JOURNAL OF CRUSTACEAN BIOLOGY, 27(2): 319–326, 2007

TWO SPECIES OF POECILOSTOMATOID COPEPODS INHABITING GALLS ON SCLERACTINIAN CORALS IN OKINAWA, JAPAN

Il-Hoi Kim and Hideyuki Yamashiro

(I-HK, corresponding author: ihkim@kangnung.ac.kr) Department of Biology, Kangnung National University, Kangnung 210-702, South Korea;
(HY) Department of Tourism, Meio University, 1220-1 Biimata, Nago, Okinawa 905-8585, Japan;
Present address: Department of Bioresources Engineering, Okinawa National College of Technology, 905 Henoko, Nago, Okinawa 905-2192, Japan; (HY: coral@okinawa-ct.ac.jp)

ABSTRACT

Two species of the poecilostomatoid copepods, *Allopodion ryukyuensis* n. sp. and *Xenomolgus varius* Humes and Stock, are recorded from galls and crypts on the scleractinian corals *Montipora informis* and *Porites* sp.(p), respectively, in Okinawa, Japan. *Allopodion ryukyuensis* is distinguished from its sole congener, *A. mirum* Humes, by having shorter caudal rami and abdominal somites, rounded lateral margins of the female genital double-somite, and a greater number of setal elements on the third exopodal segment of legs 2-4. The morphological features of the galls and crypts on the scleractinian hosts inhabited by *A. ryukyuensis* and *X. varius* are described, and it is proposed that certain other scleractinian-associated copepods likely also make use of similar habitations.

Introduction

The cnidarians, in particular the hard corals, are one of the invertebrate groups most preferred as hosts by copepod associates (Humes, 1985, 1994). These copepods are generally known to live on or inside coral polyps. Unlike these, copepods inhabiting galls on hard corals have rarely been studied. Stock (1981) was the first to record copepods inhabiting in galls on hard corals (Dojiri, 1988). He described six species of siphonostomatoid copepods, five of them as new, inhabiting galls on the stylasterine hydrocoral genera *Stylaster*, *Conopora*, and *Crypthelia* from the South Pacific and Japan. Dojiri (1988) reported *Isomolgus desmotes*, as a new genus and species of poecilostomatoid copepod, from galls on the scleractinian coral *Seriatopora hystrix* Dana in Indonesia. Dojiri and Grygier (1990) described *Pionomolgus gallicolus*, also as a new genus and species, from galls on the scleractinian coral *Echinopora lamellosa* (Esper) collected at Lizard Island on the Great Barrier Reef, Australia, with additional records of dry galls in specimens of this coral from eastern and western Australia, Indonesia, and the Philippines.

One of us (HY) noticed the frequent occurrence of gall-like formations on certain scleractinian corals living around Okinawa, Japan, and also found copepods living in them. These copepods consisted of two species, çone of which turned out to be an undescribed species. The present paper deals with these two copepod species and their gall-like habitations.

Materials and Methods

Copepod specimens removed from the host were initially fixed with 10% formalin and then preserved in 80% ethanol. Before dissection and microscopic observation, the copepod specimens were immersed in lactic acid for several hours. Dissection was made using the reversed slide method (Humes and Gooding, 1964). All figures were drawn with the aid of a drawing tube attached to a light microscope.

For histological observation of the galls induced by *Allopodion ryukyuensis*, formalin-fixed samples of the coral *Montipora informis* were decalcified in a solution of 10% acetic acid and 10% formalin. Decalcified soft tissues were dehydrated in a graded series of butanol, embedded in paraffin, cut into 10 μm sections, stained with eosin/hematoxylin, and observed under a light microscope.

Systematics

Order Poecilostomatoida Thorell, 1859
Anchimolgidae Humes and Boxshall, 1996
Allopodion Humes, 1978
Allopodion ryukyuensis n. sp.
Figs. 1-4

Material Examined.—9 ♀♀ and 1 ♂ collected from galls on the scleractinian coral *Montipora informis* Bernard on a reef flat in front of Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus, Okinawa, Japan, by H. Yamashiro, 20 August 1999. The holotype (♀, USNM 1086636), allotype (♂, USNM 1086637), and paratypes (6 ♀♀, USNM 1086638) have been deposited in the National Museum of Natural History, Smithsonian Institution, Washington, D. C., United States. Dissected paratypes (2 ♀♀) are kept in the collection of the senior author.

Other Material Examined.—3 ♀♀ and 1 damaged ♂ (abdomen detached; dissected) collected from galls of *Montipora informis* at the type locality by H. Yamashiro, June 1998.

Female.—Body (Fig. 1A, B) with expanded prosome and narrower, strongly flexed urosome. Body length about 970 μm along middle axis in lateral view. Prosome 658 μm long and distinctly tapering posteriorly in dorsal and lateral views. Greatest width of prosome 409 μm. Greatest dorso-ventral depth of prosome 403 μm. Dorsal suture line faint between cephalosome and first pedigerous somite. Fifth pedigerous somite expanded laterally, 223 μm wide, much wider than next somite (Fig. 1C). Genital double-somite 123 × 133 μm, wider than long, with rounded lateral margins and shorter dorsal length and longer ventral length. Genital areas located dorsally in anterior one-third of double-somite. Three free abdominal somites (Fig. 1D) 54 × 84, 56 × 84,

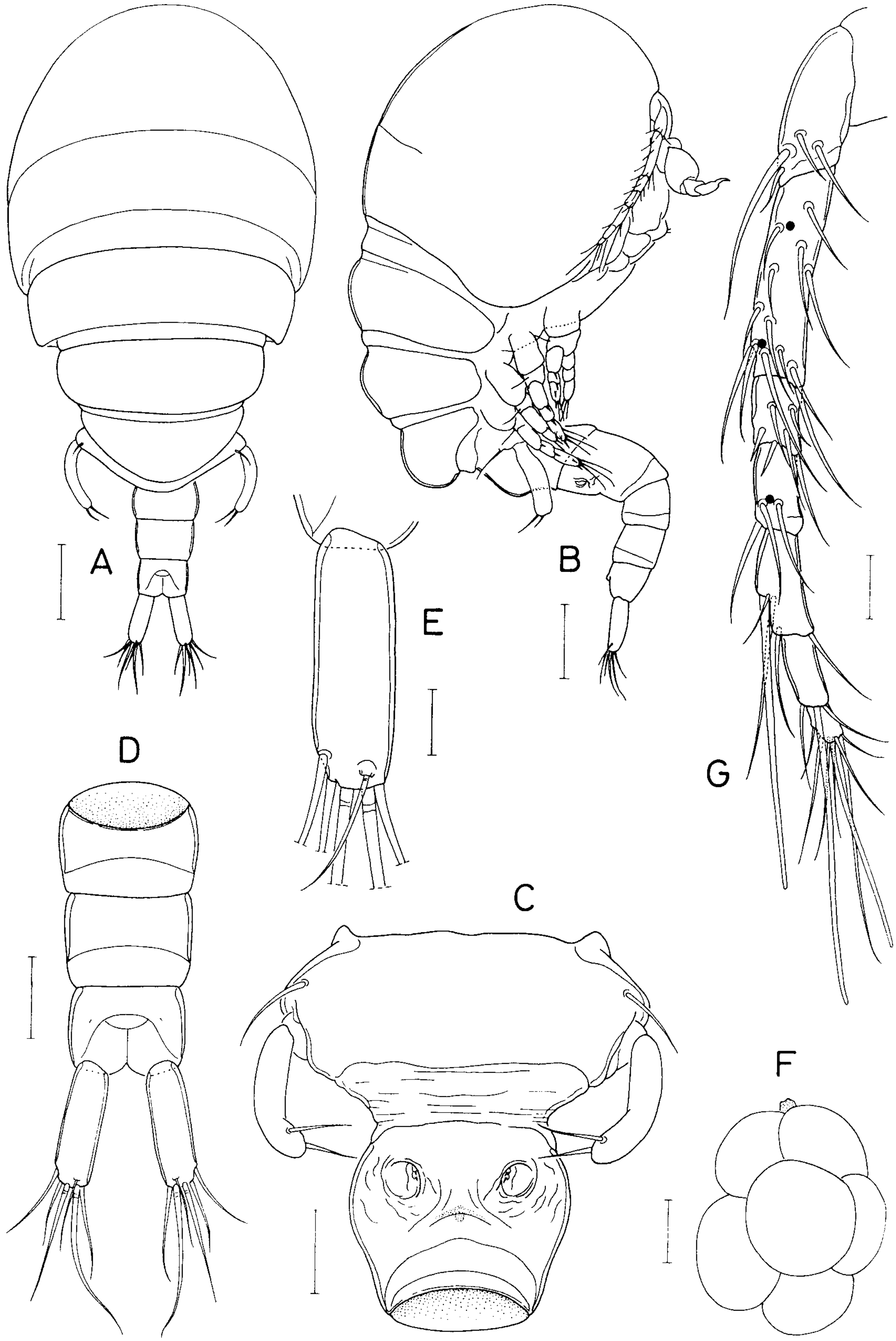

Fig. 1. *Allopodion ryukyuensis* n. sp., female. A, habitus, dorsal; B, habitus, lateral; C, fifth pedigerous and genital double somites, dorsal; D, abdomen, dorsal; E, caudal ramus, dorsal; F, egg sac; G, antennule (dots indicating insertions of additional aesthetascs in male). Scales: A, B, F, 0.1 mm; E, G, 0.02 mm; C, D, 0.05 mm.

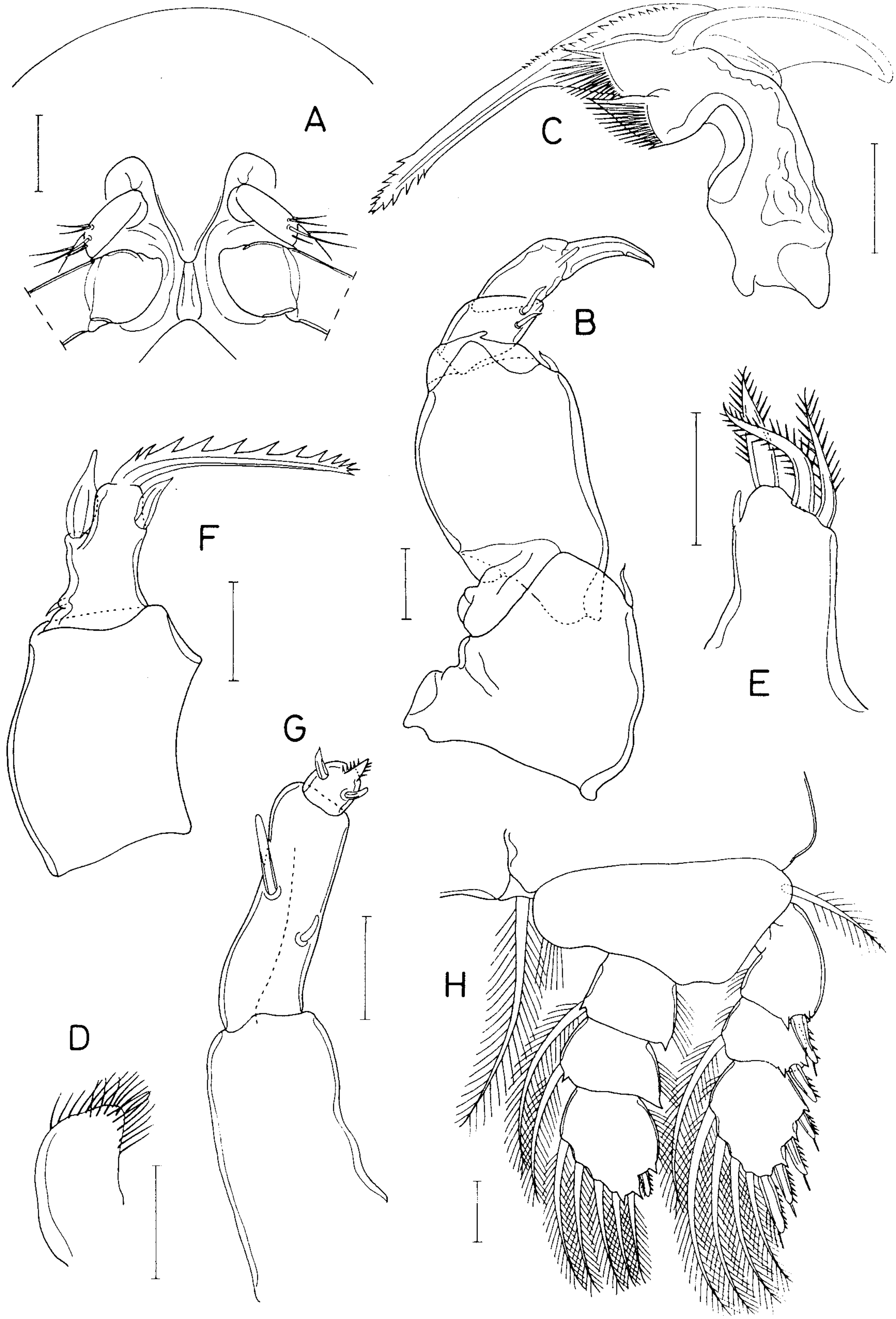

Fig. 2. *Allopodion ryukyuensis* n. sp., female. A, rostral area, ventral; B, antenna; C, mandible; D, paragnath; E, maxillule; F, maxilla; G, maxilliped; H, leg 1. Scales: A, 0.05 mm; B-H, 0.02 mm.

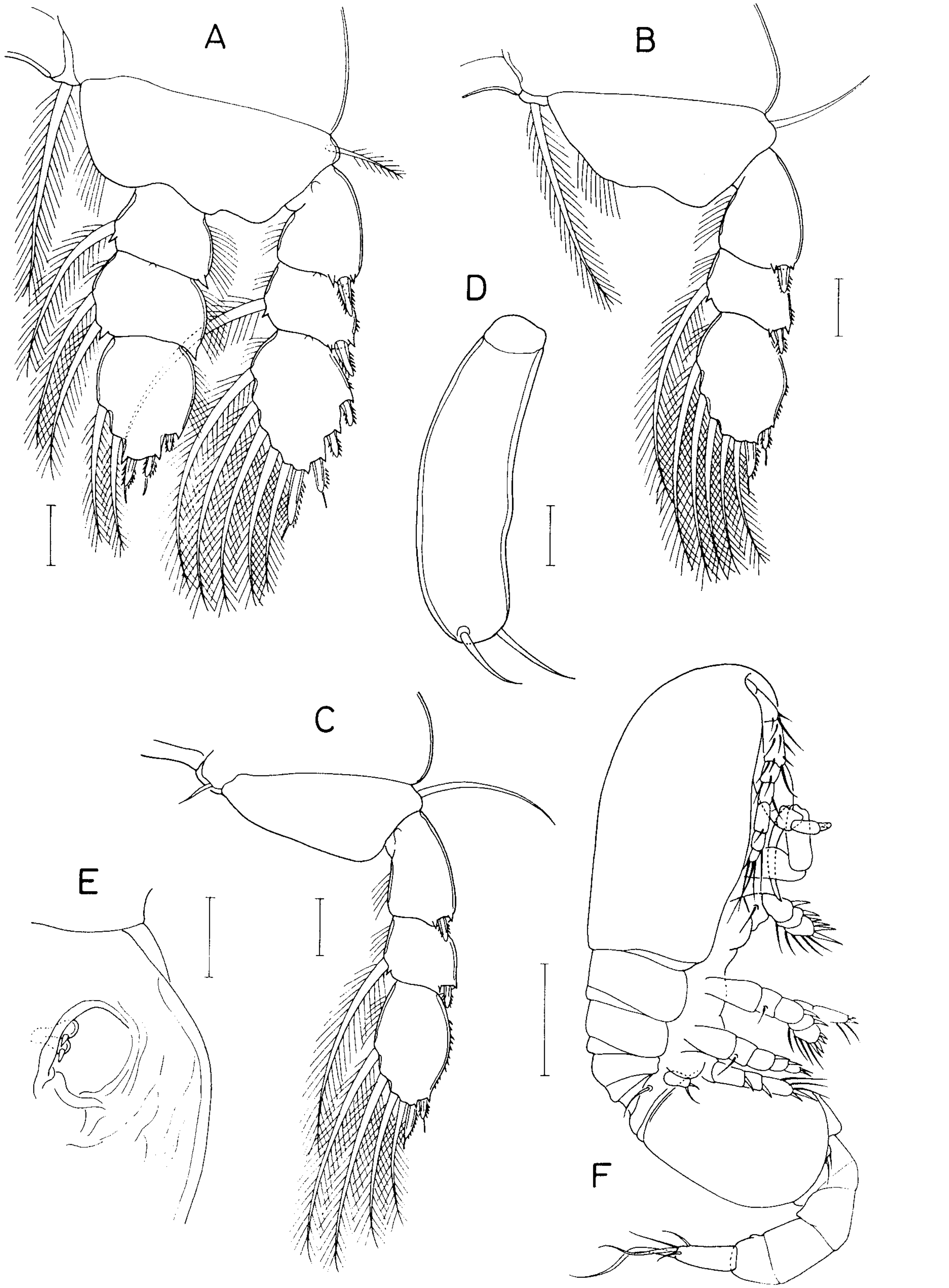

Fig. 3. *Allopodion ryukyuensis* n. sp. Female: A, leg 2; B, leg 3; C, leg 4; D, free segment of leg 5; E, right genital area. Male: F, habitus, lateral. Scales: A-E, 0.02 mm; F, 0.1 mm.

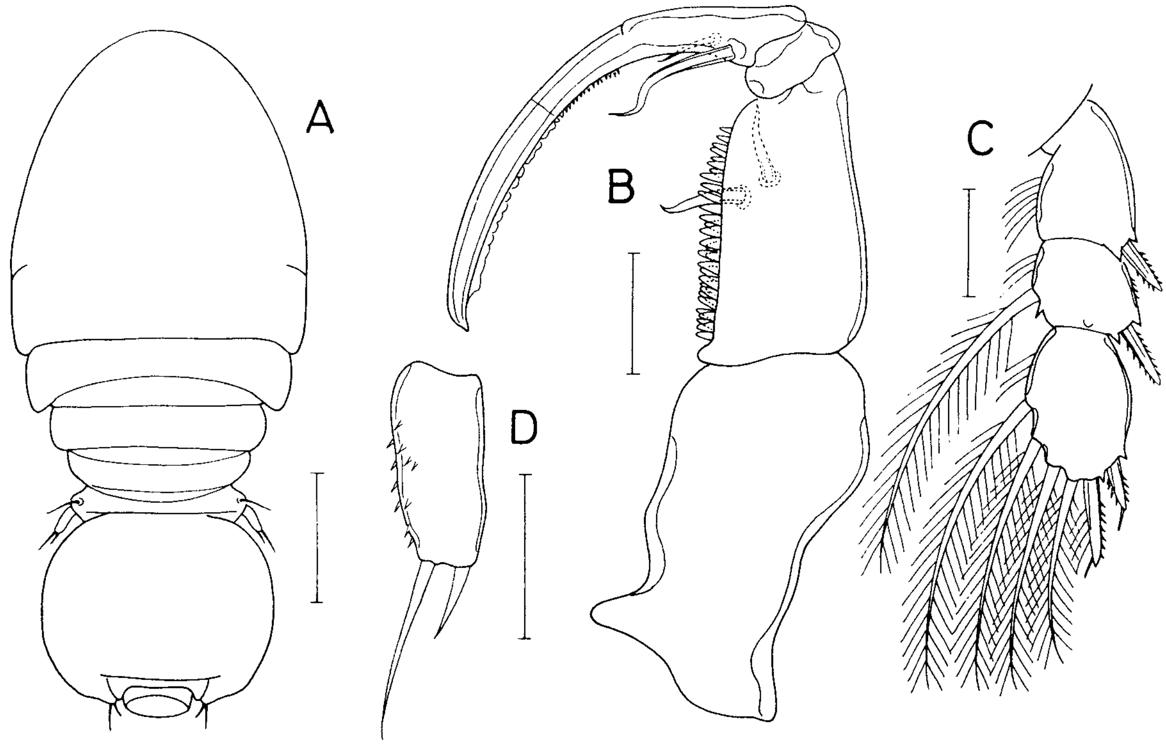

Fig. 4. *Allopodion ryukyuensis* n. sp., male. A, prosome and anterior part of urosome, dorsal; B, maxilliped; C, exopod of leg 4; D, free segment of leg 5. Scales: A, 0.1 mm; B-D, 0.02 mm.

and 53 × 70 μm, respectively, all unornamented. Caudal rami widely separated from each other (Fig. 1D). Each ramus (Fig. 1E) 79 × 25 μm (ratio of length to width 3.16 : 1), with 6 naked setae; largest caudal seta 96 μm long. Egg sac (Fig. 1F) usually containing 3-5 (at most 6) eggs; each egg about 175 μm in diameter.

Rostrum tapering, longer than width (Fig. 2A). Antennule (Fig. 1G) 227 μm long and 7-segmented, with armature formula 4, 13, 6, 3, 4 + 1 aesthetasc, 2 + 1 aesthetasc, and 7 + 1 aesthetasc. All setae naked. Antenna (Fig. 2B) 4-segmented, with armature formula 1, 1, 2, and 1 + claw. First and second segments stout. Third and fourth segments distinctly narrower than proximal 2 segments. Fourth segment about 1.7 times as long as wide. Claw as long as fourth segment.

Labrum lost. Mandible (Fig. 2C) with distinct inner proximal notch. Inner margin bilobed, each lobe armed with long spinules; proximal lobe tapering and pointed distally. Convex outer margin with large, wing-like, tapering expansion. Distal lash moderately long, straight, and distally serrate on both anterior and posterior margins. Paragnath (Fig. 2D) a simple lobe, with distal setules. Maxillule (Fig. 2E) armed with small, naked subterminal elements and 3 thick distal setae bearing thick setules; middle one of latter 3 setae strongly curved. Maxilla (Fig. 2F) 2-segmented; first segment unarmed; second segment with small outer proximal seta, expanded but distally tapering outer seta, and leaf-like inner seta. Distal lash curved proximally, forming right angle with axis of second segment, with serrate convex margin; proximal 2 serrations smaller than following ones. Maxilliped (Fig. 2G) 3-segmented. First segment largest, but unarmed. Second segment about 2.8 times as long as wide, with longitudinal wrinkle and 2 unequal, bluntly tipped setae. Third segment small, nearly as long as wide, tipped with spiniform process bearing spinules on both sides, and armed with 2 small, spiniform setae.

Legs 1 (Fig. 2H) and 2 (Fig. 3A) biramous, with 3-segmented exopod and endopod. Legs 3 (Fig. 3B) and 4 (Fig. 3C) uniramous, with 3-segmented exopod, without endopod. Inner coxal seta of legs 1-3 very large, but that of leg 4 small. Outer seta on basis of legs 1 and 2 plumous, but that of legs 3 and 4 naked. Armature formula of legs 1-4 as follows:

Leg 1: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,4;
enp. 0-1; 0-1; I,5
Leg 2: coxa 0-1; basis 1-0; exp. I-0; I-1; III,I,5;
enp. 0-1; 0-2; I,II,3
Leg 3: coxa 0-1; basis 1-0; exp. I-0; I-1; I,I,5;
enp. absent
Leg 4: coxa 0-1; basis 1-0; exp. I-0; I-1; I,I,4;
enp. absent

Free segment of leg 5 (Fig. 3D) slightly arched, 111 × 32 μm (ratio of length to width 3.47 : 1); its 2 terminal setae 32 (inner) and 27 (outer) μm long. Leg 6 represented by 2 small, spiniform setae in genital area (Fig. 3E).

Male.—Body length about 600 μm. Prosome not expanded (Fig. 4A). Urosome strongly flexed (Fig. 3F) as in female. Length of prosome 361 μm. Maximum width of prosome 226 μm. Urosome 6-segmented. Genital somite large, 147 × 177 μm, wider than fifth pedigerous somite. Abdominal somites and caudal rami not examined.

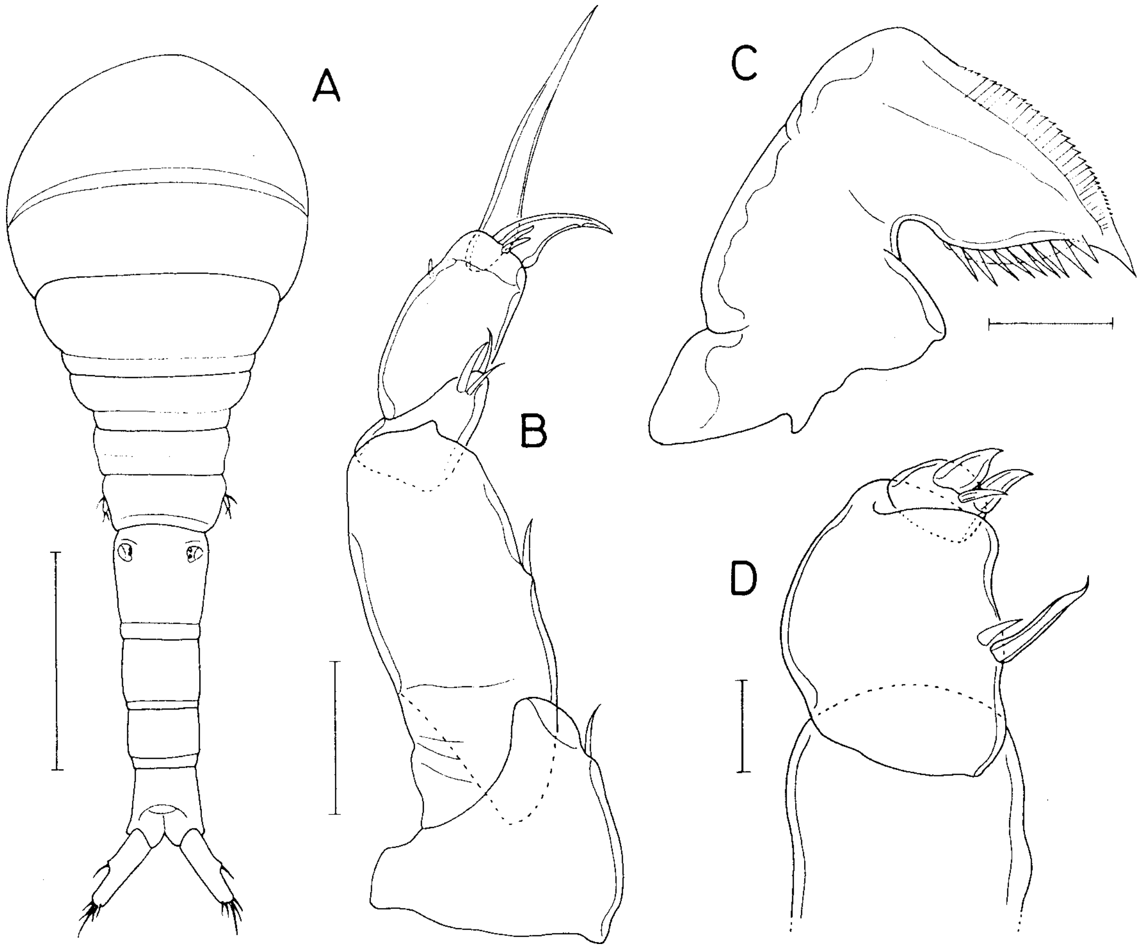

Fig. 5. *Xenomolgus varius* Humes and Stock, female. A, habitus, dorsal; B, antenna; C, mandible; D, maxilliped. Scales: A, 0.5 mm; B, 0.05 mm; C, D, 0.02 mm.

Rostrum as in female. Antennule with 3 additional aesthetascs: 2 on second and 1 on fourth segment as indicated by dots in Fig. 1G. Antenna as in female.

Labrum lost. Mandible, maxillule, and maxilla as in female. Maxilliped (Fig. 4B) consisting of 3 segments and terminal claw. First segment longest but unarmed. Second segment with 2 similar setae and 2 rows of spinules on inner margin. Small third segment unarmed. Claw strongly curved, armed proximally with 1 distally curved seta and on opposite side with 1 small seta.

Armature formula of legs 1-4 as in female, but spines on these legs larger than in female (Fig. 4C). Free segment (Fig. 4D) of leg 5 small, 24 × 11 μm (ratio of length to width 2.18 : 1), with spinules on outer side; its 2 terminal setae 22 (outer) and 9 μm (inner), respectively. Leg 6 represented by 2 small setae on genital flap of genital somite (Fig. 4A).

Etymology.—The specific name *ryukyuensis* is derived from the Ryukyu Islands, where the type locality is located.

Remarks.—*Allopodion mirum* Humes, 1978, the only previously known species of the genus, was recorded from the scleractinian coral *Montipora* sp. (cf. *M. undata* Bernard) in the Moluccas (see Humes, 1978). *Allopodion ryukyuensis* n. sp. is readily differentiated from this type species as follows: 1) the caudal rami are shorter (79 × 25 μm) than those of *A. mirum* (117 × 28 μm, according to Humes, 1978); 2) the genital double-somite of the female has a rounded lateral margin (nearly straight in *A. mirum*); 3) all of the abdominal somites are shorter than wide (longer than wide in *A. mirum*); 4) the third exopodal segment of leg 2 carries four spines and five setae (armature formula III,I,5, compared to III,I,4 in *A. mirum*); 5) the third exopodal segment of legs 3 and 4 bear the armature formulae I,I,5 and I,I,4, respectively (compared to I,5 and I,4, respectively, in *A. mirum*); and 6) the free segment of the female leg 5 is broader than that of *A. mirum*, with the ratio of the length to width 3.47 : 1 (4.39 : 1 in *A. mirum*).

Rhynchomolgidae Humes and Stock, 1972
Xenomolgus Humes and Stock, 1972
Xenomolgus varius Humes and Stock, 1973
Fig. 5

Material Examined.—Two ♀♀ (1 ♀ dissected) collected from galls of *Porites* sp.(p). (*Porites lutea* Milne Edwards and Haime and/or *P. australiensis* Vaughan) on a reef flat in

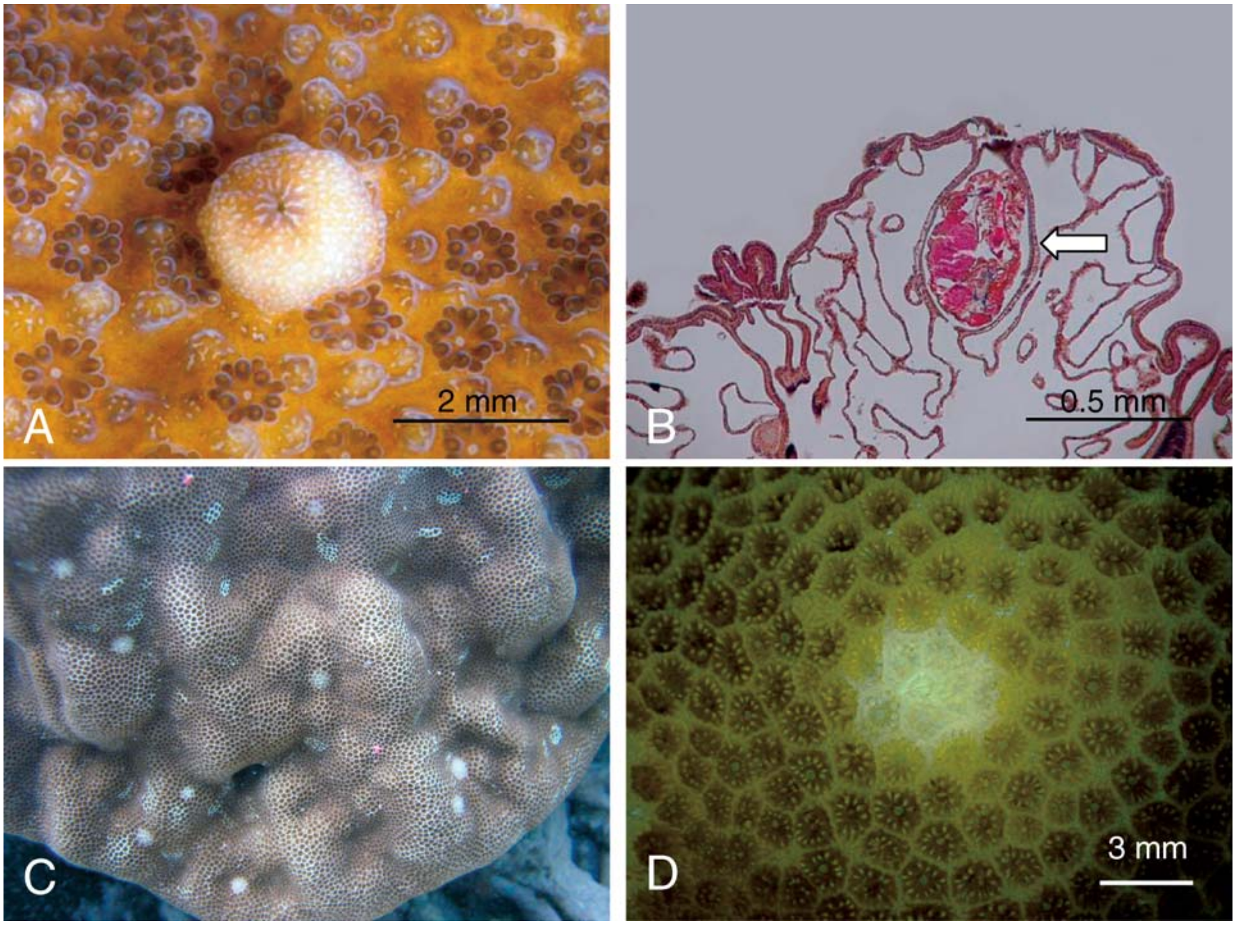

Fig. 6. Photographs of gall-like formation induced by *Allopodion ryukyuensis* (A, B) and *Xenomolgus varius* (C, D). A, a dome-shaped gall induced by *A. ryukyuensis*; B, longitudinal section of a gall, showing a female and eggs (indicated by an arrow) of *A. ryukyuensis* within the gall cavity; C, *Porites* sp. showing bleached spots each surrounding a crypt inhabited by *Xenomolgus varius*; D, magnified bleached spot, showing the aperture of a crypt formed by *Xenomolgus varius*.

front of Sesoko Station, Tropical Biosphere Research Center, University of the Ryukyus, Okinawa, Japan, by H. Yamashiro, 14 November 2005; 5 ♀♀ collected from the same site as above by H. Yamashiro, 4 January 2006.

Remarks.—Humes and Stock (1973) originally described this species based on specimens associated with *Porites* sp. in Mauritius. The body form, the presence of papilliform granules (not drawn in Fig. 5A) on the dorsal surface of cephalothorax, the shape of the caudal ramus and antenna (Fig. 5B), the structure of the maxillule and maxilla, and the leg morphology of our specimens from Okinawa are well in accord with the original description. Some minor differences of our specimens from the type specimens are observed. The body length is 1.96 mm in the female (1.63-1.76 mm in the type specimens). The mandible (Fig. 5C) has a blade that is strongly tapered, with nine spinules on the inner margin (the blade has a straight inner margin with seven spinules in the type specimens). In the female maxilliped (Fig. 5D), the terminal segment is armed with three elements (only two elements reported in the type specimens). We consider that these differences either represent infra-specific variation or are artifacts.

Gall-like Habitations of *Allopodion ryukyuensis* and *Xenomolgus varius*

The galls induced by *Allopodion ryukyuensis* are dome-shaped (Fig. 6A), with a diameter of 1.40-1.72 mm (mean = 1.56 mm; n = 54). One of these galls was examined in detail. Its inner cavity was 360 µm wide and about 600 µm long (the size decreased to almost half the original size during preparation of the histological sample). The gall cavity was occupied by a female copepod with a crouched posture and a strongly flexed urosome (Figs. 1B, 6B). The animal was accompanied by several free egg sacs in addition to the pair attached to the body. The diameter of the gall aperture was 110-310 µm (mean = 210 µm; n = 8), a size through which the mature females are not able to pass, the maximum width of the examined female copepod being 409 µm. However, the aperture is large enough for the male (prosomal width 230 µm in the examined mature male) and juveniles to leave or enter the gall, as Stock (1981) recorded for the siphonostomatoid copepods and their galls on their stylasterine hosts. The males are assumed to visit the trapped females at times for mating.

Unlike the dome-shaped galls induced by *Allopodion ryukyuensis*, the crypts induced by *Xenomolgus varius* do not project above the surface of the host coral. Instead, they are shaped like a burrow tapering downwards. Within the crypt, the female copepod is encircled by sheath-like, membranous coral tissue, with its head region facing the crypt aperture. The aperture is oval and covered by membranous tissue with a slit-like opening along its central axis (Fig. 6D). The female copepod is probably able open the slit and escape from the crypt. When viewed from the surface of the coral host, the area of the host surrounding the crypt appears as a bleached spot (Fig. 6C) due to the disappearance of symbiotic algae. The mechanism by which this bleaching occurs is unknown but its association with the presence of the copepods is clear.

The density of galls induced by *Allopodion ryukyuensis* was measured in ten colonies of *Montipora informis* having surface areas ranging from 2 to 97 cm^2. In these colonies, the mean density was 0.32 galls/cm^2. Of 77 galls examined for copepods, 70 (91%) were occupied by a female, and 31 of these 70 females were accompanied with a male. Galls and their copepod occupants on *Montipora informis* are thus not rare in Okinawa. Crypts on *Porites* sp. induced by *Xenomolgus varius* are also frequent (see Fig. 6C), when they are observed.

This frequent occurrence of galls and crypts is not assumed to be restricted to corals in Okinawa. Although Humes (1978) did not noticed any galls on the colonies of *Montipora* sp. in the Moluccas, where he discovered *Allopodion mirum*, this copepod is highly likely to be a gall inhabitant given the similar body shape of the copepods from Okinawa and the Moluccas, and their association with the same genus of host corals. Although their copepods came from a single island, Dojiri and Grygier (1990) inferred a wider distribution of *Pionomolgus gallicolus* based on finds of similar-appearing galls on dry specimens of the host coral species.

Humes (1978) based his description of *Allopodion mirum* on only four females of this species from washings of "fragments" of one colony of *Montipora* sp. Along with these copepods, he also discovered seven females of *Kawanolus paragensis* (as a new genus and species) and two females of *Haplomolgus subdeficiens* (as a new species) from the same fragments of coral. These three species of copepods display a similar body form, i.e., with a swollen prosome and slender, recurved urosome. It is notable that the urosome is not recurved in the other two species of *Haplomolgus*, *H. montiporae* Humes and Ho, 1968 and *H. incolumis* Humes, 1991 (Humes and Ho, 1968; Humes, 1991). The small numbers of specimens, the similar body form of the different species, and the discovery of these copepods from the same fragment of coral suggest that all three species are gall-inhabitants. These three copepods could have escaped through the fracturing of galls, not through the gall apertures, in the 5% alcohol-sea water solution that was used by Humes (1978) to dislodge copepods from their host.

Stock (1981) pointed out certain characteristics of the copepods that he found in the "cage-like" galls of stylasterine corals: a swollen prosome in the female and a gradual reduction in the structure and armature of legs 4 and 5. These characteristics are also displayed by *Isomolgus desmotes* and *Pionomolgus gallicolus*, both inhabiting dome-shaped galls, and *Allopodion ryukyuensis* recorded herein.

*Xenomolgus variu*s induces crypts quite different from the galls of the above species. Nevertheless, this species also displays a swollen cephalothorax and reduced structure and armature of legs 3 and 4. This copepod is considered to be able to pass readily through the flexible gall aperture. This may account for the discovery of a large number of specimens (291 females, 20 males, and six copepodids) of *X. varius* by Humes and Stock (1973) from *Porites* sp. in Mauritius. Some species of copepods recorded as associates of the coral genus *Porites* have, like *X. varius*, a swollen cephalothorax and reduced structure and armature of the posterior swimming legs. In *Ravahina tumida*, which is known from the *Porites* sp. (cf. *P. andrewsi* Vaughan), the prosome is greatly swollen, the urosome is small, legs 1-4 bear reduced setation, and the endopods of legs 3 and 4 are absent (Humes and Ho, 1968). In addition, all four known species of *Kombia*, which are mainly associated with *Porites*, show similar trends of morphology. At least some of these copepods are thus suspected to be gall or crypt inhabitants. We suggest that gall-like formations on hard corals and gall- and crypt-inhabiting copepods are far more common than previously thought.

Acknowledgements

We are grateful to Dr. Geoffery A. Boxshall, the Natural History Museum, London, and two anonymous reviewers for their kind suggestions and comments. We thank Prof. C. C. Latham, Meio University, for reading the first draft of this paper and to M. Iha for her assistance in conducting this research. This study was partially supported by grants from the Korea Research Foundation (R05-2004-000-10302-0) to IHK, and from the Research Institute of Meio University to HY.

References

Dojiri, M. 1988. *Isomolgus desmotes*, new genus, new species (Lichomolgidae), a gallicolous poecilostomatoid copepod from the scleractinian coral *Seriatopora hystrix* Dana in Indonesia, with a review of gall-inhabiting crustaceans of anthozoans. Journal of Crustacean Biology 8: 99-109.

———, and M. J. Grygier. 1990. *Pionomolgus gallicolus*, gen. et sp. nov. (Poecilostomatoida: Lichomolgidae), a gall-inducing copepod of a scleractinian coral from Australia. Australian Journal of Zoology 37: 695-703.

Humes, A. G. 1978. Lichomolgid copepods (Cyclopoida) associated with the coral genus *Montipora* in the Moluccas. Publications of the Seto Marine Biological Laboratory 24: 387-407.

———. 1985. Cnidarians and copepods: a success story. Transactions of the American Microscopical Society 104: 313-320.

———. 1991. Copepoda associated with the scleractinian coral genus *Montipora* in the Indo-Pacific. Proceedings of the Biological Society of Washington 104: 101-137.

———. 1994. How many copepods?. Hydrobiologia 292/293: 1-7.

———, and R. U. Gooding. 1964. A method for studying the external anatomy of copepods. Crustaceana 6: 238-240.

———, and J. S. Ho. 1968. Lichomolgid copepods (Cyclopoida) associated with corals in Madagascar. Bulletin of the Museum of Comparative Zoology, Harvard University 136: 353-413.

———, and J. S. Stock. 1973. A revision of the family Lichomolgidae Kossmann, 1877, cyclopoid copepods mainly associated with marine invertebrates. Smithsonian Contributions to Zoology 127: 1-368.

Stock, J. H. 1981. Associations of Hydrocorallia Stylasterina with gall-inhabiting Copepoda Siphonostomatoidea from the south-west Pacific. Bijdragen tot de Dierkunde 51: 287-312.

Received: 10 April 2006.
Accepted: 3 July 2006.