



The Tortonian-Messinian fish faunas of Piedmont (Italy) and the Adriatic trough: a synthesis dedicated to the memory of Carlo Sturani (1938-1975)

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KEY WORDS - Fishes, Teleosts, Miocene, Piedmont, Italy, Palaeoecology, Palaeobathymetry.

ABSTRACT - During the last thirty years, significant improvements increased our knowledge of the Upper Miocene fish fauna of Piedmont where the new fossiliferous localities of Cherasco, Castagnito, Roddi, and of the Tanaro River near Alba, were found and studied. Presently, around the city of Alba, a series of well-documented localities is known, ranging from the lower to middle Tortonian to the end of the Messinian. A comparison with the more or less coeval localities of Romagna and Marche shows that the Tortonian and preevaporitic Messinian fish faunas of Piedmont differ from those of Romagna and Marche by their rather high percentage of representatives of the species *Alosa elongata* Agassiz, whereas this species is almost absent in Romagna and Marche. On the other hand, in both regions the fish fauna of the evaporitic episode (Gessoso-solfifera Formation) indicates that the genesis of the studied localities (Scaparoni, Castagnito and Cherasco in Piedmont; "Vena del Gesso" and Monte Castellaro in Romagna and Marche) took place in lagoons connected with a sea having a normal salt content, as demonstrated by the occurrence of marine stenohaline fishes which coexist with fishes adapted to lagoonal environments.

RIASSUNTO - [L'ittiofauna tortoniano-messiniana del Piemonte (Italia) e dell'Avanfossa Adriatica: una sintesi dedicata al ricordo di Carlo Sturani (1938-1975)] - Gli studi sugli ittioliti del Miocene superiore del Piemonte furono avviati verso la metà del XIX secolo, con la segnalazione di alcune forme attualmente attribuite a "*Alosa*" crassa Sauvage, *Aphanius crassicaudus* (Agassiz), *Nyctophus* (*Lampanyctus*) *microsoma* (Sauvage), *Gobius craverii* Costa e al genere *Lepidopus* Gouan. Nel corso di questi ultimi trent'anni, si sono realizzati importanti progressi nella conoscenza dell'ittiofauna del Miocene superiore del Piemonte, grazie alla scoperta e allo studio dei giacimenti fossiliferi di Cherasco, Castagnito, Roddi e del Tanaro presso Alba. In tal modo, per i dintorni di Alba, si dispone ormai di dati piuttosto abbondanti sulle associazioni ad ittioliti provenienti da sezioni ben documentate, databili dal Tortoniano inferiore (o medio) alla fine del Messiniano. Si è potuto dimostrare che esiste una grande similitudine tra le faune del Tortoniano e del Messiniano inferiore, tanto che per definire l'età dei depositi fossiliferi si rendono necessarie analisi micropaleontologiche. Viene inoltre confermata l'ipotesi formulata da Carlo Sturani secondo la quale, in Piemonte, la precipitazione del gesso fu preceduta da un abbassamento del livello marino. Il confronto con i giacimenti coevi della Romagna e delle Marche dimostra che le ittiofaune piemontesi del Tortoniano e del Messiniano preevaporitico differiscono per la presenza percentualmente importante di rappresentanti di *Alosa elongata* Agassiz, specie che manca quasi del tutto nella regione adriatica. Inoltre, in entrambe le aree geografiche, l'ittiofauna dell'episodio evaporitico (Formazione Gessoso Solfifera) mette in evidenza che i giacimenti studiati (Scaparoni, Castagnito e Cherasco in Piemonte; "Vena del Gesso" e Monte Castellaro in Romagna e Marche) si sono originati in lagune comunicanti con un mare a salinità normale, come è dimostrato dalla coesistenza di pesci marini stenohalini con specie adattate ad ambienti lagunari. In particolare *Aphanius crassicaudus* (Agassiz) proliferava negli ambienti lagunari sia nelle fasi di connessione con il mare aperto sia nelle fasi di isolamento, quando solo questa specie era capace di sopportare le forti variazioni della concentrazione salina.

INTRODUCTION

The first short report concerning the Upper Miocene fishes from Piedmont was published by Sismonda (1846). Then Costa (1865) studied some fish skeletons probably found near La Morra. This material consists in a rather large clupeid belonging to the species "*Alosa*" crassa Sauvage according to D'Erasmus (1952), an incomplete fish that was supposed to be a blennioid named *Blennius craverii* Costa but which in reality is a myctophid: *Nyctophus* (*Lampanyctus*) *microsoma* (Sauvage) according to D'Erasmus [= *Myctophum* (s.l.) *licatae* (Sauvage)], and an isolated premaxillary that Costa supposed to be from a *Muraena* but that D'Erasmus correctly recognized as belonging to the genus *Lepidopus* Gouan. Later, Costa (1867) described eight other fishes collected in "un terreno marnoso propinquo a quella città" [a marly formation neighbouring this city]. They were found near Santa Vittoria d'Alba, during the construction of the railway from Bra to Alba. Among them was a pachyostosed gobioid named *Gobius craverii* Costa and

some cyprinodontids that Costa described as *Aelia pedemontana* Costa [= *Aphanius crassicaudus* (Agassiz)]. The counterparts of the two specimens of this species figured by Costa (1867, Tav. II, figs. 2-3) are still kept at Bra, in the Museo Civico Craveri (Mori, 1980, p. 150, figs. b-c). On the other hand, the type specimen of *Gobius craverii* Costa, which was originally very incomplete, was not found by D'Erasmus (1952), when he revised Costa's material in the collections of the "Museo geo-paleontologico di Napoli". For this reason Gaudant (1979b) described the new species *Gobius ignotus* Gaudant, which, like *Gobius craverii* Costa, frequently exhibits pachyostosis, but differs from it in the number of vertebrae and in the composition of the second dorsal fin.

One century later, shortly after the discovery of the Upper Miocene evaporites under the bottom of the Western Mediterranean basin, a new paradigm rapidly emerged, which is known as the "desiccation theory" (Hsü et al., 1973). According to this theory, these evaporites precipitated on the bottom of a basin lying 2000 to 3000

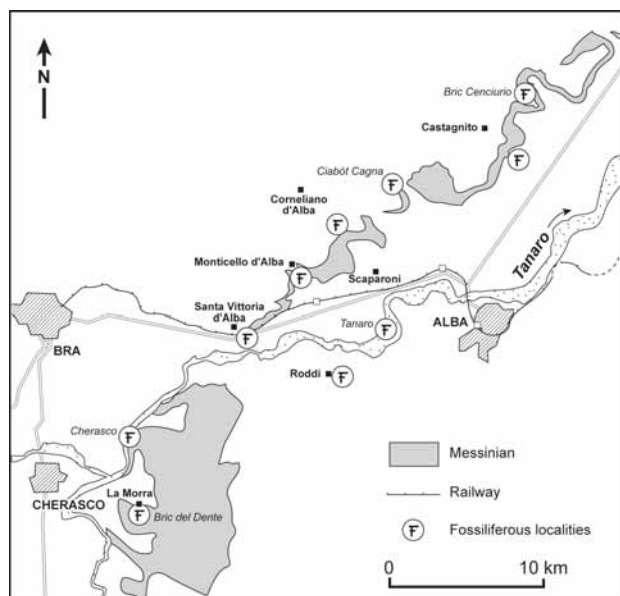


Fig. 1 - Map of the surroundings of Alba showing the main fossiliferous localities of Tortonian and Messinian fish faunas.

metres below the present sea level. An international meeting was rapidly convened by C.W. Drooger in Utrecht in March 1973. Sturani attended it and gave a lecture in which he relied on the find by Mario Macagno, at Monticello d'Alba (Fig. 1), of a small anguilliform fish for proposing his conception of the palaeoenvironmental and palaeogeographical situation of the Mediterranean during the "salinity crisis" (Sturani, 1973). In fact, Sturani was convinced that this fish is a juvenile eel (*Anguilla* sp.). Everybody knows that these fishes have a catadromous biological cycle and that, as demonstrated by Schmidt, European eels undertake impressive migrations through the Atlantic Ocean for spawning in the Sargasso Sea. However, Sturani adopted the view that recent eels from the Black Sea and the Mediterranean have their breeding grounds in the Alboran Sea, and he supposed that "this may well be a habit inherited since the Messinian closure of the Mediterranean", at a time when the Mediterranean was "a land-locked sea, but one containing enough water (i.e., a sufficiently large and deep surface layer of normal salinity water) for the eels and other catadromous fishes to breed".

However, Sturani's interpretation suffered a major weakness as it relied upon a mistaken determination of the small anguilliform fish found at Monticello d'Alba. In fact, as already noted (Gaudant, 1979c), this fish has a dorsal fin which is beginning above the posterior part of the head, whereas in the recent eels belonging to the genus *Anguilla* Shaw, the dorsal fin clearly begins behind the head, approximately above the middle between the distal part of the pectoral fin-rays and the vent.

In this paper we summarize the available data on Tortonian-Messinian Teleostean fish assemblages preserved as articulated skeletons in several localities of Piedmont and the Adriatic trough, whereas Tortonian otolith assemblages (Nolf & Steurbaut, 1983) have not been reconsidered for this synthesis.

THE FISH FAUNA FROM THE PIEDMONT BASIN

The stratigraphy of late Miocene successions of southern Piedmont has been recently treated by Irace et al. (2005), who pointed out that the most complete "normal" succession crops out in the vicinity of Alba. Here Sturani (1973) examined several exposures of the Messinian succession overlying the Tortonian, and reconstructed a well-known synthetic section (Fig. 2) in which he described the whole sequence as follows:

"5 - Current-laminated fine sands and evenly bedded massive clays (alluvial plain and marsh).

"4b - Thick beds of selenite crystal conglomerates (flash-floods by local torrential streams).

"4a - Laminated silts and silty marls with a few fine sands (closed, chott-like depression, with highly variable salinity).

"3b - Evenly laminated, fine grained primary gypsum (restricted, hypersaline lagoon; main evaporitic phase).

"3a - Sulphate-rich, thinly laminated euxinic clays with lenses of early diagenetic selenite (restricted lagoon; euxinic-evaporitic phase).

"2 - Thinly laminated silty clays with beds of sun-cracked, stromatolitic limestone (lagoon, early evaporitic phase).

"1 - Lower Messinian: rhythmically alternating fine sands (graded), silts (bioturbated) and clays (laminated) (marine, restricted and intermittently anaerobic; depth decreases from bottom to top).

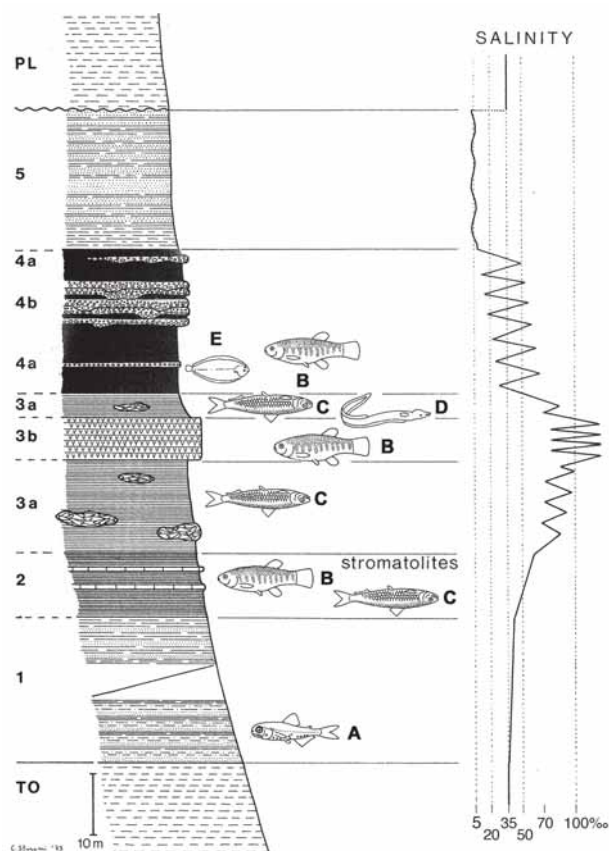


Fig. 2 - The Messinian section North-West of Alba, Piedmont (modified from Sturani, 1973). A - mictophid; B - *Aphanius*; C - *Spratelloides*; D - Sturani's "eel" (= *Muraena*? sp.); E - Soleid.

“TO - Upper Tortonian: silty clays and marls, massive (normal marine, intermediate depth facies)”.

The fish fauna from the Bric del Dente, near La Morra

Sturani collected fossil fishes at the “Bric del Dente”, 1 km south of La Morra, in a block of marly limestone reworked in a conglomerate, which is supposed to be early Messinian in age. Ten of them are kept in Torino, in the Museo regionale di Scienze naturali. Among them, six belong to the sternoptychiid species *Maurolicus muelleri* (Gmelin), three (five according to Sturani & Sampò, 1973) to *Bregmaceros albyi* (Sauvage) and the last one was determined as *Myctophum* sp.

It should be remarked that this association strikingly differs from the fish faunas from the Tortonian and Lower Miocene of this region. In fact, in both fish faunas, myctophids are dominant, whereas *Maurolicus muelleri* Gmelin, which lacks in the Tortonian of the Tanaro River, constitutes 17.1% of the Messinian fish fauna from Roddi. As for *Bregmaceros albyi* (Sauvage), it is extremely rare in the Tortonian of the Tanaro River (only one specimen known) and is limited to 2.1% of the Messinian fish fauna of Roddi.

Consequently, a micropalaeontological analysis of the matrix of the fishes from the Bric del Dente seemed to be the only possibility for determining the age of these fishes. Unfortunately, an attempt of research of nannoplankton in the samples kept in the Museo regionale di Scienze naturali of Piedmont has shown that the sediment is barren.

The Tortonian fish fauna of the Tanaro River, near Alba

The fish fauna collected in the bluish laminated marls outcropping in the bed of the Tanaro River includes at least 15 different species of teleostean fishes preserved as articulated skeletons (Gaudant et al., 2007). It should be emphasized that this material was collected in several laminated intercalations distributed in a thick succession of massive marls. Consequently, the following statistical evaluation of the composition of the fish fauna is only indicative because the studied material was collected at different levels of the Tortonian sequence. Nevertheless, it provides useful information concerning the relative frequency of the main taxa.

The myctophids, with 51.8% of the collected material, are the dominant component of the fauna, *Myctophum* (s.l.) *licatae* (Sauvage) being the most abundant (43.4%), whereas a second species, *M.* (s.l.) *dorsale* (Sauvage) makes up 8.4% of the fish fauna. This fact is significant because the myctophids are mesopelagic fishes that undertake nycthemeral migrations between depths of several hundred metres - sometimes more than 1,000 m - and the subsurface. The second important element is an epipelagic clupeid species: *Alosa elongata* Agassiz, with 22.9%. Another clupeid, *Sardina? crassa* (Sauvage) is also present (4.8%). Additionally, a trichiurid, *Lepidopus albyi* (Sauvage), has a frequency of 7.2%.

Taking also into account the composition of the mollusc fauna and the palaeoecological significance of the benthic foraminifera, it appears that the deposition depth of the Tortonian fossiliferous marls of the Tanaro

River is estimated between 50 and 200 m, corresponding to a circalittoral environment, although the benthic foraminifera may suggest deeper conditions.

The Upper Miocene fish fauna from the “Tripoli” of Pecetto di Valenza, near Alessandria

Sturani & Sampò (1973) described a new fish fauna collected in diatomitic sediments cropping out near Cascina Valnera, in the vicinity of the village of Pecetto di Valenza, at about 10 km NE of Alessandria (Piedmont) (Fig. 3). They noted that, at this locality, myctophids are the most abundant fishes with more than half the number of collected specimens. They also noted the occurrence of a clupeid: *Alosa elongata* Agassiz, a sternoptychid: *Maurolicus gregarius* (Bosniaski) [= *M. muelleri* (Gmelin)], a syngnathid: *Syngnathus albyi* Sauvage, a merlucciid: *Merluccius merluccius* (Linnaeus), a juvenile caproid: *Capros aper* (Linnaeus) [= *C. arambourgi* Baciuet al.], two trichiurids: *Lepidopus proargenteus* Arambourg and *L. albyi* (Sauvage), a carangid: *Trachurus trachurus* (Linnaeus) and a soleid: *Microchirus abropteryx* (Sauvage).

At that time, this locality was considered as being Messinian in age. However, the study of the nannoplankton and of the diatom flora throws some doubts about its age (Gaudant et al., unpublished data).

Excavations were carried out at this locality by Sturani (Sturani & Sampò, 1973) and then, in 1981, under the direction of Giulio Pavia (Pavia, 1989). Altogether, they have yielded more than two hundred fish skeletons. Among them, 54.1% belong to the myctophids, *Myctophum* (s.l.) *licatae* (Sauvage) being the most abundant species with 42.6% of the collected material, whereas *M.* (s.l.) *dorsale* (Sauvage) does not exceed 7.0%. As in the Tortonian of the Tanaro River, the clupeid *Alosa elongata* Agassiz is the second most frequent species with 20.2%. Then, we find the syngnathid *Syngnathus albyi* Sauvage (6.2%), the sternoptychid *Maurolicus muelleri* (Gmelin) (4.1%) and the trichiurid *Lepidopus* sp. (5.1%), as well as *Scomber* sp. (2.5%).

A comparison between this fish fauna and that from the Tanaro River shows that a great similarity exists between them, as demonstrated by the equivalent frequency of the myctophids and of the clupeid species *Alosa elongata* Agassiz in both localities. Although they are fossilized in different lithological facies, both fish faunas are indicative of similar bathymetrical conditions. Their sedimentological difference can be explained by the fact that upwellings were active at Pecetto di Valenza and produced the proliferation of the diatom flora, whereas the sedimentation was marly in the surroundings of Alba which was at that time near the end of the Piedmont Gulf.

The preevaporitic Messinian fish fauna of Roddi

The fish fauna from Roddi was collected during the construction of a housing estate, which had put to light a small section of laminated marls alternating with intercalations of fine sands. Sixteen different fish species were recognized in the collected material (Gaudant et al., 2008). Half of them were already present in the Tortonian of Tanaro.

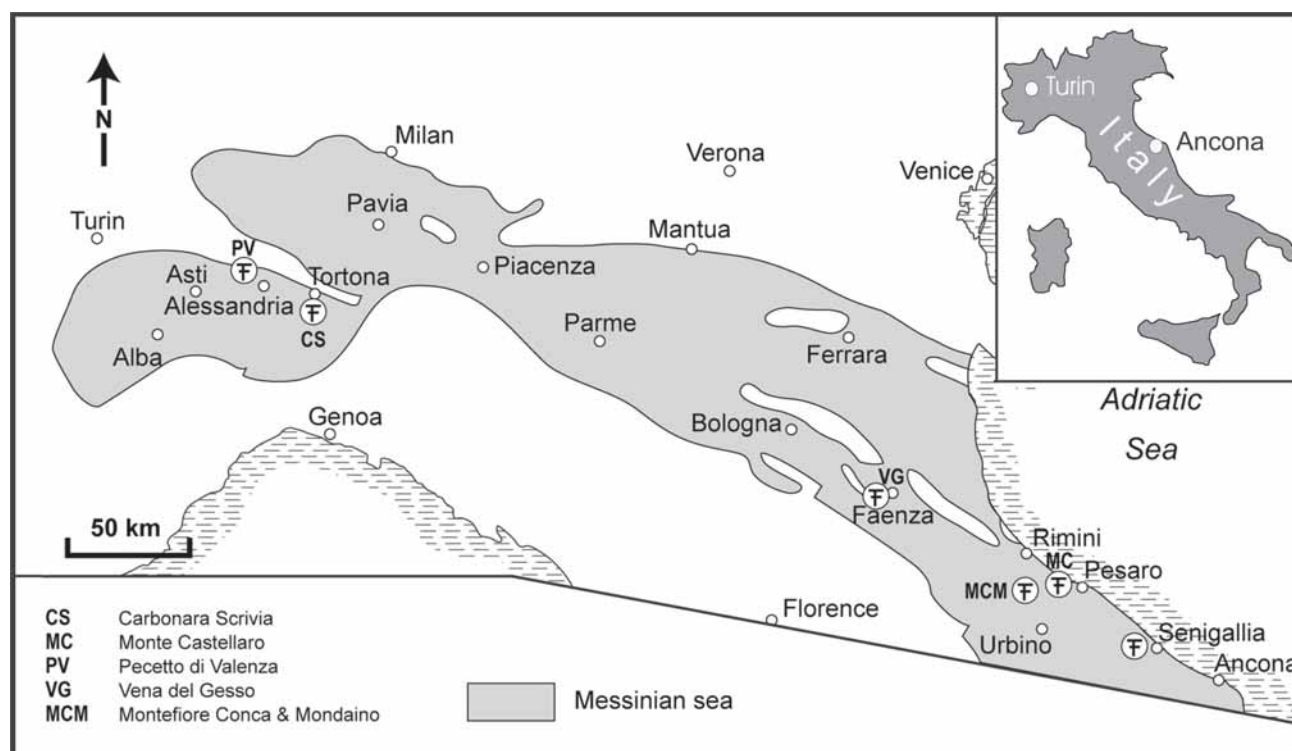


Fig. 3 - Palaeogeographical map of Northern Italy during the Messinian (adapted from Vai, 1988).

In the fish fauna from Roddi, myctophids have the same representatives as in the Tortonian of the Tanaro River: *Myctophum* (s.l.) *licatae* (Sauvage) (40.0% of the studied material) and *M.* (s.l.) *dorsale* (Sauvage) (5.0%). When adding to the myctophids the sternoptychid species *Mauroliscus muelleri* (Gmelin) (17.1%), which is principally living up to depths of 400 metres, the amount of mesopelagic fishes reaches 52.1%.

Like in the Tortonian of the Tanaro River, the clupeid species *Alosa elongata* Agassiz, which was an epipelagic fish, is rather abundant (20.7% of the studied material). All the other species are rather rare as, among the other species, only three slightly exceed 2%: *Bregmaceros albyi* (Sauvage), *Syngnathus albyi* Sauvage, and *Scomber scombrus* Linnaeus.

Like the fishes, the molluscs found at Roddi are also reminiscent of those which had been identified in the Tortonian of the Tanaro River and in the "Tripoli" of Pecetto di Valenza, the age of which is not definitely settled (Gaudant et al., unpublished data).

According to the great similarity of the fish faunas, the deposition depth of the fossiliferous marls of Roddi was apparently very similar to those of the Tortonian marls of the Tanaro River and of the "Tripoli" from Pecetto di Valenza.

The fishes from the stromatolitic preevaporitic limestone of Monticello d'Alba

Sturani collected at Monticello d'Alba, in thin calcareous stromatolitic layers intercalated in the middle of "thinly laminated silty clays", about ten small, more

or less complete, fishes that "appear to have been mummified". He reported them as belonging to the species *Pachylebias orsinii* D'Erasmus [= *Aphanius crassicaudus* (Agassiz)]. We were able to verify this fact when examining in Turin Sturani's collection in the Museo regionale di Scienze naturali. These fishes that Sturani considered as issued from the local equivalent of the "Calcare di base" of Sicily, differ from the *Aphanius crassicaudus* (Agassiz) found in the evaporitic succession of Piedmont in exhibiting only their scales instead of showing their skeleton. Their occurrence in the stromatolitic limestone is indicative of the existence of lagoonal conditions.

The primary laminated gypsum

Although Sturani (1973, fig. 1) figured an *Aphanius* in front of the "bed of primary gypsum", we did not observe any fish preserved in the "evenly laminated primary gypsum" from the surroundings of Alba.

The fish fauna from the "sulphate rich thinly laminated euxinic clay"

A rather diversified fish fauna was found in this facies, both at Scaparoni and Monticello d'Alba. Although Sturani (1973, fig. 1) noted the occurrence of *Spratelloides lemoinei* Arambourg [= *Spratelloides gracilis* (Schlegel)] under the "bed of primary gypsum", a more significant fact is the presence of a somewhat diversified fish fauna above this bed. First, Sturani noted the occurrence, just above the gypsum, of *Spratelloides lemoinei* Arambourg (Sturani, 1973, figs. 3-4; Cavallo et al., 1986, fig. 449), together with a gobiid (*Gobius* sp.)

and a small anguilliform (“*Anguilla*” sp.) [= *Muraena*? sp.] (Sturani, 1973, fig. 2; Cavallo et al., 1986, fig. 453). Later, Sturani reported the find of *Solea* sp. [= *Microchirus abropteryx* (Sauvage)] (Sturani, 1978, fig. 6C) - that he had already mentioned before as *Microchirus bassanianus* (Kramberger) in his section of the Messinian (Sturani, 1973, fig. 1) - and *Scorpaena minima* Kramberger (Sturani, 1978, fig. 6D). Just before his untimely death, Sturani (1975) was also aware of the find by Mario Macagno of an incomplete *Lepidopus albyi* (Sauvage) (Fontes et al., 1987, pl. 1, fig. 2). More recently, a juvenile carangid: *Trachurus trachurus* (Linnaeus) (Cavallo et al., 1986, fig. 463; Fontes et al., 1987, pl. 1, fig. 3) was found at Monticello d’Alba, whereas two small percoids: *Tavania sturani* Gaudant (Cavallo et al., 1986, fig. 465; Fontes et al., 1987, pl. 1, fig. 4) and a representative of the species *Gobius meneghinii* Cocchi (Fontes et al., 1987, pl. 1, fig. 1) increased the diversity of the fish fauna from Scaparoni which also includes four representatives of the atherinid species *Atherina boyeri* Risso, which was already known at Castagnito (Gaudant, 1979c).

At Scaparoni, the same beds have also yielded many *Aphanius crassicaudus* (Agassiz) exhibiting a rather moderate pachyostosis of the skeleton (only the juveniles up to 15-20 mm in standard length are not pachyostosed). An attempt of statistical evaluation of the composition of this fish fauna was made. It is based on the material from Scaparoni, which is kept both in Turin, in the Museo regionale di Scienze naturali, and at Alba, in the Museo civico “F. Eusebio”. The study of 78 specimens has shown that *Aphanius crassicaudus* (Agassiz) is by far the dominant species with 64.1% of the population. *Spratelloides gracilis* (Schlegel) is the second most frequent species with 14.1%, followed by the gobiids (*Gobius* spp., including *G. meneghinii* Cocchi) with 9.0%, *Atherina boyeri* Risso and *Microchirus abropteryx* (Sauvage), both 5.1%. The lagoonal character of this community is confirmed by the occurrence of many insect remains, especially libellulids (Cavallo & Galletti, 1987).

The study of the standard length of the fishes from these strata is also informative. As shown in Fig. 4, the species *Aphanius crassicaudus* (Agassiz) is mainly represented by juveniles, as the standard length of 2/3 of its representatives is less than 30 mm, whereas the largest one reaches 58 mm. The population of *Spratelloides gracilis* (Schlegel) includes both juveniles (standard lengths ranging from 15 to 36 mm) and more or less adults having a standard length larger than 55 mm. The representatives of *Atherina boyeri* Risso are rather small (standard length ranging from 22 to 45.5 mm), like the unique incomplete *Lepidopus albyi* (Sauvage) having an estimated standard length of 367 mm, i.e. a rather small size for a ribbon-like fish. All the other fishes found in this stratum are small: except for a specimen of *Gobius meneghinii* Cocchi having a standard length of 53 mm, the other gobiids (*Gobius* sp.), *Microchirus abropteryx* (Sauvage), *Tavania sturani* Gaudant and *Scorpaena* sp. belong to the fry, as none of them has a standard length exceeding 20.5 mm.

Higher in the series, about 9 m above the gypsum bed (Fontes et al., 1987, fig. 1), strongly pachyostosed

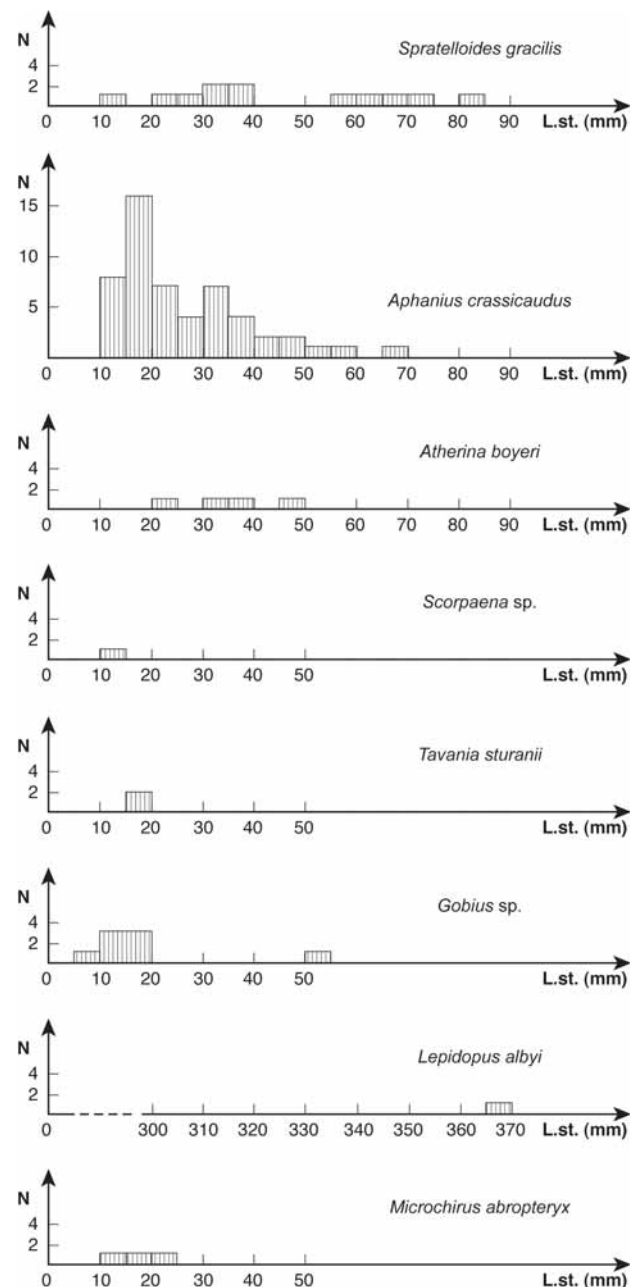


Fig. 4 - Histogram of standard length of the fishes from the “sulphate rich thinly laminated euxinic clay” overlying the bed of “primary gypsum” at Scaparoni, near Alba.

Aphanius crassicaudus (Agassiz) similar to those figured by Gaudant (1979a) are fossilized in a thinly laminated silty marl showing millimetric intercalations of gypsum. Evidently, this layer corresponds to an interruption of the connection with the sea, so that a lagoonal environment in which important variations of salt content were taking place, in relation with the alternance between humid and dry seasons during which gypsum was precipitating in the muddy bottom of the lagoon.

The evaporitic succession of Castagnito

At Castagnito, in the Bric Cenciurio section (about 8 km East of Scaparoni), the evaporitic Messinian exhibits a succession that strikingly differs from that exposed at Scaparoni (Fourtanier et al., 1991). Four gypsum beds are present at Castagnito, instead of one, although their total thickness equals about 5.5 m, i.e. approximately the thickness of the gypsum bed of Scaparoni. Additionally, a diatomitic intercalation takes place below the third gypsum bed (Fig. 5). It has yielded a skeleton of *Spratelloides gracilis* (Schlegel) and a fragment of *Lepidopus* sp., whereas the marly layers are rather rich in *Aphanius crassicaudus* (Agassiz) (Fourtanier et al., 1991). The composition of the diatom flora is indicative of a marine nearshore environment connected to the open sea and having a water depth not exceeding 50 to 100 m.

Consequently, the Bric Cenciurio section of Castagnito demonstrates the occurrence of rather small oscillations of the sea level so that, at one time, the lagoonal environment with *Aphanius crassicaudus* (Agassiz) was temporarily replaced by a shallow marine incursion, which was again giving place to lagoonal conditions.

At about 1.5 km SW of the Bric Cenciurio, another marly outcrop has yielded, together with *Aphanius crassicaudus* (Agassiz), a rather large specimen of *Atherina boyeri* Risso (Gaudant, 1979c, pl. 1, fig. 3; Cavallo et al., 1986, fig. 468) and a juvenile of the species *Solea* [= *Microchirus*] *abropteryx* (Sauvage) (Gaudant, 1979c, pl. 1, fig. 5; Cavallo et al., 1986, fig. 462).

The evaporitic succession of Cherasco

The fossiliferous locality of the "Rocca del Campione" is situated on the right bank of the Tanaro River, at about 3 km E-NE of Cherasco (Cavallo & Gaudant, 1987). There, the Messinian evaporitic succession crops out with a rather important dip southwestward. The exposed sequence, which exceeds 50 m in thickness (Fig. 6), is composed of strata of bluish to yellowish marls (A to H) alternating with six gypsum beds (1 to 6: 0.8 to 4.5 m thick). Fossil fishes were found at different levels in the section. Strata C, D, F, G, and H have yielded the cyprinodontid *Aphanius crassicaudus* (Agassiz) alone or with other taxa (in strata H).

The most interesting fossiliferous layer was excavated in the middle of stratum H (Gaudant, 1979b; Cavallo & Gaudant, 1987). It has yielded many specimens of *Aphanius crassicaudus* (Agassiz), which generally exhibit a more or less developed pachyostosis (Gaudant, 1979b, pl. 1, figs. 1-2), although some specimens collected in other layers are quite normal (Gaudant, 1979b, pl. 1, fig. 3). A more or less developed pachyostosis is also present in the gobiid species *Gobius ignotus* Gaudant (Gaudant, 1979b, pl. I, figs. 5-6; Gaudant, 1981, pl. 5, figs. 5-6; Cavallo et al., 1986, fig. 454). We have also identified an atherinid: *Atherina cavallioi* Gaudant, which is not frequent, and four species which are only known by one specimen: the clupeid *Clupeonella macagnoi* Gaudant, the salmonid *Salvelinus oliveroi* Gaudant, the cyprinid

Palaeoleuciscus cf. *oeningensis* (Agassiz), and the mugilid *Mugil?* sp.

An attempt of evaluation of the frequency of the different species in this fossiliferous layer is based on the material kept at Alba, in the palaeontological collections of the Museo civico "F. Eusebio" (130 specimens). It has shown that *Aphanius crassicaudus* (Agassiz) is by far the most abundant (79.2%) whereas *Gobius ignotus* Gaudant reaches 17.7% and *Atherina cavallioi* Gaudant only 2.3% of the collected material.

The composition of the fish fauna from this fossiliferous layer is significant for understanding the palaeogeographical context in this part of Piedmont at

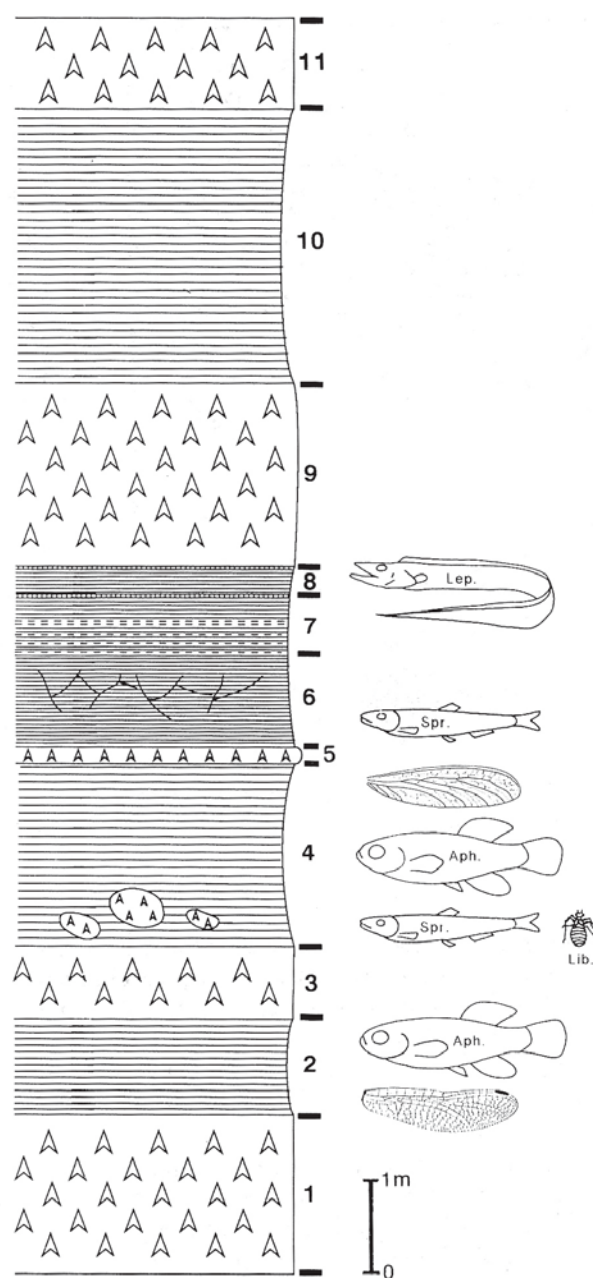


Fig. 5 - The Bric Cenciurio section, near Castagnito, Piedmont, showing the evaporitic Messinian (modified from Fourtanier et al., 1991). Aph. - *Aphanius*; Lep. - *Lepidopus*; Spr. - *Spratelloides*; Lib. - Libellulidae (larva).

the end of the Messinian evaporitic episode. In fact, *Gobius ignotus* Gaudant, which is known in other Messinian localities, is a species of marine origin that was adapted to lagoonal environments exposed to

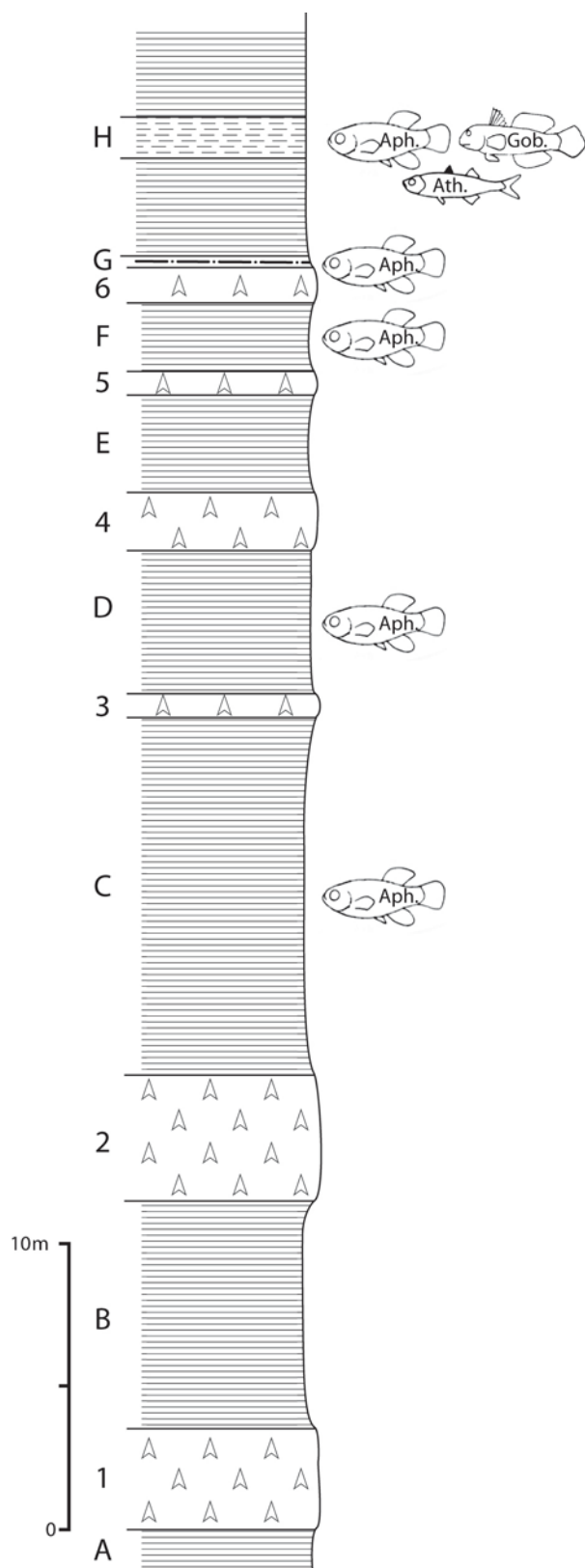


Fig. 6 - The evaporitic Messinian section of the "Rocca del Campione", near Cherasco, Piedmont. Aph. - *Aphanius*; Ath. - *Atherina*; Gob. - *Gobius*.

important variations of salt content, especially sulphates. The clupeid species *Clupeonella macagnoi* Gaudant was probably able to live in more or less brackish waters, like the recent species of this genus that are living in the basins of the Black Sea and the Caspian Sea. The mugilid *Mugil* sp. was also a marine fish adapted to live temporarily in brackish and even in fresh waters, although, like the recent mugilids, it very likely needed to return to the sea for breeding. Consequently, these three species are indicative of a connection between the Piedmont basin and the sea at the end of the evaporitic episode. On the other hand, the salmonid *Salvelinus oliveroi* Gaudant and the cyprinid *Palaeoleuciscus* cf. *oeningensis* (Agassiz) give evidence that a river was flowing toward the Piedmont basin at that time, as the first species was probably anadromous, like the recent northern populations of *Salvelinus alpinus* (Linnaeus). This interpretation is confirmed by the find in this layer of an anatid bird (Cheneval, 1993), whereas a frog (*Rana* sp.) was found in the underlying stratum (noted G in Fig. 6).

The lagoonal fish fauna of Carbonara Scrivia, near Tortona

Thirty years ago (1978), a former student of Carlo Sturani, Danilo Mori, had the opportunity to observe at several hundred metres SW from the Carbonara Scrivia railway station and about 5 km SSW of Tortona, a part of the Messinian sequence which was at that time no more hidden by the alluvium of the Scrivia River (Gaudant & Mori, 1983). This succession begins with grey yellowish marlstones, which have yielded many skeletons of *Aphanius crassicaudus* (Agassiz), together with nymphs and sometimes adults of Libellulids. It ends with a layer of bluish laminated clay with *Cyprideis* cf. *pannonica*, *Ammonia beccari tepida*. The fact that a poorly preserved incomplete skeleton, probably belonging to the genus *Spratelloides* Bleeker, was found in the fish layer suggests that this lagoonal environment had kept some connection with the sea.

The fish remains from the "Congeria facies" of Ciabòt Cagna

The laminated clay of Ciabòt Cagna section, near Sioneri (lithozone C of Cavallo & Repetto, 1988) has yielded a rich brackish water malacofauna including mainly *Melanopsis narzolina* (Michelotti), *Dreissena deshaysi* Capellini, *Theodoxus mutinensis* (D'Ancona) and *Melanoides tuberculata* (Müller). A small number of juvenile otoliths of teleostean fishes were also collected when washing and sieving the sediment. Caputo (2005) identified among them three genera of myctophids and at least two genera of gobiids.

The coexistence of these fishes having so different ecological requirements is rather difficult to explain. In fact, if some recent gobiid species are quite able to live in brackish lagoons, myctophids are marine stenohaline mesopelagic fishes that are living in rather deep seas.

It should be added that allochthonous vertebrate remains including pharyngeal teeth of freshwater cyprinid fishes (*Palaeocarassius* sp.) were found in a 20 cm thick black layer, just below the laminated clay (Cavallo et al., 1993). These remains are indicative of the presence, at

that time, of tributaries that were bringing fresh water into the sedimentary basin.

COMPARISON WITH THE MESSINIAN FISH FAUNA OF THE ADRIATIC TROUGH

For a better understanding of the significance of the Upper Miocene Piedmont fish fauna, a comparison with the more or less coeval localities of the Adriatic region appears helpful, especially because some of them have been recently either studied or revised.

The Tortonian fish fauna of Ca' Matterella, near Faenza

Thirty-four skeletons of fossil fishes were collected in the Tortonian of Ca' Matterella, near Faenza (Corsi et al., 1999). In this small fish fauna, myctophids are by far dominant with 70.6% of the total population, whereas clupeids (*Sardina* sp. and an undetermined other genus) do not exceed 8.9%. Two specimens (6.0%) belong to the paralepidids (*Paralepis* sp. and *Lestidiops* sp.) and all the other taxa (*Maurolicus* sp., *Bregmaceros* sp., *Scopelogadus* sp., and *Trichiurus* sp.) have only one representative (2.9% each). Because of the rather small number of collected specimens, the percentages of the different taxa are only indicative. However, they demonstrate the overwhelming dominance of myctophids and the reduced importance of clupeids.

The preevaporitic Messinian fish fauna of the Adriatic coast

Although the fish fauna from Mondaino is better known and relatively more diversified, our estimate of the composition of the fish fauna from the Lower Messinian of Romagna is based on the material collected by the staff of the Museo civico di Storia naturale of Verona in a diatomitic bed of the Monte Maggiore section, near Montefiore Conca. This material includes 166 specimens (Bedini et al., 1986). Among them 48.7% belong to the myctophids which, according to our criteria (Gaudant & Ambroise, 1999) have three representatives: *Myctophum* (s.l.) *dorsale* (Sauvage) (27.1%), *M.* (s.l.) *licatae* (Sauvage) (11.4%), and *M.* (s.l.) *vexillifer* (Sauvage) (2.4%), whereas 7.8% are undetermined. Then, in decreasing order, we find *Maurolicus muelleri* (Gmelin) (36.1%) and *Bregmaceros albyi* (Sauvage) (9.6%), the representatives of all the other identified species being less than 2% of the studied material.

A comparison with the material collected near Mondaino shows that a great similarity exists with the fish fauna from Monte Maggiore. At Mondaino, myctophids are still more abundant (their percentage

reaches 60.6%) and *Myctophum* (s.l.) *dorsale* (Sauvage) (29.7%) is more frequent than *M.* (s.l.) *licatae* (Sauvage) (19.0%), the two other rather significant species being *Maurolicus muelleri* (Gmelin) (23.7%) and *Bregmaceros albyi* (Sauvage) (6.9%).

Another important fish fauna is preserved in the "Tripoli" of Senigallia, at about 45 km SE of Mondaino. It is possible to estimate the composition of this fish fauna according to the study made by D'Erasmus (1930) and the revision of the material that is kept in the Museo di Paleontologia of Florence University. In this fish fauna, the myctophids are overwhelmingly dominant with 86.2% of the specimens examined by D'Erasmus. *Maurolicus muelleri* (Gmelin) is the second more frequent species with only 4.1%, whereas *Syngnathus albyi* Sauvage reaches 3.7%, like the paralepidids *Sudis sphekodes* (Sauvage) and *Paralepis* sp. that, together, do not exceed this percentage.

The evaporitic fish fauna of the "Vena del Gesso"

The Messinian evaporitic succession of the "Vena del Gesso" is exposed near Borgo Tossignano, 12 km S-SW of Imola, in the valley of an affluent of the Santerno River called Rio Sgarba. It is characterized by a cyclic gypsiferous succession in which 16 evaporitic cycles were recognized (Marabini & Vai, 1985). Each cycle begins with the deposition of an euxinic laminated pelite; the sedimentation continues with calcareous layers, preceding the precipitation of selenite gypsum.

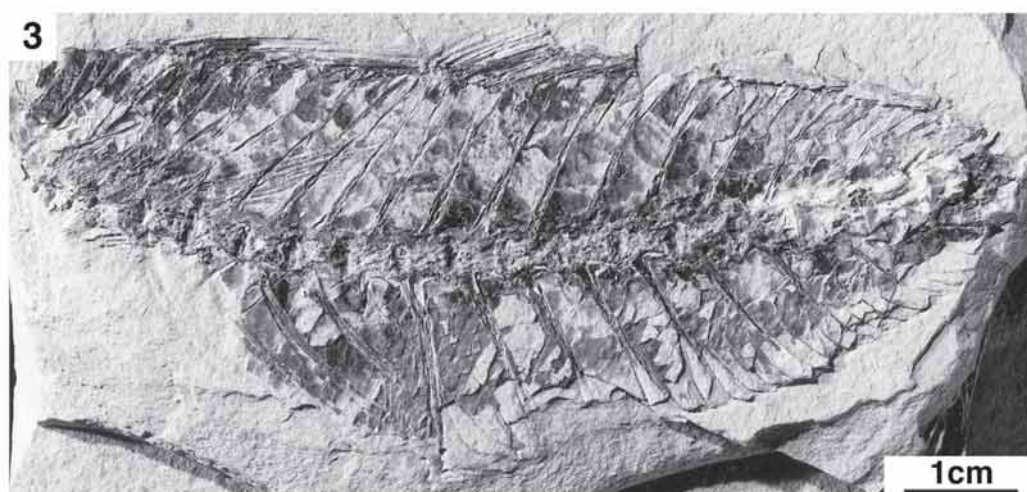
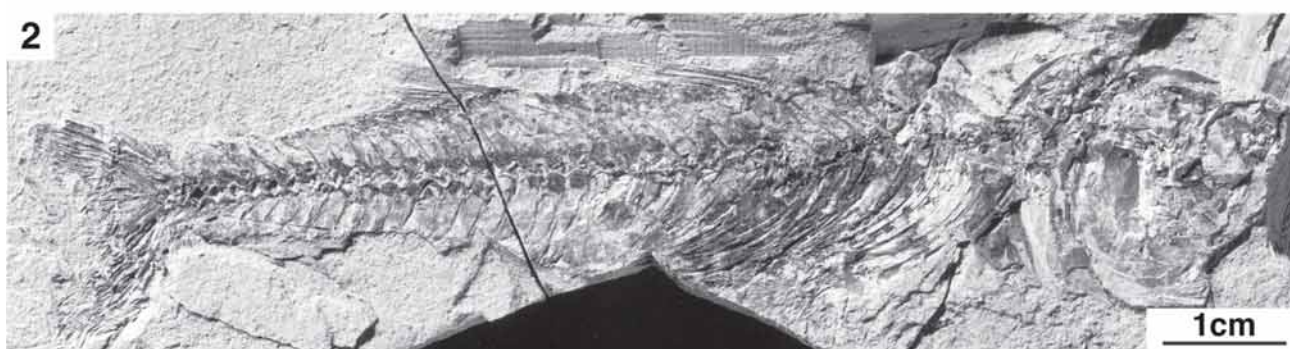
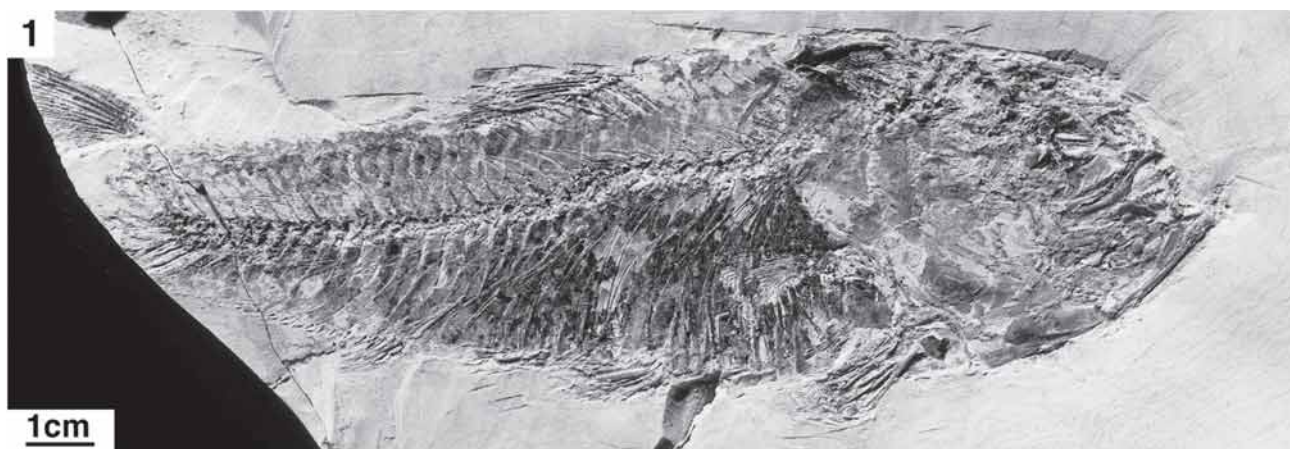
Fossil fishes were found in the bituminous shale deposited during the 13th and 14th cycle. The material collected by the staff of the Museo civico di Storia naturale of Faenza and by private collectors includes 68 specimens. Among them, *Aphanius crassicaudus* (Agassiz) is dominant with 55.9%; its representatives are either normal or strongly pachyostosed. *Gobius ignotus* Gaudant (Pl. 1, fig. 4) is the second most frequent species (30.9%); like *Aphanius crassicaudus* (Agassiz), its representatives are, or not, pachyostosed. *Atherina boyeri* Risso (Pl. 1, fig. 2) is less frequent with 7.4%. The occurrence of two specimens of a Tilapiine was reported by Landini & Sorbini (1989). They were recently described as *Oreochromis lorenzoi* (Carnevale et al., 2003).

Three other taxa are present in this fish fauna. One is a clupeid exhibiting similarities with *Clupeonella macagnoi* Gaudant, as shown by the possession of a smooth operculum, which excludes that it can belong either to the genus *Alosa* Linck or to *Sardina* Antipa (Pl. 1, fig. 1). The two other ones are carangids: *Trachurus* sp. (Pl. 1, fig. 3) and *Lichia* aff. *amia* (Linnaeus),

EXPLANATION OF PLATE 1

figs. 1-4 - Fishes from the evaporitic Messinian of the "Vena del Gesso", near Borgo Tossignano, Romagna.

- 1- Undetermined Clupeid; Cat. n. MSF 1399.
- 2- *Atherina boyeri* Risso; Cat. n. MSF 15.
- 3- *Trachurus* sp.; Cat. n. MSF 204.
- 4- *Gobius ignotus* Gaudant; Cat. n. MSF 192.



represented by a pectoral girdle and a vertebra (Carnevale et al., 2008).

The occurrence of carangids, which are stenohaline marine fishes, is significant for interpreting the palaeoenvironmental deposition conditions of the 13th and 14th evaporitic cycle of the “Vena del Gesso” as it demonstrates that normal sea water was filling the lagoon before the beginning of the evaporation of the brine which produced the precipitation of selenite crystals.

The composition of this fish fauna may be usefully compared to that of another locality of the same area, which was found at Brisighella, in the Monticino quarry. There, the fossil fishes are preserved in gypsified stromatolitic sediments, which are the equivalents of the first two evaporitic cycles of the “Vena del Gesso”. According to Landini & Sorbini (1989), this fish fauna includes marine stenohaline fishes like *Sarda* sp. and *Trachurus* sp., together with an undetermined clupeid, a gobiid (*Gobius* sp.) and *Oreochromis lorenzoi* Carnevale et al. Like that of the “Vena del Gesso”, this fish fauna was probably fossilized in a lagoon connected with the sea, so that marine fishes were sometimes able to penetrate when the lagoon was filled by marine water.

The Messinian succession of the Monte Castellaro, near Pesaro

The fish fauna from the Messinian of the Monte Castellaro section was studied by Sorbini (1988) who published a synthetic section of the strata outcropping in the cliff above the present seashore. The preevaporitic Messinian (Marnoso-arenacea Formation) is present in the lower part of the series. It is mainly represented by diatomitic sediments (“Tripoli”) overlying a marly sequence in which bituminous layers are intercalated. In these sediments, Sorbini identified myctophids, *Paralepis*, *Lepidopus*, syngnathids, *Sardina*, etc., which are frequently found in more or less coeval strata of other fossiliferous localities. Just above the “Tripoli”, Sorbini supposed that an alternance of marly limestone and diatomaceous marl is the equivalent of the “calcare di base” from Sicily. The diatomaceous marl has yielded specimens of *Capros aper* [= *Capros arambourgi* Baci et al.] and *Trichiurus* sp., which normally belong to the fish fauna of the “Tripoli”, and also small fishes that Sorbini wrongly identified as “*Aphanius* without pachyostosis”. In fact, the re-examination of this material which is kept in the Museo civico di Storia naturale of Verona has shown that these fishes are really juveniles of the marine species *Maurolucus muelleri* (Gmelin) having a standard length ranging from 12 to 25 mm. Consequently, we consider that, according to its fish fauna, this diatomaceous marl still belongs to the “Tripoli”.

Higher in the succession, a sequence of bluish bituminous marl which is about 11-14 m thick, belonging to the Gessoso Solfifera Formation, has yielded abundant skeletons of *Aphanius crassicaudus* (Agassiz) generally exhibiting a more or less developed pachyostosis. The specimens of *Gobius ignotus* Gaudant are less frequent; their skeleton is also frequently pachyostosed. Rather scarce marine stenohaline fishes were also found in the bituminous marl, especially *Epinephelus* sp. and *Zeus faber* Linnaeus, which demonstrate that the lagoonal environment was connected

with a sea having a normal salt content. Additionally, as noted by Sorbini & Tirapelle Rancan (1979), round herrings (*Spratelloides* sp.), an atherinid (*Atherina boyeri* Risso), and juvenile soleids (*Microchirus abropteryx* (Sauvage) with standard length not exceeding 16.5 mm) are present in the same layers. Near the top of the formation, the skeleton of a cichlid (*Oreochromis lorenzoi* Carnevale et al.) was found and the “strata degli insetti” has yielded disarticulated bones of a latid that Otero & Sorbini (1999) considered as being remains of the Recent nilotic perch *Lates niloticus* Cuvier & Valenciennes.

As shown by the labels of the specimens, Sorbini tried to define a series of 13 fossiliferous layers in the Monte Castellaro section. Layer 1 corresponds to the “diatomaceous marl” in which *Capros* and a juvenile *Trichiurus* were found together with small fishes which are not “*Aphanius* without pachyostosis” but *Maurolucus muelleri* (Gmelin) (see above). Specimens of true *Aphanius crassicaudus* (Agassiz) are present in layers 4, 8, 9, 10, 11, and 13, whereas *Spratelloides* sp. and *Microchirus abropteryx* (Sauvage) come from layers 8 and 9. Unfortunately, Sorbini (1988) did not report this numbering in his published schematic section of Monte Castellaro.

At Ancona and in the area around Urbino, a series of fossiliferous localities were found in the Messinian “marne bituminose” of the Montecalvo in Foglia-Isola del Piano Basin (especially in the surroundings of Fossombrone and Urbino) and between Lunano and Peglio, in the “Bacino Marchigiano interno”. All have yielded monospecific fish faunas with *Aphanius crassicaudus* (Agassiz) (Savelli & Wezel, 1978; Gaudant et al., 1988). In the same region, the fish fauna from the gypsiferous marls overlying the “Tripoli” of Senigallia is more diversified. There, *Aphanius crassicaudus* (Agassiz), which is dominant, is associated to another cyprinodontid (*Cryptolebias senogalliensis* Cocchi), a gobiid (*Gobius meneghinii* Cocchi), and a clupeid (*Alosa* [= *Sardina*?] *crassa* Sauvage) (Gaudant, 1978, 1981).

CONCLUSIONS

The study of the Tortonian and Messinian fish fauna of Piedmont has completed and partially confirmed Sturani’s interpretations.

First, it is possible to demonstrate that a great similarity exists between the Tortonian and lower Messinian fish faunas. This similarity is so important that a micropalaeontological analysis was requested for determining the age of the fish fauna from Roddi, near Alba. The Tortonian fish fauna of the Tanaro River and that of the lower Messinian of Roddi (Fig. 7A) are characterized by the dominance of myctophids and the significant presence of the clupeid species *Alosa elongata* Agassiz, the depth of the sea being probably less than 200 m. On the contrary, in Romagna and Marche this species is almost totally absent and the myctophids are overwhelmingly dominant (Figs. 7B-C), so that the sea is supposed to have been deeper. Another difference is the absence in the lower Messinian of Piedmont of a

species, *Myctophum vexillifer* (Sauvage), which, originally described at Licata, Sicily, is also present at Montefiore Conca and Mondaino, Romagna, and possibly at Senigallia, Marche.

As shown by the observations made by Sturani at Monticello d'Alba, a lowering of the sea level took place before the beginning of the precipitation of the gypsum, during the deposition of "thinly laminated silty clays" including some beds of stromatolitic limestone in which small *Aphanius crassicaudus* (Agassiz) were mummified. Then took place the precipitation of the gypsum.

Just above the gypsum, a connection was again established with the sea, so that marine fishes (mainly juveniles) were able to enter the lagoon in which the species *Aphanius crassicaudus* (Agassiz) was proliferating. Higher in the section, the lagoon lose its connection with the sea and *Aphanius crassicaudus* (Agassiz) was the only species able to live in an environment subjected to important variations of the salt content. However, this schematic interpretation is suffering some lateral variation, as shown by the Castagnito and Cherasco sections. In the first place, a diatomitic event took place within the evaporitic

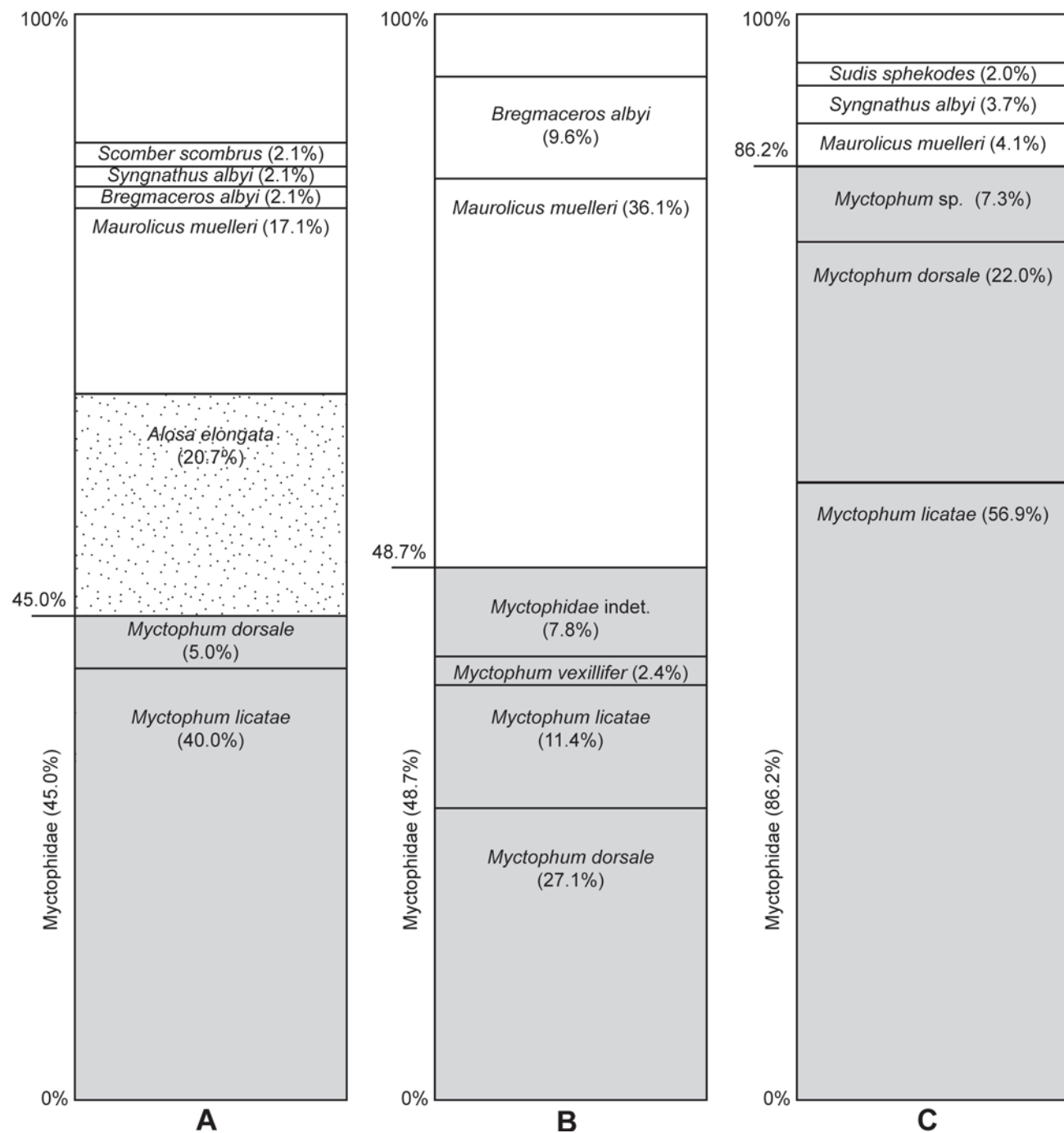


Fig. 7 - Comparative composition of the fish faunas from the preevaporitic Messinian of Roddi, Piedmont (A), of the Monte Maggiore, near Montefiore Conca, Romagna (B), and of Senigallia (C).

sequence. In the second one, the lagoon was again connected with the sea after a period of more or less complete isolation.

Finally, a more or less brackish environment took place in the Piedmont basin, as shown by the presence of otoliths of gobiids in the “Facies a Congerie” which is mainly characterized by its brackish malacofauna (*Melanopsis*, *Dreissena*, *Theodoxus*, *Melanoides*, etc.).

The study of the coeval fossiliferous localities of the Adriatic region (Romagna and Marche) shows that the fish fauna of the preevaporitic Messinian is characterized by a higher percentage of the mesopelagic myctophids and an almost complete lack of the epipelagic clupeid *Alosa elongata* Agassiz, probably related to a deeper environment.

At the “Vena del Gesso”, the fish fauna found in the upper part of the evaporitic sequence indicates that a sea having a normal salt content was present at that time in the vicinity, as shown by the occurrence of the marine stenohaline fishes *Trachurus* sp. and *Lichia* aff. *amia* (Linnaeus) in this lagoonal environment. This impression is confirmed by the find of marine fishes like *Epinephelus* sp. and *Zeus faber* Linnaeus, which have the same requirements as *Trachurus* sp. and *Lichia* aff. *amia* (Linnaeus), above the gypsum bed of the Gessoso Solfifera Formation exposed in the Monte Castellaro section.

Finally, in the uppermost part of the Colombacci Formation, otoliths of sciaenids (87.2%) and gobiids (12.0%) were recently collected in the Ca' Ciuccio section, in the vicinity of Urbino, suggesting a “coastal shallow marine environment strongly influenced by freshwaters of continental origin” (Carnevale et al., 2006). However, the presence of extremely scarce otoliths of myctophids (less than 1%) is rather difficult to explain.

ACKNOWLEDGEMENTS

The first author wishes to acknowledge the colleagues who facilitated the study of the fossil fishes which are kept in public collections: Franca Campanino Sturani and Daniele Ormezzano (Museo regionale di Scienze naturali, Torino), Roberto Zorzini and Anna Vaccari (Museo civico di Storia naturale, Verona), Gian Paolo Costa, Marco Sami, and Mauro Diversi (Museo civico di Scienze naturali, Faenza), Elisabetta Cioppi (Museo paleontologico dell'Università, Firenze) and Ettore Molinaro (Museo civico Craveri, Bra). Eliana Fornaciari is also warmly acknowledged for the determination of the nannoplankton.

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Manuscript received 30 December 2007

Revised manuscript accepted 04 March 2008

