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Diversity and dynamics of an interstitial Tardigrada population in the Meloria Shoals, Ligurian Sea, with a redescription of *Batillipes similis* (Heterotardigrada, Batillipedidae)

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ABSTRACT

Quantitative samples of sediment for the study of the meiofauna were collected monthly beween March 1996 and February 1997 from a 7-m-deep site in the Meloria Shoals, Livorno Italy. In the Tuscan Shoals, 16 species of tardigrades were found belonging to the families Stygarctidae, Halechiniscidae, and Batillipedidae. *Megastygarctides orbiculatus* and *Actinarctus doryphorus* are reported for the first time in the Mediterranean Sea, and a redescription of *Batillipes similis* is proposed. Global density of the Tardigrada population fluctuated between 8 ind./ 10 cm^2 in May 1996 and 285 ind./ 10 cm^2 in January 1997. The lowest value of the Shannon-Wiener biodiversity index (H' = 1.09) was found in September 1996, whereas the highest score (H' = 2.46) was obtained in March 1996. Pielou's evenness index (J) fluctuated between 0.40 and 0.88, values attained in January 1997 and March 1996, respectively. The study confirms the notion that the organogenic detritus of the Shoals represents a very favourable environment for meiofaunal organisms in general, and Tardigrada in particular.

KEY WORDS: Tardigrada - Mediterranean Meiofauna - Benthos - Biodiversity - Population dynamics.

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INTRODUCTION

Although tardigrades are known as typical and important components of the permanent marine meiofauna, relatively few studies have attempted to shed light on the basic aspects of their ecology. The paucity of data in this respect, particularly for the subtidal taxa, is a consequence either of the small size that makes the study of these animals difficult, or of the low number of specimens frequently found.

As part of an extensive survey of the meiobenthos associated with the organogenic sand of the Meloria Shoals, Livorno (Italy), the local tardigradofauna was studied over a 12-month period from quantitative samples collected on a monthly basis. As previously found, the Shoals represent a very favourable habitat for tardigrades which are generally present with several species and conspicuous numbers of specimens, and hence represent an environment particularly suitable for carrying out ecological studies on these animals (Renaud-Mornant, 1979; Grimaldi De Zio *et al.*, 1983, 1988; D'Addabbo Gallo *et al.*, 1986, 1987, 1989, 1992). The sediment of the Meloria Shoals has already proved to be inhabited by a very interesting, rich and diverse assemblage of meiofauna organisms (Huys & Todaro, 1997; Todaro, 1998 a, b; Todaro & Kristensen, 1998). Herein we report on the tardigrade species found, on the temporal fluctuations of the community attributes, and on the distribution within the sediment of specific taxa. Moreover, the finding in Meloria Shoals sediment of numerous individuals of *Batillipes similis* Schulz, originally described from *Amphioxus* sand of the Gulf of Naples (Schulz, 1955), allowed us to enrich the original description with additional, more detailed information about characteristics previously overlooked or underestimated.

MATERIALS AND METHODS

Sediment samples were collected monthly from March 1996 to February 1997, at a 7-m-deep site located 300 m NW of the Meloria Shoals lighthouse, Livorno, Italy (43°32' N; 10°12' E). Samples in four replicates were obtained by SCUBA divers hand coring 15 cm into the sediment with Plexiglas corers, 3.55 cm internal diameter (10 cm^2 area). Due to adverse weather conditions in November, sediment could not be collected; two samplings were taken in December, instead. An additional set was collected in April 1996 from a nearby site located at 18 m depth; in this instance, the sediment was covered by a thick layer of dead leaves of *Posidonia oceanica*. To have clues about fauna vertical profiles at 7 m depth, one core for each of the April, June, October 1997, and January 1998 collections was dissected from top to bottom in five-intervals, the first four intervals of 2.4 cm each, the fifth of 5.4 cm.

Meiofauna was fixed *in situ* with 5% buffered formalin, prestained with Rose Bengal, after being narcotized using an isotonic 7% $MgCl_2$ solution. At the time of each sampling, the temperature at the sediment-water interface and the salinity of the interstitial water were measured. In the laboratory, the sediment of two additional cores was analysed for granulometry and total organic content according to Todaro (1992). In the laboratory, meiofaunal taxa were extracted from sand by the multiple decantations technique and collected on a 63-µm-mesh sieve (Pfannkuche & Thiel, 1988). Tardigrades were sorted using a

Zeiss STEMI DV4 stereomicroscope at 40× magnification, and subsequently prepared for taxonomic analysis. For this purpose, specimens were transferred singly on microslides, mounted either in Kaiser's Glycerol-Gelatine or Hoyer's fluid, and observed with a Leitz Diaplan phase contrast microscope. Several specimens were observed with a Phillips XL 40 SEM after being dehydrated through an ethanol series, critical point dried, mounted on aluminum stubs, and sputter-coated with gold-palladium. The sediment devoid of fauna was analysed for granulometry.

Abbreviations and convention

L, Total body length; W, body width; mC, medial cirrus; iC, internal cirrus; eC, external cirrus; lC, lateral cirrus; Cl, primary clava; B W pharingeal bulb width, B H pharyngeal bulb height; CE, cirrus E; Pr 1, lateral process 1; Pr 2, lateral process 2; Pr 3, lateral process 3; P_1, 1st leg sense organ; P_2, 2nd leg sense organ; P_3, 3rd leg sense organ; P_4, 4th leg sense organ; C, caudal process; AG, anus-gonopore distance. SEM, Scanning electron microscopy.

RESULTS

Microhabitat characteristics

The sediment was a well-sorted coarse organogenic detritus with sorting values (σ_i) ranging from 0.33 to 0.55 φ, and mean grain size of the sediment particles from -0.07 to 0.50 φ; the salinity was 38 psu during all the year, while the water temperature varied from 12° C in winter to 24° C in summer. The content of total organic matter did not vary markedly during the year (from 2.16% to 0.95% of sediment dry weight) (Table I).

Ecology

Tardigrades were constantly present in the meiofaunal community of the pit bottom of the Meloria Shoals between March 1996 and February 1997 with extremely variable frequencies in comparison with other meiobenthic groups. The mean values of the population, represented by a total of 3986 specimens, fluctuated between the lowest density of 8 ind./10 cm^2 (1.14% of the total meiobenthos) in May and 9.5 ind./10 cm^2 (1.69%) in December, and the highest density of 285 ind./10 cm^2 (11.72%) in January and 196 ind./10 cm^2 (10.4%) in February (Table II).

The taxonomic study revealed the presence of 16 species, 15 of which belonging to the families Stygarcti-

TABLE I - *Value of the temperature, salinity, organic matter, mean grain size and sorting coefficient in the Meloria Shoals, from March 1996 to February 1997.*

Month	Temperature (° C)	Salinity (‰)	Organic matter (%)	Mean grain size (φ)	Sorting σi
M	12	-	-	-0.07	0.33
A	13	38	2.16	0.48	0.54
M	19	-	0.95	-0.04	0.54
J	20	-	1.45	-0.04	0.44
J	24	38	1.42	0.48	0.43
A	24	-	-	0.11	0.55
S	21	38	1.41	0.50	0.44
O	19	38	1.57	0.26	0.49
D_1*	14	38	1.01	0.05	0.48
D_2*	15	38	-	-0.05	0.53
J	13	38	1.44	0.39	0.42
F	12	38	1.64	-0.20	0.53

*D_1: 3/12/1996; *D_2: 19/12/1996

TABLE II - *Tardigradofauna in the pit bottom of the Meloria Shoals, from March 1996 to February 1997.*

	Month											
	M	A	M	J	J	A	S	O	D_1	D_2	J	F
Mean density (ind./10 cm^2)	16.50	41.25	8.00	43.75	63.25	67.25	94.50	143.50	28.00	9.50	285.25	196.00
Standard deviation	11.39	15.65	4.24	14.31	32.79	76.55	41.55	35.69	7.26	7.19	20.15	20.96
% of total meiofauna	1.66	2.10	1.14	10.44	2.57	3.36	6.06	8.86	4.99	1.69	11.72	10.4
Number of species	7	8	4	8	4	5	4	8	6	5	8	9

dae, Halechiniscidae and Batillipedidae found in the monthly samples collected at 7 m, and only one species belonging to Stygarctidae, found in the additional sample collected in April 1996 at 18 m depth.

Since fluctuations, both in number of individuals and in species composition of the taxocenosis, were evident, the values of both the indices of biodiversity (Shannon-Wiener index = H') and equitability (Pielou index = J) were calculated monthly (Table III). The highest value of the biodiversity index was reached in March (H'= 2.46) when in a population of only 16.50 ind./10 cm^2, 7 species were present. On the contrary, in September with a population value of 94.50 ind./10 cm^2, but with only 4 species, the H' value was at its lowest (H' = 1.09). In March, also the equitability index was high (J = 0.88), whereas both in January and in February it reached the lowest values with, respectively, 0.40 and 0.41. These low values clearly depend on the high frequency of only one species, *Chrysoarctus flabellatus*, which represented 78% and 75% of the population, in January and in February, respectively.

Taxonomic account

Family STYGARCTIDAE Schulz, 1951

Subfamily STYGARCTINAE Schulz, 1951

Genus *Parastygarctus* Renaud-Debyser, 1965

Parastygarctus sterreri Renaud-Mornant, 1970

Remarks – This is one of the most frequent species of the Tardigradofauna (15%) in the Meloria Shoals pit bottom sediment at 7 m depth. The specimens found in all the samples were 89 adult males, 110 adult females, 130 2nd stage, and 64 1st stage larvae. The species is widespread in intertidal and subtidal sediments in the Mediterranean Sea (Binda *et al.*, 1995) and in the Atlantic, Indian, and Pacific Oceans, and can be considered cosmopolitan.

Subfamily MEGASTYGARCTIDINAE B ello & De Zio Grimaldi 1998

Genus *Megastygarctides* McKirdy *et al.*, 1976

Megastygarctides orbiculatus McKirdy *et al.*, 1976

Remarks – The only specimen found, perhaps a preadult, was recovered from a sample of sediment collected in April 1996 at 18 m depth below a 1-m-thick coat made up of dead leaves of the sea grass *Posidonia oceanica*. The finding represents the first record of the genus *Megastygarctides* in the Mediterranean Sea; previously, *M. orbiculatus* was known to occur only in the intertidal medium-fine sand (20 cm deep) of the Galapagos Archipelago (McKirdy *et al.*, 1976).

Family HALECHINISCIDAE Thulin, 1928

Subfamily HALECHINISCINAE Thulin, 1928

Genus *Halechiniscus* Richters, 1908

Halechiniscus greveni Renaud-Mornant & Deroux, 1976

Remarks - Numerous specimens (183, 165 of which only in August), were collected; they constitute approximatively 5% of the Tardigradofauna found in the Meloria Shoals. Adults and larvae were present. The species, found for the first time at Roscoff, France, has subsequently been found to be widespread in all the Mediterranean region.

Halechiniscus paratuleari Grimaldi De Zio *et al.*, 1988

Remarks – Six specimens of this species were collected, only in April 1996. The species was previously found in the Tyrrhenian Sea, in the Orosei Gulf in Sardinia at 40-45 m depth in organogenic detritus analogous to that of the Meloria Shoals, and in the Ionian Sea in similar sediment.

Halechiniscus tuleari Renaud-Mornant, 1979

Remarks – Occasionally found in different periods of the year with 31 specimens, *H. tuleari* is a subtidal species previously recorded in Madagascar, Polynesia, and in the Mediterranean Sea.

Genus *Chrysoarctus* Renaud-Mornant, 1984

Chrysoarctus flabellatus (Grimaldi De Zio *et al.*, 1982)
Syn. *Halechiniscus flabellatus* Grimaldi De Zio *et al.*, 1982

Remarks – This represents the most abundant species in the samples of the Meloria Shoals (2364 specimens, 60% of total tardigradofauna). Because of the presence of so many individuals, an accurate study of its morphology was carried out; this revealed the presence, in the cephalic region, of club-shaped secondary clavae, previously overlooked (Figs 1, 6A). In the Mediterranean basin, the species was previously recorded from the Tyrrhenian and Ionian Seas (Grimaldi De Zio *et al.*, 1982).

TABLE III - *Tardigradofauna composition and biodiversity in the Meloria Shoals, from March 1996 to February 1997 (% values in parenthesis).*

	Month												
Taxon	M	A	M	J	J	A	S	O	D1	D2	J	F	Total
STYGARCTIDAE													
Parastygarctus sterreri	8 (12.1)	53 (31.5)	14 (45.2)	99 (56.2)	54 (21.2)	40 (14.8)	50 (13.2)	108 (18.8)	6 (5.5)	21 (55.2)	52 (4.5)	61 (7.7)	566 (14.2)
HALECHINISCIDAE													
Halechiniscus greveni	-	2 (0.9)	-	-	-	165 (61.3)		8 (1.4)		2 (5.2)	4 (0.3)	2 (0.2)	183 (4.5)
Halechiniscus paratuleari	-	6 (3.6)	-	-	-	-	-	-	-	-	-	-	6 (0.1)
Halechiniscus tuleari	4 (6.1)	5 (2.9)	-	-	-	13 (4.8)	-	1 (0.1)	-	-	-	8 (1.0)	31 (0.7)
Chrysoarctus flabellatus	14 (21.2)	62 (36.9)	10 (32.3)	54 (30.6)	107 (42.1)		287 (75.9)	328 (57.2)	8 (7.3)	2 (5.2)	898 (78.7)	594 (75.7)	2364 (59.3)
Florarctus hulingsi	-	-	-	-	-	-	-	-	3 (2.7)	2 (5.2)	-	-	5 (0.1)
Styraconyx nanoqsunguak	-	-	-	3 (1.7)	-	-	-	-	-	-	-	-	3 (0.1)
Styraconyx sardiniae	4 (6.1)	-	-	1 (0.5)	-	-	-	1 (0.1)	-	-	-	2 (0.2)	8 (0.2)
Styraconyx tyrrhenus	-	-	-	-	-	3 (1.1)	-	4 (0.7)	-	-	-	-	7 (0.1)
Tholoarctus natans pedunculatus	-	8 (4.8)	-	3 (1.7)	-	-	5 (1.3)	-			3 (0.2)	2 (0.2)	21 (0.4)
Tanarctus longisetosus	2 (3.0)	15 (8.9)	6 (19.4)	11 (6.2)	5 (1.9)	-	-	65 (11.3)	64 (58.7)	-	70 (6.1)	81 (10.3)	319 (8.0)
Actinarctus doryphorus	12 (18.2)	-	1 (3.2)	1 (0.5)					25 (22.9)		68 (5.9)	6 (0.7)	113 (2.8)
Dipodarctus subterraneus	22 (33.3)	-	-	4 (2.2)	-	-	-	-	-	11 (28.9)	-	-	37 (0.9)
BATILLIPEDIDAE													
Batillipes littoralis											1 (0.1)		1 (0.1)
Batillipes similis	-	17 (10.1)	-	-	88 (34.6)	48 (17.8)	36 (9.5)	58 (10.1)	3 (2.7)		44 (3.8)	28 (3.5)	322 (8.0)
Total	66	168	31	176	254	269	378	573	109	38	1140	784	3986
Biodiversity													
Species richness	7	8	4	8	4	5	4	8	6	5	8	9	15
Shannon-Wiener (H') index	2.46	2.31	1.66	1.65	1.64	1.57	1.09	1.77	1.73	1.66	1.21	1.29	2.01
Pielou (J) index	0.88	0.77	0.83	0.55	0.82	0.68	0.55	0.59	0.67	0.71	0.40	0.41	0.51

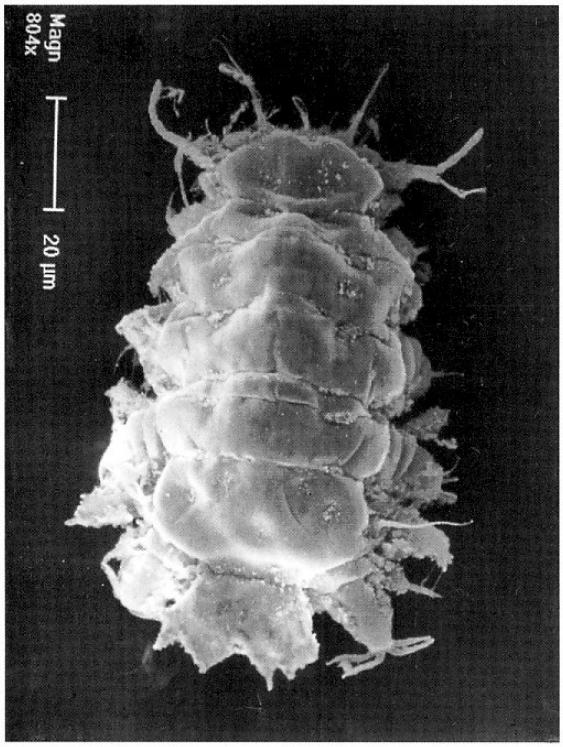

Fig. 1 - *Chrysoarctus flabellatus*: dorsal view (SEM micrography).

Subfamily FLORARCTINAE Renaud-Mornant, 1982

Genus *Florarctus* Delamare Deboutteville & Renaud-Mornant, 1965

Florarctus hulingsi Renaud-Mornant, 1976

Remarks – Only five specimens of *F. hulingsi* were collected, in December. The species has been recorded in the Indian Ocean, and in numerous localities of the Mediterranean Sea both in the intertidal and in the subtidal zones.

Subfamily STYRACONYXINAE Kristensen & Renaud-Mornant, 1983

Genus *Styraconyx* Thulin, 1926

Styraconyx nanoqsunguak Kristensen & Higgins, 1984

Remarks – *S. nanoqsunguak* is a subtidal species present in organogenic detritus. Found for the first time off the Greenland coasts, it was then collected in different localities of the Italian coasts in the Tyrrhenian and Ionian Seas. In the Meloria Shoals, only 3 specimens were found in June samples.

Styraconyx sardiniae D'Addabbo Gallo *et al.*, 1989

Remarks - Only eight speciemens were found in different periods of the year. In the Mediterranean Sea the species was previously known from the Gulf of Orosei in Sardinia.

Styraconyx tyrrhenus D'Addabbo Gallo *et al.*, 1989

Remarks – Only seven specimens of this species were found in the samples of August and October. The species was so far known only from the Tyrrhenian Sea.

Genus *Tholoarctus* Kristensen & Renaud-Mornant, 1983

Tholoarctus natans pedunculatus D'Addabbo Gallo *et al.*, 1992

Remarks – Only 1st and 2nd stage larvae (21 specimens) were found with fairly constant frequency during the whole year. The species has also been found in Sardinia, in the Aeolian Islands (Tyrrhenian Sea), and Ionian Sea always in organogenic detritus at from 30 to 100 m depth.

Subfamily TANARCTINAE Renaud-Mornant, 1980

Genus *Tanarctus* Renaud-Debuser, 1959

Tanarctus longisetosus Grimaldi De Zio *et al.*, 1982

Remarks – The species is present throughout the year with the exception of August and September. With 319 individuals, it represents 8% of all the Tardigrada. In addition to adults, males and females, and 2nd stage larvae, also two finger larvae (1st stage) were found for the first time. The species was already known in the Mediterranean, where it has been found previously both in the Tyrrhenian and Ionian Seas.

Genus *Actinarctus* Schulz, 1935

Actinarctus doryphorus Schulz, 1935

Remarks – Found in the Meloria Shoals throughout the year with the exception of the summer months; this represents the first record of this species in the Mediterranean. Previously found in Helgoland, Roscoff and Brest, this tardigrade lives interstitially both in the intertidal and in the subtidal zone (Schulz, 1935). Considered as a possible commensal on the sea urchin *Echinocyamus pusillus* (Grell, 1937), it is usually present in coarse organogenic detritus (*Amphioxus* sand).

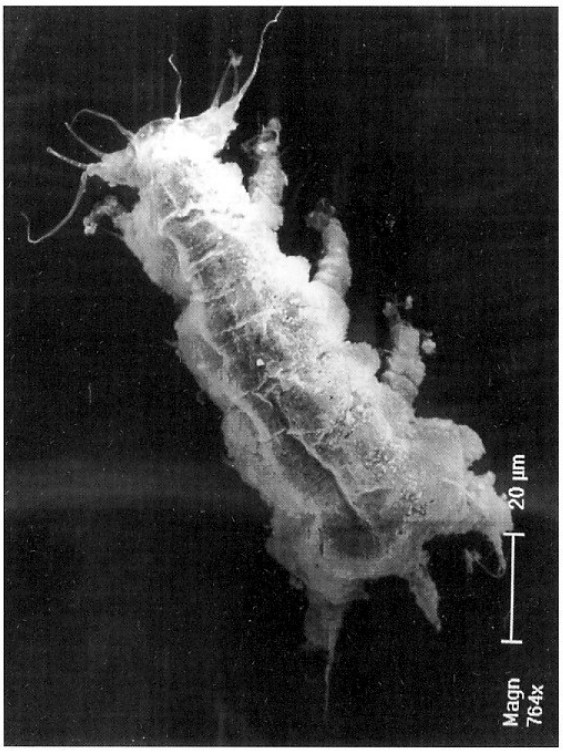

Fig. 2 - *Batillipes similis*: dorsal view (SEM micrography).

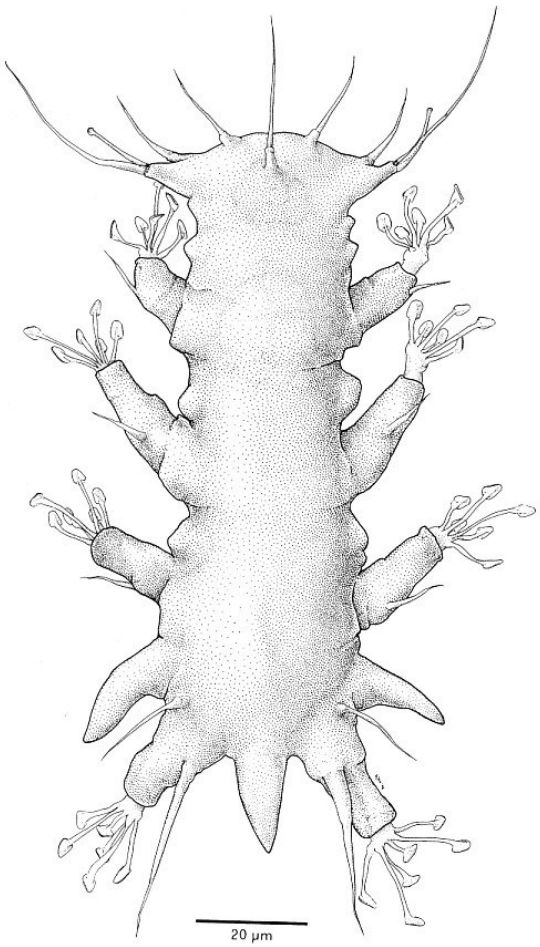

Fig. 3 - *Batillipes similis*: drawing of the dorsal surface.

Subfamily DIPODARCTINAE Pollock, 1995

Genus *Dipodarctus* Pollock, 1995

Dipodarctus subterraneus (Renaud-Debyser, 1959)
Syn. *Halechiniscus subterraneus* Renaud-Debyser, 1959;
Hemitanarctus subterraneus (Renaud-Debyser, 1959)

Remarks - The species, known from the Indian Ocean and the Mediterranean Sea, was collected from the Meloria Shoals with 37 specimens in March, June, and December.

Family BATILLIPEDIDAE Ramazzotti, 1962

(Discopodidae Marcus, 1934)

Genus *Batillipes* Richters, 1909

Batillipes littoralis littoralis Renaud-Debyser, 1959

Remarks – The presence of only one specimen in the Meloria Shoals detritus confirms the previous records of this taxon in the Mediterranean.

Redescription of *Batillipes similis* Schulz, 1955
(Figs 2, 3; Table IV)

Remarks – The original description of *Batillipes similis* dates from 1955, when Schulz found 13 specimens of this species in *Amphioxus* sand in the Gulf of Naples. The presence of 322 individuals (adults, males and females, and 1st and 2nd stage larvae) in sediments of the Meloria Shoals, allowed us to enrich the original description with more detailed information about some previously underestimated characteristics.

Family BATILLIPEDIDAE Ramazzotti, 1962.

Diagnosis – Arthrotardigrada with legs bearing four or six adhesive toes; claws absent. Type genus *Batillipes* Richters, 1909.

Table IV - *Measurements (in µm) of larval 2nd stage and adults of* Batillipes similis.

	2nd stage larvae					Males					Females				
	n	$\bar{X}$	σ	min	max	*n*	$\bar{X}$	σ	min	max	*n*	$\bar{X}$	σ	min	max
L	10	103	12.46	79	127	10	119	12.91	102	141	10	119	9.77	101	136
W	10	27	5.71	20	36	10	39	7.56	23	48	10	35	7.15	27	51
mC	10	25	2.21	22	28	10	26	4.98	21	33	9	25	5.08	16	34
iC	10	20	2.46	15	24	10	21	1.08	19	22	10	22	1.90	19	26
eC	8	14	2.00	12	17	10	18	2.84	13	22	10	17	2.61	13	20
lC	9	33	5.11	26	42	9	32	6.34	25	47	10	37	3.59	32	41
Cl	10	17	3.37	12	22	10	18	4.15	13	25	10	21	6.93	13	39
B (W)	10	18	2.91	13	22	10	19	2.13	16	23	10	19	2.35	17	29
B (H)	10	15	2.12	10	17	10	16	2.23	13	21	10	19	3.67	17	26
CE	10	18	2.39	14	22	10	16	3.63	11	22	8	19	4.83	12	29
Pr 1	6	6	2.38	3	10	7	5	1.40	4	7	9	5	1.36	3	6
Pr 2	8	7	0.98	6	8	10	6	0.83	4	7	10	6	1.79	4	10
Pr 3	10	15	3.90	9	21	10	16	4.24	11	23	10	17	1.42	13	18
P_1	9	8	1.74	6	12	10	8	1.57	6	11	10	8	0.95	7	10
P_2	9	8	2.40	6	14	9	7	0.88	6	9	8	9	1.84	7	12
P_3	9	8	1.00	6	9	9	10	4.69	7	22	9	10	1.32	8	12
P_4	10	20	2.46	17	24	10	21	1.91	18	24	10	22	4.82	14	30
C	10	16	3.78	11	22	10	18	4.09	12	23	10	21	3.28	16	26
A-G						10	7	1.65	5	11	10	10	1.36	8	12

n, number of specimens examined.

Genus *Batillipes* Richters, 1909

Diagnosis – Batillipedidae with four stalked toes bearing adhesive ends in the first juvenile instar and six toes in subsequent instars. Cephalic cirri simple (not comprised of distinct sections), but well-developed. Secondary clavae, if present, are dome-shaped papillae. Gonopores dimorphic.

Redescription

Neotype: adult male (slide 20 Secca Meloria 22/8/1996) 113 µm long and 23 m wide. The anteriormost part of the head is distinctly delimited by a narrowing, under which two lateral processes, 'auricolae', are evident.

The frontal edge, between the two internal cirri is slightly ondulated with a low medial depression. The medial cirrus, 24 µm long, is 6 µm distant from the rostral edge, where the two internal cirri (22 µm) are located. The external cirri (18 µm) have a short pedestal very close to the cirrophorus which supports both the primary clava and the lateral cirrus. The drumstick-like primary clava (17 µm) has a terminal swelling basally delimited by a thick cuticular band (2 µm) and an evident terminal pore. Inside its base, the Van der Land's organ is evident. Dorsally to it, the lateral cirrus (26 µm) is located. The distance between the two lateral cirri is 40 µm. All the cephalic cirri have the terminal part rounded. Between the internal and external cirri, a flat secondary clava (2 µm) is present (Pollock, 1989). This is not always visible, but its inner innervation is always very clear.

The ventral mouth opening, which has in its inner part numerous small teeth, is surrounded by a large sucker-like ring. The pharyngeal bulb is oval, 18 µm long and 16 µm wide.

The 19-µm-wide neck constriction, is followed by two lateral processes, usually named 'auriculae', which are similar to the lateral processes present between the 1st and 2nd pair of legs, and between the 2nd and 3rd. These processes are conical and 4 µm long. Between the 3rd and 4th pair of legs, the largest lateral process is present; it is 13 µm long and its tip is turned backward. The legs all have six toes of different length ending in an oval sucker; the toes are two and short, ventral, of different length, two medium-sized, lateral, and two long, dorsal. Tibial spike-like sense organs are present on all legs. The spikes of the first three legs are 8, 7, and 9 µm long, whereas the fourth pair sense organ is 21 µm long and has the Van der Land's organ inside its proximal part.

Dorsally to the fourth lateral process, cirrus E (20 µm long) is present with a refringent basal ring. The dorsal cuticle is punctuated with pillars 2 µm long. In the ventral region, the pillars are shorter. The caudal process is conical and 16 µm long. This structure is very variable in length and shape in the different specimens. The male gonopore is, as usual, a crescent-shaped fold, 7 µm from the anus. Sexual dimorphism does not exist; only the female gonopore is a rosette-like opening surrounded by six cells, 10 µm from the anus. The first stage larvae, as usual in *Batillipes*, lack anus and gonopore and have only four toes, whereas the second stage are similar to adults, but lack gonopore.

Taxonomic affinities

Taking into account the body shape, the cephalic region morphology, the arrangement of the cephalic appendages, the morphology and the length of the fourth leg papilla, *B. similis* appears closely related with *B. littoralis*, *B. dicrocercus* Pollock, 1970, and *B. bullacaudatus*, McGinty & Higgins, 1968 (Pollock, 1970; 1989; McKirdy, 1975). We should add to this group, *B. orientalis* Chang & Rho, 1997 which differs from *B. similis* in the absence of the caudal spike (Renaud-Debyser, 1959; McGinty & Higgins, 1968; Chang & Rho, 1997). Peculiar of *B. similis* is its drumstick-like primary clava. The secondary clava cannot be used as a diagnostic character because, even if present, it is frequently so flat as to be indistinguishable; but in permanent glycerol mounts, its inner innervation is easily visible even though the clava is not evident.

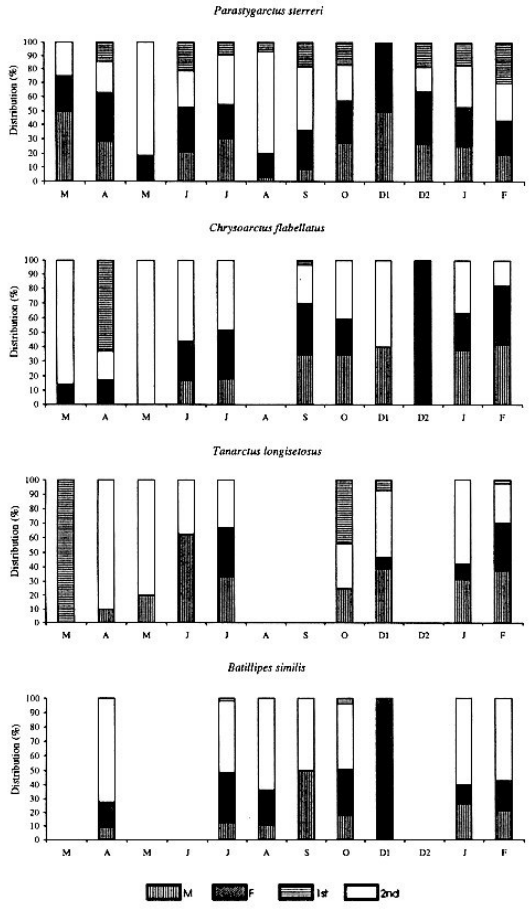

Fig. 4 - Frequencies of adult males (columns with vertical lines), adult females (columns with oblique lines), larvae of first stage (columns with horizontal lines), and larvae of second stage (open columns) of the four most abundant species (*Parastygarctus sterreri*, *Chrysoarctus flabellatus*, *Tanarctus longisetosus*, and *Batillipes similis* from top to bottom) from March 1996 to February 1997.

Taking into account these elements, the diagnosis of *B. similis* can be amended as follows: *Batillipes* with drumstick-like primary clava. Evidently punctuated cuticle. Toes of different length in all the legs.

Biology and ecology

Four of the 15 species of the pit sediment were more regularly present throughout the year, namely: *P. sterreri* always present *C. flabellatus* absent only in August, *T. longisetosus* absent in August and December, and *B. similis* absent in March, May, June, and December$_2$. The constant presence both of adults and larval stages of the four species, is further evidence that they reproduce throughout the year (Fig. 4); yet the four species increase their reproductive activity in quite different periods. In fact, with the exception of October, when all four species have high values of presence, the highest percentages are reached in June by *P. sterreri*, in January and February by *C. flabellatus* and *T. longisetosus*, and in July by *B. similis*. Therefore, even if present all the year *P. sterreri*, is more frequent at the beginning of the summer and in autumn, *B. similis* fluctuates between low frequency periods (spring and winter) and high frequency periods (summer - autumn), whereas *C. flabellatus* and *T. longisetosus*, are more frequent in autumn and winter (Fig. 5).

Also in *T. longisetosus*, as in *B. pennaki* and *Actinarctus doryphorus* (Grimaldi De Zio & D'Addabbo Gallo, 1975a, b; Gallo D'Addabbo *et al.*, 1999), all the phases of spermatogenesis, from spermatogonies to spermatids, can be observed in the mature males (Fig. 6C), whereas sperms are evident only in the seminal receptacle ducts of the females (Fig. 6D). In *C. flabellatus*, on the contrary, all the maturative processes, up to sperms, are concluded in the males. (Fig. 6B).

The seasonal vertical distribution indicates a preference for the superficial layers when all tardigrades are considered, irrespective of season; however, the vertical profile of the four most frequent species shows that taxa may

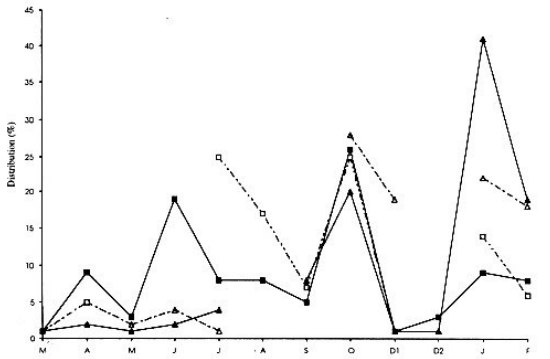

Fig. 5 - Changes in frequencies of the four most abundant species from March 1996 to February 1997. Filled square, *Parastygarctus sterreri*; open triangle: *Tanarctus longisetosus*; open square: *Batillipes similis*; filled triangle: *Chrysoarctus flabellatus*.

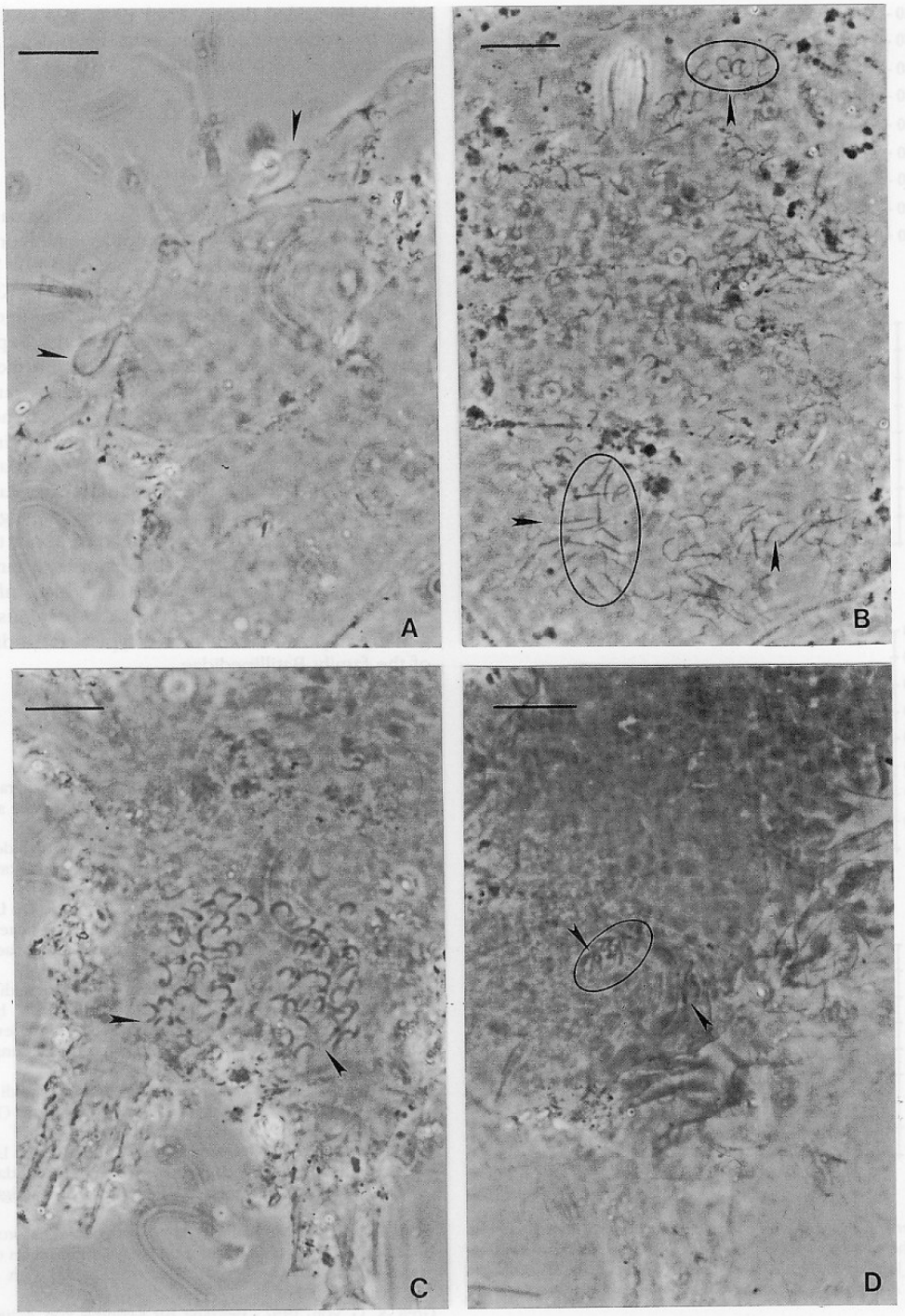

Fig. 6 – **A**, *Chrysoarctus flabellatus*: cephalic region with secondary clavae (arrowheads); **B**, *Chrysoarctus flabellatus*: mature male with spermatids in the apex of the gonad (upper arrowhead) and spermatozoa in the genital ducts (lower arrowheads); **C,** *Tanarctus longisetosus*: mature male with spermatides (arrowheads) in the genital ducts. **D,** *Tanarctus longisetosus*: mature female with sperms (arrowheads) in the seminal receptacle ducts. Staining by Rose Bengal; bar length, 10 μm.

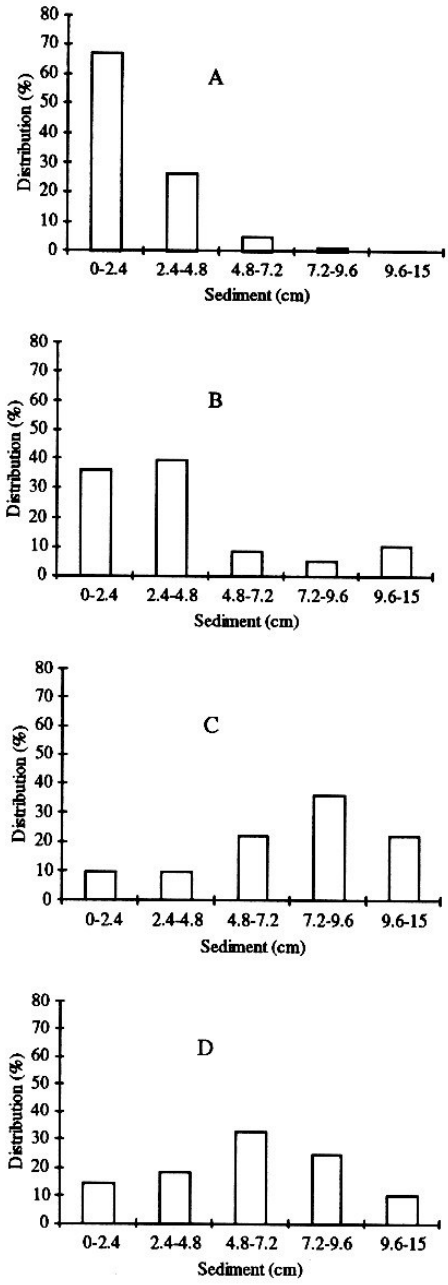

Fig. 7 - Vertical distribution (percentage values), in 15 cm of sediment, of the four most abundant species in April, July and October 1996 and January 1997. **A**, *Chrysoarctus flabellatus*; **B**, *Batillipes similis*; **C**, *Parastygarctus sterreri*; **D**, *Tanarctus longisetosus*.

have a different bathymetric distribution, namely: *C. flabellatus* and *B. similis* are more abundant between 0 and 5 cm, even though with different frequencies, whereas the other two species have a similar distribution with only a slight increase between 5 and 10 cm (Fig. 7). It should be added that in April 1996, in a sediment covered by *Posidonia* dead leaves at 18 m depth, only one specimen of *M. orbiculatus McKirdi et al.*, 1976 was found.

CONCLUSIONS

This study on the Meloria Shoals Tardigrada, supports the results of previous ones on other meiofaunal groups in the same habitat (Huys & Todaro, 1997; Todaro & Huys, 1997, Todaro 1998a, b; Todaro & Kristensen, 1998), corroborating the notion that organogenic detritus, and therefore the Shoals sediments, represents a very favourable environment for different meiobenthic taxa. In fact, in these sediments Tardigrada are present with high biodiversity because they are abundant both as specimens and as species (a total of 3986 individuals and 16 species were found), some of which are reported for the first time in the Mediterranean Sea. Furthermore, the monthly sampling strategy throughout one entire year allowed us to acquire data about the reproductive biology of subtidal species of both families Stygarctidae and Halechiniscidae, for which information was lacking. These data confirm the previous ones regarding *B. pennaki*, which is a typical intertidal species of the family Batillipedidae.

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