/1.5 for TL = 55–19 mm) (Bouriga *et al*., 2014). According to Boudinar *et al.* (2016a), in the Mellah lagoon (Algeria), four age groups could be present (0^+, 1^+, 2^+ and 3^+); the global F/M sex ratio = 1.6/1 (770 M, 523 F); males dominated up to 4.5 cm TL and then the proportion of females increased gradually to reach 96% for the size class (TL) of 7.5–8.0 cm. In the Guadalquivir, the population was divided into three age groups (0^+, 1^+, 2^+) and the sex ratio was generally balanced, although males dominated in April and females in January–February.

In the freshwater Lake Trasimeno (Italy), five age classes could coexist (0^+ to 4^+); the global sex ratio favored females (411 M/583 F), but males dominated in the lower size and age classes (M/F = 1.43 among the 0^+ group; 1.22 among the 1^+ group; 0.76 among the 2^+ group and 0.007 among the 4^+ group).

Predation certainly plays an important role in structuring Atherinidae populations. In fact, this species is well known as the prey of many birds and fish, such as the gobie burbot *Zosterisessor ophiocephalus* (Grinbart, 1960; Pavlov, 1960; Pinchuk in Miller, 2004) and eel.

1.1.1.5. *Food and feeding behavior*

Atherinidae in lagoons are mainly zooplanktivorous (copepods) in deep lagoons and zoobenthivores (amphipods) in less deep lagoons (Kiener and Spillmann, 1969; Marfin, 1982b; Trabelsi *et al*., 1994a) (Table 1.1). Some authors believed that this species, whose feeding regime changes depending on size, is opportunistic (Vizzini and Mazzola, 2002). This opportunism is especially true of large specimens. Alessio *et al.* (1990) also concluded that Atherinidae from various sites in the Viareggio region (Italy), including the Massaciuccoli lagoon, are opportunistic. In the Prévost lagoon (France), Kohler (1976) showed that the size of prey (between 0.2 and 5 mm) increases with that of fish: for an individual of 4 cm TL, prey measure about 0.7 cm and have an average of 1.7 cm for a TL of 8 cm. Marfin (1982b) gave a very detailed analysis of the feeding regimes of Atherinidae collected by beach drag-nets between 10 and 16h in the Bourdigou estuary (France, the eastern Pyrenees). The results were given according to sex, size, the condition of individuals and the month of collection. The size of prey is directly linked to that of the consumer. Small Atherinidae (40–50 mm SL) feed on copepods of size of about 0.5 mm and nauplii of size 0.2 mm, and large Atherinidae (SL ≥ 60 mm) feed on amphipods such as *Corophium volutator* of size 0.8–5.8 mm and *Gammarus inaequicauda* of size 0.8–8.4 mm. According to Hureau's (1977) classification, amphipods (*Corophium volutator*, *Gammarus inaequicauda*) are the main prey, and both harpacticoid copepods and ostracods are secondary prey; however, the "E" index (called a "predation effort index") showed that the total contribution of prey ingested is significant for planktonic copepods (41.8%,), corophiidae (20%), harpacticoid copepods (14.6%), cladocera (9%) and gammarids (2.8%). Predation activity is especially important in spring and autumn, and shows notable differences according to year and seasons. Thus, during the months of April, May and June 1978, corophiidae and gammarids, and then benthic harpacticoid copepods dominated, whereas in 1979 (March, April and May), planktonic copepods were almost exclusive. During the month of July 1978, harpacticoid copepods and corophiidae were abundant. In autumn (September–November 1978), benthic harpacticoid copepods, planktonic copepods and cladocera were present in the same proportions. Finally, in winter, large crustaceans clearly dominated (mysidacea, isopods and then gammarids). In the Massaciuccoli lagoon and its backwaters (Burlamacca canal and the port of Viarregio), Alessio *et al.* (1990) showed notable differences according to the size and habitat occupied by the 188 specimens studied. In lagoons relatively influenced by continental waters, Atherinidae of 31–50 mm TL consume in order of preference, for example chironomidae, hymenoptera and then spheroma; those measuring 51–70 mm feed on chironomidae, gammarids and then spheroma; those measuring 71–90 mm feed on spheroma, gammarids, then ostracods and chironomidae. In the canal, regardless of the size, chironomidae dominate; those measuring 51–90 mm additionally consume gammarids and spheroma. In the port, individuals of size 51–70 mm feed on chironomidae, decapods, gammarids and spheroma. In the Po delta (Sacca di Scardovari), during summer, young 0^+ zooplanktivores feed on polychaete larvae, mollusks, crustaceans; larger individuals consume macroplankton (mysidacea, large crustacean larvae) and meso-macrobenthos (annelids, amphipods) (Ferrari and Rossi, 1993).

In the Marsala lagoon (Sicily), Atherinidae display a primarily nocturnal feeding activity (Mirto *et al.*, 1994). This is a relatively voracious species that competes with other fish (Klovach, 1980; Mazzola *et al.*, 1999), for example mosquitofish (Gisbert *et al.*, 1996) during their planktivorous phase, as well as with other species at the adult stage, as in the Marsala lagoon (Sicily) where its competitors are small gobies, young mullets and the cyprinodont *Aphanius fasciatus* (Mazzola *et al.*, 1999). The voracity of Atherinidae has been highlighted in the Sea of Aral where they were introduced between 1953 and 1954 (Konovalov, 1959). In the space of a decade, the biomass of the copepod *Diaptomus salinus* was dramatically reduced, before exploiting the copepod *Calanipeda aquaedulcis* (Markevich, 1977).

Prey	Males				Females			
	NP (NE)	Av.	F	Cn%	NP (NE)	Av.	F	Cn%
Crustaceans	/	/	/	/	/	/	/	/
–Copepods	187(2)	93.50	0.01	17.24	/	/	/	/
–Amphipods	/	/	/	/	/	/	/	/
Corophiidae	292(42)	6.95	0.21	26.91	218(24)	9.08	0.25	40.37
Gammarids	68(44)	1.55	0.22	6.27	34(27)	1.26	0.28	6.30
Total	360(75)	4.80	0.38	33.18	252(42)	6.00	0.43	46.67
–Isopods	/	/	/	/	/	/	/	/
Idoteidae	81(32)	2.53	0.16	7.47	24(9)	2.67	0.09	4.44
Spheromidae	95(34)	2.79	0.17	8.76	47(16)	2.94	0.16	8.70
Total	176(55)	3.20	0.28	16.22	71(22)	3.23	0.23	13.15
–Ostracods	2(2)	1.00	0.01	0.18	53(2)	26.50	0.02	9.81
–Mysidacea	1(1)	1.00	0.01	0.09	4(2)	2.00	0.02	0.74
–Indeterminate	2(2)	1.00	0.01	0.18	3(3)	100	0.03	0.56
Total	727(110)	6.61	0.55	67.00	383(64)	5.98	0.66	70.93
Annelids	140(31)	4.52	0.16	12.90	59(14)	4.21	0.14	10.93
Mollusks	1(1)	1.00	0.01	0.09	/	/	/	/
Insects	5(3)	1.67	0.02	0.46	/	/	/	/
Syngnathid	1(1)	1.00	0.01	0.09	/	/	/	/
Spawning	7(7)	1.00	0.04	0.65	2(2)	1.00	0.02	0.37
Vegetation	30(30)	1.00	0.15	2.76	15(15)	1.00	0.15	2.78
Scales	26(26)	1.00	0.13	2.40	14(14)	1.00	0.14	2.59
Sand	17(17)	1.00	0.09	1.57	10(10)	1.00	0.10	1.85
Indeterminate	130(130)	1.00	0.65	11.98	57(57)	1.00	0.59	10.56
Total	1085(199)	5.45	2.06	/	540(97)	5.57	1.99	/
Cv	/	0.19	/	/	/	0.15	/	/
Ish	/	3.06	/	/	/	2.81	/	/

Table 1.1. *Feeding regime of* Atherina *lagunae in the Ichkeul lagoon (Tunisia). N: number of specimens for a given prey; NE: number of stomachs containing a given prey; Av: average; F: frequency; CN: percentage; Ish: Shannon diversity index; Cv: emptiness index (according to Trabelsi, 1994)*

According to Kohler (1976), in the fairly shallow Prévost lagoon (France), Atherinidae are polyphagous with a change in their feeding regime when they reach the size of 60 mm TL; benthic gammarids then become their preferred prey. In the Fumemorte canal and the Relonges seas (Camargue) with a salinity ranging from 0.2 to 3.5 $g.l^{-1}$, Atherinidae primarily feed on crustaceans (cladocera and copepods) and Diptera larvae, and secondarily on ostracods and amphipods. Individuals from 32 to 55 mm FL mainly consume zooplankton, Diptera and ostracod larvae; the occurrence of insects (larvae and adults), amphipods and decapods increases with size, and the size of prey is significantly correlated with the size of Atherinidae (Rosecchi and Crivelli, 1992). In the Sabaudia lagoon (Italy), the isotopic composition ($\delta^{13}C$ and $\delta^{15}N$) of Atherinidae indicates that in summer, their prey are benthic and in winter they prefer to consume zooplankton (Sara *et al.*, 2002). In the lagoons of the Po delta, Ferrari and Rossi (1983) showed that the feeding regime changes according to the size of the fish, and that amphipods and polychaete gradually become dominant. In the Marsala lagoon (Sardinia), Vizzini and Mazzola (2002, 2003, 2005) studied the structure of the feeding chain leading to Atherinidae (15–50 mm and 30–40 mm SL) using stable isotopes, the $^{13}C/^{12}C$ ratio of the isotopic composition $\delta^{13}C$ and $\delta^{15}N$. The results obtained indicate that, in this fairly shallow lagoon (mean 1 m), feeding is composed exclusively of benthic prey. As Vizzini and Mazzola (2005) emphasize, divergences observed between the composition of stomach contents and the results of isotopic studies are due to the fact that stomach content reflects short-term composition (hours or a day) of prey ingested and not always assimilated, whereas stable isotopes in muscles give information about feeding assimilated over months by the predator.

Zooplankton dominated in the feeding of 1,236 Atherinidae (4.5–11.6 cm TL) in the estuary of the river Mala Neretva (Croatia), which was examined between March 2001 and February 2002 (Bartulovic *et al.*, 2004a). Copepod crustaceans (45%), especially harpacticoids, were the most abundant prey, followed by gammarid amphipods (34%), cladocera (13%) and decapod larvae (12%). However, freshwater species (Daphnies, Cyclops) appeared only occasionally. Copepods mainly dominated in autumn and winter at the very time, moreover, when overall species diversity was higher. The number of empty stomachs was highest during the spawning season (spring, summer). Atherinidae in the freshwater Lake Trikonis (Greece) are also planktivores (Chrisafi *et al.*, 2007). The feeding regime of 240 individuals (35–112 mm TL) caught in January and December 1997 varied according to the season and depended on the relative composition and abundance of available planktonic prey (bivalve mollusk larvae from January to May; copepods and cladocera from June to December). The importance of copepods and cladocera decreased with the size of Atherinidae; those of bivalve larvae and fish eggs increased along with the size of Atherinidae. The number of empty stomachs was highest in winter (50% in January). Overall, larvae of the bivalve *Dreissena polymorpha*, the copepod *Eudiaptomus drieschi* and the cladocera *Diaphanosoma brachyurum* were the dominant prey in this lake (Chrisafi *et al*., 2007). In the same lake, Doulka *et al.* (2012) indicated that Atherinidae choose their prey at the species level depending on size. They feed on adult *Eudiaptomus* (copepod), *Diaphanosoma* and *Daphnia* (cladocera) and avoid nauplii, copepodites and rotifers. Selection of large prey increases with age and large individuals even become cannibals, that is, they feed on their own species' larvae and *Economichthys trichonis*. According to Doulka *et al.* (2012), *Atherina* can have an impact on the abundance and composition of the plankton community. In the Laki lagoon (Evros delta, north-east Aegean), the predation of *Atherina* on benthic invertebrates could even be the root cause of the "decline in the density of some invertebrates" (*Cerastoderma glaucum, Gammarus aequicauda, Ventrosia maritima*) at the end of autumn and winter, when plankton become rarer (Mogias and Kevrekidis, 2005). In the fairly shallow hypersaline water of Bardawil lagoon (Egypt), the stomach content of *Atherina* mainly consists of copepods (80% of 130 stomachs examined), benthic harpacticoids (*Paramphiascella* sp.), plankton (*Euterpina* sp.), calanoid amphipods (19.2% of stomachs examined) (*Corophium* sp.) and veligers (4.8% of the stomachs examined) (Gon and Ben-Tuvia, 1983; Ben-Tuvia and Golani, 1993). Occasionally, chironomidae larvae (*Cricotopus mediterraneus*) are found. Trabelsi *et al*. (1994a) analyzed the stomach content of 720 specimens (38–108 mm TL) from the fairly shallow Ichkeul lagoon (Tunisia) with very variable salinity and the marine zone of Monastir between June 1984 and May 1985. In the lagoon, feeding was varied, which comprised amphipods, corophidae, gammarids and occasionally isopods, annelids and copepods. In the sea, prey were almost exclusively copepods and secondarily annelids, isopods (*Idotea*) and amphipods (gammarids). In lagoons, the stomach emptiness index was more substantial in autumn and winter than during spring and summer, and the species diversity index (Ish = 3.09) was higher than in the sea (ISh = 0.89). This difference can be attributed to the spatial and temporal heterogeneity of Lake Ichkeul.

Shaiek *et al.* (2015), who studied the feeding regime of 16 fish species in the Ichkeul lagoon, indicated that *A. lagunae* fed primarily on crustaceans (gammarids, spheromes, *Idotea*, corophium, ostracods) and secondarily on the gasteropod *Hydrobia* sp. Its main competitor is *Aphanius fasciatus*. Bouriga *et al.* (2010) compared the water, protein, lipid and ash content of Atherinidae from the Bizerte lagoon, Tunisia (*A. lagunae*), and the sea (*A. boyeri*) adjacent to the lagoon. The authors also compared the fatty acid and amino acid content of the Atherinidae population. They found that saturated fatty acids represented up to 43.54% of lipids in marine *A. boyeri* compared with 33.64% in lagoon *A. lagunae*. The tissues of lagoon and marine Atherinidae were rich in glutamic acid. Methionine content was fairly low in *A. boyeri*, whereas the essential amino acid tryptophan was least well-represented in *A. lagunae*.

1.1.1.6. *Reproduction and reproductive behavior*

Sexuality: *Atherina lagunae* is gonochoric. Only the right ovary is present (Arru, 1968). Its structure is heterogeneous. In this species, Fernandez-Delgado *et al.* (1998) distinguished three groups of oocyte: 1) transparent ovocytes with a diameter less than 0.6 mm; 2) white-yellow opaque ovocytes with a diameter less than 0.9 mm; 3) mature ovocytes, with a diameter greater than 1.0 mm, opaque, yellow-orange in color with droplets of oil and filaments. In Mar Menor (Spain) the GSI of males and females is at a maximum between the end of April and the end of May and is higher in 2+ females than in 1+ females (Andreu-Solar *et al.*, 2006b) and in 2^+ females than in 1^+ males. In the Prévost lagoon (France), the GSI is maximum in April and then decreases until July and increases from December (Kohler, 1976). In this lagoon, the relative weight of the gonads increases along with the size of individuals. In the same region (Figure 1.4), in the lagoons of Méjean, Prévost and Mauguio, GSI = Wo × 100/Ws (Ws = Wt–Wo) reached its highest value in April 1992, 1993 and 1994 with the respective maximums of 33.6, 43.5 and 33.6% (the mean maximum GSI in April being 20%) (Tomasini *et al.*, 1996). The diameter of mature ovocytes varies between 1.38 and 1.94 mm. It is positively correlated with the size of females, but declines (Figure 1.5) regardless of their size during the spawning season (Tomasini *et al.*, 1996). In the Camargue, in the Fumemorte canal and the Ralongues seas (salinity 0.2–3.5 $g.l^{-1}$), GSI (gutted body weight, EW) reached a mean maximum of 9.06% in males in April and 13.3% in May in females (Rosecchi and Crivelli, 1992). The frequency distribution of ovocyte diameters in the ovary is bi- or tri-modal (extreme diameters: 0.1–0.7, 0.75–1.1 and 1.3–2.0 mm), which indicates a fractionated spawning. In the Bizerte lagoon (Bourriga *et al.*, 2014), the maximum GSI (M = 6%, F = slightly more than 6% of total weight) was reached in April–May. In Lake Tunis, the maximum GSI (total body weight TW) of females is 11.29% and that of males is 10.03% (Ayed *et al.*, 2012). According to Boudinar *et al.* (2016a), in the Mellah lagoon (Algeria) the maximum GSI (TW) of females is 11.2% and that of males is 5.8% in April. In the Guadalquivir estuary, the GSI (Wo × 100/TW) is maximum in April (8% in females and 4% in males) and minimum in June–July (Fernandez-Delgado *et al.*, 1998).

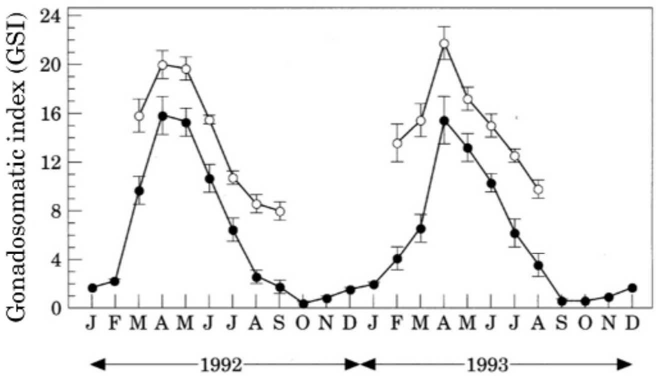

Figure 1.4. *Monthly variations in the gonadosomatic index (GSI) of* Atherina lagunae *from January 1992 to December 1993 in the Mauguio lagoon, France. General average (filled circles) and averages for mature adult females (empty circles) (according to Tomasini* et al.*, 1996)*

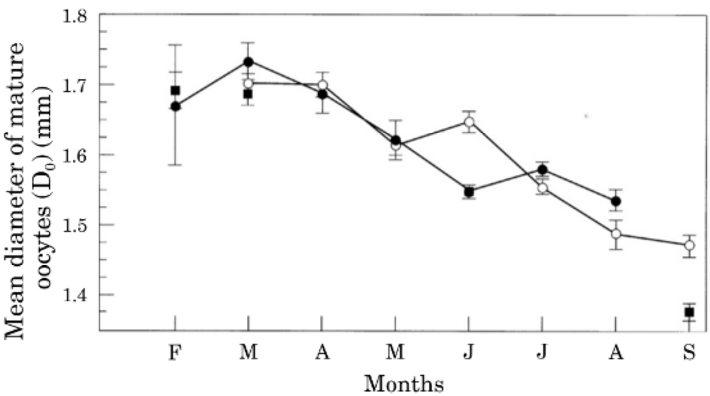

Figure 1.5. *Monthly variations in the diameter (mm) of intra-ovarian mature ovocytes for cohorts of* Atherina lagunae *from 1992 (○), 1993 (●) and 1994 (■) in the Mauguio lagoon (according to Tomasini* et al.*, 1996)*

First sexual maturity: according to Andreu-Soler *et al.* (2006b, 2006c), in the Mar Menor sea (Spain), all individuals of 39–94 mm FL (ages 1^+ to 3^+) are sexually mature. In the Prévost lagoon (France), Kohler (1976) indicated that the "average" size at first maturity was 5 cm. In the Mauguio lagoon (France), the minimum size at first maturity for females was 34 mm FL (age about 12 months) (Quignard *et al.*, 1993); in those of Méjean, Prévost and Mauguio, it was 38 mm TL in 1992 and

40 mm TL in 1993 (Tomasini *et al.*, 1996). In the Camargue, in the Fumemorte canal and the Ralongues seas, the smallest sexually mature female measured 34 mm FL, and from 41 mm FL (average size of 1^+), 100% of the population reproduced (Rosecchi and Crivelli, 1992). In the Impérial lagoon (Camargue), first sexual maturity appeared at 38 mm TL, but the authors (Bardin and Pont, 2002) did not specify sex. In the Neretva estuary (Croatia), the smallest mature female measured 5.20 cm TL and 50% of them were mature at 7.75 cm TL and 4.3 cm SL (Bartulovic *et al.*, 2006). In the lagoons of Messolonghi and Etolikon (Greece), individuals born at the beginning of the spawning season could be "mature" (well-developed gonads, but not necessarily laying) at the end of the first year of life at an average size of 34 mm TL (Leonardos and Sinis, 2000). In Turkey, regardless of the biotope (Ömerli reservoir, the Homa lagoon or Bay of Izmir), age at first sexual maturity was estimated as 1 year, and sizes at first sexual maturity were 4.1, 4.6 and 5.1 cm TL respectively. In the Suez Canal, the smallest adult female measured 2.7 cm SL (Fouda, 1994) and in the Bardawil lagoon (Egypt), first sexual maturity was reached at 34 mm SL (Gon and Ben-Tuvia 1983). In the North Lake of Tunis, the first mature females were 3.9 cm TL and 50% of them were mature at 5.8 cm TL (Ayed *et al.*, 2012). In the Mellah lagoon (Algeria), age at first sexual maturity was 1 year in males and females, and size at first sexual maturity ($TL_{50\%}$) was 4.35 cm for females and 4.20 cm for males. In addition, all individuals of 3 cm TL and below were juveniles; all females over 6.7 cm and all males over 6.2 cm were adults. In the space adjoining the Mediterranean, the Guadalquivir (Fernandez-Delgado and Casal, 1982; Fernandez *et al.*, 1988), size at first maturity was 4.00 cm FL for both males and females, with an average age of 1 year.

Spawning sites and periods: sites favorable for spawning are those that display great richness in erect algae and phanerogams on which the females can "hang" their ovocytes.

In the Mar Menor, spawning extends from March to July–August, with a maximum GSI at the end of April for males and at the end of May for females (Andreu-Soler *et al.*, 2006b, 2006c). In the Prévost lagoon (France), spawning extends from April to July with a maximum in May–June (Kohler, 1976). In the Mauguio lagoon (France), it extends from March to June (Quignard *et al.*, 1993). In the lagoons of the Gulf of Lion (Méjean, Pérols, Mauguio), mature females can be observed from the end of February to the end of August and sometimes in September, with a maximum in April–May (Figure 1.4), with spawning being particularly intense from April to June (Tomasini *et al.*, 1996, 1999; Tomasini and Laugier, 2002). Large specimens begin to lay earlier and stop later than smaller ones (April–June–July). Spawning in the Fumemorte canal and the temporary Relongues seas (Camargue) extends from the end of March to the end of June. At the beginning of the spawning season all the females lay eggs but at the end only the largest females will be spawning (Rosecchi and Crivelli, 1992), as in the lagoons of Méjean, Prévost and Mauguio (Tomasini *et al.*, 1999), whereas the reverse is true in the Thau lagoon (Bach, 1995). Some females that flee the Ralongues seas (Camargue) because of poor hydroclimatic conditions do not stop laying, and thus they distribute their ovocytes between Ralongues and Fumemorte where they end up (Rosecchi and Crivelli, 1992). In the Impérial lagoon (Camargue), all individuals were mature in March (samples collected on 23–24 March) (Bardin and Pont, 2002). In the lagoon of Venice, spawning mainly extend from May to August (Boscolo, 1970). In the lagoon of Lesina, it extends between February and June (Trotta *et al.*, 2009), and perhaps in October according to Vaglio *et al.* (1998 in Trotta *et al.*, 2009). In the Neretva estuary (Croatia), Atherinidae lay from April to July (Bartulovic *et al.*, 2006); their GSI is maximum in April (5.4% in females and 4.7% in males, raw body weight, ungutted) and reach a minimum size in August (< 1%). These authors indicated the low maximum GSI value recorded for females compared to those indicated in other Mediterranean lagoons (1.3%–10.60% in the south of France) (Rosecchi and Crivelli, 1992; Tomasini and Lauguier, 2002); however, it is similar to that for female Atherinidae in the Suez Canal (5.3% according to Fouda, 1994). In the lagoons of Messolonghi and Etolikon (Greece), spawning takes place from March to the end of July (Leonardos and Sinis, 2000); the maximum GSI value is reached in May (average: 13% in females and 8.2% in males). In the freshwater Lake Iznik (Turkey), Ozeren (2009) found that spawning takes place from March to July, especially in May, when GSI reaches its maximum (11.72 for females and 11.02 for males) with the diameter of ovocytes being generally maximum (1.10 mm). In the hypersaline lagoon of Bardawil (Egypt), the spawning season extends from March to the end of September (Gon and Ben-Tuvia, 1983), and in Lake Karoun (Egypt), gonads are mature during winter and spring (El Zarka, 1968). In the North Lake of Tunis, according to GSI values, spawning takes place perhaps as early as March, but mainly from May to July (Ayed *et al.*, 2012). In the Bizerte lagoon (Bourriga *et al.*, 2014), the maximum GSI (M = 6%, F = slightly more than 6% of total weight) is reached in April–May and minimum in August–September. The spawning period extends from April to July (August). In the Mellah lagoon (Algeria), similar to females, the GSI of males is maximum in April (5.8 and 11.2%); for females, the GSI is very low in June–August (about 2%) and minimum in September, and for males, it is very low in July–August (about 1.5%) and minimum in September. According to the data given by the authors, for females, we can suppose that spawning occurs from March to June. In the Guadalquivir estuary, spawning mainly took place between March and June with a maximum in April, but large individuals (2^+) could lay as early as January (Fernandez-Delgado and Hernando, 1982; Fernandez *et al.*, 1988). In the Italian freshwater Lake Trasimeno (Lorenzoni *et al.*, 2015), the reproductive period occurred from March to September following a change in the GSI (GSI_{max} 16% of total weight in April; GSI_{min} in October).

Fecundity: Fernandez-Delgado *et al*. (1998) expressed fertility (cumulative number of opaque white oocytes > 0.6 mm and opaque yellow-orange oocytes > 0.9 mm) according to the size ($F = 0.865FL^{2,486}$) of mature females from Guadalquivir. In the Mauguio lagoon (France), ovarian fertility (mature oocytes) varies according to size, between 10 and 339 oocytes per spawning activity (Quignard *et al*., 1993). In the lagoons of Méjean, Prévost and Mauguio, this same fertility varies according to size: F = 4 mature ovocytes at 43 mm TL, F = 12 at 60 mm TL, F = 391–447 at 96 mm TL, F = 419 at 101 mm TL. At a given time, and for a given size, fecundity is maximum between April and June (Figure 1.6) (Tomasini *et al*., 1996).

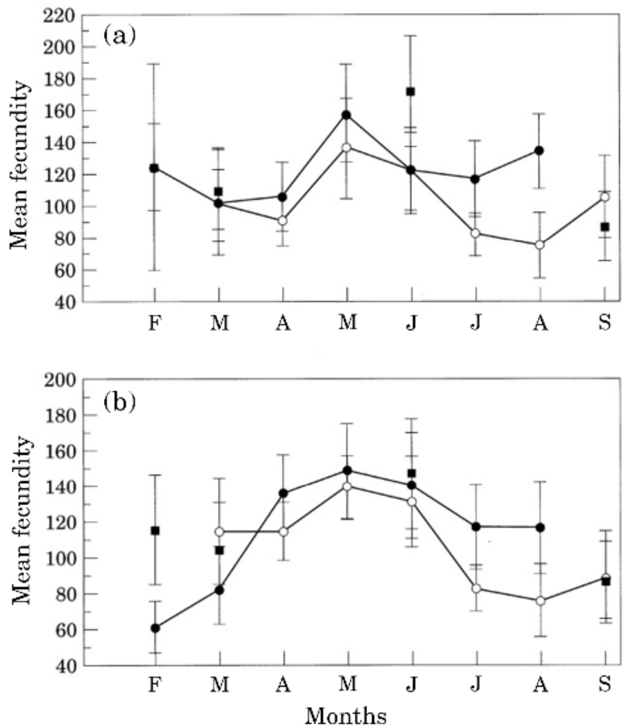

Figure 1.6. *Monthly variations in the fecundity (number of mature intra-ovarian ovocytes) of* Atherina lagunae *collected from the Mauguio lagoon in 1992 (○), 1993 (●) and 1994 (■). a) Averages calculated for all mature females. b) Averages calculated for mature females measuring between 55 and 94 mm TL (according to Tomasini* et al.*, 1996)*

In the Camargue (Fumemorte and Ralongues), fecundity (number of ovocytes spawned) per spawning activity is positively correlated with size (FL) and body weight (W) of the females (Rosecchi and Crivelli, 1992). According to fertility/length at the fork equations (Rosecchi and Crivelli, 1992), it can be estimated that for FL = 40–100 mm, fertility per spawning activity ranges from 14 to 623 oocytes. In Turkey, in the freshwater Lake Iznik, fecundity is positively correlated with size, age and weight of gonads (Ozeren, 2009). It is 450 for mature age group 1 (TL = 47 mm), 754 for age group 2 (TL = 70 mm), 1,490 for age group 3 (TL = 76.8 mm) and 1,724 for age group 4 (TL = 99,3 mm). In the Bardawil lagoon (Egypt), fecundity estimated in 30 individuals (40–50 mm SL) in February–March 1974 ranged between 502 and 568 ovocytes (522 on average) (Gon and Ben-Tuvia, 1983). In the Suez Canal, fecundity is very low and varies from 12 to 68 ovocytes (38 on average) (Fouda 1995).

Reproductive behavior: iteroparous species with fragmented (multiple) spawning during the season (Quignard *et al*., 1993). The female fixes her ovocytes with the help of fine filaments (Quignard *et al*., 1993; Daoulas *et al.*, 1997) on structures that are usually supple: algae, blooms, fishing nets, etc. The males that follow the females immediately fertilize the ovocytes laid. The eggs are immediately abandoned by the brooders.

Condition, reproduction and survival: in the Mar Menor, the condition (somatic body weight) grows in summer and remains stable from autumn until spring, then decreases until the end of June for females and until the end of July for males, just before the end of the spawning season (Andreu-Soler *et al*., 2006b); hepatic activity is continuous and only decreases during the spawning period. Visceral, hepatic and muscular lipid reserves in females from the lagoons of Méjean, Prévost and Mauguio (France) are at their maximum in autumn, and even earlier for visceral fat (Tomasini *et al*., 1999). The fat displays a second maximum weight in April that coincides with the maximum GSI, and thus with the beginning of the reproductive period. The increase in muscle reserves in small individuals and visceral reserves in large specimens before the end of the spawning season may be considered relevant to a strategy that aims to avoid exhaustion after spawning and thus reduce the risk of winter mortality, thereby ensuring reproductive success the following spring (Tomasini *et al*., 1999). The energy cycle of males is generally very similar to that of females (Tomasini and Laugier, 2002): fat reserves accumulated immediately after spawning, just before winter, are used for winter maintenance and to meet the needs for the coming reproductive season.

Egg, larva and ontogenesis: descriptions of eggs and larvae were provided by Holt (1899), Lo Bianco (1909), Viailli (1937), Jorne-Safriel and Shaw (1966), Boscolo (1970), Arru (1968), Economou *et al.* (1994), Ré and Meneses (2009).

From all these data, we can conclude that the eggs, provided with long and very fine filaments, have a diameter of 1.5–1.9 mm, and that the larva at hatching measures 5.5–6.0 mm. Dulčić *et al*. (2008) experimentally obtained fertile ovocytes of 1.58–2.05 mm (1.75 ± 0.10 mm on average). At 19.2°C, they develop in 211 h 32 min to 213 h 54 min. At hatching, the larvae measure 4.4–4.7 mm TL (4.5 ± 0.15 mm on average). Their vitelline vesicle is resorbed in 3 days. In the freshwater lagoon of Lake Trichonis (Greece), the "fresh" spherical eggs have a diameter of 1.5 mm; they contain many droplets of oil and have long, fine filaments that hold them to aquatic plants (Daoulas *et al*., 1997). The larvae, collected at hatching and preserved in 4% formaldehyde, measure 5.6–6.0 mm from the tip of the snout to the tip of the notochord, and their mouth is open. The vitelline vesicle is resorbed at 6.1–6.5 mm TL (2nd day). Scales appear at 19–20 mm SL (length of the snout at the rear end of the hypural plates). At all stages, the larvae display positive phototactism. Trotta *et al*. (2009) recorded spawning and development of eggs in an aquarium. The larvae fed with rotifers for a few days, then with artemia nauplii for a week and then with granules (Pellets Perla Plus I.O) reached 3 cm in 3 months (t° = 20°C; S‰ = 20–25).

1.1.1.7. *Pollution*

Atherina is very sensitive to water quality. The structure of its populations and the "quality" of its individuals respond rapidly to deterioration in the biotope. In fact, malformations in the skeleton (lordosis, scoliosis, etc.) have been reported in pollution "hot spots", such as in the Neretva estuary of Croatia (Tutman *et al.*, 2000) and the North Lake (lagoon) of Tunis (Ayed *et al*., 2008, 2009–2010). These malformations can be linked to the presence of high concentrations of copper and aluminum in the tissues of individuals collected in the North Lake of Tunis (Ayed *et al.*, 2009).

Moreover, high mortality rates were observed in fish, including Atherinidae, in the Etolikon lagoon of Greece, following the combined presence of gypsum from the watershed and organic matter, causing production of toxic H_2S and anaerobiosis (Leonardos and Sinis, 1997). Brehmer *et al.* (2011) suggested that *Atherina* can be a good indicator of the level of eutrophication in lagoons.

1.1.1.8. *Economic importance*

Atherinidae, regardless of their species, have a non-negligible economic importance on a local basis. For example, in the Greek lagoons of Vistonis and Porto Lagos, fishing was estimated at a rate of 285 metric tons in 1999 (Koutrakis, 2000); in the lagoon of Trikonis, it was estimated at an annual rate of 500 tons during 1990–2000 (Leonardos, 2001). In the Lesina lagoon (51.4 km^2, Italy), production is about 40 kg/ha/year (Trotta *et al*., 2009). These authors believe that this species is overfished.

1.1.1.9. *Protection and conservation status*

– IUCN global red list: LC.

– IUCN Mediterranean red list: LC.

1.2. References

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