Zoological Studies **47**(5): 605-613 (2008)

Zoological Studies

Pseudocyclops giussanii (Copepoda: Calanoida: Pseudocyclopidae), a New Species from Lake Faro (Central Mediterranean Sea)

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(Accepted March 14, 2008)

Giacomo Zagami, Cinzia Brugnano, and Giuseppe Costanzo (2008) *Pseudocyclops giussanii* (Copepoda: Calanoida: Pseudocyclopidae), a new species from Lake Faro (central Mediterranean Sea). *Zoological Studies* **47**(5): 605-613. A new species of the calanoid copepod genus *Pseudocyclops* is described from a Mediterranean coastal lake on Sicily (Italy). Out of 34 species comprising the genus *Pseudocyclops*, the new species and *P. mirus* are characterized by an unsegmented endopod of leg 1, a very narrow and elongate prosome, similar armature of the female leg 5, and an antennule with 16 segments. Since a combination of these characters is unique within the genus, these 2 species, together with *Pseudocyclops* sp., which is as yet undescribed but is very close to *P. giussanii* sp. nov., should be recognized in a distinct species group, referred to here as the *mirus*-group, which is geographically distributed around the eastern Atlantic-Mediterranean region. The record of *P. giussanii* sp. nov. increases the number of known Mediterranean species of *Pseudocyclops* to 5, of which *P. xiphophorus*, *P. costanzoi*, *P. giussanii* sp. nov., and *Pseudocyclops* sp. are so far known to occur exclusively in Lake Faro. The discovery in Lake Faro of 4 other *Pseudocyclops* species (*P. umbraticus*, *P. xiphophorus*, *P. costanzoi*, and *Pseudocyclops* sp.), in addition to the new species, is particularly interesting with regard both to their biogeographic distribution patterns and evolutionary history. Ecological, biological, and zoogeographical notes are also provided. http://zoolstud.sinica.edu.tw/Journals/47.5/605.pdf

Key words: Taxonomy, New species, *Pseudocyclops*, Lake Faro, Mediterranean coastal lake.

Recent studies of the shallow coastal and brackish waters of the Stagnone di Marsala and Lake Faro, respectively located in western and eastern Sicily (Italy), have revealed an assemblage of calanoid copepods including several species new to science (Costanzo et al. 2000, Zagami et al. 2000, Baviera et al. 2007), in addition to several new records for the Mediterranean Sea (Campolmi et al. 2001 2002, Zagami et al. 2005). Some of these species belong to genera with tropical biogeographic distribution patterns and could be considered thermophilic relicts (e.g., *Metacalanus* Cleve 1901; *Ridgewayia* Thomson and Scott 1903; and *Exumella* Fosshagen, 1970). Other genera, with wider distributional patterns, also occur at higher latitudes (*Pseudocyclops* Brady, 1872; *Stephos* T. Scott, 1892; and *Paramisophria* T. Scott, 1897). The genus *Pseudocyclops* has a worldwide distribution from temperate to tropical waters, and brackish coastal lagoons (Campolmi et al. 2002, Zagami et al. 2003, Boxshall and Halsey 2004).

Although most calanoid copepod species are planktonic, *Pseudocyclops* species are bentho-planktonic, since during the daytime, they are demersal, but some of them perform diel vertical migrations, because they have been collected in nightly zooplankton samples (Esterly 1911, Gurney 1927, Sewell 1932, Vervoort 1964, Yeatman 1975, Dawson 1977, Othman and Greenwood 1989, Alldredge and King 1980, Haridas et al. 1994, Campolmi et al. 2002, Zagami et al. in press).

The genus *Pseudocyclops* belongs to the mono-generic family Pseudocyclopidae, one of the

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most primitive of the Calanoida Copepoda (Huys and Boxshall 1991). To date, *Pseudocyclops* comprises 34 species, four of which occur in the Mediterranean Sea: *P. obtusatus* Brady and Robertson, 1873; *P. umbraticus* Giesbrecht, 1893; *P. xiphophorus* Wells, 1967; and *P. costanzoi* Baviera, Crescenti and Zagami, 2007.

In this paper, we describe a new *Pseudocyclops* species from Lake Faro. Ecological, biological, and zoogeographical notes are also provided.

MATERIALS AND METHODS

The *Pseudocyclops* specimens were sorted from zooplankton samples taken at night in Lake Faro (Fig. 1a) with a zooplankton net (with a mouth area of 0.18 m^2 and a mesh size of 200 μm) equipped with a flow meter (Hydrobios, Kiel-Holtenau Germany). Zooplankton samples were collected in May, June, and Nov. 2004, and Jan., Apr., May, June, and Aug. 2005. The *Pseudocyclops* specimens were fixed in a 4% neutralized formalin/lake water solution. Drawings were made using a “Reichert Visopan” projection microscope. Terminology follows Huys and Boxshall (1991). The type specimens are deposited in the Zoological Museum “Cambria” (ZMC), Department of Animal Biology and Marine Ecology, Messina Univ., Messina, Italy. Three paratypes are deposited in the collection of the Department of Zoology, Natural History Museum (BMNH), London.

Study area

Lake Faro is a coastal basin located on the northeastern tip of Sicily. (Fig. 1). It has typical features of a meromictic basin, characterized by an oxic epilimnion and an anoxic hypolimnion. These layers are separated by a metalimnion, within which strong blooms of anoxygenic phototrophic bacteria cause the periodic development of a red water layer (Truper and Genovese 1968). Lake Faro is characterized by large oscillations in physicochemical parameters, especially temperature (10-28°C), salinity (34-37 psu), and dissolved oxygen (ranging from absent, near the bottom of the central area, to 8.3 mg/L at the surface) (Abruzzese and Genovese 1952).

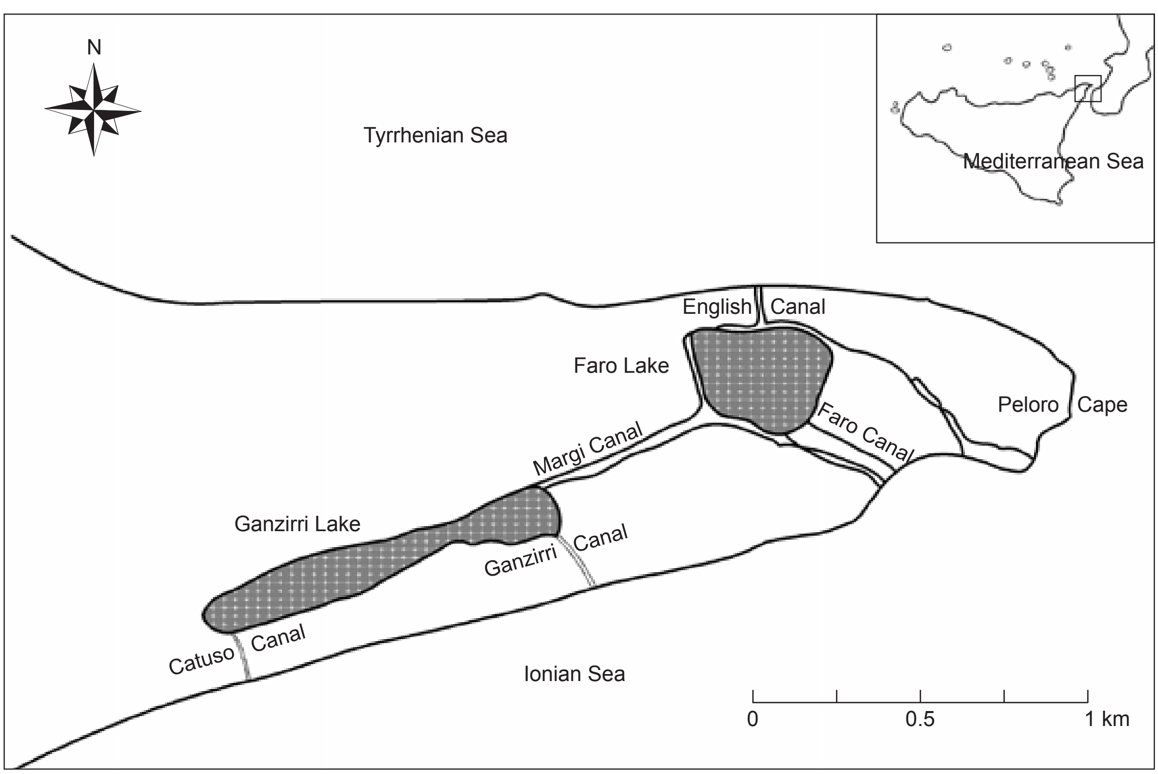

Fig. 1. Lake Faro: geographical position.

SYSTEMATICS

Subclass Copepoda H. Milne Edwards, 1830
Order Calanoida G.O. Sars, 1903
Family Pseudocyclopidae Giesbrecht, 1893
Genus *Pseudocyclops* Brady, 1872
***Pseudocyclops giussanii* sp. nov.**
(Figs. 2-4)

Material examined: 20 adult ♀♀ from Lake Faro, at 2 m depth, Apr., May, and June 2005.

Body length: Body length ranging 0.53-0.60 (mean, 0.56 ± 0.03) mm (n = 10); prosome length and width 0.42 and 0.14 mm, respectively.

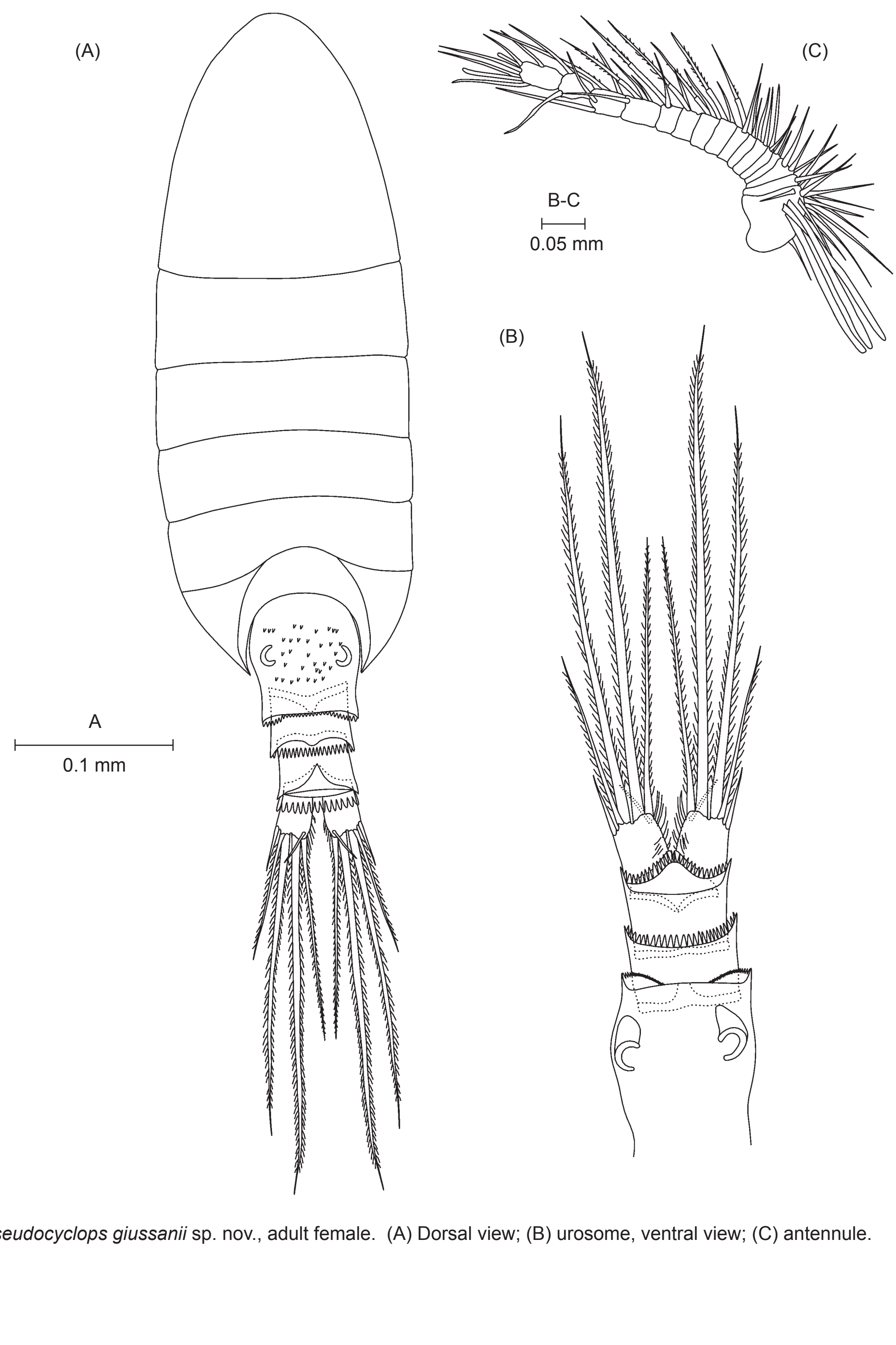

Fig. 2. *Pseudocyclops giussanii* sp. nov., adult female. (A) Dorsal view; (B) urosome, ventral view; (C) antennule.

Types

Holotype: 1 adult ♀, dissected and mounted on glass slides.

Paratypes: 1 adult ♀, whole specimen (ZMC reg. no. 2007.5622); 3 adult ♀♀, whole specimens (BMNH reg. nos. 2007.177-179).

Description of adult female (holotype)

Body length 0.53 mm (Fig. 2A), body compact; prosome oval in dorsal view, narrow and elongated, length/width ratio about 3.0. Cephalosome partially separated from 1st pedigerous somite: frontal margin with prominent rostrum. Fourth and 5th pedigerous somites separated. Posterolateral angles of prosome rounded. Urosome (Fig. 2B) 4 segmented. Genital double-somite symmetrically ornamented with minute spinules dorsally, posterodorsal margin with serrate hyaline frill, posteroventral margin not serrate in central area; gonopores and copulatory pores paired, opening within common longitudinal slit on either side. Second urosomite with serrate distal margin. Third urosomite bearing denticulate hyaline frill. Anal somite short, telescoped inside preceding somite. Caudal rami symmetrical, furnished with row of setules along inner margin and armed with 6 setae; seta I lacking, seta II cuneiform, seta V longest, seta VII located dorsally at distomedial angle of ramus.

Antennule (Fig. 2C) 16 segmented; armature elements as follows: 1, 12 + 3 aesthetascs; 2, 2; 3, 3; 4, 2; 5, 2; 6, 2; 7, 2; 8, 2; 9, 2; 10, 2; 11, 2; 12, 2; 13, 4; 14, 4; 15, 2; 16, 5 + 2 aesthetascs.

Antenna (Fig. 3A) biramous. Coxa and basis each bearing 1 seta at distomedial angle. Exopod indistinctly 7 segmented, segments 1-4 each bearing 1 seta, segments 5 and 6 each with 2 setae, segment 7 with 3 apical setae; endopod 3 segmented, 1st segment with 2 setae on medial margin, 2nd with 8 setae, and 3rd with 7 setae apically. Second and 3rd segments each ornamented with small spinules on outer surface.

Mandible (Fig. 3B) with cutting edge of mandibular gnathobase comprised of 7 cuspidate teeth. Ventralmost tooth largest, stocky, unicuspidate, separated by wide space from 2 adjacent teeth, of which 1st is larger than 2nd, narrower and sharp; intermediate tooth tricuspidate; 2 adjacent teeth shorter and unicuspidate; dorsalmost tooth curved dorsally. Palp biramous; basis with 2 setae on inner margin; exopod indistinctly 4 segmented, setal formula 1, 1, 1, 3; endopod 2 segmented, proximal segment with 4 setae at distomedial angle; distal segment with 10 setae on distal margin.

Maxillule (Figs. 3C-D) well developed; precoxal arthrite carrying 9 marginal strong spines plus 5 slender submarginal setae; coxal epipodite with 6 setae; coxal endite with 3 setae (Fig. 3C); basis with 1 short seta representing basal exite, proximal basal endite with 4 setae; distal basal endite indistinct, with 4 setae; exopod with 11 marginal setae; endopod with 16 marginal setae (Fig. 3D).

Maxilla (Fig. 3E) indistinctly 4 segmented. Precoxa with proximal endite carrying 5 long marginal setae and 1 submarginal rudimentary element; distal endite with 3 setae; both coxal endites with 3 setae; basis and 1st endopodal segment fused to form allobasis, bearing 7 setae; endopod reduced, indistinctly segmented and carrying 7 setae.

Maxilliped (Fig. 3F) 7 segmented. Syncoxa partly subdivided; armed with 1, 2, 4, and 3 setae representing precoxal and coxal endites; basis incorporating proximal endopodal segment, with 3 + 2 setae; free endopod 5 segmented, 1st and 2nd segments each bearing 4 setae; 3rd segment with 3 setae, 4th segment with 3 setae and 1 outer seta, 5th segment with 4 setae.

Swimming legs 1-4 (Fig. 4), each comprised of coxa, basis, and 3 segmented exopod and endopod, with exception of 1 segmented 1st leg endopod. Leg 1 (Fig. 4A) with coxa bearing long inner seta, and with pointed distolateral angle; basis with long rounded process protruding between rami, and with short, stout inner spine non-articulated basally to segment; endopod 1 segmented, curved outwards distally, with 8 inner setae, and with serrated subdistal inner margin. Leg 2 (Fig. 4B) with distomedial denticles on coxa, distomedial angle of basis sharply pointed. Leg 3 (Fig. 4C) with stout outer spine; large pointed inner process on distal angle of basis. Leg 4 (Fig. 4D) ornamented with rows of denticles on anterior surface and slender seta on distolateral angle of basis.

Armature of legs as follows:

	Coxa	Basis	Exopod segment	Endopod segment
Leg 1	0-1	0-I	I-1; I-1; II, I, 4	0-8
Leg 2	0-1	0-0	I-1; I-1; II, I, 5	0-1; 0-2; 2, 2, 4
Leg 3	0-1	I-0	I-1; I-1; III, I, 5	0-1; 0-2; 2, 2, 4
Leg 4	0-1	1-0	I-1; I-1; III, I, 5	0-1; 0-2; 2, 2, 3

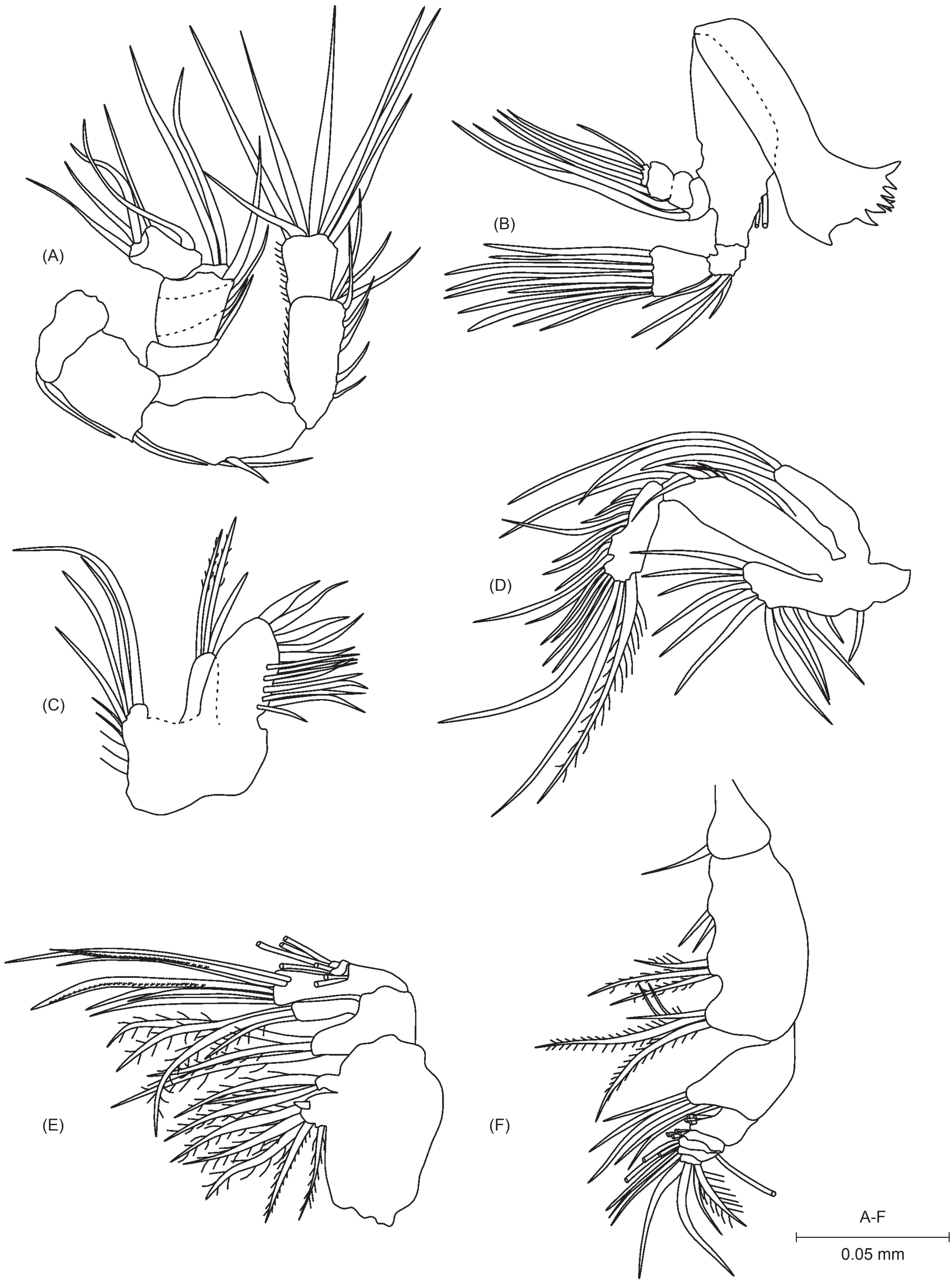

Fig. 3. *Pseudocyclops giussanii* sp. nov., adult female. (A) antenna; (B) mandible; (C, D) maxillule; (E) maxilla; (F) maxilliped.

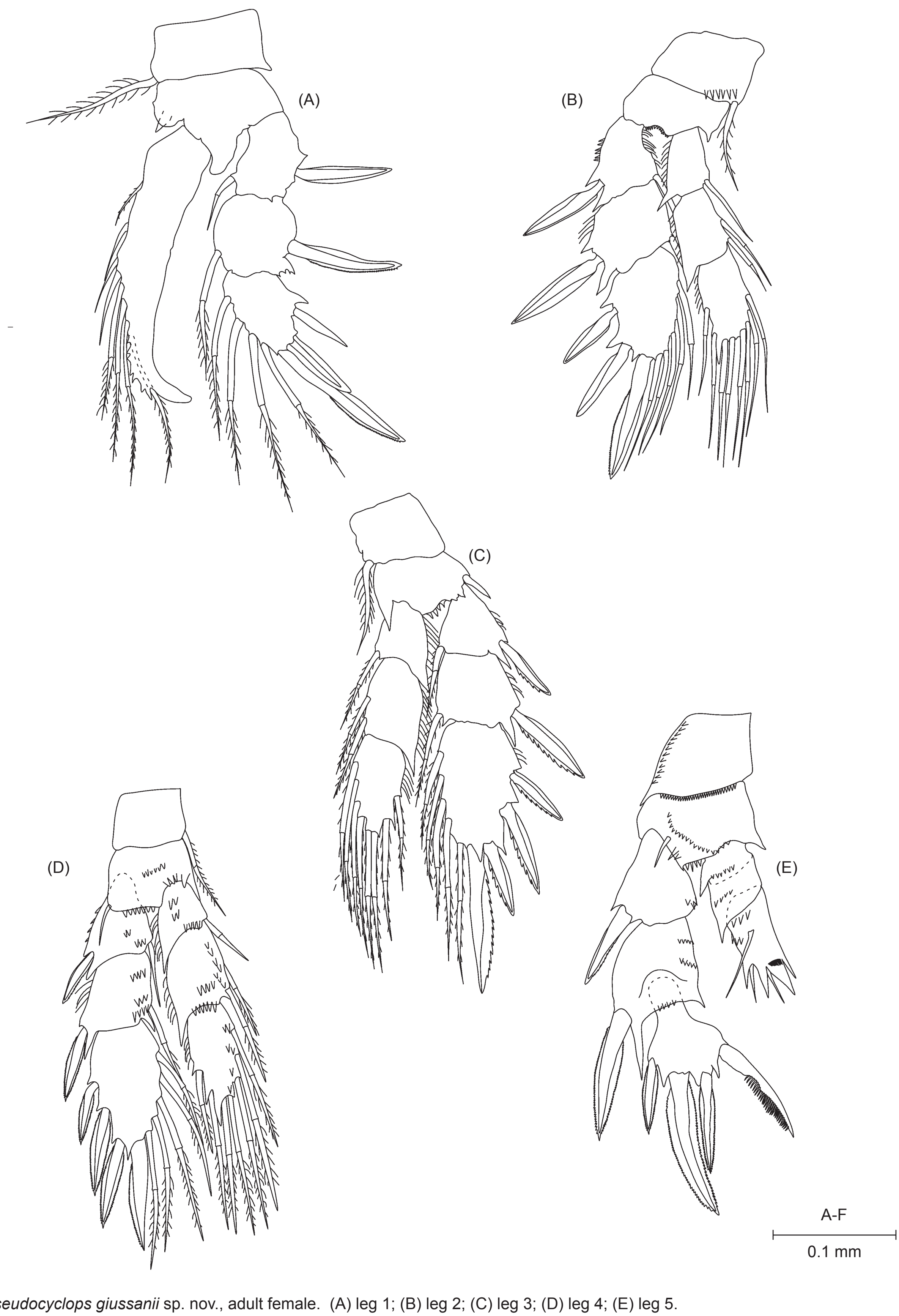

Fig. 4. *Pseudocyclops giussanii* sp. nov., adult female. (A) leg 1; (B) leg 2; (C) leg 3; (D) leg 4; (E) leg 5.

Fifth leg symmetrical, with 3 segmented exopod and 2 segmented endopod; coxa unarmed, ornamented with rows of minute denticles on outer and distal margins; basis bearing submedial seta, ornamented with transverse and distal rows of minute denticles, and with pointed distomedial angle.

Exopod and endopod both ornamented with rows of minute denticles. First exopod segment with outer spine; 2nd segment with outer spine and elongate pointed process adjacent to it; 3rd segment with 1 outer and 2 terminal serrate spines, plus 1 inner pectinate spine. First endopod segment with 2 outer pointed processes; 2nd segment with 1 medial seta at mid-length, 2 distal setae, and 4 pointed distal processes.

Remarks: The new species is similar to *P. umbraticus*, *P. pumilis*, *P. mirus* Andronov, 1986, *P. cokeri* Bowman and Gonzalez, 1961, and *P. xiphophorus* in having a 2 segmented endopod of female leg 5.

The new species has a very narrow and elongate female prosome that is shared only with *P. pumilis* and *P. mirus* within the genus. In addition, it is similar to these 2 species in having 16 segmented antennules and in the presence of an outer basal spine on leg 3.

Of 34 species comprising the genus *Pseudocyclops*, the new species and *P. mirus* are characterized by an unsegmented endopod of leg 1, a very narrow and elongate prosome, similar armature of female leg 5, and an antennule with 16 segments. Since a combination of these characters is unique within the genus, these 2 species, together with the as yet undescribed *Pseudocyclops* sp., from Lake Faro, which is very close to *P. giussanii* sp. nov., should be recognized as a distinct species group, referred to here as the *mirus*-group; it is geographically distributed around the eastern Atlantic-Mediterranean region.

The new species can easily be distinguished from *P. mirus* by: (1) the body length, which is within a wider range of 0.53-0.60 mm; (2) the different shape of the cutting edge of the mandibular gnathobase, as between the ventralmost tooth and adjacent one there is a wide gap, the intermediate tooth is tricuspidate, and the dorsalmost seta is lacking; (3) the presence of a minute outer basal seta on leg 4; (4) the presence of a minute submedial basal seta on leg 5; (5) the absence of an inner seta on the 2nd exopod segment of leg 5; and (6) the longer acute outer process on the 2nd exopod segment of leg 5.

The 5 *Pseudocyclops* species occurring in Lake Faro (*P. umbraticus*, *P. xiphophorus*, *P. costanzoi*, *P giussanii* sp. nov., and *Pseudocyclops* sp.) are all characterized, according to Ohtsuka et al. (1999), by the following synapomorphies and advanced features: (1) a 2 segmented endopod of the female leg 5; (2) the distal endopod segment of the female leg 5 with 1 medial and/or 2 terminal setae, and acute processes terminally; and (3) the number of antennule segments of both sexes being 16 or 17. The *mirus*-group shares synapomorphies as follows: (1) the absence of exopodal setae along the inner margin of female leg 5; and (2) the unarmed proximal endopod segment of female leg 5, with 2 acute pointed processes; the distal endopod segment of the female leg 5 with 1 medial and 2 distal setae, and 3 or 4 processes terminally.

Etymology: The species name is in honor of Don Luigi Giussani, the founder of “Comunione e Liberazione”, who introduced, with his charisma, entire generations of young people to a critical and systematic knowledge of reality.

DISCUSSION

Pseudocyclops giussanii, together with other hyperbenthic calanoid copepod species such as *P. xiphophorus*, *P. umbraticus*, *Pseudocyclops* sp., *Ridgewayia marki minorcaensis* Razouls and Carola, 1996, and *Exumella mediterranea* Jaume and Boxshall, 1995 were collected during night sampling. None of them was recorded in daytime samples, suggesting that these species make daily vertical migrations from the hyperbenthic to the planktonic environment (Zagami et al. 2003). In contrast, the single specimen of *P. costanzoi* was collected in muddy sediment and wash water from *Pinna nobilis* Linnaeus, 1758 (Mollusca: Bivalvia) (Baviera et al. 2007). The hyperbenthic copepod species may represent an “ecological group”, and although they constitute only a small percentage of the benthonic and planktonic communities (Campolmi et al. 2002, Zagami et al. in press), they are still important in terms of their contribution to species richness.

The spatial distribution of this “ecological group” is very broad and varied, extending from submarine caves to brackish lagoons, and from shallow coastal waters to deeper waters at depths of over 4000 m (Ohtsuka et al. 1998, Nishida et al. 1999, Jaume et al. 2000, Campolmi et al. 2002, Zagami et al. 2003, Bradford-Grieve 2004). The hyperbenthic copepod populations of the deep sea differ in species composition from those in shallow coastal, shelf waters, lagoons, and submarine caves. The known number of deep-sea species is small, most hyperbenthic calanoids having been taken at slope depth and in shallow coastal waters. This is probably due to a combination of the low abundances of hyperbenthic copepod species, coupled with difficulties in sampling them in their environments.

The discovery in Lake Faro, in addition to the new species, of 4 other *Pseudocyclops* species (*P. umbraticus*, *P. xiphophorus*, *P. costanzoi*, and *Pseudocyclops* sp.), one of which is as yet undescribed, (Zagami pers. com., Baviera et al. 2007) is particularly interesting with regard to both their biogeographic distribution patterns and evolutionary history. *Pseudocyclops umbraticus* is distributed in the Mediterranean Sea and Suez Canal, and along Mauritanian coasts, while *P. costanzoi* is known from the Mediterranean Sea; both species have similar morphological characters. *Pseudocyclops xiphophorus* was described from Mozambique. The new species is very similar to *P. mirus*, known only from Mauritanian coastal waters (Andronov 1986). The separation and isolation of these species of hyperbenthic calanoid copepods possibly by oceanographic barriers that interrupted gene flow between the ancient populations, could have favored allopatric speciation. The species that followed separate evolutionary lines, together with others that maintained the ancestral characters and acquired the status of relict populations, constitute the current Mediterranean hyperbenthic calanoid copepod community. The isolation of the Mediterranean populations suggests that they are evolving independently of the Atlantic and Indo-Pacific populations, and that the Mediterranean Sea is a site of active speciation events.

The record of *P. giussanii* sp. nov. increases the number of known Mediterranean species of *Pseudocyclops* to 5, of which *P. xiphophorus*, *P. costanzoi*, *P. giussanii* sp. nov., and *Pseudocyclops* sp., are only known so far to occur exclusively in Lake Faro.

In lagoons, estuaries, and harbor systems, the community consists of a series of congeneric associates (Jeffries 1967). In particular, the number of *Pseudocyclops* species ranges from 2 to 8 (Bowman and Gonzalez 1961, Fosshagen 1968, Ohtsuka et al. 1999, Campolmi et al. 2002). The occurrence of 5 congeneric *Pseudocyclops* species in Lake Faro raises the question of competition among them. During the day in Lake Faro, *P. xiphophorus* has the widest distribution and has achieved habitat differentiation by being the only species of *Pseudocyclops* living in the interstices of the fouling community attached to submerged ropes and mooring posts. The other *Pseudocyclops* species are distributed on the bottom around the shallow margins of the lake, around the deeper anoxic part, with segregated spatial patterns, characterized by maximum abundance areas of the different species (Zagami et al. in press). Their spatial distributions in different habitats, determined mainly by substrate type and dependent on the degree of heterogeneity in space of the environmental parameters, are probably one of the factors serving to reduce interspecific competition.

Biological notes

Laboratory observations on egg production allowed us to infer the general pattern of egg-laying and egg-production rates of species of the genus *Pseudocyclops* collected in Lake Faro (Zagami et al. 2003, Brugnano et al. 2006). The species *P. umbraticus* and *P. xiphophorus* release eggs more or less continuously throughout the day, from 2 to 3 d after achieving maturity, almost until the end of their life cycle. Egg laying in these species is very interesting, because they do not release eggs directly into the water. Instead, after a pair of eggs is extruded from the paired gonopores, the female swims with a pair of eggs attached to either side of the genital double-somite, until the eggs are released by a rapid urosome stroke. After releasing the egg pair, the female swims over them with a rotary motion, probably secreting a substance, which facilitates the adhesion of the egg to the bottom of the Petri dish or to any hard surface, such as wood fragments, nylon filaments, filamentous algae, leaves, etc. This female behavior can be considered an early example of parental care in invertebrates. Some *Pseudocyclops* species live in the interstices of filamentous algae attached to the lower parts of *Thalassia* leaves (Bowman and Gonzalez 1961) or in fouling organisms attached to submerged posts and ropes of brackish lakes (Zagami et al. 2005). This female behavior probably produces a higher survival rate for the eggs, by preventing them from floating freely in the water column, where they could easily be eaten by predators, or falling to the bottom of the lake, where oxygen availability is a limiting environmental factor.

Acknowledgments: The authors wish to thank Prof. G. Lo Paro, director of the Department of Animal Biology and Marine Ecology, Messina Univ., Messina, Italy for his help in carrying out the research program. We are grateful to Prof. G.A. Boxshall for reading and making constructive criticisms of the manuscript. Further, they would like to thank Mr. Antonio Celona for his valuable help during sampling at Lake Faro, and Eng. Giuseppe De Luca for his assistance with computer graphics.

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