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A NEW SPECIES OF *PSEUDOCYCLOPS* (COPEPODA: CALANOIDA) FROM LAKE FARO (CENTRAL MEDITERRANEAN SEA)

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TAXONOMY
PSEUDOCYCLOPS FAROENSIS SP. NOV.
DEMERSAL COPEPODS
LAKE FARO
MEDITERRANEAN COASTAL LAKE

ABSTRACT. – A new calanoid copepod species *Pseudocyclops faroensis* sp. nov. is described from a Mediterranean coastal lake on Sicily (Italy). The discovery of *P. faroensis* sp. nov. increases the number of species of *Pseudocyclops* known from the Mediterranean to six. Out of 35 species comprising the genus *Pseudocyclops*, *P. faroensis* sp. nov., *Pseudocyclops giussanii*, and *Pseudocyclops mirus* are characterized by a narrow, elongate prosome, a female antennule of 16 segments, and an unsegmented endopod of leg 1. Since the combination of these characters is unique to these three species within the genus, they are recognized in a distinct species group: the *mirus*-group, which is geographically distributed around the Eastern Atlantic-Mediterranean region. Moreover, *P. faroensis* sp. nov. can easily be distinguished from these two species by the number of setae in the sub-distal inner margin on the endopod of female leg 1 with a conspicuous process in *P. faroensis*, serrated in *P. giussanii*, smooth in *P. mirus*; the submedial basal seta of leg 5 (present in *P. faroensis* and *P. giussanii*; absent in *P. mirus*); the inner margin of the exopod of female leg 5 (naked in *P. faroensis* and *P. giussanii*; with a seta on second exopod segment in *P. mirus*). The morphological and geographical relationships between the new species and other related species are discussed.

INTRODUCTION

Pseudocyclops is one of the many calanoid genera which is bottom-living in shallow coastal and lagoon waters. The low abundance of *Pseudocyclops* populations in their restricted habitats (Campolmi *et al.* 2001, Zagami *et al.* 2008a), coupled with difficulties in sampling them by traditional benthonic and/or planktonic methods, have the effect that our knowledge of this genus is limited. Recently, sampling using detritus-sledge or SCUBA diving has increased the rate of discovery so the number of *Pseudocyclops* species is growing rapidly.

The genus *Pseudocyclops* belongs to the mono-generic family Pseudocyclopidae, one of the most plesiomorphic of the Calanoida Copepoda (Huys & Boxshall 1991). To date, *Pseudocyclops* accommodates 35 species, five of which occur in the Mediterranean Sea: *Pseudocyclops obtusatus* Brady & Robertson 1873; *Pseudocyclops umbraticus* Giesbrecht, 1893; *Pseudocyclops xiphophorus* Wells, 1967; *Pseudocyclops costanzoi* Baviera, Crescenti and Zagami, 2007; *Pseudocyclops giussanii* Zagami, Brugnano & Costanzo 2008.

The genus *Pseudocyclops* has a worldwide distribution from temperate to tropical and subtropical regions (Brady 1872, Giesbrecht 1893, Esterly 1911, Gurney 1927, Sewell 1932, Nicholls 1944, Noodt 1958, Bowman & Gonzalez 1961, Vervoort 1964, Wells 1967, Fosshagen 1968, Por 1968, Dawson 1977, Andronov 1986, Barr and Ohtsuka 1989, Othman and Greenwood 1989, Haridas *et al.* 1994, Ohtsuka *et al.* 1999, Campolmi *et al.* 2001, Baviera *et al.* 2007, Zagami *et al.* 2005, 2008a,b).

The present article describes a new *Pseudocyclops* species from Lake Faro.

MATERIAL AND METHODS

A total of five female *Pseudocyclops faroensis* specimens were sorted from zooplankton samples taken at night in Lake Faro (Fig. 1) with a zooplankton net (mouth area 0.18 m²; mesh size 200 µm) equipped with a flowmeter (Hydrobios). Zooplankton samples were collected in April, May and June 2005. Day and night samples were taken along five sampling tracks: four located around the margins of the lake and one in the centre. The net was towed horizontally between the sub-surface and 1-2 m depth, by motor boat. 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 & Boxshall (1991). The type specimens are deposited in the Zoological Museum "Cambria" (ZMC) – Department of Animal Biology and Marine Ecology – Messina University, Italy, and in the Zoology collections of the Natural History Museum (BMNH), London.

Study area: Lake Faro (surface area 263,600 m², max depth 28 m) is a coastal basin located on the North-eastern tip of Sicily, Italy (Fig. 1). It has the 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 & Genovese 1968). Along the shores of Lake Faro the bottom is

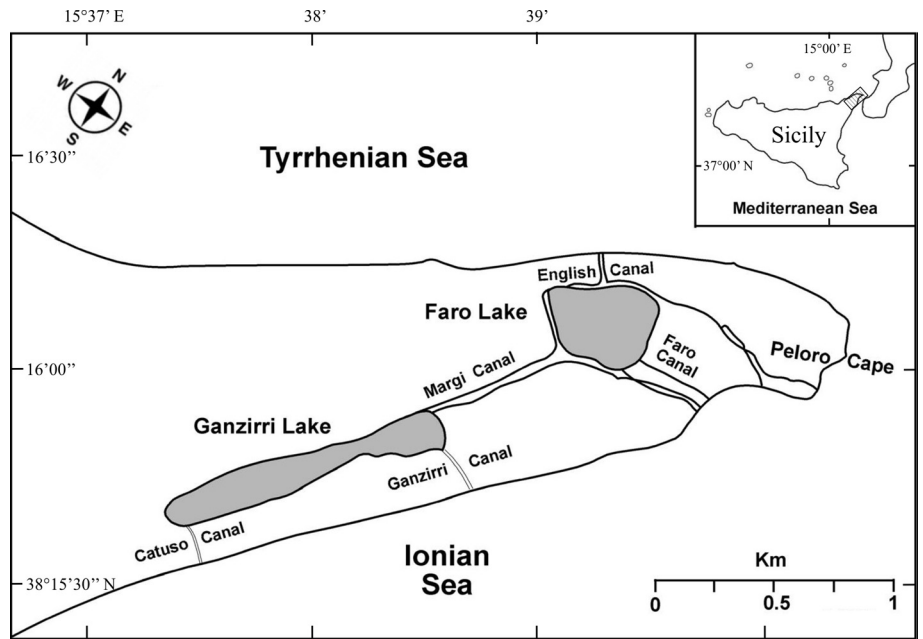


Fig. 1. – Lake Faro: geographical position.

muddy, rich in organic detritus, and covered by great masses of the chlorophyte algae *Chaetomorpha linum* (O. F. Muller) and *Ulva laetevirens* Areschoug, and the phanerogam plant *Cymodocea nodosa* (Ucria) Ascherson

Lake Faro is characterized by large oscillations in physico-chemical 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) (Abbruzzese & Genovese 1952).

Systematics

Subclass Copepoda H. Milne Edwards, 1830

Order Calanoida G.O. Sars, 1903

Family Pseudocyclopidae Giesbrecht, 1893

Genus *Pseudocyclops* Brady, 1872

Pseudocyclops faroensis sp. nov.

(Figures 2–4)

Material examined: Five adult females from Lake Faro, collected at 1–2m depth, from April to June 2005. No males were found. Total body length ranging from 0.54 to 0.56 mm; mean prosome length and width 0.39 mm and 0.14 mm, respectively, with length/width ratio about 2.8; mean urosome length 0.20 mm, with mean length prosome/urosome ratio about 1.9.

Types: Holotype: 1 adult female, dissected and mounted on glass slides, (ZMC reg. n° 2009.5623. Paratypes 1 adult female, whole specimen (ZMC reg. n° 2009.5624), 1 adult female (BMNH reg. n° 2009.7), 2 adult females stored in the authors' personal collection.

Description of adult female (holotype): Body length 0.54 mm (Fig. 2A), body compact; prosome particularly narrow and elongate in dorsal view, length/width ratio about 2.6. Cephalosome/

urosome length ratio is 1.9. Cephalosome distinctly separate from first pedigerous somite; produced ventrally into strong, pointed rostrum. Fourth and fifth pedigerous somites separate. Posterolateral angles of prosome rounded. Urosome (Fig. 2B) 4-segmented. Genital double-somite slightly asymmetrical, and characterized by annular narrowing on posterior part; ornamented with one row of minute spinules on either side; posterodorsal and ventral margins naked; gonopores and copulatory pores paired, opening in common semicircular slit. Second urosomite with distal margin naked. Third urosomite with dorsal and ventral distal margins finely serrate (Fig. 2A–B). Anal somite short, partially telescoped into penultimate somite. Caudal rami symmetrical, longer than wide, furnished with 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) with 16 free segments; armature element as follows: 1, 12+3 long 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 clearly separate, each with seta at distomedial angle. Exopod 7-segmented, segments 1–4 each with seta, segments 5 and 6 each bearing two setae and segment 7 with three setae; endopod 3-segmented, first segment bearing 2 setae on inner medial margin, second with 8 setae, and third with 7 setae apically.

Mandible (Fig. 3B–C) with 7 strong denticulate processes on cutting edge of mandibular gnathobase. Ventralmost unicuspidate tooth largest, separated by large space from two adjacent teeth; intermediate tooth tricuspidate; dorsalmost tooth curved dorsally (Fig. 3B). Palp biramous; basis with 2 setae on inner margin; exopod indistinctly 4-segmented with setal formula 1, 1, 1, 3; endopod 2-segmented, bearing 4 setae on first segment and 10 setae on distal margin of second segment (Fig. 3C).

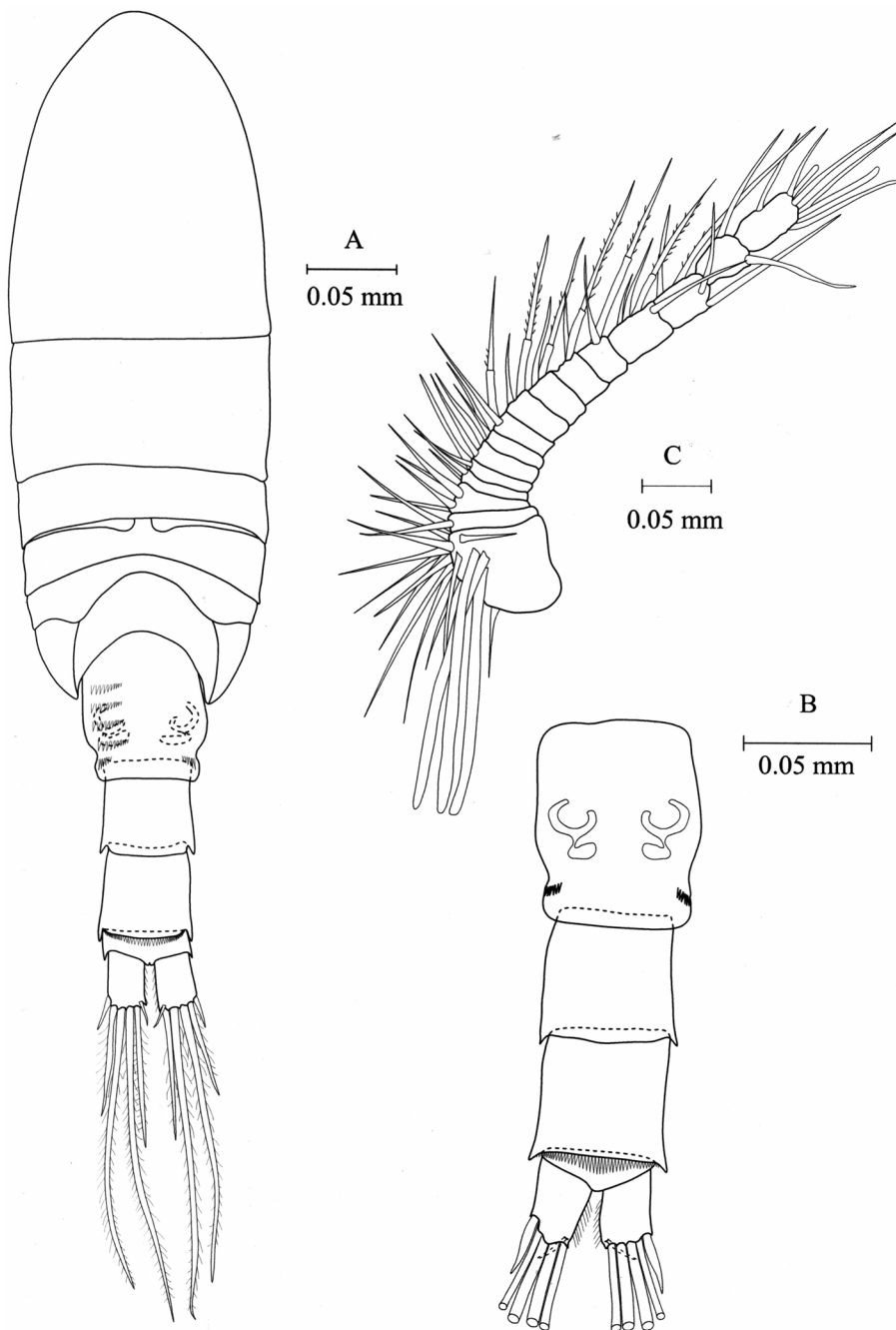


Fig. 2. –*Pseudocyclops faroensis* sp. nov., adult female (holotype): (A) dorsal view; (B) urosome, ventral view; (C) antennule.

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

Maxilla (Fig. 3F) indistinctly 4-segmented, bearing five inner lobes. Precoxa with proximal endite carrying 5 long marginal setae and 1 submarginal rudimentary element; distal precoxal and both coxal endites each bearing 3 setae; basis and first endopodal segment fused to form allobasis with 7 setae; endopod short, indistinctly segmented with 7 setae.

Maxilliped (Fig. 3G) with syncoxa bearing 1, 2, 3, and 3 setae on first to fourth endites, respectively; basis incorporating proximal endopodal segment, with 3 and 2 setae; free endopod 5-segmented, carrying 4, 4, 3, 4, and 4 setae, respectively.

Swimming legs 1-4 biramous; all rami 3-segmented, except for unisegmented first leg endopod. Leg 1 (Fig. 4A) with coxa carrying long inner seta; basis with wide rounded process protruding between rami, and with short, stout inner spine non-articulated basally to the segment; endopod 1-segmented, curved outwards distally, bearing 7 inner setae, of which 4 are articulated and plumose, and with distinct process on sub-distal inner margin. Leg 2 (Fig. 4B) with coxa bearing one row of dis-

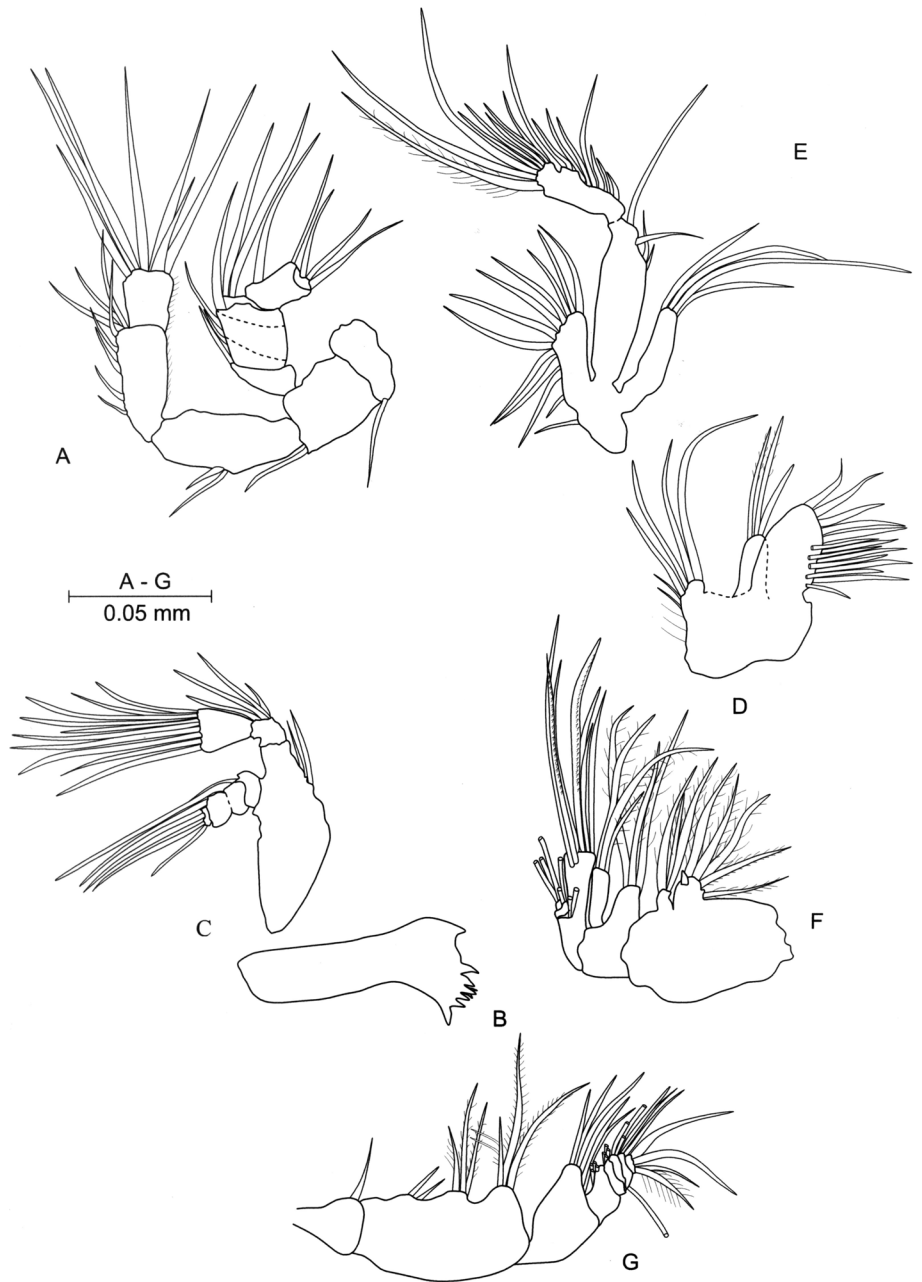


Fig. 3. –*Pseudocyclops faroensis* sp. nov., adult female (holotype): (A) antenna; (B-C) mandible; (D-E) maxillule; (F) maxilla; (G) maxilliped.

tomedial denticles; leg 3 (Fig. 4C) with outer spine and inner and outer processes on distal angles of basis; leg 4 (Fig. 4D) with slender seta on distolateral angle of basis and ornamented on anterior surface with spinules.

Spine and seta formula of swimming legs:

	Coxa	Basis	Exopod segment	Endopod segment
Leg 1	0 - 1	0 - I	I-1; I-1; II, I, 4	0-7
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

Leg 5 (Fig. 4E) symmetrical, with coxa bearing rows of minute spinules on outer and distal margins; basis with pointed

distal inner angle, ornamented with transverse and distal minute spinules, and short submedial seta; exopod and endopod segments both bearing surface spinules; first and second exopod segments both with 1 outer spine; third segment with 1 outer

and 2 terminal serrate spines, plus 1 inner pectinate spine; first endopod segment with a trace of a transverse subdivision of the compound proximal endopod segment, bearing 2 outer pointed processes; second segment with medial long seta, 2 distal setae, and 4 distal processes.

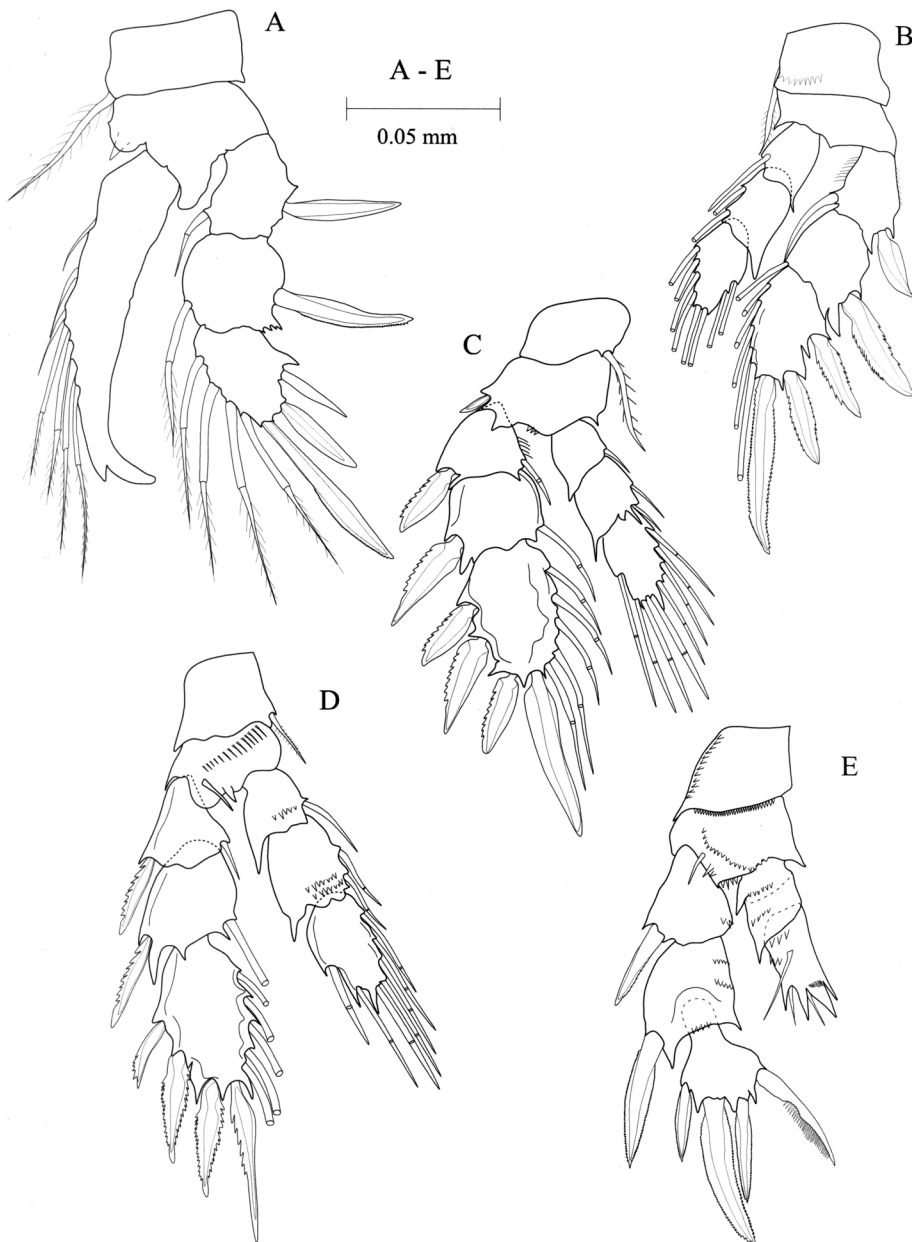


Fig. 4. – *Pseudocyclops faroensis* sp. nov., adult female (holotype): (A) leg 1 anterior; (B) leg 2 anterior; (C) leg 3 anterior; (D) leg 4 anterior; (E) leg 5 anterior.

Remarks: *P. faroensis* sp. nov. is similar to *P. umbraticus* Giesbrecht, 1893, *Pseudocyclops magnus* Esterly, 1911, *Pseudocyclops latens* Gurney 1927, *Pseudocyclops cokeri* Bowman & Gonzalez 1961, *P. xiphophorus* Wells 1967, *Pseudocyclops bilobatus* Dawson 1977, *Pseudocyclops pumilis* Andronov 1986, *Pseudocyclops mirus* Andronov 1986, *P. costanzoii* Baviera, Crescenti & Zagami 2007, and *P. giussanii* Zagami, Brugnano & Costanzo 2008 in having 15-17 antennule segments in female, and a 2-segmented endopod of female leg 5. However, the new species is most closely related to *P. magnus*, *P. latens*, *P. xiphophorus*, *Pseudocyclops bilobatus*, *P. pumilis*, and *P. giussanii* in the absence of exopodal setae along the inner margin of the female leg 5.

The new species is very similar to *P. giussanii* and *P. mirus*. However, the new species can easily be distinguished from these

two species by the following characters: (1) the greater length and very scarce ornamentation of the urosome; the cephalosome length/width ratio 2.6 in *P. faroensis* and 3.0 in *P. giussanii*; the length ratio cephalosome/urosome is 1.9 in *P. faroensis* and 2.8 in *P. giussanii*; (2) the annular narrowing on posterior part of the genital double-somite, in *P. faroensis*; (3) the number of setae on the endopod of female leg 1 (7 in *P. faroensis*, 8 in *P. mirus* and *P. giussanii*); the sub-distal inner margin of the endopod female leg 1, with a conspicuous process in *P. faroensis*, serrated in *P. giussanii*, smooth in *P. mirus*; (4) the acute outer process adjacent to the outer spine on the second exopod segment of leg 5 (short in *P. faroensis* and *P. mirus*; long in *P. giussanii*); submedial basal seta of leg 5 (present in *P. faroensis* and *P. giussanii*; absent in *P. mirus*); the inner margin of the exopod

of female leg 5 (naked in *P. faroensis* and *P. giussanii*; 1 seta on second exopod segment in *P. mirus*).

Out of 35 species comprising the genus *Pseudocyclops*, *Pseudocyclops faroensis* sp. nov., *P. giussanii* from Lake Faro, Italy, and *P. mirus* from Cape Blanc, Mauritania, are characterized by a very narrow and elongate prosome, antennule with 16 segments, unisegmented endopod of leg 1, presence of a distolateral outer spine on the basis of leg 3 instead of a seta, 2-segmented endopod in the female leg 5, absence of exopodal setae along the inner margin of the female leg 5, with the exception of *P. mirus*, which has only one seta on second exopod. Since a combination of these characters is unique within the genus, these three species could be recognized as the *mirus*-species group.

The *mirus*-group shares synapomorphies as follows: (1) the number of antennule segments in female is 16; (2) reduced segmentation and setation in the female leg 5, with 2-segmented endopod and the absence of exopodal setae along the inner margin, with the exception of *P. mirus*, which has only one seta on second exopod; (3) the unarmed proximal endopod segment of the female leg 5, with two acutely pointed outer processes; (4) the distal endopod segment of the female leg 5 with one medial, and two setae, and 4 processes terminally.

Etymology: The specific name *faroensis* refers to the locality, Lake Faro, in which the new species occurs.

DISCUSSION

Some *Pseudocyclops* species exhibit a diel migration, entering the water column during the night time, and they occur in zooplankton night samples (Esterly 1911, Gurney 1927, Sewell 1932, Vervoort 1964, Yeatman 1975, Dawson 1977, Othman & Greenwood 1989, Haridas *et al.* 1994, Ohtsuka *et al.* 1999, Campolmi *et al.* 2001). *Pseudocyclops faroensis* was collected during night sampling in Lake Faro, together with *P. giussanii*, *P. xiphophorus*, *P. umbraticus*. None of them was recorded in daytime samples, suggesting that this species group performs a daily vertical migration or enters the water column during night time (Zagami *et al.* 2008a). In contrast the single specimen of *P. costanzo* was collected in muddy sediment (Baviera *et al.* 2007).

This *Pseudocyclops* species assemblage is characterized by very low abundance values, when compared with the planktonic calanoids collected during night time (Campolmi *et al.* 2001, Zagami *et al.* 2008a).

According to Ohtsuka *et al.* (1999), four distinct species groups can be recognized within *Pseudocyclops*: *lepidotus*, *kulai*, *crassiremis* and *magnus* groups. In addition to these, in the light of the new species, *P. giussanii* and *P. faroensis* found in the Lake Faro, and *P. mirus* from Mauritania, we recognise the *mirus*-species group, as a fifth species group in *Pseudocyclops*, which is geographically distributed around the Eastern Atlantic-Mediterranean region (Zagami *et al.* 2008b).

Out of 35 species comprising the genus *Pseudocyclops*, this last group, in particular, is characterized by a unisegmented endopod of leg 5.

The recognition of a new *Pseudocyclops* species-group, based on these new records, gives strength to Boxshall and Halsey's (2004) hypothesis, that this monogeneric family, and this heterogeneous genus should be revised. The different species groups could be a prelude to new genera within the family Pseudocyclopidae. In *Pseudocyclops* it is common for new species to be described on the basis of a single sex, and on one or few specimens from plankton hauls, or collected along coral sandy bottoms by hand-nets using SCUBA diving.

The presence in Lake Faro, in addition to the new species, of *P. umbraticus*, *P. xiphophorus*, *P. costanzo*, and *P. giussanii* is very interesting with regard to their zoogeographic distribution patterns. *Pseudocyclops umbraticus* occurs in the Mediterranean Sea, Suez Canal, and along the Mauritanian coast; *P. xiphophorus* is distributed in shallow coastal waters in Mozambique, Hong Kong (Brugnano *et al.* 2009) and the Mediterranean coastal Lake Faro; *P. costanzo*, *P. giussanii* and *P. faroensis* sp. nov. occur only in this lake. *P. giussanii* and *P. faroensis* are very similar to *P. mirus*, known only from Mauritanian coastal waters (Andronov 1986). *Pseudocyclops xiphophorus*, found in Lake Faro and in Hong Kong, exhibited morphological variations and sexually dimorphic specialization of the right swimming leg 2. Reproduction experiments made in the laboratory on couples of the different morphotypes excluded the possibility of considering them as different species, but further investigation will need to undertake a molecular analysis in order to estimate genetic differences between *P. xiphophorus* morphotypes (Brugnano *et al.* 2009). The distribution of the genus *Pseudocyclops*, or at least for some of the species groups, with a wide distribution pattern within tropical/subtropical regions, shows a full Tethyan track and, as Stock (1993) has suggested, that these calanoid copepod species must have existed ever since the Tethyan Sea.

The discovery of *P. faroensis* sp. nov. increases the number of Mediterranean *Pseudocyclops* species to six, of which *P. xiphophorus*, *P. costanzo*, *P. giussanii*, and *P. faroensis* sp. nov., are to date, known to occur exclusively in Lake Faro.

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