

TWO NEW SPECIES OF *PARASTENOCARIS* (COPEPODA,
HARPACTICOIDA, PARASTENOCARIDIDAE) FROM GROUNDWATER OF
SARDINIA AND SICILY

BY

VEZIO COTTARELLI, M. CRISTINA BRUNO¹⁾ and RAFFAELLA BERERA

Department of Environmental Sciences, University "della Tuscia", Largo dell'Università snc,
Viterbo, I-01100 Italy

ABSTRACT

Two species of harpacticoid copepods, *Parastenocaris altitudinis* sp. nov. and *Parastenocaris luciae* sp. nov., are described herein and their taxonomic position within the genus *Parastenocaris* is discussed. The new species were collected from the interstitial phreatic habitat of a small temporary stream at the top of Mount Limbara (Sassari province, Sardinia) and the river mouth of the temporary stream Cerasella (Palermo province, Sicily), respectively.

Parastenocaris altitudinis sp. nov. is characterized by the lack of the P4 endopod in males; this apomorphy is shared with three other species from Sardinia, one from the French Pyrenees and one from northern Portugal. The last two species were, so far, the only two in the *dianae* species group.

Parastenocaris luciae sp. nov. belongs to the *hera* species group, and can be distinguished from the other eight species of the group by the unusually large size of the maxillar endopodite, its pitted body surface, and the presence of one seta on the sixth segment of the male A1 and on the fifth segment of the female A1. Phylogenetically informative characters in the *hera* group are defined on the basis of the morphology of the maxillar endopod.

Information on the collecting stations and the accompanying harpacticoid fauna are also provided.

RIASSUNTO

Nel presente lavoro vengono descritte due specie di copepodi harpacticoidi, *Parastenocaris altitudinis* sp. nov. e *Parastenocaris luciae* sp. nov., e viene discussa la loro posizione all'interno del genere *Parastenocaris*. Le due nuove specie sono state raccolte in ambiente interstiziale freatico rispettivamente di un piccolo torrente temporaneo situato sulla cima del Monte Limbara (provincia di Sassari, Sardegna) e alla foce del torrente temporaneo Cerasella (provincia di Palermo, Sicilia).

Parastenocaris altitudinis sp. nov. è caratterizzata dall'assenza dell'endopodite P4 nei maschi; questa apomorfia è condivisa con altre tre specie sarde, con una dei Pirenei francesi, e con una del Portogallo settentrionale. Le ultime due specie sono, finora, le uniche due del gruppo di specie *dianae*.

¹⁾ Corresponding author; e-mail: mcbruno@unitus.it

Parastenocaris luciae sp. nov. appartiene al gruppo di specie *hera*, e si distingue dalle altre otto specie del gruppo per le notevoli dimensioni dell'endopodite della seconda mascella, per la superficie corporea variolata, e per la presenza di una setola sul sesto segmento dell'antennula del maschio e sul quinto segmento di quella della femmina. Vengono inoltre definite alcune condizioni filogeneticamente informative per il gruppo *hera*, sulla base della morfologia dell'endopodite delle seconde mascelle.

Si presentano anche informazioni sulle stazioni di raccolta e sulla fauna associata.

INTRODUCTION

This work is the last in a long series of taxonomic, faunistic, and biogeographic research papers on interstitial Harpacticoida from major and minor Italian islands (Cottarelli, 1969, 1970; Pesce et al., 1988; Cottarelli & Bruno, 1994a; Cottarelli et al., 1995, 1999; Berera et al., 2001; Berera & Cottarelli, 2003). Ten species of *Parastenocaris* have been described for Sardinia and adjacent islands (Cottarelli et al., 1996), with three more species still under study: *Parastenocaris* sp. C from Mount Limbara (Cottarelli et al., 2002), *Parastenocaris* cf. *tyrrhenidis*, and *Parastenocaris* sp., collected, respectively, on Mount Gennargentu and Asinara Island (V. Cottarelli, unpubl.). The interstitial harpacticoid fauna of Sicily has been less intensively studied: so far, only two named species of *Parastenocaris* are known from there (Pesce et al., 1988). Although the minor Sicilian islands were repeatedly investigated by V. Cottarelli from 1985 to 1993, no species of *Parastenocaris* were ever collected in that area.

The discovery of these new species strengthens the role of the stygofauna in increasing the biodiversity value of these islands, both in terms of species richness and in degree of endemism. *Parastenocaris altitudinis* sp. nov., previously listed as *Parastenocaris* sp. D in Cottarelli et al. (2002), is the first Sardinian *Parastenocaris* collected at high altitude from a temporary stream that dries out in summer months. *Parastenocaris luciae* sp. nov. was collected in the estuarine interstitial habitat from a stream that dries in summer as well, and it represents the first Sicilian representative of the *hera*-group as defined by Berera & Cottarelli (2003). This species group has a peculiar ecology, because it so far includes only taxa from estuarine interstitial habitats collected on the coasts of peninsular and insular Italy, Spain, and Greece.

Within the family Parastenocarididae, the genus *Parastenocaris* is currently under revision (Reid, 1995; Galassi & De Laurentiis, 2004; Cottarelli et al., 2007): in accordance with Galassi & De Laurentiis (2004) we consider as *Parastenocaris* sensu stricto only the species belonging to the *brevipes*-group of Lang (1948), subsequently redefined by Reid (1995), and thus we include the species described here in *Parastenocaris* sensu lato.

MATERIAL AND METHODS

Parastenocaris altitudinis sp. nov. was collected in a small sand deposit (about 2.5×1.5 m) on the right bank of a stream, underneath the last bridge of the Tempio Limbara state road, almost at the top of the Mount Limbara. At the collecting site, the stream was about 2 m wide and 50 cm deep; the sediment consisted mostly of medium-fine sand with abundant organic detritus and a few larger rocks covered with moss, which was collected, washed, and rinsed to obtain harpacticoids as well. The stream water was very clear. The station was investigated six times from 1997 to 2001.

Parastenocaris luciae sp. nov. was collected from sand bars in the rivermouth of the Cerasella stream during a period of very low flow in the dry season. At the collecting station, sediment was represented by medium sand with abundant organic detritus; the interstitial water had a temperature of 24.3°C .

Specimens were collected with the Karaman-Chappuis method (Delamare Deboutteville, 1960), and fixed in the field with 5% buffered formalin, sorted, and mounted on permanent slides in Faure's medium. Drawings were made at 1250 X magnification, with an oil immersion lens, using a drawing tube mounted on a Zeiss Axioskop[®] phase-contrast microscope.

The following abbreviations are used throughout the text and figures: ae, aesthetasc; enp, endopod; exp, exopod; A1, antennule; mx2, maxilla; P1-P5, thoracic appendages 1-5. The nomenclature and descriptive terminology follow Huys & Boxshall (1991).

The holotype and allotype of both species are deposited in the Museo Civico di Storia Naturale di Genova (MCSNG); the remaining material is located in the senior author's collection in the Environmental Sciences Department, University "della Tuscia", Viterbo (DSAUT).

TAXONOMIC ACCOUNT

Family PARASTENOCARIDIDAE Chappuis, 1940

Genus *Parastenocaris* Kessler, 1913 sensu lato

***Parastenocaris altitudinis* sp. nov.** (figs. 1, 2)

Material examined. — Holotype: male, dissected and mounted on slide labelled MCSNG 54178. Allotype: female, dissected and mounted on slide labelled MCSNG 54179. Paratypes: 6 males, each dissected and mounted on slides labelled nos. 1-6, respectively (DSAUT); 14 females, 10 dissected, all mounted on slides, labelled nos. 1-14, respectively (DSAUT).

All material collected by V. Cottarelli on 8 May 1999 and 14 April 2000, on the banks of a small stream on Mount Limbara, 1280 m a.s.l., $40^{\circ}51'20.55''\text{N}$ $9^{\circ}9'59.45''\text{E}$ (Sassari province, Sardinia).

Description of male. — Body vermiform, slender, unpigmented, eyeless. Length, measured from rostrum to apex of caudal rami, 0.434 mm. Hyaline frills of

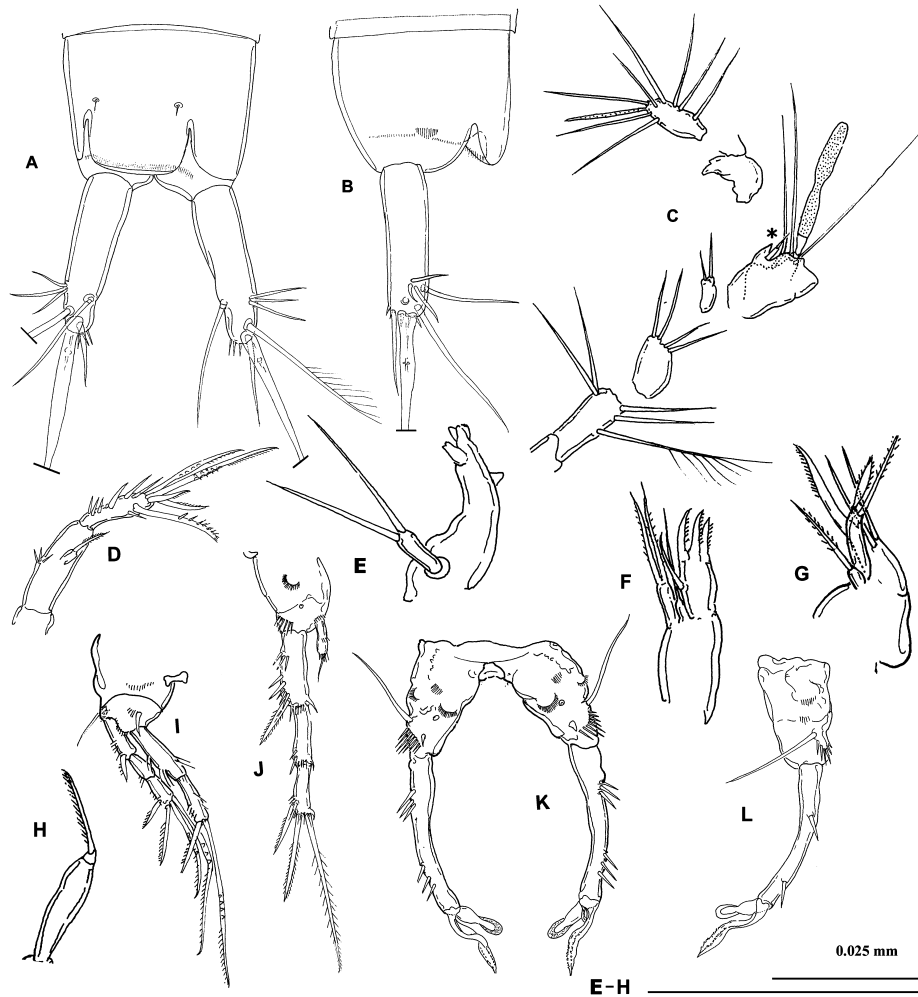


Fig. 1. *Parastenocaris altitudinis* sp. nov. A-K, holotype, male; L, paratype, male. A, anal somite, anal operculum, caudal rami, dorsal view; B, anal somite, anal operculum, caudal rami, lateral view; C, antennule, disarticulated; D, antenna; E, mandible; F, maxillule; G, maxilla; H, maxilliped; I, P1; J, P2; K, P3; L, P3.

cephalothorax, thoracic and abdominal somites, and urosome smooth. Cephalothorax with round dorsal integumental window. Genital somite and first three abdominal somites with oval dorsal integumental windows, shapes and sizes as in fig. 2C. Anal somite (fig. 1A, B) with paired sensilla on dorsal side and one transverse row of proctodeal spinules. Anal operculum (fig. 1A, B) with straight, smooth distal margin. Caudal rami (fig. 1A, B) as long as last abdominal somite; length/width ratio 3.5. Anterolateral accessory seta (I), anterolateral seta (II), and posterolateral seta (III) short and subequal, all three setae inserted together at 3/4 length of

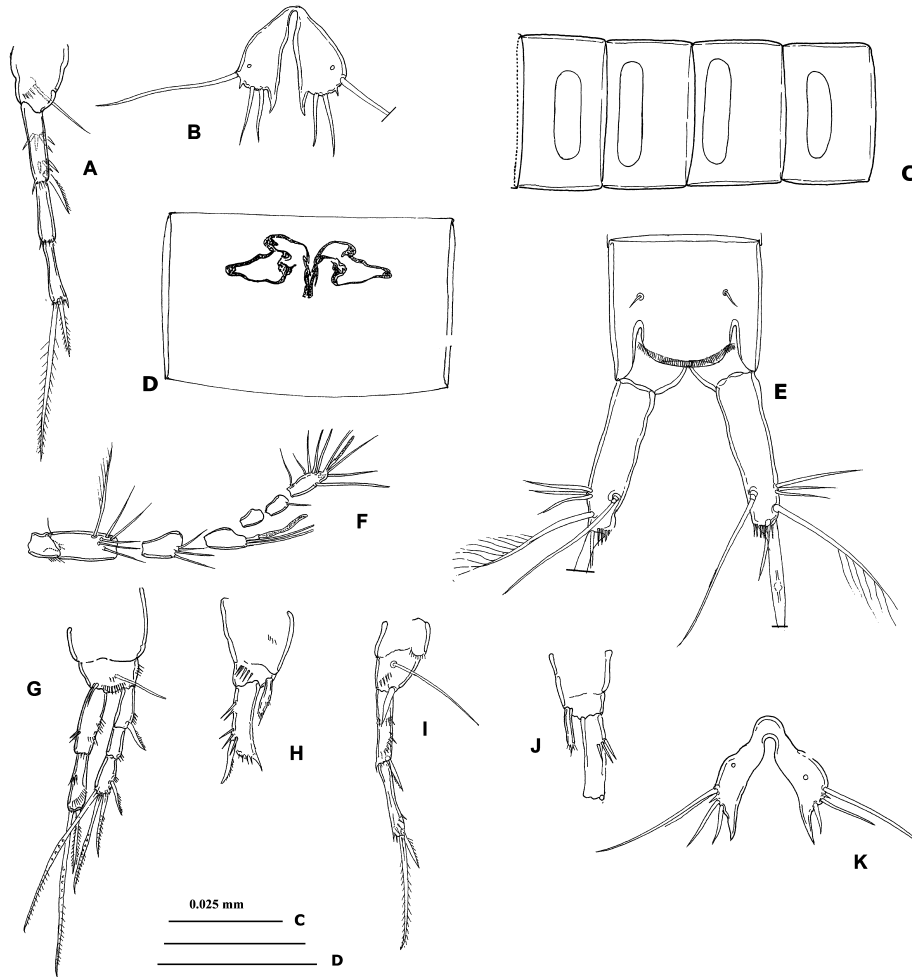


Fig. 2. *Parastenocaris altitudinis* sp. nov. A-C, holotype, male; D-K, allotype, female. A, P4, medial view; B, P5; C, dorsal integumental windows on genital somite and abdominal somites 1-3, dorsal view; D, genital double-somite and genital field, ventral view; E, anal somite, anal operculum, caudal rami, dorsal view; F, antennule, partly disarticulated; G, P1; H, P2 endopod; I, P3, medial view; J, P4 endopod; K, P5.

the caudal ramus. Outer terminal seta (IV) short (length seta/length caudal ramus: 1.05), unipinnate. Inner terminal seta (V) without fracture plane. Terminal accessory seta (VI) short (length seta/length caudal ramus: 0.51) and smooth, with row of spinules near its insertion. Dorsal seta (VII) articulate, short (length seta/length caudal ramus: 0.77).

Rostrum (fig. 1C): small, reaching to midlength of first segment of antennule, with two apical sensilla.

Antennule (fig. 1C): geniculate, eight-segmented. First segment bare. Second segment with five setae, one of these uniserially plumose. Third segment with four distal setae. Fourth segment represented by U-shaped sclerite with two short setae. Fifth segment a little enlarged, bearing on its ventral side a seta and distal tubercle, the latter with two equal setae and one aesthetasc, slightly constricted at midlength, and reaching the end of the antennule; a triangular and pointed apophysis and a small transformed seta (marked with an asterisk in fig. 1C) present on dorsal side of segment; apophysis matching the one on seventh segment. Sixth segment partially merged with fifth one, bare. Seventh segment bare, prolonged into bilobate apophysis (fig. 1C). Eighth segment with eight setae and short, thin, apical aesthetasc. Armature formula: 1-[0], 2-[1 uniplumose + 4 bare], 3-[4 bare], 4-[2 bare], 5-[1 bare + 1 modified + (2 + ae)], 6-[0], 7-[0], 8-[8 bare + ae].

Antenna (fig. 1D): coxa unarmed; allobasis with a transverse row of three spinules on medial margin. Exopod one-segmented, with short, pinnate apical spine. Endopod bearing on its apex two unipinnate geniculate setae and two shorter spiniform unipinnate setae. One subapical transformed seta with spinule near its insertion. Six spinules along medio-distal margin of endopod.

Mandible (fig. 1E): coxal gnathobase bare, cutting edge with two apical and one subapical strong teeth. One-segmented palp, with two distal setae of equal length.

Maxillule (fig. 1F): praecoxal arthrite with three claw-like spines and one subapical curved seta. Coxa with one apical seta, basis with two apical pinnate setae.

Maxilla (fig. 1G): syncoxa with two endites; proximal endite short, with pinnate seta; distal endite long, with two pinnate setae, one enlarged. Allobasis prolonged into apical pinnate claw, which is distally spinulose; endopod represented by two setae of equal length arising at about 1/3 distally along medial margin of allobasis.

Maxilliped (fig. 1H): prehensile. Syncoxa small and unarmed; basis slim and elongate, unarmed; endopod represented by distally unipinnate claw.

P1 (fig. 1I): basis with thin lateral seta; stout spine and longitudinal row of spinules near endopod insertion. Exopod three-segmented, shorter than endopod. Third segment with two geniculate and one normal pinnate apical setae, and one subapical pinnate seta. Endopod two-segmented, enp-2 with long, geniculate pinnate seta, and short pinnate seta on apex.

P2 (fig. 1J): basis with pore and a row of spinules, without lateral seta. Exopod three-segmented, with fringed extension on medial distal corner of each segment, armature shown in fig. 1J. Endopod reaching to midlength of exp-1, represented by a cylindrical segment with apical seta surrounded by short spinules. Transverse row of spinules at midlength and another row of spinules around endopod insertion.

P3 (fig. 1K): slender and elongate, basis with long lateral seta, pore, and longitudinal row of spinules. Endopod reduced to short, thickened spine. Exp-1

distally slender, two groups of three spines each on lateral margin at about 1/4 and 3/4 of its length. Distal thumb represented by leaf-like, pointed segment; exp-2 fused with exp-1 and prolonged into a short, bulbous, and inwardly curved apophysis. In one male paratype, exp-1 (fig. 1L) has one spine at about 1/4 of its length and one at 3/4 of its length instead of two groups of three setae each.

P4 (fig. 2A): basis with lateral seta; exopod three-segmented, slender; exp-1 markedly longer than exp-2; armature shown in fig. 2A. Endopod absent.

P5 (fig. 2B): without intercoxal sclerite, represented by two almost trapezoidal plates fused at their bases. On free distal margin, from medial to lateral: strong, outwardly curved spiniform process, two subequal setae, small spiniform process, and long basipodal lateral seta with pore near its insertion.

Description of female. — Length, measured from rostrum to apex of caudal rami, 0.447 mm. Genital somite and second and third abdominal somites with oval dorsal integumental windows similar to those of male but larger. Genital somite and first abdominal somite fused, forming genital double-somite (fig. 2D). Genital field located in proximal 1/3 of genital double-somite (fig. 2D). Anal somite, anal operculum, rostrum, antenna, oral appendages, maxilliped, P1 exopod and endopod, P2 basis and exopod, and P4 exopod as in male. Caudal rami (fig. 2E) similar to those of male, length/width ratio 3.70; some spinules near insertion of seta VI.

Antennule (fig. 2F): seven-segmented, aesthetasc on fourth segment shorter and more slender than that of male, not reaching to end of seventh segment. First segment with a row of short spinules. Armature formula: 1-[0], 2-[1 pinnate + 5 bare], 3-[4 bare], 4-[2 + ae], 5-[0], 6-[1], 7-[7 bare + (2 + ae)]. Apical trithek represented by two subequal setae and slender, short aesthetasc similar to that of male.

P1 basis (fig. 2G): lateral ornamentation as in male, with longer and thinner seta on medial margin.

P2 endopod (fig. 2H): slightly thinner and shorter than in male, with shorter apical seta.

P3 (fig. 2I): exopod two-segmented, as normal in genus. Endopod represented by thin, pointed segment, reaching to midlength of exp-1.

P4: endopod (fig. 2J) represented by a small, cylindrical segment reaching to midlength of exp-1, with short apical spine and some subapical spinules.

P5 (fig. 2K): without intercoxal sclerite, but right and left legs coalescent; suture surface between left and right legs larger than in male; legs trapezoidal, more elongate than in male, with the same ornamentation but with longer medial spiniform process and shorter medialmost seta.

Etymology. — The specific name, a noun in the genitive singular, is derived from the Latin noun *altitudo*, thus meaning “of the height”. This is the insular species of Italian *Parastenocaris* collected at the highest altitude thus far.

Ecological remarks. — *Parastenocaris altitudinis* sp. nov. was collected together with other harpacticoids typical of high-altitude streams. Seven taxa were collected, three having a wide distribution: *Bryocamptus* (*Rheocamptus*) *pygmaeus* (G. O. Sars, 1863), *Epactophanes richardi* Mrázek, 1893, and *Moraria* (*Moraria*) *poppei* Mrázek, 1893. Two species are new to science: *P. altitudinis* sp. nov. and another *Parastenocaris*, still in study, reported as *Parastenocaris* sp. C in Cottarelli et al. (2002), which has some interesting morphological features new for the family. Three species are new records for Sardinia and two of these might be new species: *Maraenobiotus* cf. *vej dovskyi* (reported as *Maraenobiotus* sp. in Cottarelli et al., 2002), with only a few specimens collected, and *Bryocamptus* (*Arcticocamptus*) sp., which was always collected together with *Bryocamptus* (*Arcticocamptus*) *cuspidatus* (Schmeil, 1893). The last two species are typical of high altitudes, but at our sampling site they had a different ecology: *Bryocamptus* (A.) sp. was very abundant in the interstitial habitat and rare in mosses, whereas *Bryocamptus* (A.) *cuspidatus* was very rare in the interstitial, but abundant in mosses.

***Parastenocaris luciae* sp. nov. (figs. 3-5)**

Material examined. — Holotype: male, dissected and mounted on slide labelled MCSNG 54176. Allotype: female, dissected and mounted on slide labelled MCSNG 54177. Paratypes: 14 males, ten of which dissected, each mounted on slides labelled nos. 1-14, respectively (DSAUT); six females, four dissected, each mounted on slide labelled nos. 1-6, respectively (DSAUT), 4 copepodites, each mounted on slides labelled no. 1-4, respectively.

All material collected by Dr. Roberta Raschioni on 2 August 2002, about 150 m from the mouth of the Cerasella stream, near Terrasini village, 38°04'44.69"N 13°03'50.30"E (Palermo province, Sicily).

Description of male. — Body vermiform, slender, unpigmented, eyeless, body surface slightly pitted. Length, measured from rostrum to apex of caudal rami, 0.397 mm. Hyaline frills of cephalothorax, thoracic and abdominal somites, and urosome smooth. Cephalothorax with round dorsal integumental window (fig. 3A). Genital somite and first three abdominal somites with oval dorsal integumental windows, their shape and size as in fig. 3B. Anal somite (fig. 3C, D) with paired sensilla on dorsal side and two rows of small proctodeal spinules. Anal operculum (fig. 3C, D) with convex, smooth distal margin. Caudal rami (fig. 3C, D) approximately cylindrical, shorter than last abdominal somite; length/width ratio 2.3. Anterolateral accessory seta (I) and anterolateral seta (II) short and subequal, posterolateral seta (III) slightly longer, all three setae almost subapical, i.e., inserted beyond 3/4 length of caudal ramus. Outer terminal seta (IV) long (length seta/length caudal ramus: 1.8), uniserially pinnate. Inner terminal seta (V) without breaking

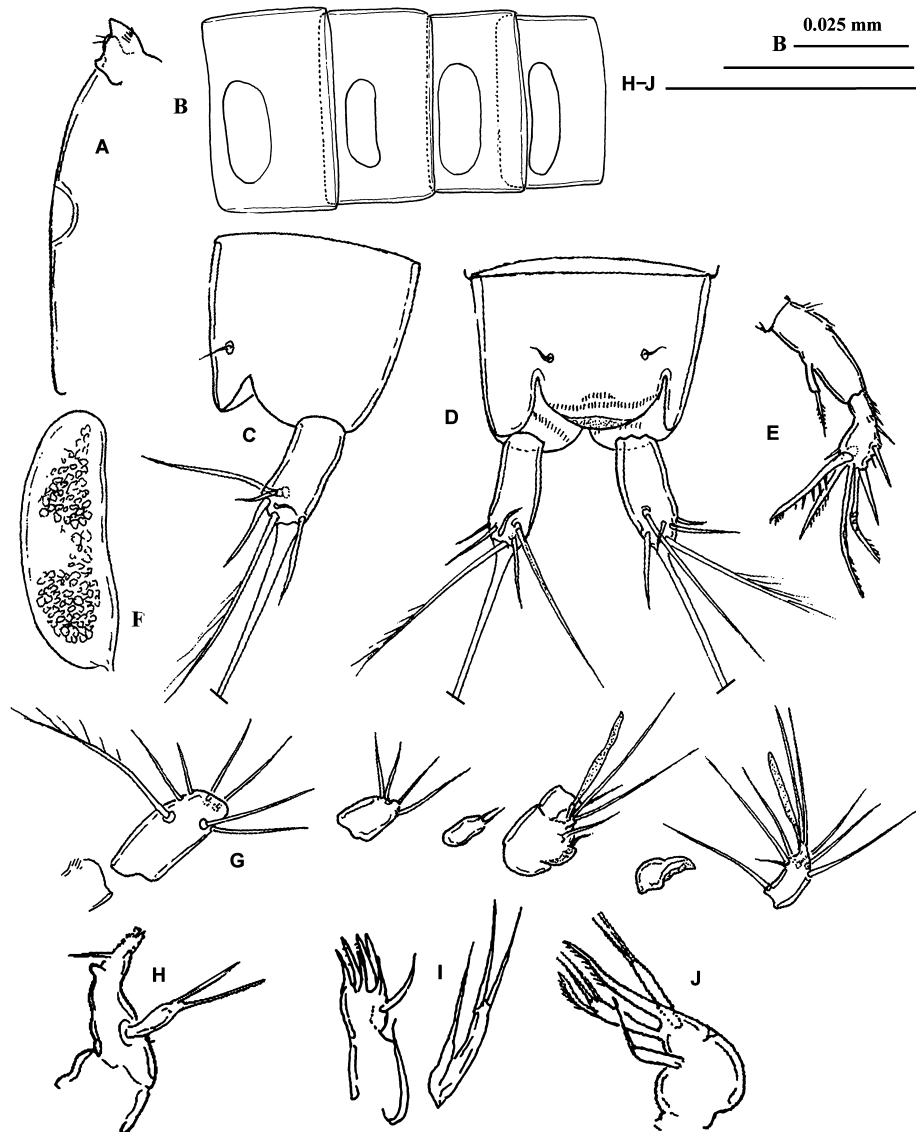


Fig. 3. *Parastenocaris luciae* sp. nov. A, B, D-J, holotype, male; C, paratype, male. A, rostrum and dorsal integumental window on cephalothorax, lateral view; B, dorsal integumental windows on genital somite and abdominal somites 1-3, dorsal view; C, anal somite, anal operculum, caudal rami, lateral view; D, anal somite, anal operculum, caudal rami, dorsal view; E, antenna; F, spermatophore; G, antennule, disarticulated; H, mandible; I, maxillule; J, maxilla.

plane. Terminal accessory seta (VI) short (length seta/length caudal ramus: 0.9) and smooth. Dorsal seta (VII) articulated (length seta/length caudal ramus: 1.6). Spermatophore as in fig. 3F.

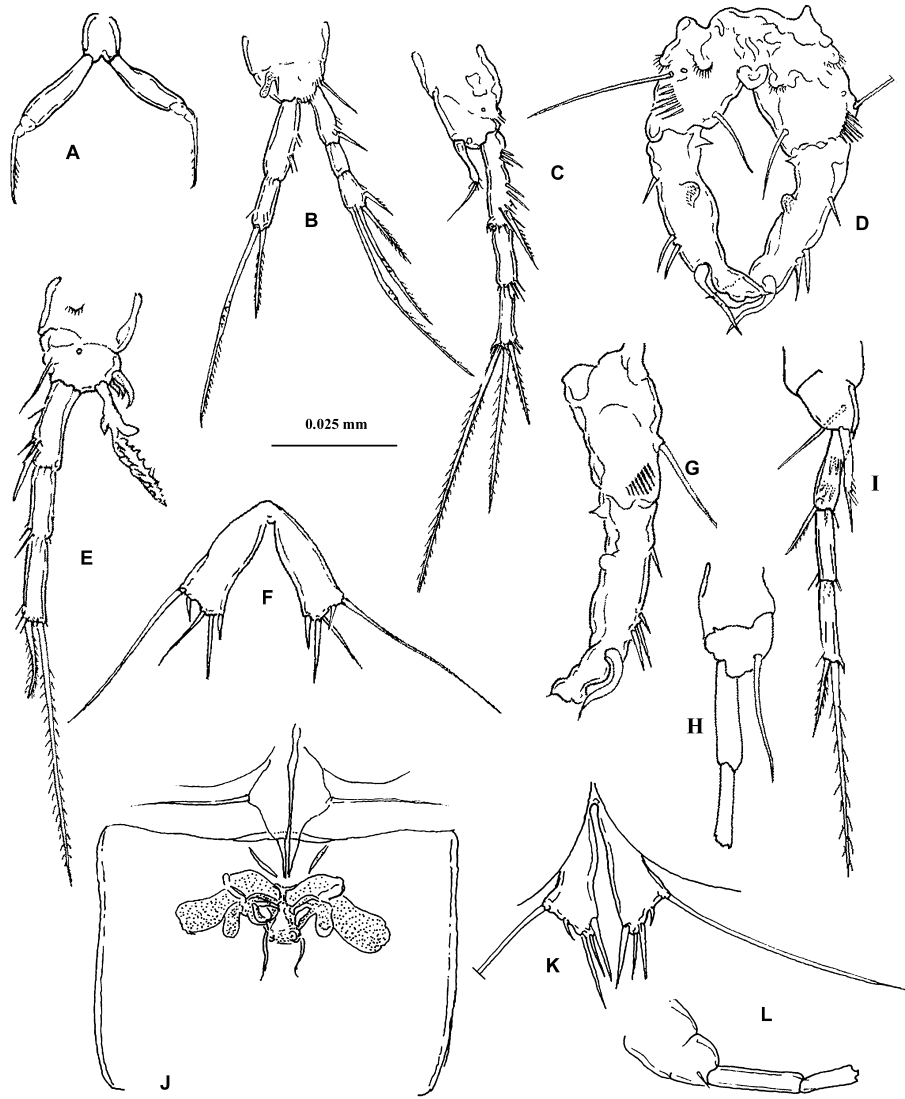


Fig. 4. *Parastenocaris luciae* sp. nov. A-F, holotype, male; G, paratype, male; H-L, allotype, female. A, maxilliped; B, P1; C, P2; D, P3; E, P4; F, P5; G, P3; H, P3 endopod; I, P4; J, genital double-somite and genital field, ventral view; K, P5; L, P1 basis and endopod, medial view.

Rostrum (fig. 3A): small, reaching to midlength of first segment of antennule, with two apical sensilla.

Antennule (fig. 3G): geniculate, eight-segmented. First segment bare with a transverse row of distal spinules. Second segment with seven setae, one of these uniseriably plumose. Third segment with four distal setae. Fourth segment represented by U-shaped sclerite with two short setae. Fifth segment enlarged,

bearing on its ventral distal corner a seta and a tubercle, the latter with two setae and an aesthetasc slightly constricted at midlength and reaching end of antennule. Same segment with a medially expanded hyaline membrane with small apical seta. Sixth segment partially merged with fifth one, with short apical seta. Seventh segment short, prolonged into medio-distal apophysis with curved, pointed tip, bordered with hyaline membrane. Eighth segment with seven setae and apical trithec consisting of two subequal setae and one aesthetasc slightly shorter than that on fifth segment. Armature formula: 1-[0], 2-[1 unipinnate + 6 bare], 3-[4 bare], 4-[2 bare], 5-[2 bare + (2 + ae)], 6-[1], 7-[0], 8-[7 bare + (2 + ae)].

Antenna (fig. 3E): coxa unarmed; allobasis with two transverse rows of spinules on medial margin. Exopod one-segmented, not defined at base, with short, pinnate apical spine. Endopod bearing on its apex two unipinnate and geniculate setae, one transformed seta, two distal pinnate spiniform setae, a third smaller subapical spiniform seta, and some spinules along medio-distal margin.

Mandible (fig. 3H): coxal gnathobase with subterminal short seta, cutting edge with two strong teeth and a row of smaller teeth and one seta near dorsal corner; one-segmented palp with two distal setae.

Maxillule (fig. 3I): praecoxal arthrite with three large claw-like pinnate spines and three smaller bare ones, and a subapical curved seta. Coxa with distal seta, basis with two apical setae.

Maxilla (fig. 3J): syncoxa with two endites, proximal one with one seta, distal one elongated and with three setae, subapical one leaf-like and pinnate. Allobasis prolonged into pinnate apical claw. Endopod very long, with two setae.

Maxilliped (fig. 4A): prehensile. Syncoxa small and unarmed; basis slim and elongate, unarmed; endopod represented by a distally unipinnate claw.

P1 (fig. 4B): basis with thin lateral seta and enlarged chitinous protrusion with rounded tip and a short seta near the endopod insertion. Exopod three-segmented, as long as endopod. Third segment with two geniculate and one normal pinnate apical setae, and a subapical pinnate seta. Endopod two-segmented, exp-2 with two apical setae: one long, geniculate, and pinnate, the other short and pinnate.

P2 (fig. 4C): basis with pore and a row of spinules, without lateral seta. Exopod three-segmented, with fringed extension on medial distal corner of segments 1 and 3, armature shown in fig. 4C. Endopod reaching to midlength of exp-1, represented by a small, outwardly curved, cylindrical segment with one apical seta surrounded by short spinules.

P3 (fig. 4D): squat, basis with long lateral seta, pore, and a longitudinal row of spinules; endopod reduced to thin and relatively long seta. Exp-1 short, bare, with a spine at about 1/3 of its length, and two spines at about 2/3 of the length of the lateral margin; small, pointed expansion proximally on medial margin, and a large, round tubercle at midlength of the same margin. Exp-2 fused with exp-1

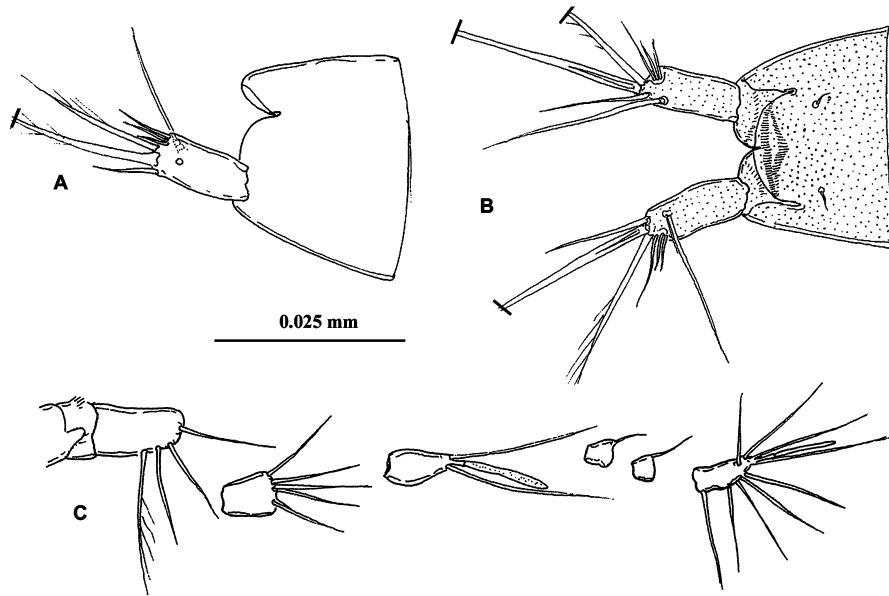


Fig. 5. *Parastenocaris luciae* sp. nov. A, paratype, female; B, C, allotype, female. A, anal somite, anal operculum, caudal rami, lateral view; B, anal somite, anal operculum, caudal rami, dorsal view; C, rostrum and antennule, partly disarticulated.

and ending in enlarged, inwardly curved apophysis with pointed tip. Outer spine of exp-1 represented by pointed thumb as long as apophysis. The P3 exp-1 of one male (fig. 4G) has three spines instead of the usual two at about 2/3 of its length.

P4 (fig. 4E): basis with lateral seta and pore; exopod three-segmented, armature shown in fig. 4E. Endopod slightly shorter than the first two segments of the exopod, bearing on its proximal part two sharp and opposing expansions, and continuing into leaf-like lamina with crenulate margin. Three curved spines near insertion of endopod, inner one being the longest.

P5 (fig. 4F): without intercoxal sclerite, represented by two almost trapezoidal, elongated plates fused at their bases. On free distal margin, from medial to lateral: one spine, two subequal setae, one spiniform seta, and one very long basipodal lateral seta.

Description of female. — Length, measured from rostrum to apex of caudal rami, 0.436 mm. Body surface slightly pitted as in male (fig. 5B). Cephalosome with integumental window as in male. Genital somite and second and third abdominal somites with oval dorsal integumental windows similar to those of male but larger. Genital and first abdominal somites fused, forming genital double-somite (fig. 4J). Genital field located at proximal 1/3 of genital double-somite (fig. 4J). Anal somite, anal operculum, rostrum (fig. 5C), antenna, oral appendages,

maxilliped, P1 exopod and endopod, and P2, as in male. Caudal rami (fig. 5A, B) similar to those of male, with one pore.

Antennule (fig. 5C): seven-segmented, with aesthetasc on fourth segment similar to that of male, not reaching to end of segment no. seven. First segment with row of short spinules. Armature formula: 1-[0], 2-[1 pinnate + 3 bare], 3-[4 bare], 4-[2 + ae], 5-[1], 6-[1], 7-[7 bare + (2 + ae)]. Apical trithec represented by two subequal setae and one slender, short aesthetasc.

P1 basis (fig. 4L): lateral ornamentation as in male, medial margin with slender, short seta near endopod insertion.

P3: exopod two-segmented as usual in the genus. Endopod (fig. 4H) represented by thin, pointed segment longer than exp-1.

P4 (figs. 4I): basis with lateral seta and pore. Exopod similar to that of male. Endopod slightly longer than exp-1, represented by a small cylindrical segment with an apical seta and some subapical spinules.

P5 (fig. 4K): without intercoxal sclerite, represented by two almost trapezoidal, elongated plates fused at their bases. On free distal margin from medial to lateral: one long spine, two subequal setae, one curved spiniform seta, and one very long basipodal lateral seta.

Etymology. — We are honoured to dedicate the new species to our dear friend, Prof. Lucia Mastrolia, full Professor of Comparative Anatomy, Tuscia University. The specific epithet is a feminine noun in the genitive singular.

Ecological remarks. — *Parastenocaris luciae* sp. nov. was collected together with numerous specimens of *Psammopsyllus maricae* Cottarelli, Saporito & Puccetti, 1983, a new record from Sicily. At least in Italy, *Psammopsyllus maricae* is always associated with species of *Parastenocaris* of the *hera*-group as well as with species of the genus *Ichnusella* Cottarelli, 1971; members of these genera are commonly found associated in estuarine interstitial communities (Berera et al., 2001; Berera & Cottarelli, 2003).

DISCUSSION

Parastenocaris altitudinis sp. nov. is characterized by the lack of the P4 endopod in males; this apomorphy is shared with other species from Sardinia (*P. tyrrhenidis* Cottarelli, 1970; *P. amatheia* Cottarelli, 1970; *P. cf. tyrrhenidis*, see below), the French Pyrenees (*P. diana*e Chappuis, 1955), and northern Portugal (*P. mateusi* Noodt & Galhano, 1969). Noodt & Galhano (1969) stated that the last two species could be included in a new species group, which they suggested to call *diana*e, but which was never formally defined. However, the following characterizing features

were identified (Noodt & Galhano, 1969): (1) lack of male P4 endopod; (2) caudal rami strongly developed; (3) P5 similar in both sexes.

Noodt & Galhano (1969) observed the *dianae*-group would be very close to the *clujensis*-group established by Lang (1948), represented by *P. clujensis* Chappuis, 1925 and *P. glareola* Herzog, 1936. These two species lack the male P4 endopod, but as already observed by Noodt & Galhano (1969), the loss of the P4 endopod might have occurred independently and at different times in the two species, “dans plusieurs lignées de la famille” (Rouch, 1988).

The four species from Sardinia could be included in the *dianae*-group as well, though they differ from *P. dianae* and *P. mateusi* by the morphology and ornamentation of the male P3 and P5. Unfortunately, the description of *P. dianae* and part of that of *P. mateusi* lack several details, thus the definition of the *dianae*-group cannot be accomplished unless new material of *P. dianae* will be collected and studied.

However, the four Sardinian species constitute a quite homogeneous and clearly characterized group; their distribution and affinities with *P. dianae* and particularly with *P. mateusi* could have great biogeographical significance. In fact, their distribution, which includes the northern Portugal mountain ranges, the Pyrenees, and Sardinia, has been reported for several invertebrate taxa (Fochetti, 1994; Ketmaier et al., 2003), and corresponds to tectonic events that occurred in the Early Miocene, 13 MyA, leading to the fragmentation of the Sardinian-Corsican microplate and the formation of the Western Mediterranean Basin (Alvarez et al., 1974; Bernini & Avanzati, 1980). This scenario suggests vicariance events; but this hypothesis cannot be confirmed until the phylogenetic relationships of these species will have been more clearly assessed.

Parastenocaris altitudinis sp. nov. has the strongest affinities with *P. tyrrhenidis* (see also Cottarelli & Torrisi, 1977). The re-examination of topotypes of *P. tyrrhenidis* and of specimens recently collected from Bassacutena Creek (Sassari province, Sardinia) allowed a more detailed comparison among the species. The two species have similarities in the following features: (1) similar ornamentation and morphology of the caudal rami in both sexes (although the caudal rami are longer with sub-parallel margins in the new species and cone-shaped in *P. tyrrhenidis*); (2) maxilla with the same setal ornamentation, the endopod is present, although reduced to a well-recognizable tubercle in *P. tyrrhenidis*, but lacking in *P. altitudinis* sp. nov.; (3) P2 of both sexes and female P3 of a similar shape (whereas the male P3 are longer and thinner in *P. altitudinis* sp. nov.); (4) similar P5 of both sexes (except for the morphology of the armature elements on the distal margin, which carries three setae in *P. tyrrhenidis* and two subequal setae and one small spiniform process in *P. altitudinis* sp. nov.); (5) cephalothoracic and dorsal

integumental windows of similar number and shape, although proportionally smaller in *P. tyrrhenidis*.

A remarkable difference between the two species is represented by the female P4 endopod, which is long and pointed with three basal spines in *P. tyrrhenidis*, and short and without basal ornamentation in *P. altitudinis* sp. nov.

Parastenocaris altitudinis sp. nov. and *P. amatheia* have a similar morphology and ornamentation of P2 in both sexes, of the female P4 endopod, and of the male P5. The two species differ in the morphology of the P1-P4 exopods in both sexes (longer and thinner in *P. amatheia*); in the ornamentation of the caudal rami of both sexes; and in the armature of male P3 and female P5. Differences in the morphology of the cephalothoracic and dorsal integumental windows are not detectable because the specimens of *P. amatheia* in our collection have become very diaphanous, making those structures, if present, no longer observable.

The affinities of *P. altitudinis* sp. nov. and *P. mateusi* are indicated by the similar morphology of cephalothoracic and dorsal integumental windows, size and ornamentation of the caudal rami, and the P2 endopod in both sexes, the female P3 endopod, and the male A1. Regarding the male antennule, a further affinity is shown by the sensillum on the fifth segment, which is larger in the male than in the female in both species.

There are fewer recognizable affinities between the new species and *P. diana*e, e.g., the shape of the anal operculum and the size and ornamentation of the caudal rami in both sexes. The peculiar morphology of the male P5 of *P. diana*e discriminates well between the two species.

We analysed the structure and ornamentation of the male A1 in *P. altitudinis* sp. nov., *P. tyrrhenidis*, and *P. amatheia* in detail: they share an eighth-segmented A1, with the fourth segment represented by a small, U-shaped sclerite; the fifth and seventh segments are similar as well, the fifth segment having a triangular apophysis, the seventh segment a characteristic, bilobate apophysis, and an aesthetasc on the fifth segment larger in males than in females.

The P1 basis in males of *P. tyrrhenidis* and *P. amatheia* has a medial seta (shorter and thinner in *P. amatheia*), which was not reported in the original description and subsequent ones (Cottarelli, 1970, 1971); this seta differs from the spine of *P. altitudinis* sp. nov., which has an additional row of spinules. Females of the three species have similar setae on the P1 basis, and a similar shape and location of the genital field in the genital somite.

It is worth noticing that *P. corsica* Cottarelli, Bruno & Berera, 2000, described from Corsica, lacks the male P4 endopod as does *P. altitudinis* sp. nov., and the two species have similar P2 endopods, P5, and caudal rami in both sexes, and a similar P3 endopod in females. In *P. corsica*, however, the female P4 lacks the endopod, and this feature, very rare in *Parastenocaris* (see Rouch, 1988; Cottarelli

et al., 2000; Apostolov, 2005), assigns this species to a different, although closely related, phylogenetic lineage than that of the other above-discussed species of *Parastenocaris*.

Parastenocaris luciae sp. nov. can be distinguished from the other eight species attributed so far to the *hera* species-group as defined by Berera & Cottarelli (2003) (i.e. *P. andalusica* Enckell, 1965; *P. hera* Cottarelli, 1969; *P. admete* Cottarelli, 1980; *P. stellae* Cottarelli, Saporito & Puccetti, 1981; *P. oligoalina* Cottarelli, Bruno & Venanzetti, 1994; *P. rivi* Cottarelli & Bruno, 1994; *P. etrusca* Cottarelli, Bruno & Venanzetti, 1995; *P. aphroditis* Cottarelli & Bruno, 1997; *P. sibaritica* Berera & Cottarelli, 2003) by the unusually large size of the maxillar endopodite, the pitted body surface (a feature never recorded for any Italian *Parastenocaris*, but, very interestingly, reported for species living in the tropics such as *P. lyncaea* Cottarelli & Bruno, 1994 from Sierra Leone (Cottarelli & Bruno, 1994b), as well as for members of other genera of the family) and the presence of one seta on the sixth segment of the male A1 and on the fifth segment of the female A1 (a rare feature in *Parastenocaris*, see below). All the other features of *P. luciae* sp. nov. are those typical of the *hera*-group, as defined by Berera & Cottarelli (2003): (1) P5 represented by a rectangular or trapezoidal plate, always longer in females than in males, prolonged into a distal inner spiniform process; (2) caudal rami cylindrical, shorter than last abdominal somite, with the three anterolateral setae on the distal third of the caudal rami; (3) dorsal integumental windows on cephalothorax and urosomites; (4) male A1 eight-segmented, seventh segment lengthened into a curved tip; (5) male P1 basis with hook and seta near endopod insertion; (6) male P3 exp-1 with one or two groups of outer spines, ending in leaf-like apophysis slightly shorter than exp-2; endopod represented by thin seta; (7) male P4 endopod ending in narrow lamina with acute tip.

All the species of *Parastenocaris* belonging to this group have a similar morphology represented by the features listed above, and they also share some less-commonly used features, that are valuable to distinguish and characterize the species within the group. In males, the morphology and ornamentation of P3 (with two groups of spines on exp-1), the P4 endopod (with two sharp, opposing processes on the proximal part and three curved spines near the insertion of the endopod), and the P5 (carrying a medial distal spine), allow us to define this species as close to *P. stellae* and *P. rivi*, both species collected from rivermouths in Sardinia. *Parastenocaris aphroditis* Cottarelli & Bruno, 1997 from Greece has two groups of, respectively, one and four spines on the P3 exp-1 as has *P. luciae* sp. nov., but differs from the latter in numerous other features (such as the morphology and ornamentation of the caudal rami and P5 of both sexes, the P4 endopod of males, and the medial ornamentation of the P1 basis in both sexes). For females,

the strongest affinities are with *P. sibaritica*, a species collected at the mouth of the Crati River in Calabria (southern Italy), in the morphology of the P4 endopod (a cylindrical segment with one apical seta) and P3 endopod (a long and pointed process without ornamentation, longer than the corresponding exp-1). The P5 of *P. altitudinis* sp. nov. carries only setae as in *P. rivi*.

The peculiarly large size of the maxillar endopod of *P. luciae* sp. nov. allows us to distinguish three phylogenetically informative conditions in the *hera* group: (1) maxillar endopod reduced to a very small tubercle, shorter than the proximal endite, and carrying only one seta, reported for *P. hera* and *P. stellae*. This is the most apomorphic state (Huys & Boxshall, 1991) involving the reduction of segmentation and ornamentation of the mouthparts; (2) maxillar endopod reduced to a tubercle carrying two setae: this is probably an intermediate apomorphic status, and it is common in the *hera*-group, being reported for *P. oligoalina*, *P. etrusca*, *P. rivi*, *P. aphroditis*, and *P. sibaritica*; (3) maxillar endopod not reduced, longer than the proximal endite, with two setae: this plesiomorphic state is present only in *P. luciae* sp. nov.

Parastenocaris hera, a widespread species in estuarine habitats in central and southern Italy, has further apomorphies of the mx2 as a whole, in that the proximal endite is lacking, and the distal endite carries only two non-transformed setae. The proximal endite is also lacking, but the endopod is still present, although reduced in *P. oligoalina*, in which the remaining distal endite has two setae, one of which is transformed (leaf-like). The most transformed condition of the second maxilla among the Italian species of *Parastenocaris* is recorded for *P. triphyda* Cottarelli & Bruno 1993, a stygobiotic species from Sardinia so far included in the *minuta*-group of Lang (1948), a species group requiring revision, but phylogenetically close to the *hera* group (Berera & Cottarelli, 2003). In *P. triphyda*, the endopod is reduced to a very small tubercle with one seta and there is only one small endite with one seta. Another species of the *minuta*-group, *P. silvana* from Corsica, has only one distal endite but with two setae, one of which is transformed, and the endopod is represented by a small tubercle with two setae.

Different transformations and reductions of the second maxilla occur in species of other groups. In *Parastenocaris ima* Cottarelli, 1989, a species of the *proserpina*-group (Kunz, 1938), collected in a deep phreatic habitat of Maddalena Island (Sardinia), the endopod is reduced to a small tubercle with one seta, the proximal endite is represented by one seta, and the distal endite is short and carries two non-transformed setae. In *Parastenocaris* cf. *glacialis* (Cottarelli et al., 2007) the proximal endite is lacking, the distal one carries two setae, one of which transformed, and the small endopod carries one seta. In *P. altitudinis* sp. nov. the endopod is lacking but the two setae maintain the ancestral topology of the endopod.

These observations show that the morphology and armature of the second maxilla, often lacking in species descriptions, is diversified within the same species-group and among groups. These micro-characters will have to be carefully taken into account in assessing phylogenetic lineages within *Parastenocaris* sensu lato.

ACKNOWLEDGEMENT

We are very grateful to the anonymous referee who greatly improved the manuscript, and to Dr. Roberta Raschioni (Tuscia University) for collecting the material of *Parastenocaris luciae* sp. nov. This research was partly granted by the Italian “Ministero dell’Università e della Ricerca” ex-60% funds to Vezio Cottarelli.

REFERENCES

- ALVAREZ, W., T. COCOZZA & F. C. WEZEL, 1974. Fragmentation of the Alpine orogenic belt by microplate dispersal. *Nature*, London, **248**: 309-314.
- APOSTOLOV, A., 2005. Stygobiotic harpacticoid copepods of France. 7. Description of two new copepods of the genus *Parastenocaris* Kessler, 1913. *Crustaceana*, **78**: 95-111.
- BERERA, R. & V. COTTARELLI, 2003. Two new species of interstitial harpacticoids from southern Italy and proposal of a new *Parastenocaris* species-group. *Italian Journ. Zool.*, **70**: 261-268.
- BERERA, R., V. COTTARELLI & M. C. BRUNO, 2001. *Ichnusella improvisa* sp. nov. from subterranean waters of Sardinia (Italy) and remarks on *Itunella intermedia* and *Itunella muelleri* (Copepoda, Harpacticoida). *Italian Journ. Zool.*, **68**: 327-334.
- BERNINI, F. & A. AVANZATI, 1980. Notulae chernetologicae XII – Le Oribatelidae (Acaridae, Oribatia) viventi sul massiccio sardo-corso. Il popolamento animale e vegetale della Sardegna. *Lav. Soc. Italiana Biogeogr.*, (n. ser.) **8**: 347-399.
- BRUNO, M. C., V. COTTARELLI & R. BERERA, 1998. Preliminary remarks on the cladistic systematics in some taxa of Leptopontidae and Parastenocarididae (Copepoda, Harpacticoida). *Mem. Mus. civ. St. nat. Verona*, (2) **13**: 69-79.
- CHAPPUIS, P. A., 1940. Die Harpacticoiden des Grundwassers des unteren Maintales. *Arch. Hydrobiol.*, **36**: 286-305.
- COTTARELLI, V., 1969. Una nuova *Parastenocaris* di Sardegna (Crustacea, Copepoda, Harpacticoida). *Istituto Lombardo, (Rend. Sc.) (B)* **103**: 255-268.
- , 1970. *Parastenocaris tyrrhenidis* n. sp., nuovo arpacticide interstiziale di Sardegna (Crustacea, Copepoda). *Fragm. Entomol.*, **7**: 61-71.
- , 1971. Una nuova *Parastenocaris* (Crustacea, Copepoda) della falda iporreica del fiume Liscia (Sardegna). *Riv. Idrobiol.*, **9**: 93-107.
- COTTARELLI, V., R. BERERA & B. MAIOLINI, 2002. Annotazioni faunistiche ed ecologiche su Copepodi di alta e media quota di sorgenti e corsi d’acqua alpini, appenninici e sardi. *Studi Trentino Sci. nat., (Acta Biologica)* **78**: 25-30.
- COTTARELLI, V. & M. C. BRUNO, 1994a. *Parastenocaris rivi* n. sp. di acque iporreiche dell’isola di S. Pietro (Sardegna). [Crustacea, Copepoda, Harpacticoida]. In: *Ricerche zoologiche della nave oceanografica ‘Minerva’ (C.N.R.) sulle isola circumsarde. XXI. Annali Mus. civ. St. nat. G. Doria, Genova*, **90**: 509-519.

- — & — —, 1994b. *Parastenocaris lyncaea* n. sp. and *Stygoelaphoidella africana* n. sp. (Crustacea, Copepoda, Harpacticoida) from interstitial continental waters of Sierra Leone. *Quad. Acc. naz. Lincei*, **267**: 97-109.
- COTTARELLI, V., M. C. BRUNO & R. BERERA, 1999. Remarks on the genus *Ichmusella* (Crustacea, Copepoda, Harpacticoida) and description of two species from subterranean freshwater habitats in Latium and Sardinia, Italy. *Vie Milieu*, **49**: 129-143.
- —, — — & — —, 2000. *Parastenocaris corsica* sp. nov. and *Parastenocaris silvana* sp. nov., first Parastenocarididae from groundwater of Corsica (Copepoda, Harpacticoida). *Crustaceana*, **73**: 345-364.
- —, — — & — —, 2007. Interstitial harpacticoids from Tuscany (central Italy) groundwater: *Parastenocaris reidae* sp. nov., *Nitocrella ensifera* sp. nov., and notes on the morphology of *Parastenocaris* cf. *glacialis* Noodt (Crustacea: Copepoda). *Italian. Journ. Zool.*, **74**: 83-99.
- COTTARELLI, V., M. C. BRUNO & C. FORNIZ, 1996. Copepodi Arpacticoidi e Sincaridi (Crustacea) di acque sotterranee delle isola circumsarde. *Biogeographia*, **18**: 261-272.
- COTTARELLI, V., M. C. BRUNO & F. VENANZETTI, 1995. Two new species of *Parastenocaris* from the interstitial waters of rivermouths in Latium and Sardinia (Crustacea, Copepoda, Harpacticoida). *Fragm. Entomol.*, **26**: 229-247.
- COTTARELLI, V. & M. R. TORRISI, 1977. Su alcune *Parastenocaris* di acque interstiziale sarde (Crustacea, Copepoda, Harpacticoida). *Fragm. Entomol.*, **13**: 284-297.
- DELAMARE DEBOUTTEVILLE, C., 1960. *Biologie des eaux souterraines littorales et continentales*: 1-740. (Hermann, Paris).
- FOCHETTI, R., 1994. Biochemical systematics and biogeographical patterns of the Italian and Corsican species of the *Protonemura corsicana* species group. *Aquat. Insect.*, **16**: 1-15.
- GALASSI, D. M. P. & P. DE LAURENTIIS, 2004. Towards a revision of the genus *Parastenocaris* Kessler, 1913: establishment of *Simplicaris* gen. nov. from groundwater in central Italy and review of the *P. brevipes*-group (Copepoda, Harpacticoida, Parastenocarididae). *Zool. Journ. Linn. Soc., London*, **140**: 417-436.
- HUYS, R. & G. A. BOXSHALL, 1991. Copepod evolution: 1-468. (The Ray Society, London).
- KESSLER, E., 1913. *Parastenocaris brevipes* nov. gen. et nov. spec., ein neuer Süßwasser harpacticide. *Zool. Anz.*, **42**: 514-520.
- KETMAIER, V., R. ARGANO & A. CACCONE, 2003. Phylogeography and molecular rates of subterranean aquatic stenaseiid isopods with a peri-Tyrrhenian distribution. *Mol. Ecol.*, **12**: 547-555.
- KUNZ, H., 1938. Harpacticoiden vom Sandstrande der Kurischen Nehrung (Studien an marinen Copepoden, III). *Kieler Meeresf.*, **3**: 148-157.
- LANG, K., 1948. *Monographie der Harpacticiden*, **1, 2**: 1-1682. (Nordiska Bokhandeln, Stockholm).
- NOODT, W. & M. H. GALHANO, 1969. Studien an Crustacea subterranea (Isopoda, Syncarida, Copepoda) aus dem Norden Portugals. *Publ. Inst. Zool. A. Nobre*, **107**: 1-75.
- PESCE, G. L., D. M. P. GALASSI & V. COTTARELLI, 1988. First representative of the family Parastenocarididae from Sicily (Italy), and description of two new species of *Parastenocaris* Kessler (Crustacea: Copepoda: Harpacticoida). *Bull. Zool. Mus. Univ. Amsterdam*, **11**: 137-141.
- REID, J. W., 1995. Redescription of *Parastenocaris brevipes* Kessler and description of a new species of *Parastenocaris* (Copepoda: Harpacticoida: Parastenocarididae) from the U.S.A. *Canadian Journ. Zool.*, **73**: 173-187.
- ROUCH, R., 1988. *Parastenocaris vandeli* n. sp., nouvel Copépode Harpacticide psammique des Pyrénées. *Crustaceana*, **54**: 163-170.

First received 7 June 2007.

Final version accepted 26 July 2007.