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Three new species of abdominal shrimp parasites (Crustacea: Isopoda: Bopyridae: Hemiarthrinae) from the Indo-West Pacific

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Abstract

Three new species of the parasitic isopod subfamily Hemiarthrinae Markham, 1972 are described. *Allodiplophryxus unilateralis* **n. sp.** is described from Western Australia, infesting the palaemonid shrimp *Jocaste lucina* (Nobili, 1901), and females differ from the only other species in the genus in possessing six pleomeres, an asymmetrical first oostegite and pleopods restricted to the short side of the body. *Loki athanus* **n. sp.** is described from Madagascar, infesting the alpheid shrimp *Athanas parvus* de Man, 1910, and females differ from the only other species in the genus in possessing well-developed lateral plates on pleomere 4 and four pairs of uniramous pleopods. *Hemiarthrus alphei* **n. sp.** is described from French Polynesia, infesting the alpheid shrimp A*lpheus crinitus* Dana, 1852, and females differ from the four other known *Hemiarthrus* species in having pleomeres with well-developed, symmetrical lateral plates, a barbula with three pairs of projections and a pointed pleotelson. Keys to species of *Hemiarthrus* and all genera of the Hemiarthrinae are presented.

Key words: *Allodiplophryxus*, Bopyridae, Caridea, coral reefs, Hemiarthrinae, *Hemiarthrus*, Isopoda, *Loki*, parasite

Introduction

The 28 genera that constitute the bopyrid subfamily Hemiarthrinae all parasitize caridean shrimp, and most are attached near the anterior of the ventral surface of the abdomen (Markham 1985; Boyko *et al*. 2008; Williams & Boyko 2012). Species in five genera attach elsewhere: *Anomophryxus* Shiino, 1937 to the ventral margin of the fifth abdominal segment (Shiino 1937), *Metaphrixus* Nierstrasz and Brander à Brandis, 1931 to the dorsolateral surface of the first abdominal segment (Bruce 1965), *Filophryxus* Bruce, 1972 to the dorsal midline of the fourth abdominal segment (Bruce 1972b), *Orophryxus* Bruce, 1972 to the buccal (beneath the pterygostomial) region of the host (Bruce 1972a), while *Sigyn* An, Boyko & Li, 2015 occupies the branchial chamber of the host (An *et al*. 2015).

Hemiarthrinae was erected to replace Phryxidae Bonnier, 1900 based on *Phryxus* Rathke, 1843 (non *Phryxus* Rafinesque, 1815 (Hemiptera); =*Hemiarthrus* Giard & Bonnier, 1887), and Phrixinae Caroli, 1949, based on *Phrixus* Caroli, 1930 (incorrect spelling); see Markham (1972) for a detailed discussion.

Giard and Bonnier (1887) erected *Hemiarthrus* for *Bopyrus abdominalis*, noting that it did not fit in *Phryxus*, where it was previously placed. This was the result of some confusion, because the type of *Phryxus* (*Phryxus hippolytes* Rathke, 1843), was a subjective synonym of the type of *Hemiarthrus* (*Bopyrus abdominalis*). Soon Bonnier (1900) reverted to using *Phryxus* for this group. Caroli (1930) divided *Phryxus* into several subgenera which were later raised to generic rank by Nierstrasz and Brander à Brandis (1931). Markham (1985) recognized three species in *Hemiarthrus*: *H. abdominalis* (Krøyer, 1840), *H. nematocarcini* Stebbing, 1914 and *H. synalphei* (Pearse, 1950). Boyko and Williams (2004) described a fourth, *Hemiarthrus surculus*, from the Bahamas. At present these four species are known from the North Atlantic, North Pacific, and South Africa.

Markham (1985) erected *Allodiplophryxus* for *A. floridanus*, parasitizing *Urocaris longicaudata* Stimpson, 1860 (as *Periclimenes longicaudatus*) from Florida. Markham (1972) erected *Loki*, for *Loki circumsaltanus* Markham,

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1972, parasitizing *Thor floridanus* Kingsley, 1978, also from Florida. Both genera have remained monotypic to date.

Up to now 23 genera and 39 species of Hemiarthrinae have been recorded from the Indo-West Pacific. Here we describe three new species of hemiarthrines from the collections of the Florida Museum of Natural History, University of Florida. These species extend the range of *Hemiarthrus*, *Loki,* and *Allodiplophryxus* to the Indo-West Pacific. A key to the five species of *Hemiarthrus* is given, and a comprehensive key to all genera of Hemiarthrinae is also presented.

Key to 28 genera of subfamily Hemiarthrinae Markham, 1972 (based on females)

1	Pleon without appendages	*Orophryxus* Bruce, 1972a
-	Pleon with appendages	2
2	Pleon without lateral plates	3
-	Pleon with lateral plates	7
3	With sucker-like organ on the dorsum of the cephalon	*Neophryxus* Bruce, 2007
-	Without sucker-like organ on the dorsum of the cephalon	4
4	Pereomere 1–6 with elongated, filiform coxal plates	*Filophryxus* Bruce, 1972b
-	Pereomeres without any coxal plates	5
5	With four pairs of biramous pleopods	6
-	With four pairs of uniramous pleopods	*Anomophryxus* Shiino, 1937
6	With globose uropods	*Epiphrixus* Nierstraz & Brender à Brandis, 1932
-	Without uropods	*Hemiphryxus* Bruce, 1978
7	With biramous lateral plates	8
-	With uniramous lateral plates	11
8	With two pereopods on convex side of the body	*Allodiplophryxus* Markham, 1985
-	With more than two pereopods on convex side of the body	9
9	With seven pereopods on convex side of the body	*Cataphryxus* Shiino, 1936
-	With three or four pereopods on convex side of the body	10
10	With three pereopods on convex side of the body	*Diplophryxus* Richardson, 1904
-	With four pereopods on convex side of the body	*Micropodiphryxus* Boyko, 2012
11	Pereon with prominent coxal plates	*Izuohshimaphryxus* Saito, 2015
-	Pereon without coxal plates	12
12	With seven pereopods on convex side of the body	13
-	With fewer than seven pereopods on convex side of the body	16
13	Pleon with four segments	*Apophrixus* Nierstraz & Brender à Brandis, 1931
-	Pleon with five segments	14
14	With four pairs of biramous pleopods	*Eophrixus* Caroli, 1930
-	Without biramous pleopods	15
15	With four pairs of uniramous pleopods	*Sigyn* An, Boyko & Li, 2015
-	With three pairs of uniramous pleopods	*Loki* Markham, 1972
16	With four pereopods on convex side of the body	17
-	With fewer than four pereopods on convex side of the body	19
17	With three pairs of uniramous pleopods, without uropods	*Mesophryxus* Bruce, 1973
-	With four pairs of uniramous pleopods, with uropods	18
18.	Pleon with five segments	*Eriphrixus* Markham, 1990
-	Pleon with four segments	*Pliophrixus* Caroli, 1930
19	With three pereopods on convex side of the body	20
-	With fewer than three pereopods on convex side of the body	21
20	Second oostegite on long side arching over to dorsal surface	*Mediophrixus* Markham, 1990
-	Second oostegite on long side not arching over to dorsal surface	*Dicropleon* Markham, 1972
21	With two pereopods on convex side of the body	22
-	With one pereopod on convex side of the body	26
22	Pleon with five pleomeres	23
-	Pleon with three pleomeres	25
23	With four pairs of uniramous pleopods	24
-	With four pairs of biramous pleopods	*Hyperphrixus* Nierstraz & Brender à Brandis, 1931
24	Attached dorsolaterally on host, pleomeres distinct dorsally	*Metaphrixus* Nierstraz & Brender à Brandis, 1931
-	Attached ventrally on host, pleomeres fused dorsally	*Anisarthrus* Giard, 1907
25	With three pairs of uniramous pleopods, plus uropods	*Miophrixus* Barnard, 1955
-	With three pairs of biramous pleopods, without uropods	*Anchiarthrus* Markham, 1992
26	With three pairs of biramous pleopods, plus uropods	*Hypohyperphrixus* Nierstraz & Brender à Brandis, 1932

- With four pairs of uniramous pleopods, without uropods 27
27 Pleon of five segments, with lateral plates of same size . . . . . *Hemiarthrus* Giard & Bonnier, 1887
- Pleon of four segments, with lateral plates of first three pleomeres small, but very large on fourth . . . . . *Azygopleon* Markham, 1985

Material and methods

Materials examined were deposited in the Florida Museum of Natural History, University of Florida (UF); the Australian types were transferred to the Western Australian Museum (WAM). Specimens were viewed and drawn using a Nikon 1500 dissecting microscope, figures were scanned using Canon Scan 9900F, and edited using Adobe Photoshop CS6. Final line drawings were created by tracing with a drawing tablet using Adobe Illustrator. References are provided for the authors of epicaridean taxa, but not of hosts.

Results

Systematics

Order ISOPODA Latreille, 1817

Family BOPYRIDAE Rafinesque, 1815

Subfamily Hemiarthrinae Markham, 1972

Genus *Allodiplophryxus* Markham, 1985

Type species: *Allodiplophryxus floridanus* Markham, 1985 by original designation

Allodiplophryxus unilateralis n. sp.

Fig. 1

Material examined. *Holotype* female, ovigerous, 1.53 mm (maximum length, from anterior end of head to uropods), *paratype* male, 0.94 mm, WAM C75202 & C75203 (ex UF Arthropoda 23161), Australia, Western Australia, Ningaloo Reef, S shallow bommies, back reef, patchy corals on sand, in rubble 2–3 meters snorkel, by hand, 22.7415°S, 113.6836°E, coll., Robert Lasley, 15 May 2009. Infesting *Jocaste lucina* (Nobili, 1901) WAM C75204 (ex UF Arthropoda 21490).

Description. *Holotype female* (WAM C75202) length 1.53 mm, pleonal length 0.67 mm. Body outline oval, sinistrally distorted (Fig. 1A, B).

Head subovate, embedded in pereon, not visible in dorsal view, covered by oostegite 2. *Eyes* not discernible (Fig. 1A). *Antennulae* with two articles; antennae absent (Fig. 1C). *Right maxilliped* articulated, anterior article triangular, much large than posterior one, without palp, plectron short and blunt, (Fig. 1D). Anterior apex of *left maxilliped* rolled inward (Fig. 1E). *Barbula* (Fig. 1F) with 12 irregular marginal projections, as well as two pairs of short, blunt projections on raised layer.

Pereon with segments distinct on concave side only (Fig. 1A). Pereomere 2 ventrally produced into several irregular fleshy projections (Fig. 1B). First oostegite of two sides different, left (Fig. 1G) much wider than right (Fig. 1H, I); right with long, slender posterior part and internal ridge with two tubercles (Fig. 1H, I); left with broad posterior part and internal ridge nearly entire (Fig. 1H). *Five pereopods* discernible on short side, anterior two well developed, while posterior three small and clustered together. Three pereopods present on long side, first two well developed (Fig. 1J), third represented only by scar-like basis.

Pleon of six pleomeres, first four bearing biramous lateral plates (Fig. 1A), fifth with uniramous lateral plates, pleotelson small and globose, embedded into fifth pleomere (Fig. 1K). Biramous pleopods present on first four pleomeres only, restricted to short side (Fig. 1B).

Paratype male (UF 23161) length 0.94 mm, maximum width (across pereomere 4) 0.39 mm, head length 0.18 mm, head width 0.25 mm, pleonal length 0.18 mm. Black pigmentation on dorsal surface of first pereomere and head.

Head oblong; black eyes near lateral margin (Fig. 1L). Antennulae and antennae each with 3 articles (Fig. 1M, N).

Pereon segments distinct (Fig. 1L), with truncate margins and lacking midventral projections (Fig. 1M). First three pereopods with large dactyli, decreasing in size posteriorly, last four pereopods with smaller dactyli; all dactyli sharp and pointed (Fig. 1O, P). Carpi and meri of first pereopods larger than those of others (Fig. 1M, O, P).

Pleon fused into single piece, but with obscure indentation demarcating first pleomere; narrower than the last pereomere (Fig. 1M); with scattered black pigmentation on ventral surface. Pleopods and uropods absent.

Etymology. The specific name, *unilateralis*, refers to the restriction of pleopods to the short side of the body in the female.

Remarks. Species in four genera within the Hemiarthrinae have biramous lateral plates on the pleon: *Allodiplophryxus*, *Diplophryxus*, *Micropodiphryxus*, and *Cataphryxus*. The present specimens are placed in *Allodiplophryxus* because the female has biramous lateral plates and two prominent pereopods on the long side but five on the short side, and because the male has a fused pleon. The new species differs from the only congener, *A. floridanus* Markham, 1985, in the following characters of the female (character states in *A. floridanus* given in parentheses): 1) pleon with six segments (five segments); 2) first oostegite asymmetrical (symmetrical); 3) pleopods restricted to short side (pleopods on both sides). The new species extends the range of *Allodiplophryxus* from the West Atlantic to the Indo-West Pacific.

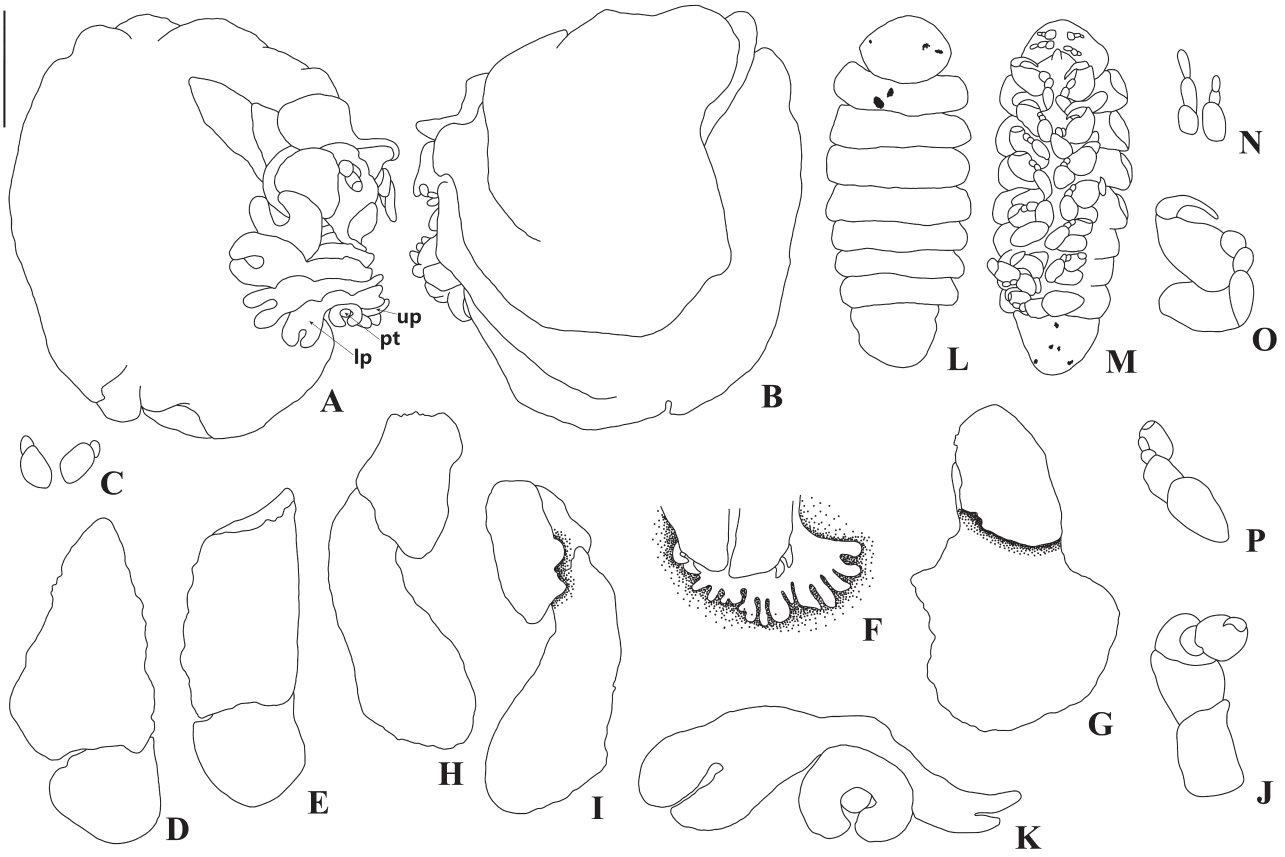

FIGURE 1. ***Allodiplophryxus unilateralis*** **n. sp.**, holotype female (UF 23161) (A–K), paratype male (UF 23161) (L–P): A, dorsal view (lp = lateral plates; pt = pleotelson; up = uniramous pleopod); B, ventral view; C, antennule; D, right maxilliped, external view; E, left maxilliped, internal view; F, maxilliped and barbula; G, left oostegite 1, internal view; H, right oostegite 1, external view; I, right oostegite 1, internal view; J, left pereopod 7; K, dorsal view of pleomeres 4–6; L, dorsal view; M, ventral view; N, right antennula and antenna; O, right pereopod 1; P, right pereopod 7. Scale bar: A, B = 1 mm; C, J = 0.21 mm; D, E, K–M = 0.31 mm; F, G–I = 0.63 mm; N–P = 0.13 mm.

Genus *Loki* Markham, 1972

Type species: *Loki circumsaltanus* Markham, 1972, by original designation

Loki athanus n. sp.

Figs 2, 3

Material examined. *Holotype* female, ovigerous, 1.06 mm, *paratype* male, 0.5 mm, UF Arthropoda 18690, Madagascar, Nosy Be, across bay from CNRO complex, off Lokobe Reserve, 1–3 meters, 13.4139°S, 48.3056°E, coll. G. Bakary, H. Bruggemann, F. Michonneau, G. Paulay, and T. Werner, 16 May 2008. Infesting *Athanas parvus* de Man 1910 (UF Arthropoda 14367) (Fig. 2).

FIGURE 2. *Athanas parvus* (UF 14367) with type of *Loki athanus* **n. sp.** (UF 18690) attached; image of live specimens.

Description. *Holotype female* (UF 18690) length 1.06 mm, head length 0.29 mm, head width 0.35 mm, pleonal length 0.40 mm (Fig. 3A).

Head subquadrate, white, with black *eyes* near anterior margin. *Antennulae* with two articles, antennae with three articles, without setae (Fig. 3B). *Barbula* with one falcate lateral projection on each side (Fig. 3C). *Maxilliped* without palp, and with short, blunt plectron (Fig. 3D).

Pereon yellow. First three pereomeres merged into ring encircling the head. Other pereomeres distinct on short side of the body but fused on long side (Fig. 3A). Brood pouch pigmented, swollen, full of eggs, covering entire ventral surface of head and pereon. First oostegite with unadorned internal ridge, with broad notch along posterior margin (Fig. 3E). All *pereopods* of similar size and shape (Fig. 3F), with stout ischia and short, blunt dactyli. First two pairs of pereopods clustered near head; other five on short side in line along pereon, while on long side pereopod 3 is near middle of brood pouch, 4, 5 near posterolateral border of brood pouch, and 6, 7 near posterior end of brood pouch.

Pleon of five pleomeres (Fig. 3A), first four produced into uniramous lateral plates, with uniramous pleopods, fifth without lateral plates, with divergent pair of uniramous uropods.

Paratype male (UF 18690) length 0.5 mm, maximum width (across pereomere 1) 0.19 mm, head length 0.09 mm, head width 0.15 mm, pleonal length 0.12 mm (Fig. 3G, H).

Head semicircular, with large black eyes near posterolateral margin (Fig. 3G). Antennae visible from dorsal view, antennulae and antennae with 3 and 5 articles respectively, terminal articles setose (Fig. 3I).

Pereon with first segment fused with head, two to seven distinct laterally, but slightly fused near midline (Fig. 3G); with curved margins; first segment widest. Pair of pigmented lines extending from third to seventh pereomere (Fig. 3G). All pereopods with short dactyli; first two pereopods slightly larger than others, but similar in structure (Fig. 3J, K).

Pleon fused into triangular piece, narrower than last pereomere (Fig. 3G, H). Pleopods and uropods absent.

Etymology. The specific name, *athanus*, refers to the host genus.

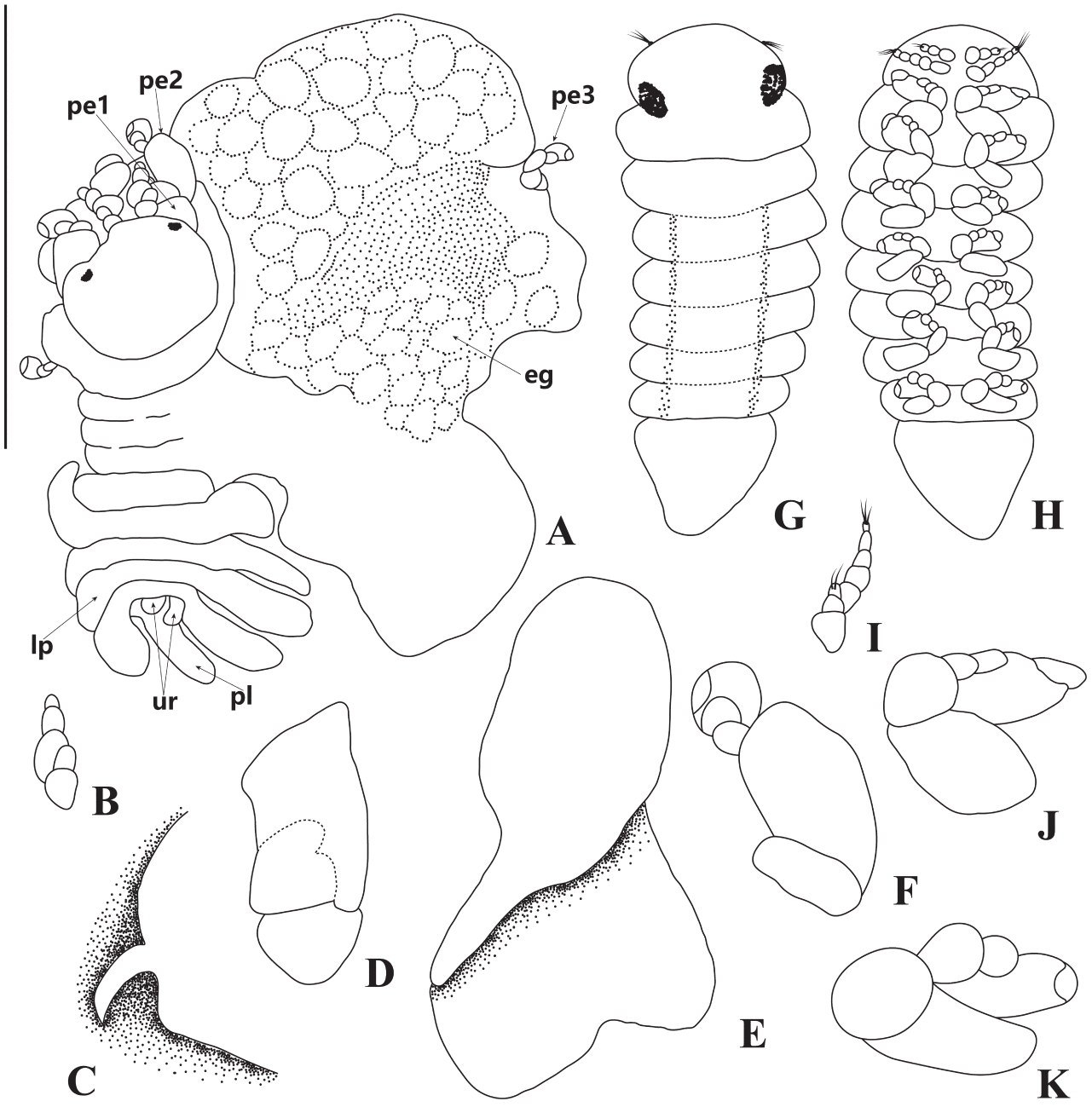

FIGURE 3. ***Loki athanus*** **n.sp.**, holotype female (UF18690) (A–F), paratype male (UF18690) (G–K): A, dorsal view (lp = lateral plates; ur = uropods; pl = pleopod; pe1 = pereopod 1; pe2 = pereopod 2; pe3 = pereopod 3; eg = eggs); B, right antennula and antennae; C, right part of barbula; D, right maxilliped, external view; E, left oostegite 1, internal view; F, right pereopod 2; G, dorsal view; H, ventral view; I, right antennula and antenna; J, left pereopod 1; K, left pereopod 7. Scale bar: A = 1 mm; B, D–F = 0.63 mm; C, G, H= 0.44 mm; I–K=0.13 mm.

Remarks. The present specimens are placed in the previously monotypic genus *Loki* because the female has 7 pairs of pereopods which on the long side have the following position: first two clustered around the head, third near middle of brood pouch, last four clustered around posterior of brood pouch. It further matches *Loki* because the fifth

pleomere lacks lateral plates and has divergent uropods. The male fits *Loki* because it has a triangular pleon and the head is completely fused with the first pereomere. The new species differs from *L. circumsaltanus* Markham, 1972 in the following characters (character states in *L. circumsaltanus* given in parentheses): female with well-developed lateral plates on pleomere 4 (pleomere 4 with reduced lateral plates on short side, without lateral plates on long side) and with four pairs of uniramous pleopods (three pairs of uniramous pleopods); male with large black eyes (lacking eyes), and with pleon distinctly separated from pereomere 7 (pleon medially fused with pereomere 7). The new species extends the range of *Loki* from the west Atlantic to the Indo-West Pacific.

Genus *Hemiarthrus* Giard & Bonnier, 1887

Type species: *Hemiarthrus abdominalis* (Krøyer, 1840) by monotypy

Hemiarthrus alphei n. sp.

Figs 4, 5

Material examined. *Holotype* female, ovigerous, 1.97 mm, *paratype* male, 1.06 mm, UF Arthropoda 15685 (Fig. 4C, D), French Polynesia, Society Island, Moorea, N end of Temae, near lighthouse, outer reef slope, 29 meters, from within rubble, 17.479°S, 149.7643°W, coll. J. Poupin, 17 October, 2008. Infesting ovigerous *Alpheus crinitus* Dana, 1852 (species complex) UF Arthropoda 15684 (Fig. 4A, B).

Description. *Holotype female* (UF 15685) length 1.97 mm; head length 0.57 mm; head width 0.8 mm; pleon length 0.86 mm. Body extremely asymmetrical, 45°dextral distortion; no pigmentation (Fig. 5A).

Head oval, anterior margin deeply bilobate anteriorly, posterior margin rounded (Fig. 5A). *Eyes* absent. Both *antennulae* and *antennae* rudimentary, with one article, without setae (Fig. 5C). *Barbula* (Fig. 5D) with three slender falcate pointed lateral projections on each side. *Maxilliped* (Fig. 5E) with two segments, anterior segment subtriangular and much larger than irregularly-shaped posterior one, without palp, plectron slender.

Pereon broadest across seventh pereomere (Fig. 5A). Pereomeres 3–7 separated along middle region but fused along both sides. Coxal plates absent. Brood pouch enclosed by oostegites, open medially (Fig. 5B). First oostegites highly asymmetrical; left one (Fig. 5F, G) with two subequal articles, internal ridge entire, with blunt posterolateral point; right one (Fig. 5H, I) with anterior article approximately three times longer than posterior article, internal ridge entire, with sharp posterolateral point. Seven *pereopods* on right side of pereon, but only first pereopod discernible on left side. Pereopod with stout basis, small meri and carpi, short but pointed dactyli (Fig. 5J).

Pleon of five pleomeres, extending away from pereomere 7 in dorsal view (Fig. 5A). First four pleomeres with uniramous, symmetrical lateral plates and four pairs of similar, uniramous pleopods. Terminal pleomere extending to form rounded pleotelson, terminating in sharp point (Fig. 5B).

Paratype male (UF 15685) length 1.06 mm; maximum width (across pereomere 5) 0.39 mm; head length 0.15 mm; head width 0.20 mm, pleon length 0.31 mm. All pereomere regions distinct; pleon fused (Fig. 5K, L).

Head elliptical, with rounded anterior margin, posterior margin fused with first pereomere; irregular dark eyes near posterolateral corners (Fig. 5K). Antennulae and antennae with three and five articles respectively, terminally setose; antennae prominently extending beyond head, visible in dorsal view. (Fig. 5L, M).

Pereon with seven segments (Fig. 5K). Pereomeres 3–5 subequal in width, lacking midventral projections, with patches of pigmentation on pereomeres 4–5 (Fig. 5K). Pereopods subequal, except last pair slightly larger than others (Fig. 5L, N, O).

Pleon fused into single piece (Fig. 5L), inflated, with scattered black pigmentation on dorsal surface. Pleopods and uropods absent.

Etymology. The specific name, *alphei,* refers to the host genus, *Alpheus.*

Remarks. This new species is placed in *Hemiarthrus* because the female has 5 pleomeres, four pairs of uniramous lateral plates and uniramous pleopods, and only one pereopod on the long side. It can be distinguished from the other species of *Hemiarthrus* by the barbula of the female having three pairs of falcate pointed lateral projections, pleomeres having well-developed, symmetrical lateral plates, and the pleon ending in a sharp point. The present species is most similar to *H. synalphei*, but it can be distinguished from *H. synalphei* (character states in *H.*

synalphei given in parentheses) because the barbula of the female has three pairs of lateral projections (only two pairs); the pleotelson is short and oval (long and cylindrical); and the head of the male is fused with pereomere 1 (head separated from pereomere 1); it lacks sucker discs on the oostegite (with sucker discs on the oostegite).

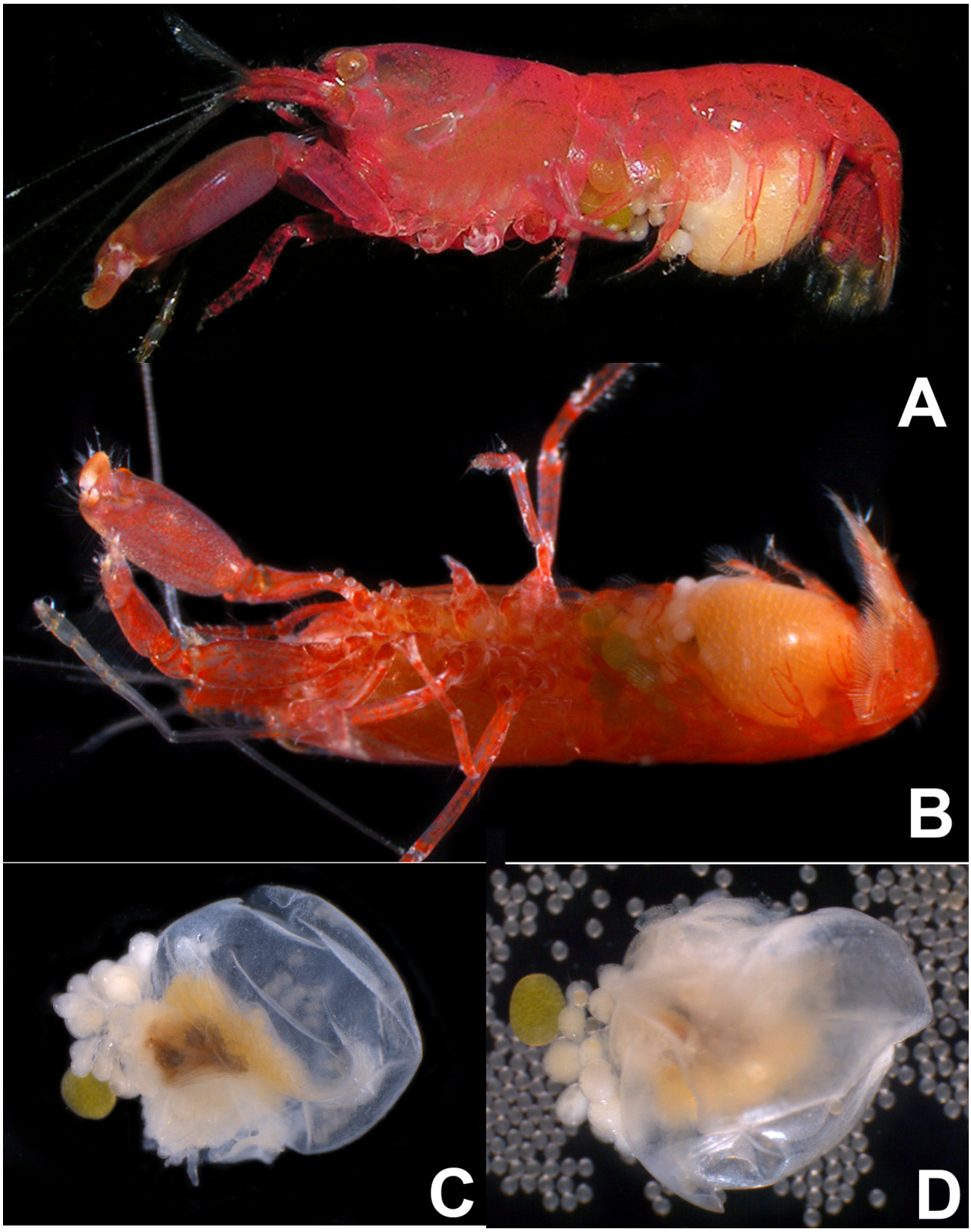

FIGURE 4. *Alpheus crinitus* (species complex) (UF 15684), with type of *Hemiarthrus alphei* **n. sp.** (UF 15685) attached; image of live specimens; host and parasite (A, B), parasite (C, D).

Hemiarthrus surculus, H. synalphei and *H. alphei* infest alpheid shrimp, *H. abdominalis* infests pandalid and hippolytid shrimp, while *H. nematocarcini* is parasitic on nematocarcinid shrimp. Chopra (1923) thought *Palaemon* specimens parasitized by bopyrids are difficult to identify owing to the fact that the parasite inhibits sexual activity and prevents the full manifestation of secondary sexual characters, and females never carry eggs. Rajkumar *et al*., (2011) found that infestation with *Epipenaeon ingens* had a significant effect on reproduction in *Metapenaeopsis stridulans*. But the host of *H. alphei* was ovigerous, suggesting that hosts can remain reproductive after bopyrid infestation.

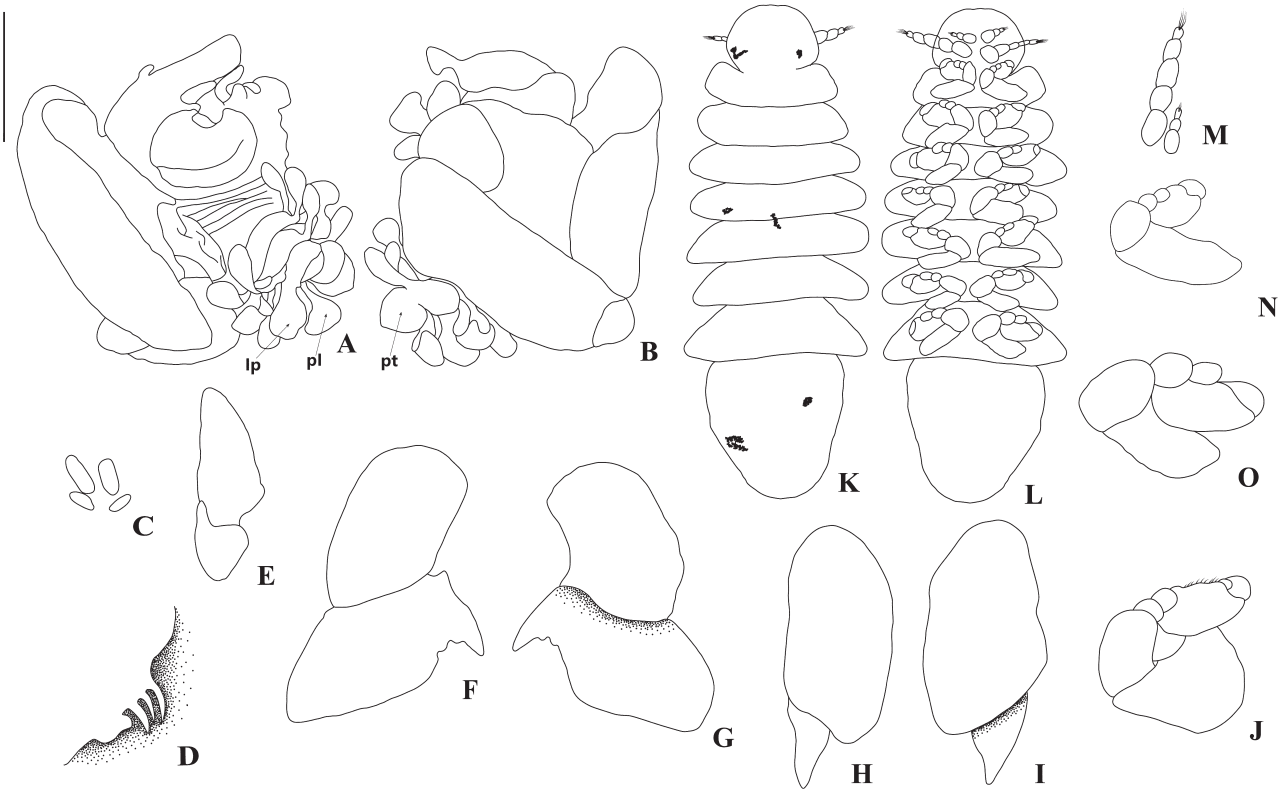

FIGURE 5. ***Hemiarthrus alphei*** **n. sp.**, holotype female (UF 15685) (A–J), paratype male (UF 15685) (K–O): A, dorsal view (lp = lateral plates; pl = pleopod; pt = pleotelson); B, ventral view; C, antennae; D, barbula, left side; E, left maxilliped, external view; F, left oostegite 1, external view; G, left oostegite 1, internal view; H, right oostegite 1, external view; I, right oostegite 1, internal view; J, right pereopod 2; K, dorsal view; L, ventral view; M, right antennula and antenna; N, left pereopod 1; O, left pereopod 7. Scale bar: A, B, D = 1 mm; E = 0.64 mm; F–I = 0.8 mm; C, J–L = 0.28 mm; M, N, O = 0.12 mm.

Key to 5 species of genus *Hemiarthrus* (based on females)

1	Pleon with bifurcated end	*H. abdominalis* (Krøyer, 1840)
-	Pleon ending in a single point	2
2	Pereomeres almost completely fused	*H. surculus* Boyko & Williams, 2004
-	Pereomeres separated	3
3	Barbula with three pairs of projections	*H. alphei* **n. sp.**
-	Barbula with fewer than three pairs of projections	4
4	Lateral plates of pleon with distal, hook-like projection	*H. nemaocarcini* Stebbing, 1914
-	Lateral plates of pleon entire, without any projections	*H. synalphei* (Pearse, 1950)

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