Fish otoliths from the Messinian of Strada degli Archi (Tuscany, Italy) – Taxonomy and palaeoecology

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(With 3 figures, 1 plate and 1 table)

Abstract

The taxonomy and palaeoecology of a fish otolith assemblage deriving from the lower Messinian terrigenous deposits of the Strada degli Archi section, Fine Basin, Tuscany, have been investigated. The assemblage displays an evident oligotypic character and consists of 11 species-level taxa belonging to five families: Atherinidae, Cyprinodontidae, Gobiidae, Hemiramphidae and Polynemidae. Gobiids strongly dominate the taxonomic structure with seven taxa representing more than 93 % of the specimens examined, followed by atherinids (4.67 %), and cyprinodontids (0.77 %). Hemiramphids and polynemids are extremely rare, both represented by juveniles. The composition of the assemblage indicates a coastal lagoon permanently connected to the sea as the original depositional environment. The analysis of the ecotrophic guilds (ecological guilds, habitat, substratum preference, food preference) has revealed some structural and physiographic features of the original depositional environment, which was possibly characterized by a moderate degree of confinement, a soft and densely vegetated bottom, and a reduced spatial complexity. Finally, the analysis of the stratigraphic distribution of the recognized taxa has revealed that some of them are also members of the late Messinian 'Lago-mare' assemblages, implying that structurally similar marine-dependent brackish fish communities possibly occur in the Mediterranean throughout the whole Messinian.

Keywords: Fossil fish, otoliths, Messinian, palaeoenvironment, Italy.

Introduction

Fish remains, mostly articulated skeleton, are rather common in lower Messinian deposits of the Mediterranean areas (see Gaudant 2002). In general, the abundance of fish remains is clearly dependent from the physico-chemical character of the depositional environment. In particular, the abundance of articulated fish skeleton in lower Messinian sediments (Arambourg 1925, 1927; D'Erasmo 1928, 1929, 1930; Leonardi 1959; Bradley & Landini 1984; Bedini et al. 1986; Gaudant 1992; Gaudant et al. 1996; Carnevale 2004) is primarily due to the hypoxic condition of the sea floor that occurred during the rhythmic diatomitic-sapropel deposition that affected the whole Palaeomediterranean in response to the precessional forcing of ocean stratification (Filippelli et

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al. 2003; Perez-Folgado et al. 2003). Teeth and otoliths are also widely distributed in terrigenous and carbonate sediments of early Messinian age (see e.g. Mas & Fiol 2002; Bellas et al. 1998). The large part of the early Messinian fish assemblages is characterized by a sharp dominance of pelagic taxa, with a subordinate number of coastal neritic species. Thus, a detailed knowledge of the early Messinian oceanic fish communities of the Mediterranean has been assembled in the last decades, providing a tremendous opportunity to infer about the evolutionary patterns of the Mediterranean fish biota and its relationships to the climatic and geodynamic events that occurred in last portion of the Neogene. Therefore, even though the structure and composition of coastal pelagic and oceanic comunities is relatively well-known, the character of Messinian paralic and estuarine fish assemblages remains completely unknown. This is due to the rarity of fossiliferous brackish deposits of early Messinian age throughout the circum-Mediterranean region. The purpose of this paper is to describe the early Messinian fish otoliths from Strada degli Archi, in the Fine Basin, Tuscany, central Italy. The taxonomic analysis strongly suggests that the fauna from Strada degli Archi represents a paralic assemblage that inhabited a brackish coastal lagoon permanently connected to the sea. The fossils described herein provide the first evidence of transitional fish assemblage of early Messinian age known to date.

Geological and stratigraphic setting

The Neogene stratigraphic section of Strada degli Archi is located NW of the Colline Livornesi, in the northern part of the Fine Basin (fig. 1). The Fine Basin is one of the Neogene basins of Tuscany placed to the west of the metamorphic Middle Tuscan Ridge. These tectonic depressions are developed on the already delineated Apennines thrust-fold belt. Their origin is usually related to the extensional tectonic regime resulting from the opening of the Tyrrhenian sea, followed by north-eastern migration of the thrust front (Malinverno & Ryan 1986; Patacca et al. 1990; Moratti & Bonini 1998). However, some authors hypothesized that the extensional tectonic regime was periodically interrupted by compressive events (Boccaletti et al. 1995; Boccaletti & Sani 1998). The Neogene sedimentary record of these basins is commonly known as that "neoautochthonous succession"; these sedimentary successions are well exposed in the Tuscany basins such as the Fine Basin, the Radicondoli-Volterra-Chiusdino Basin and the Volterra Basin (Bossio et al. 1981; Aldinucci et al. 2005; Carnevale et al. 2006b), which are filled by clastic successions strongly influenced by tectonic and eustatic factors. The clastic succession started in the Tortonian with the "Arenarie di Ponsano", and finished with the Plio-Pleistocene continental sediments (Aldinucci et al. 2005).

The Fine Basin consists of an elongated tectonic depression characterized by a synclinal structure, with a N-NNW trending 25 km-long axis (Moratti & Bonini 1998), which is bounded by the Colline Livornesi to the West and by the Castellina Mountains to the East (Bossio et al. 1981; Aldinucci et al. 2005). The sedimentation in the Fine Basin started in the late Tortonian with the deposition of the fluvio-lacustrine "Serie Lignitifera", followed by a complex succession of four different units (Acquabona-Spicchiaiola, Castelnuovo, Evaporitic and 'Lago-mare') of Messinian age. These units are overlained by Pliocene clays and sands and by Quaternary continental deposits (Bossio et al. 1981; Aldinucci et al. 2005).
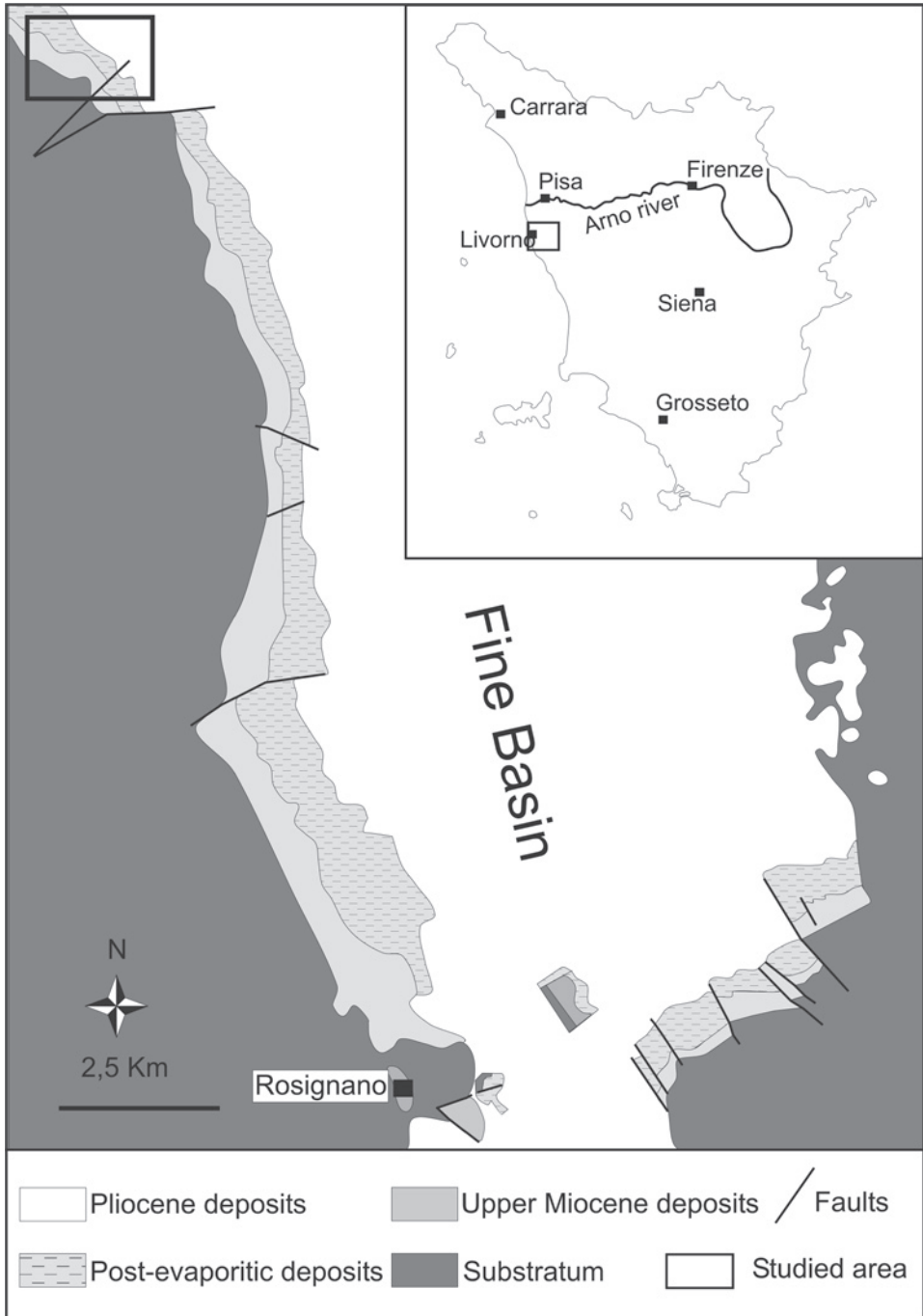
Fig. 1. Schematic geological map of the Fine Basin, Tuscany (modified after CARNEVALE et al. 2006b).
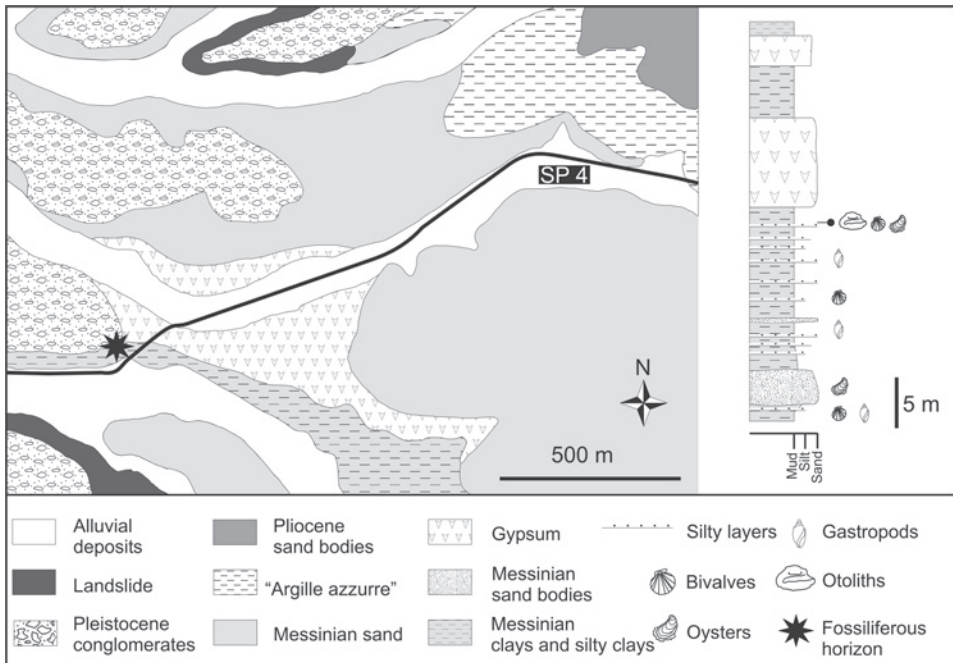
Fig. 2. Geological map and columnar log of the Strada degli Archi section, Fine Basin, Tuscany (modified after Bossio et al. 1981).

The strada degli Archi section is located along the western margin of the Fine Basin. Messinian sediments outcrop at base of the Strada degli Archi section (fig. 2). The base of the section is represented by sand bodies alternated to clayey and silty layers. Abundant oysters characterize the lowest sand body, whereas local concentration of *Cerastoderma*, *Cerithium* and *Mactra* can be easily observed in clayey and silty layers. The analysis of the foraminifers content has revealed the presence of a relatively rich assemblage, which apparently dates back to the early Messinian (Bossio et al. 1981). These sediments are overlained by the gypsum intervals. Bossio et al. (1981) correlated the gypsum layers to the widespread Mediterranean evaporites linked to the Messinian Salinity Crisis event. The gypsum beds are followed by sands and clays characterized by rare molluscs, such as *Dreissena*, *Hydrobia*, *Limnocardium*, *Melanopsis*, and brackish ostracods referred to the Messinian post-evaporitic 'Lago-mare' facies (Bossio et al. 1993). Messinian sediments are overlained by early Pliocene sand and clays and, subsequently, by the Pleistocene *Artica islandica* clays (Bossio et al. 1981).

The investigated fossiliferous horizon occurs 1.5 metres below the first gypsiferous layers and is characterized by the presence of fish otoliths (fig. 2), bivalves of the genus *Cerastoderma*, brackish gastropods, ostracods and foraminifers. The deposits placed below the first gypsum layer are characterized by a moderately abundant microfossil content. The ostracod assemblage is poorly diversified, with a sharp dominance of *Cyprideis* gr. *torosa*, *Heterocythereis* aff. *albomaculata*, *Loxoconcha* aff. *agilis*, *Loxoconcha* aff. *elliptica*, and *Xestoleberis reymenti*, while foraminifers are mostly represented by elphidiids and species of the genera *Ammonia* and *Cribrononion* (Bossio et al. 1981).

Materials and methods

The material documented herein was collected from the fossiliferous horizon below the first gypsiferous layer. The otoliths were extracted from a 70 kg sample after processing with hydrogen peroxide, drying and sieving (smallest screen 0.5 mm).

Otoliths are calcareous structures associated with the ear of fish involved in vestibular and acoustic functions (POPPER & FAY 1993). Although fishes possess three pairs of otoliths, only the largest, the sagitta, is commonly used in palaeontological studies. These calcareous structures are often characterized by a wide interspecific morphological variability, and for this reason are used in species-level taxonomic studies. Fossil otoliths are very common in Cenozoic marine and brackish deposits, representing the most common remains of teleost fishes (NOLF 1985). Because of their abundance and diversity, fossil otoliths usually provide a large amount of palaeoecological and palaeogeographical data which are necessary for palaeoenvironmental reconstruction (NOLF 1985). All the otoliths described in this paper are sagittae. The morphological terminology used in the following description is that proposed by NOLF (1985).

The biological characteristics of the recognized taxa have been determined using literature about their recent relatives and each taxon was assigned to some ecotrophic guilds according to the classification proposed by ELLIOTT & DEWAILLY (1995). These ecotrophic guilds used in that study are ecological guilds, vertical distribution guilds, substratum preference guilds, and feeding guilds. The designated ecological guilds are those of estuarine residents (ER) and marine migrants (MM); estuarine residents include the taxa that spend their life in brackish biotopes influenced by marine waters, while marine migrants have regular visits to the brackish biotopes during their juvenile or adult phase. Vertical distribution guilds provide information about the dependence of the fish taxa on the substrate: (P) pelagic taxa, living in the main water column; (D) demersal taxa, living in the water layer just above the substrate; (B) benthic taxa, living on or in the substrate. The category of substratum preference guilds has been for benthic and demersal taxa to assess their preference for a determinate substrate; these are: (S) Soft bottom, for taxa living on sandy or muddy substrate; (V), for species living above or amongst the vegetation. Finally, the category of feeding guilds gives information of the food preference of each taxon: (Pl) plankton, (I) invertebrates, (F) other fishes.

The described material is deposited in the Dipartimento di Scienze della Terra, Università di Pisa.

Results and palaeoenvironmental discussion

Despite the moderately abundant quantity of processed material, the detected otolith assemblage is poorly diversified showing an evident oligotypic character. A total of 258 identifiable otoliths were counted from the investigated sample, amongst which 11 species-level taxa representing five families were recognized (tab. 1). The gobiids strongly dominate the assemblage composition, represented by more than 93 % of the specimens (fig. 3). Approximately 5 % of the investigated material belong to the family Atherinidae, while the remaining families, Cyprinodontidae, Hemiramphidae, and Polynemidae, are extremely rare, with a total of four specimens. The analysis of the
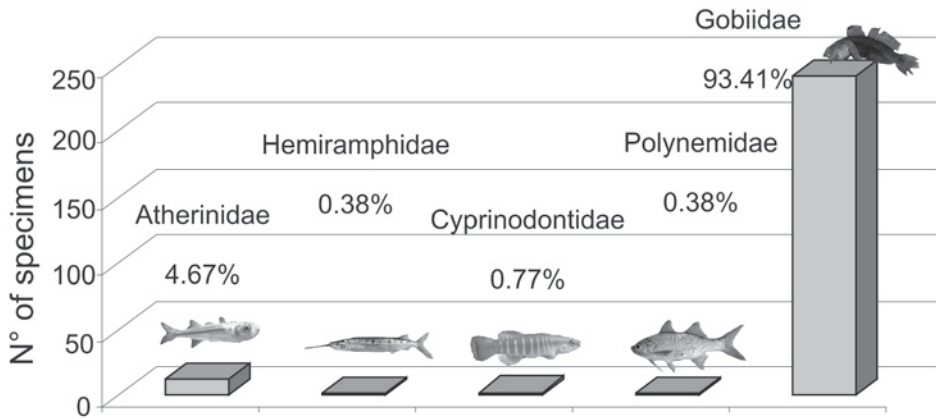
Fig. 3. Relative percentage of the fish families in the Messinian fossil assemblage of Strada degli Archi.

dominance hierarchies within the species-level taxa has revealed that the otolith assemblage is clearly dominated by *Gobius* aff. *multipinnatus* (53 % of the specimens), followed by *Aphia minuta* (18 %), *Lesueurigobius* aff. *vicinalis* (~ 10 %), and *Gobius* aff. *niger* (about 7 %); as documented above, *Atherina* aff. *boyeri* comprised slightly less than 5 % of individuals.

The most representative families identified in this study are Atherinidae and Gobiidae, which are common constituents of paralic assemblages world-wide and appear to be among the best adapted to this type of ecosystem (REBELO 1992; HARRISON & WHITFIELD 1995; THOMAS & CONNOLLY 2001). Members of the family Gobiidae (gobies) are small benthic euryhaline fishes that are extremely important in terms of number of

Tab. 1. Distribution of taxa and ecotrophic guilds within the assemblage. B, benthic; D, demersal; ER, estuarine resident; F, other fishes; I, invertebrates; MM, marine migrant; P, pelagic; Pl, plankton; S, soft bottom; V, vegetated bottom.

Family	Taxon	N°	%	Ecological guild	Habitat	Substratum	Feeding
Atherinidae	*Atherina* aff. *boyeri*	12	4.67%	ER	P	I	Pl
Hemiramphidae	Hemiramphidae indet.	1	0.38%	MM	P	I	I
Cyprinodontidae	*Aphanius crassicaudus*	2	0.77%	ER	P	I	I
Polynemidae	Polynemidae indet.	1	0.38%	MM	D	S, V	I,F
Gobiidae	*Aphia minuta*	46		ER	P	I	Pl
	Gobius aff. *guerini*	14		ER	B	S, V	I
	Gobius aff. *multipinnatus*	136		ER	B	S, V	I
	Gobius aff. *niger*	17	93.41%	ER	B	S, V	I,F
	Gobius sp.	1		ER	B	S, V	I
	Lesueurigobius aff. *vicinalis*	25		MM	B	S, V	I
	Mesogobius sp.	3		ER	B	S, V	I

species and relative abundance within estuarine and coastal lagoons fish assemblages (e.g., MALAVASI et al. 2005). The highly diverse group of euryhaline gobies includes a number of species of marine origin that reside in brackish environments for most of their juvenile and/or adult life but have a marine larval phase. Atherinids (sand smelts) are small-sized pelagic planktivore fishes that usually resides in estuaries or coastal lagoons and can complete their short life cycles within these systems (NORDLIE 2003), mostly in vegetated areas (e.g., FRANCO et al. 2006). As far as the poorly represented families are concerned, polynemids and hemiramphids usually make broad use of vegetated brackish biotopes during their juvenile life stages (e.g., WHITFIELD 1999; MOTOMURA 2004), while cyprinodontids of the genus *Aphanius* are typical inhabitants of coastal lagoons and estuaries. More particularly, the species *Aphanius crassicaudus* was a dominant constituent of the Mediterranean brackish and hyperhaline lagoons during the Messinian (e.g., GAUDANT 1979, 2002).

Thus, in terms of diversity and biomass, the most important taxa point to a paralic biotope, such as coastal lagoons, certainly characterized by brackish waters. Such a palaeoenvironmental interpretation is consistent with the data derived from the mollusc, ostracod, and benthic foraminifer assemblages, which are indicative of a lagoon (BOSSIO et al. 1981). Similarly to those typical of other paralic habitats, fish taxa living in lagoons use these biotopes in different ways. As documented above, the taxa recognized at Strada degli Archi have been assigned to an ecological guild in order to understand in much detail their environmental role in the hypothesized palaeobiotope (tab. 1). The taxa belonging to the ecological guild of estuarine residents are sharply dominant, with the 73 % of recognized taxa followed by marine migrants that accounted for about 27 %. Coastal lagoons are extremely rigorous biotopes, characterized by highly variable physical and biological conditions. Environmental, physical, geochemical and hydrodynamical parameters greatly influence the community structure and composition in coastal lagoons. These are known as sites of low diversity, with dramatic seasonal and diurnal shifts in the composition of biological communities, where only a few species are permanently resident. These species are usually low trophic level with high ecological efficiency and productivity (AKIN et al. 2003). In addition, these biotopes are important as nurseries because of their high productivity and structural heterogeneity provide both foraging opportunities and sites of refuge from predators for juvenile fishes (KNEIB 1997). The broad dominance of gobies in the fossil assemblage is clearly indicative of the ecological relevance of this group in the hypothesized palaeobiotope. The relatively high diversity and quantitative abundance of taxa belonging to the guild of estuarine residents is indicative of the presence of seagrass meadows or densely vegetated environments (PATERSON & WHITFIELD 2000). Diversity of lagoon fish communities depends on connections with neighbouring biotopes, acting as sources for marine or freshwater species (POIZAT et al. 2004). Therefore, the occurrence of marine species is primarily due to their recruitment from the sea, through connections that are temporarily variable (VEIGA et al. 2006). The low abundance in terms of biomass and number of species-level taxa of marine migrants could be explained with a reduced spatial heterogeneity and structural complexity of the depositional environment, while the virtual absence of diadromous (migrant species that use the brackish biotopes to pass between salt and fresh waters for spawning of feeding) and freshwater adventitious (freshwater species that enter coastal lagoons or estuaries when conditions are favour-

able) species appears to be indicative of the restricted influence of freshwater outflow. The relative percentage of the represented ecological guilds and the apparent absence of members of marine adventitious visitors (marine stenohaline taxa that irregularly appear in brackish biotopes) suggest that the original depositional environment was characterized by a moderate degree of confinement (Zones II and III of the confinement scale sensu GUELORGET & PERTHUISOT 1992). In a recent study, MARIANI (2001) demonstrated that the spatial distribution of lagoon fish communities may be correlated with the level of marine influence on these ecosystems, and, consequently, that the spatial pattern of fish distribution can provide a useful tool in defining the levels of marine influence on coastal lagoons. Thus, based on the quantitative analysis of the ecological guilds, it is possible to conclude that a moderately confined coastal lagoon characterized by a persistent marine influence can be interpreted as the original depositional environment. This hypothesis is also supported by the clear dominance of invertebrativores (see Tab. 1), mostly meiobenthivores, within the represented the feeding guilds, which appears to be typical of moderately confined paralic biotopes characterized by a reduced but persistent occurrence of marine taxa (BOUCHEREAU et al. 2000).

In summary, the analyses of taxonomic diversity and distribution of ecotrophic guilds (sensu ELLIOTT & DEWAILLY 1995) enable to define some structural and physiographic features of the original depositional environment. The qualitative and quantitative composition of the fossil fish assemblage are indicative of a moderately confined coastal lagoon with restricted continental inflows and permanently open connections with the sea. Such a lagoon was possibly characterized by a soft and densely vegetated bottom, reduced spatial complexity, and by a poorly diversified mollusc community with a relatively high abundance of individual taxa. The molluscs, together with other benthic invertebrates (e.g., anellids, crustaceans), represented the main food source for gobies and other resident fishes. Moreover, the lagoon acted as a nursery area for migratory fishes which were possibly attracted by the vegetated habitat and abundance of food typical of these systems (GUELORGET & PERTHUISOT 1992).

Concluding remarks

Overall, the present study documented the first early Messinian paralic fish assemblage known to date in the Mediterranean region. The taxonomic study has revealed the presence of 11 species-level taxa, among which gobies (family Gobiidae) are by far the most quantitatively abundant and diversified. Both the faunal composition and relative distribution of ecotrophic guilds (tab. 1) concur to point to a coastal lagoon permanently connected to the sea as the original depositional environment.

The analysis of the stratigraphic distribution of the recognized taxa showed that four species-level taxa (*Aphanius crassicaudus*, *Aphia minuta*, *Gobius* aff. *multipinnatus*, *Gobius* aff. *niger*) are also common constituents of the late Messinian 'Lago-mare' estuarine/lagoon assemblages (CAPUTO 2007; CARNEVALE et al. 2006a, 2006b, 2008), thereby suggesting that structurally similar brackish fish communities (characterized by thalassic influences) possibly persisted in the Mediterranean area throughout the Messinian, including the evaporitic and post-evaporitic phases of the Messinian Salinity Crisis event (see e.g., KRIJGSMAN et al. 1999).

Systematic Part

Subdivision Teleostei *sensu* PATTERSON & ROSEN, 1977

Order Atheriniformes ROSEN, 1964

Family Atherinidae RISSO, 1826

Genus *Atherina* LINNAEUS, 1758

Atherina **aff.** *boyeri* **(RISSO, 1810)**
(pl. 1, fig. 1)

M a t e r i a l : 12 specimens.

Ratio length/height (L/H) : 1.20 to 1.42.

D e s c r i p t i o n : The otoliths are ovoid in outline, with concave outer face, and slightly convex inner face. The ventral rim is regularly convex. The dorsal rim is convex. The posterior rim is rounded to slightly pointed. The sulcus acousticus is narrow, with an ovoid and deeply incised ostium. The cauda is straight, with a poorly evidenced end. The crista superior is well developed. The dorsal area depressa is present.

D i s c u s s i o n : The general physiognomy of the specimens and, in particular, the structure and morphology of the dorsal and ventral rims and of the sulcus are typical of the genus *Atherina*. The otoliths appear to be closely related to the extant species *Atherina boyeri*, from which they slightly differ by having a less developed rostrum, poorly ornamented margins (see REICHENBACHER 2004), and a more convex and rounded posterior rim (see GIRONE et al. 2006).

D i s t r i b u t i o n : Fossil otoliths assigned to *Atherina boyeri* have been described from the lower Pleistocene deposits of Calabria (GIRONE et al. 2006).

The atherinids are extremely abundant in paralic environments all over the world (NORDLIE 2003). Three species of the genus *Atherina*, including *Atherina boyeri*, and a single species of the genus *Atherinomorus*, *Atherinomorus lacunosus*, inhabit the Mediterranean today (QUIGNARD & PRAS 1984).

Order Beloniformes BERG, 1940

Family Hemiramphidae GILL, 1859

Hemiramphidae indet.
(pl. 1, fig. 2)

M a t e r i a l : 1 specimen.

Ratio length/height (L/H): 1.40.

D e s c r i p t i o n : The sagitta is very thin and ovoid in outline. The outer face is concave and inner face is convex. The ventral rim is gently and regularly convex. The

posterior rim is slightly pointed. The dorsal margin is convex and characterized by a marked anterodorsal angle. The ventral and dorsal rims are crenulated. The anterior rim is characterized by a short and pointed antirostrum, and a short rostrum separated by a deeply incised excissura. The sulcus is elongate, sigmoid, not clearly separated into ostium and cauda.

D i s c u s s i o n : The structure of the rims, the general outline, and the sigmoid morphology of the sulcus are typical of the family Hemiramphidae. In particular, the specimens share many features with the otoliths of *Arrhamphus sclerolepis*, *Hyporhamphus melanochir* and "*genus Hemiramphidarum*" sp. (see NOLF & STEURBAUT 1979), from which it differs by having a strongly incised excissura and the morphology of the anterior end of the sulcus. The specimen shows some similarities with that assigned to *Hemiramphus* sp. from the Pliocene of Tertiary Piedmont Basin (NOLF & CAVALLO 1995), from which it differs by having a narrower sulcus. Moreover, the specimen differs from genus "*Hemiramphidarum*" sp., figured by NOLF & LAPIERRE (1979), by having a less convex dorsal rim and a more pointed rostrum. Even though the morphology and structure of the material documented herein justify the inclusion within the family Hemiramphidae, its juvenile nature does not allow a more detailed taxonomic assignment.

D i s t r i b u t i o n : Otoliths belonging to the family Hemiramphidae are relatively rare in the fossil record. Fishes of the family Hemiramphidae occur in all the oceans and, some species inhabit the inland waters. Two marine species (*Hemiramphus far* and *Hyporhamphus picarti*) live in the Mediterranean today (COLLETTE & PARIN 1984).

Order Cyprinodontiformes *sensu* PARENTI, 1981

Family Cyprinodontidae GILL, 1865

Genus *Aphanius* NARDO, 1827

Aphanius crassicaudus (AGASSIZ, 1839)
(pl. 1, fig. 3)

1988   *Aphanius crassicaudus* (AGASSIZ, 1839) – GAUDANT, GUERRERA & SAVELLI, p. 195, fig. 7.
2006b   *Aphanius crassicaudus* (AGASSIZ, 1839) – CARNEVALE, LANDINI & SARTI, p. 78.
2008   *Aphanius crassicaudus* (AGASSIZ, 1839) – CARNEVALE, LONGINELLI, CAPUTO, BARBIERI & LANDINI, fig. 3I.

M a t e r i a l : 2 specimens.

Ratio length/height (L/H): 1.01 to 1.19.

D e s c r i p t i o n : The otoliths are approximately triangular in shape. The ventral rim is gently convex with a poorly developed crenulation. The dorsal rim is strongly convex. The posterior rim is straight with a marked ornamentation. The anterior rim is characterized by the presence of a marked and pointed antirostrum, a rounded and thick rostrum, and an incised excisura. The sulcus is straight and narrow. A clear separation between ostium and cauda is not visible. The end of the sulcus is hooked and characterized by

a rounded profile. The crista superior is well developed and straight. The dorsal area is remarkably developed.

D i s c u s s i o n : The morphology of the anterior rim and the presence of an indistinct ostium, as well as the general physiognomy of the specimens, support the assignment to the species *Aphanius crassicaudus* (see GAUDANT et al. 1988). Compared with the material described by GAUDANT & al. (1988), the specimens documented herein show a more straight posterior rim. Such a difference can be easily justified by the broad morphological variability observed in extant cyprinodontid otoliths (see REICHENBACHER & SIENKNECHT 2001).

D i s t r i b u t i o n : Otoliths of *Aphanius crassicaudus* were described by GAUDANT et al. (1988) from the gypsiferous marls of the Marche region. More recently, CARNEVALE et al. (2006b, 2008), recognized some otoliths of this species in the post-evaporitic deposit of Cava Serredi in Tuscany.

The species of the genus *Aphanius* mostly inhabit coastal waters, lagoons and small rivers around the Mediterranean basin (REICHENBACHER & SIENKNECHT 2001). In particular, the Mediterranean extinct species *Aphanius crassicaudus* mostly occurred in the hyperhaline lagoons of the evaporitic phase of the Messinian (GAUDANT 1979; LANDINI & SORBINI 1989).

Order Perciformes *sensu* JOHNSON & PATTERSON, 1993

Family Polynemidae CUVIER,1828

Polynemidae indet.
(pl.1, fig. 4)

M a t e r i a l : 1 specimen.

Ratio length/height (L/H): 1.87.

D e s c r i p t i o n : The sagitta is moderately elongated with a convex inner face. The outer face is slightly concave. The ventral rim is straight and moderately rounded in its anterior sector. The posterior rim is straight and vertical. The dorsal rim is slightly convex centrally and passes to the anterior rim through a marked anterodorsal angle. The posterodorsal angle is well developed, preceded by a marked indentation. The anterior rim is characterized by a prominent rostrum and a poorly developed antirostrum, separated by a short excisura. The sulcus acousticus is narrow. The ostium is ovoid in outline and the cauda is straight, with a distinct hooked end.

D i s c u s s i o n : The otolith resembles that of *Polydactylus virginicus* (see NOLF & MARTINELL 1980; NOLF 1985) from which it differs for the presence of a well defined excisura and a more developed area. The specimen shows some similarities with the juvenile otoliths of "*Polynemidarum*" sp. from the Pliocene of Catalunya and the Miocene deposits of Montpeyroux (NOLF & CAPPETTA 1980; NOLF & MARTINELL 1980), but differs from these in having a more straight ventral rim and a pronounced hooked end of the cauda. In summary, the overall morphology of the specimen justifies its placement

within the family Polynemidae, even though its juvenile character does not allow a more precise taxonomic placement.

D i s t r i b u t i o n : Polynemids inhabit the tropical and subtropical coastal waters (less than 150 m) of all oceans, mostly in the Indo-Pacific region; a single species, *Galeoides decadactylus*, sporadically occurs in the south-western portion of the Mediterranean. Members of the family Polynemidae often occur in the coastal lagoons and estuarine environments and a few species inhabit inland waters.

Family Gobiidae BONAPARTE, 1832

Genus *Aphia* RISSO, 1827

Aphia minuta (RISSO, 1810)
(pl. 1, fig. 5)

2006   *Aphia minuta* (RISSO, 1810) – GIRONE, NOLF & CAPPETTA, p. 15, pl. 7, figs. 5, 6.
2008   *Aphia minuta* (RISSO, 1810) – CARNEVALE, LONGINELLI, CAPUTO, BARBIERI & LANDINI, fig. 6L.

M a t e r i a l : 46 specimens.

Ratio length/height (L/H): 0,55 to 1.

D e s c r i p t i o n : The sagittae are rather thin and ovoid in outline. The outer face is strongly convex and the inner face is concave. The dorsal rim is irregular in shape and generally convex, whereas the ventral rim is slightly convex. The anterior and posterior rims are vertical. In many cases the anterior rim is gently convex. The sulcus acousticus is relatively shallow, irregular or roughly ovoid. The dorsal area is poorly developed.

D i s c u s s i o n : The otoliths are consistent with those of the extant species *Aphia minuta* (see NOLF & MARQUES DA SILVA 1997; GIRONE et al. 2006).

D i s t r i b u t i o n : Otoliths of the species *Aphia minuta* have been found in the middle Pleistocene deposits of Gravina section, Southern Italy (GIRONE et al. 2006). Fossil otoliths belonging to this species have been recently found in the Messinian post-evaporitic deposits of the Podere Torricella section by CARNEVALE et al. (2008).

Today this species mostly occurs in coastal shallow waters of Atlantic Ocean, Mediterranean and Black sea (KOVAČIĆ 2003).

Genus *Gobius* LINNAEUS, 1758

Gobius aff. *guerini* (CHAINE & DUVERGIER, 1931)
(pl. 1, fig. 6)

M a t e r i a l : 14 specimens.

Ratio length/height (L/H): 0.9 to 1.22.

D e s c r i p t i o n : The otoliths have a quadrangular shape. The outer face is convex, and sometimes concave near the dorsal margin. The inner face is slightly convex. The ventral rim is straight. The anterior rim is nearly vertical. The posterior rim is slightly oblique with a concavity in its midheight. The dorsal rim is convex. A small concavity is present slightly before the posterodorsal projection. The sulcus is wide, shallow, with simple rims. The dorsal area and the ventral furrow are less developed.

D i s c u s s i o n : The specimens are characterized by a great variability of the general morphology and extension of the posterodorsal projection. The morphology of the dorsal rim and the shape of the sulcus are close to those of *Gobius guerini* (see NOLF & CAPPETTA 1989; NOLF & MARTINELL 1980; NOLF & CAVALLO 1995), to which the material is tentatively referred.

Distribution : Material referred to the extinct species *Gobius guerini* has been described from the Pliocene deposits of the Tertiary Piedmont Basin (NOLF & CAVALLO 1995; NOLF & GIRONE 2006), southern France (NOLF & CAPPETTA 1989) and Catalunya (NOLF & MARTINELL 1980).

Gobius aff. *multipinnatus* (H. v. MEYER, 1852)
(pl. 1, fig. 7)

2006b   *Gobius* aff. *niger* (LINNAEUS, 1758) – CARNEVALE, LANDINI & SARTI, p. 78.
2007   *Gobius* aff. *multipinnatus* – CAPUTO, pp. 91-92, fig. 3D.
2008   *Gobius* aff. *multipinnatus* – CARNEVALE, LONGINELLI, CAPUTO, BARBIERI & LANDINI, fig. 3P.

M a t e r i a l : 136 specimens.

Ratio length/height (L/H): 0.77 to 1.12.

D e s c r i p t i o n : The otoliths are roughly quadrangular in shape. The outer face is slightly convex and the inner face is flat. The dorsal and ventral rims are slightly convex. A developed posterodorsal angle is also present. The posterior rim is slightly concave in its midheight. The dorsal area is present but scarcely developed and the ventral furrow is slightly incised. The sulcus is narrow and irregular in shape with a pointed posterior end.

D i s c u s s i o n : The morphology of the specimens is close to that of *Gobius multipinnatus* (REICHENBACHER & CAPPETTA 1999), from which they differ for a more oblique posterior rim.

D i s t r i b u t i o n : Sagittae of the extinct species *Gobius multipinnatus* are common in the Miocene deposits of the Eastern Atlantic region, Mediterranean basin and Paratethys (NOLF & CAPPETTA 1980; RADWAŃSKA 1992; REICHENBACHER 1993, 1998; REICHENBACHER & CAPPETTA 1999), and in the Pliocene deposits of Portugal (STEURBAUT & JONET 1981).

Gobius aff. *niger* (LINNAEUS, 1758)
(Pl 1, Fig 8)

2006b   *Gobius* aff. *niger* (LINNAEUS, 1758) – CARNEVALE, LANDINI & SARTI, p. 78.
2008   *Gobius* aff. *niger* (LINNAEUS, 1758) – CARNEVALE, LONGINELLI, CAPUTO, BARBIERI & LANDINI, figs. 3Q, 6I.

M a t e r i a l : 17 specimens.

Ratio length/height (L/H): 1 to 1.28.

D e s c r i p t i o n : The otoliths are squared in outline. The outer face is convex. The inner face is slightly convex. The ventral rim is straight. The dorsal rim is convex, with a marked anterodorsal angle. The anterior rim is straight and the posterior rim is concave in its midheight. The sulcus is wide and deep. The dorsal area and ventral furrow are well developed.

D i s c u s s i o n : The general morphology of the specimens justifies their placement in the genus *Gobius*. The specimens are consistent with those of *Gobius niger* (see NOLF 1978; RADWAŃSKA 1992; REICHENBACHER & CAPPETTA 1999) from which they slightly differ for the absence of a reduced dorsal lobe.

D i s t r i b u t i o n : Otoliths close to those of the living *Gobius niger* are very common in the Messinian 'Lago-mare' deposits of Cava Serredi (Tuscany) (CARNEVALE et al. 2006b, 2008). Today the black goby lives in coastal environments of the eastern sector of the Atlantic Ocean, from Norway to Mauritania, and in the Mediterranean Sea (BOUCHEREAU & GUELORGET 1997) and Black Sea.

Gobius sp.
(pl. 1, fig. 9)

M a t e r i a l : 1 specimen.

Ratio length/height (L/H): 1.20.

D e s c r i p t i o n : The single specimen examined is moderately preserved, with an eroded and flat inner face. The otolith is quadrangular in shape. The outer face is regularly convex. The ventral rim is straight. The posterior rim is characterized by the marked concavity in its midheight. The posterodorsal and the posteroventral projections are equally developed. The anterior rim is straight and vertical, with a gentle crenulation. The dorsal rim is convex and crenulated, with a concavity in its anterior sector. The sulcus is wide and central. The ventral furrow is scarcely developed.

D i s c u s s i o n : The overall morphology of specimen supports its placement within the family Gobiidae. It shows a certain degree of similarity to the otoliths of *Gobius francofurtanus* (REICHENBACHER 2000), thereby suggesting that it might be assigned to the genus *Gobius*.

Genus *Lesueurigobius* WHITLEY, 1950

Lesueurigobius aff. *vicinalis* (KOKEN, 1891)
(pl. 1, fig. 10)

M a t e r i a l : 25 specimens.

Ratio length/height (L/H) : 1.03 to 1.18.

D e s c r i p t i o n : The otoliths are quadrangular in outline. They are characterized by a convex outer face and a slightly convex inner face. The ventral rim is straight. The dorsal rim is strongly convex. The anterior rim is short, with a concavity in its midheight. The posterior rim is characterized by a developed posterodorsal projection and by a concavity approximately in the middle part of the rim. The sulcus is poorly incised, with a rounded profile. The ostium is wider than the cauda. The dorsal area and the ventral furrow are well developed.

D i s c u s s i o n : The specimens are very close to those of *Lesueurigobius vicinalis* (see REICHENBACHER & CAPPETTA 1999), to which they are tentatively referred.

D i s t r i b u t i o n : Otoliths belonging to the species *Lesueurigobius vicinalis* were present along the eastern Atlantic coasts and in Mediterranean Basin since the early Miocene (STEURBAUT 1984; REICHENBACHER & CAPPETTA 1999); in the Parathethys domain they occurred in middle Miocene (RADWAŃSKA 1992; BRZOBOHATÝ 1994).

The genus *Lesuerigobius* consists of five living species that inhabit prevalently the Eastern Atlantic, from Scandinavia to northern Namibia, and the Mediterranean Sea.

Genus *Mesogobius* BLEEKER, 1874

? *Mesogobius* sp.
(pl. 1, fig. 11)

M a t e r i a l : 3 specimens.

Ratio length/height (L/H): 1.26 to 1.53.

D e s c r i p t i o n : The otoliths are flat and rectangular in outline. Some of them are strongly elongated. The outer face is slightly concave and the inner face is slightly convex. The ventral rim is straight. The anterior and posterior rims are vertical. The dorsal rim is slightly convex, with a developed anterodorsal angle. The otoliths are characterized by a marked posterodorsal projection. The sulcus is wide, with a pointed anterior end.

D i s c u s s i o n : The otoliths are similar to those of *Mesogobius batracocephalus* figured by NOLF & CAVALLO (1995), from which they differ in having a less incised sulcus. The specimens also resembles those of ?*Mesogobius* sp. described by NOLF & CAVALLO (1995), but differ from these in having a more straight ventral rim and a pointed end of the sulcus.

D i s t r i b u t i o n : Otoliths belonging to the genus *Mesogobius* are extremely rare in Neogene deposits. This species has been reported from the Pliocene deposits of the Tertiary Piedmont Basin by Nolf & Cavallo (1995).

Today, the genus *Mesogobius* is endemic of the Ponto-Caspian region.

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Plate 1

Fig. 1. *Atherina* aff. *boyeri* (RISSO, 1810)

Fig. 2. Hemiramphidae indet.

Fig. 3. *Aphanius crassicaudus* (AGASSIZ, 1839)

Fig. 4. Polynemidae indet.

Fig. 5. *Aphia minuta* (RISSO, 1810)

Fig. 6. *Gobius* aff. *guerini* (CHAINE & DUVERGIER, 1931)

Fig. 7. *Gobius* aff. *multipinnatus* (H. v. MEYER, 1852)

Fig. 8. *Gobius* aff. *niger* (LINNAEUS, 1758)

Fig. 9. *Gobius* sp.

Fig. 10. *Lesueurigobius* aff. *vicinalis* (KOKEN, 1891)

Fig. 11. ?*Mesogobius* sp.

Scale bar equals 1 mm.