

A New Species of *Neoscolecithrix* (Crustacea; Copepoda; Calanoida) from off Okinawa, Southwestern Japan, with Comments on the Generic Position in the Superfamily Clausocalanoidea

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Abstract A new species of the deep-water hyperbenthic calanoid genus *Neoscolecithrix*, *N. japonica*, is described, the first from Japan. This is the fifth member of the genus, and it can be readily distinguished from other congeners by relatively short antennules of both sexes, the segmentation and armature of male leg 5, no ornamentation of the female urosome, and the exopodal armature of female leg 5. The position of the genus within the group of five calanoid families with sensory setae on the mouthparts is discussed. *Neoscolecithrix* is here considered as a part of the family Scolecitrichidae complex and it may represent an early offshoot of the lineage leading to the crown group of the Scolecitrichidae.

Key words: *Neoscolecithrix*, Scolecitrichidae, Clausocalanoidea, Calanoida, sensory setae

In 2002, the first Japanese representative of the enigmatic hyperbenthic calanoid copepod genus *Neoscolecithrix* was discovered from off Okinawa, southwestern Japan. The genus was established by Canu (1896) to accommodate *N. koehlerii* from deep waters (950–1,710 m deep) in the Bay of Biscay. Alvarez (1985) and Hulsemann (1985) independently concluded that the six species known at that time could be divided into two groups on the basis of the morphological differences. Bradford-Grieve (2001) has re-considered the status of these two groups, and established a new genus, *Cenognatha*, to accommodate the second group sensu Hulsemann (1985): *C. farrani* (Smirnov, 1935) (North Atlantic, 170–1,016 m deep: Fosshagen, 1972; Sirenko *et al.*, 1996); *C. watersae* (Grice, 1972) (Northeastern Pacific, 1,465–1,500 m deep: Grice, 1972), and *C. antarctica* (Hulsemann, 1985) (off the Antarctic Peninsula, 200–1,040 m deep: Hulsemann, 1985). *Neoscolecithrix* s.s. now comprises the following four nominal

species: *N. koehlerii* Canu, 1896 (North Atlantic, 950–1,710 m deep: Canu, 1896; Scott, 1909); *N. magna* (Grice, 1972) (Pacific, 452–1,500 m deep: Grice, 1972; Bradford-Grieve, 2001); *N. caetani* Alvarez, 1985 (Brazil slope, 900 m deep: Alvarez, 1985); and *N. ornata* Bradford-Grieve, 2001 (New Zealand slope, 306 m deep: Bradford-Grieve, 2001). The genus is considered to be a truly hyperbenthic member of deep waters (Hulsemann, 1985; Bradford-Grieve, 2001).

The systematic position of *Neoscolecithrix* has been debated since it was established, because it exhibits a mixture of characters of several of the calanoid families characterised by the possession of sensory setae on the mouthparts: Diaixidae, Parkiidae, Phaennidae, Scolecitrichidae, and Tharybidae (Sars, 1902; Fleminger, 1957; Fosshagen, 1972; Bradford, 1973; Bradford *et al.*, 1983; Hulsemann, 1985; Ferrari & Markhaseva, 1996; Bradford-Grieve, 2001). In describing the present new species, we also consider the problem of differentiating between these five families.

Materials and Methods

Copepods were collected from the hyperbenthic zone off Ie Island, Okinawa Prefecture, south-western Japan (26°48.23'N, 127°52.18'E~26°42.28'N, 127°52.80'E, 337~340 m in depth) on May 27, 2002, using a NORPAC plankton net (mesh size 0.33 mm) attached to the mouth of a beam trawl, towed along the bottom for 20 min at a speed of 2 knot. Samples were fixed with 10% neutralized formalin/sea-water immediately after capture. Type specimens are deposited at the National Science Museum, Tokyo. Terminology follows Huys & Boxshall (1991).

Neoscolecithrix japonica n.sp.

(Figs. 1-4)

Material examined (type specimens). Holotype: adult male, appendages mounted on glass slides, body in vial (NSMT-Cr 14828). Paratypes: 2 adult females, appendages mounted on glass slides, body in vials (NSMT-Cr 14829); 3 adult males, whole specimens (NSMT-Cr 14830).

Body length. Adult male: 3.38 mm (holotype), 3.31, 3.33, 3.41 mm (paratypes) (N=4). Adult female (paratypes): 3.23, 3.33 mm (N=2).

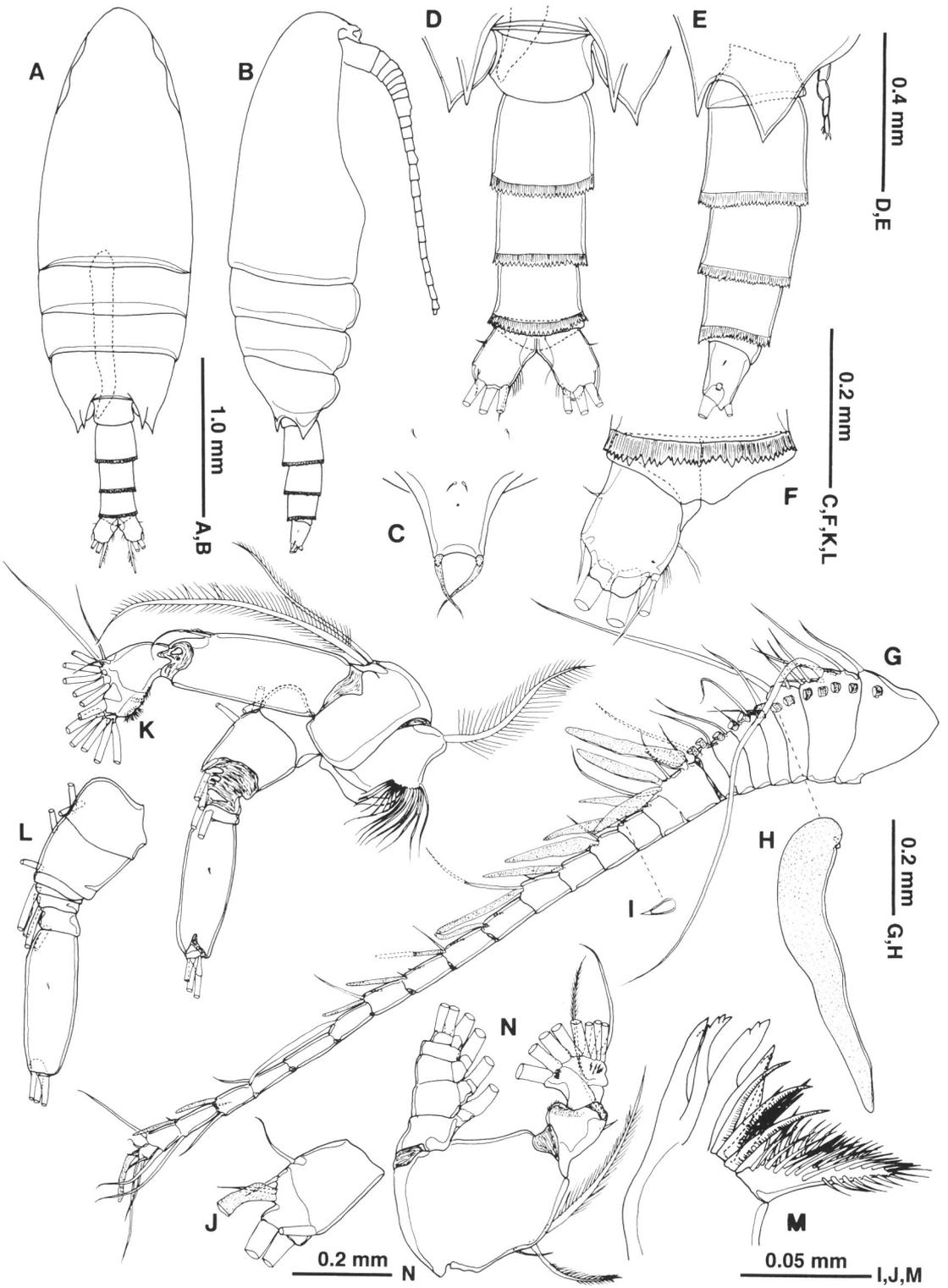
Description. Male (Figs. 1-3). Body (Fig. 1A, B) well chitinized, with compact prosome; cephalosome completely fused with first pediger; fourth and fifth pedigers almost completely coalescent with fusion line visible laterally, produced posteriorly into pairs of acutely pointed, dorsolateral and lateral processes (Fig. 1A, B, D, E); lateral process nearly reaching one third of first abdominal somite, whereas dorsolateral process slightly beyond genital somite (Fig. 1D, E). Rostrum (Fig. 1B, C) produced ventrally, with pair of filaments. Urosome (Fig. 1A, B, D, E) 5-segmented, with first abdominal segment

longest; gonopore posteriorly opening at left lateral corner; first to third abdominal somites each with posterior fringe; anal somite (Fig. 1F) small, almost telescoped into preceding somite dorsally. Caudal rami (Fig. 1D, E, F) symmetrical, with minute seta I at midlength and seta VII ventrally near base of seta VI; setae III missing in all specimens.

Antennule (Fig. 1G-J) with 23 free segments; first to seventh segments each with highly developed aesthetasc(s) (Fig. 1H); eighth segment composed of 3 ancestral segments X to XII, with fusion line clearly visible between X-XI and XII. Fusion pattern and armature elements as follows: I-1+ae; II-IV-6+4ae; V-2+2ae; VI-2+ae; VII-2+2ae; VIII-2+ae; IX-2+2ae; X-XII-minute process+1+4ae; XIII-minute process (Fig. 1I)+ae; XIV-minute process+1+ae; XV-1+ae; XVI-2+ae; XVII-2+ae; XVIII+ae; XIX-2+ae; XX-2+ae; XXI-ae; XXII-1; XXIII-1; XXIV-1+1+ae; XXV-1+1+ae; XXVI-1+1; XXVII-XXVIII (Fig. 1J)-6+ae. Antenna (Fig. 1K, L) with row of long setules and plumose seta on coxa; basis with 2 setae of unequal length. Exopod (Fig. 1K, L) longer than endopod, incompletely 7-segmented; setal formula 1, 3, 1, 1, 1, 1, 1 (rudimentary) +3. Endopod (Fig. 1K) 2-segmented; proximal segment with 2 setae subterminally; distal segment bilobed, bearing 8 setae on outer lobe and 1 rudimentary and 6 setae on inner lobe.

Mandible (Fig. 1M, N) with heavily chitinized gnathobase; cutting edge bearing 4 well chitinized, multicusped teeth plus 4 spiniform teeth and thick, spinulose seta. Palp (Fig. 1N) with 3 inner setae on basis, one of which rudimentary; endopod 2-segmented, proximal segment bearing 1 plumose and 1 rudimentary seta, distal segment with nine setae; exopod 5-segmented, setal formula 1, 1, 1, 1, 2. Maxillule (Fig. 2A, B) with 6

Fig. 1. *Neoscolecithrix japonica* n.sp. Adult male (holotype). A. Habitus, dorsal view; B. Habitus, lateral view; C. Rostrum; D. Prosomal ends and urosome, dorsal view; E. Prosomal ends and urosome, lateral view; F. Anal somite and right caudal ramus, ventral view; G. Antennule; H. Distal large aesthetasc on third segment (V); I. Spiniform element on ninth segment (XIII); J. Distal compound segment (XXVII-XXVIII) of antennule; K. Antenna; L. Antennary exopod; M. Mandibular gnathobase; N. Mandibular palp.



well chitinized, 3 spinulose and 4 posterior setae on praecoxal endite; coxal endite and epipodite bearing 3 and 9 setae, respectively; first basal endite with 4 setae; second basal endite probably fused to endopod; exopod lamellar, with 10 setae; endopod at least 2-segmented, setal formula 3, 5. Maxilla (Fig. 2D–I) compact; proximal praecoxal endite with 1 rudimentary and 4 long setae; distal with 3 setae; proximal coxal endite with 1 brush-like sensory (Fig. 2E) and 2 long setae; distal coxal endite (Fig. 2F) with 3 setae; basal endite with 1 vermiform sensory, 1 heavily chitinized and 2 long setae; endopod indistinctly 2-segmented, first segment with 2 brush-like sensory setae, second segment with 1 brush-like and 5 large, vermiform (Fig. 2I) sensory setae plus rudimentary seta (Fig. 2H). Maxilliped (Fig. 2J, K) with first to fourth endites bearing 1, 2, 3 and 3 setae, respectively; syncoxa partly subdivided by surface suture, praecoxal endite bearing 1 seta and row of spinules; 1 vermiform and 1 brush-like sensory seta on second and third syncoxal endite, respectively; basis slightly longer than syncoxa, bearing patch of minute spinules along one third length and 3 setae midway; first endopodal segment almost incorporated into basis; first to sixth endopodal segments bearing 2, 4, 4, 3, 3+1, 3+1 setae, respectively.

Legs 1–4 (Fig. 3A–D) with armature as in *N. cf. magna* described by Bradford-Grieve (2001). Leg 1 (Fig. 3A) with coxa and basis each bearing row of long setules along inner margin; endopod unisegmented, protruded at inner midlength, on which patch of minute spinules present.

Legs 2 (Fig. 3B) and 3 (Fig. 3C) similar to each other except for endopodal segmentation and setation; each with 2 spinules near base of endopod on posterior surface; second exopodal segment bearing spinular row along anterodistal

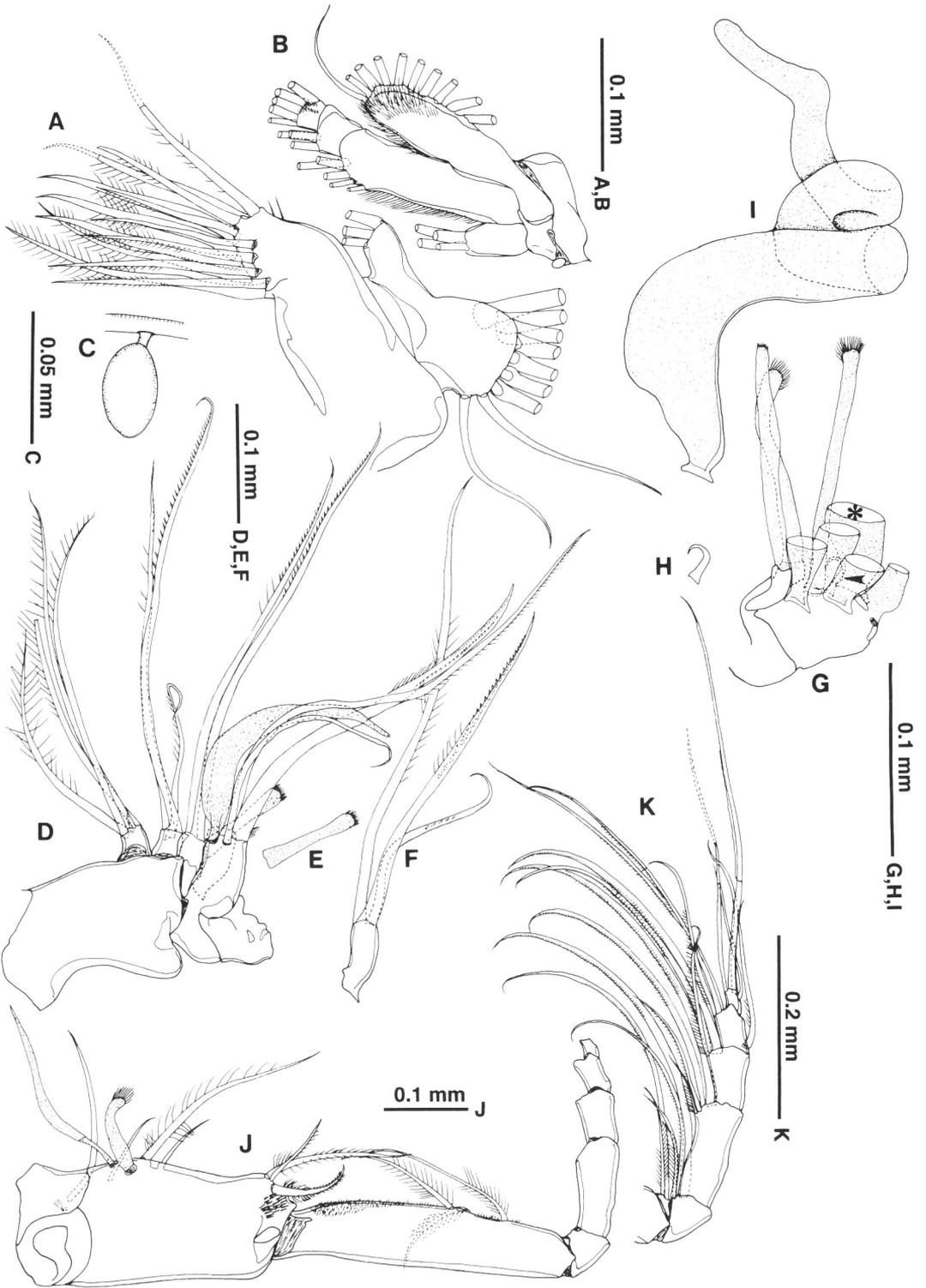
margin. Leg 4 (Fig. 3D) lacking of basal spinules on posterior surface.

Leg 5 (Fig. 3E–G) with both coxae and intercoxal sclerite fused to form common base; right leg much shorter than left leg, at most reaching midlength of left basis. Right leg composed of basis and 2-segmented exopod (Fig. 3F), first segment with outer distal spine, second furnished with 2 terminal spines of almost equal length; both margins sparsely decorated by fine setules. Left leg consisting of basis and 3-segmented exopod, all of which partly or entirely covered with minute spinules on posterior surface; first exopodal segment longest, nearly equal to distal two segments combined, bearing minute distal spine; second exopodal segment unarmed; third exopodal segment small, bearing 1 long recurved and 2 minute outer spines.

Female (Fig. 4). Body (Fig. 4A, B) similar to that of male, but having slightly wider prosome; paired terminal processes of prosome much more developed than in male, lateral process reaching to posterior end of genital double-somite; genital double-somite (Fig. 4E, F) with ventral protrusion at one third length, on which relatively small, circular genital operculum present; paired seminal receptacles laterally extended and terminated into bulbous sac; anal somite (Fig. 4C, D) almost telescoped into preceding somite; caudal rami (Fig. 4D) as ornamented as in male.

Antennule (Fig. 4G, H) with 24 free segments; no large-sized aesthetasc present on proximal segments as in male; fusion pattern and armature element as follows: I–3; II–IV–6+ae; V–2+ae; VI–2; VII–2+ae; VIII–2; IX–2+ae; X–XI–4+ae; XII–1; XIII–1; XIV–1+ae; XV–1; XVI–2+ae; XVII–2; XVIII–2; XIX–2; XX–2; XXI–1+ae; XXII–1; XXIII–1; XXIV–1+1; XXV–1+1; XXVI–

Fig. 2. *Neoscolecithrix japonica* n.sp. Adult male (holotype). A. Maxillary praecoxa and coxa; B. Maxillary basis and rami; C. Phoront of apostome ciliate (?) on maxillary seta; D. Maxilla, elements on second coxal endite and endopod omitted; E. Brush-like sensory seta on first coxal endite of maxilla; F. Second coxal endite of maxilla; G. Maxillary endopod, asterisk and arrowhead meaning largest vermiform sensory seta illustrated in "I" and rudimentary element in "H", respectively; H. Rudimentary element on maxillary endopod; I. Largest vermiform sensory seta of maxillary endopod; J. Maxilliped, setae on endopod omitted; K. Maxillipedal endopod.



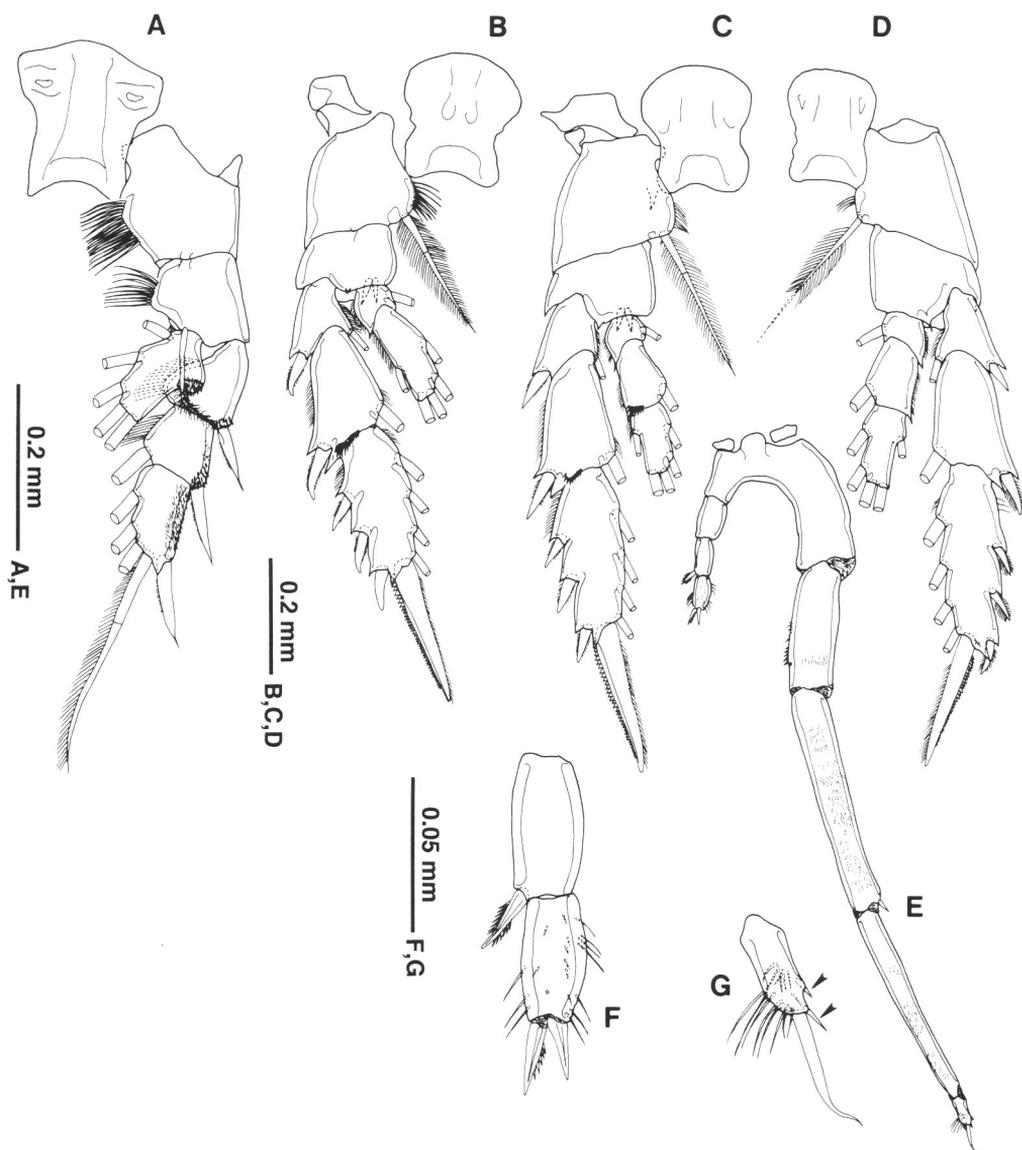
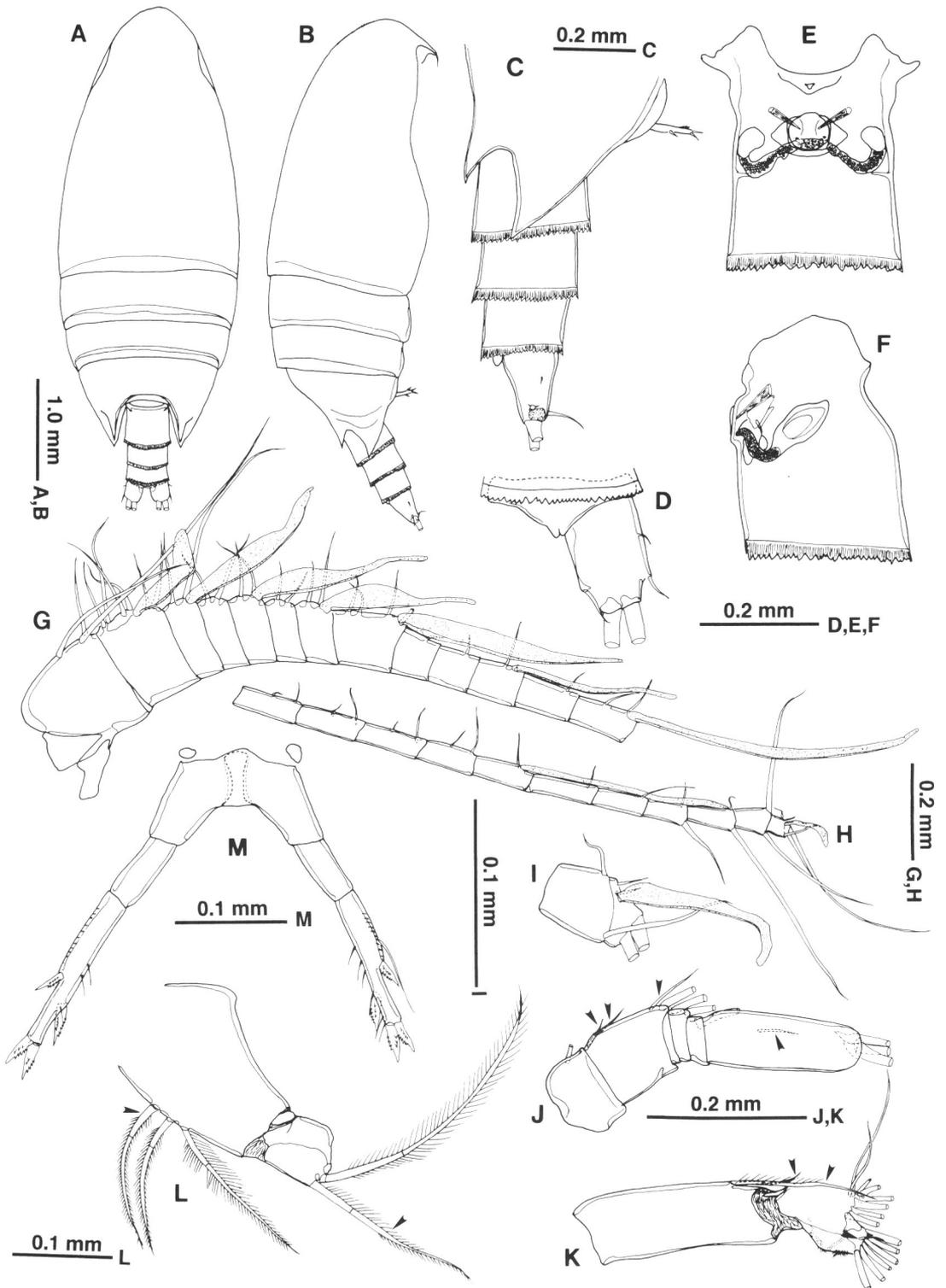


Fig. 3. *Neoscolecithrix japonica* n.sp. Adult male (holotype). A. Leg 1, anterior surface; B. Leg 2, anterior surface; C. Leg 3, anterior surface; D. Leg 4, anterior surface; E. Leg 5, anterior surface; F. Right exopod of leg 5, anterior surface; G. Terminal exopodal segment of left leg 5, anterior surface, arrowheads indicating minute outer spines.

Fig. 4. *Neoscolecithrix japonica* n.sp. Adult female (paratypes). A. Habitus, dorsal view; B. Habitus, lateral view; C. Prosomal end and urosome, lateral view; D. Anal somite and left caudal ramus, ventral view; E. Genital double-somite, ventral view; F. Genital double-somite, lateral view; G. First to 13th antennular segments (I to XVI); H. Fourteenth to 24th antennular segments (XVII to XXVIII); I. Terminal compound antennular segment (XXVII-XXVIII); J. Antennary exopod, arrowheads showing sexual differences (compare to Fig. 1L); K. Antennary endopod, arrowheads showing sexual differences (compare to Fig. 1K); L. Mandibular palp, arrowheads showing sexual differences (compare to Fig. 1N); M. Leg 5, anterior surface.



1+1; XXVII-XXVIII (Fig. 4I)–6+ae. Antenna similar to that of male except for following points: exopod with setal formula 1, 3, 1, 1, 1, 1, 1+3; 3 setae on second exopodal segment minute (indicated by 3 arrowheads in Fig. 4J); larger seta (arrowed in Fig. 4J) on sixth exopodal segment; endopod with 2 subterminal setae longer than in male (arrowed in Fig. 4K); longer setule on terminal lobe of second endopodal segment (arrowed in Fig. 4K). Mandibular palp (Fig. 4L) similar to that of male except for longer proximal seta on basis (arrowed); proximal seta on first endopodal segment longer than in male (arrowed).

Maxillule, maxilla, maxilliped and legs 1–4 similar to those of male.

Leg 5 (Fig. 4M) with right leg longer than left leg; both coxae and intercoxal sclerite fused to form common base; basis unarmed; exopod 1-segmented, right exopod approximately 1.2 times as long as left exopod, similarly ornamented, with 1 outer, 1 inner and 2 terminal spines; proximal outer margin furnished with long setules (most missing, but only scars present in Fig. 4M).

Remarks. The present new species well fits the diagnosis of *Neoscolecithrix* s.s. proposed by Bradford-Grieve (2001), and is readily distinguished from other congeners by the combination of the following features (that in parentheses for other congeners): (1) no ornamentation on the female urosome (some females furnished with scale-like structure or spinules/setules); (2) short antennules of both sexes at most reaching to the posterior end of the second pedigerous somite (up to the third to fifth pedigerous somite); (3) 3-segmented baseopod of the maxillule (1- or 2-segmented); (4) leg 4 unarmed with spinules on the posterior surface (present on the coxa, basis and/or rami in some species); (5) the unisegmented exopod of female leg 5 with 2 terminal spines clearly separated (armed with 3 spines separated from the segment or with 2 spines, one of which is coalescent to the segment); (6) the terminal exopodal segment of right male leg 5 not reaching the distal end of the left

basis, with only 2 spines terminally (beyond the proximal exopodal segment of left leg 5, with 3 or more spines).

The fifth copepodid stage of *Neoscolecithrix* described as *Oothrix bidentata* by Chen & Zhang (1965) may be identical to the present new species in consideration of the prosomal ends and female leg 5. However it differs from *N. japonica* in the much longer antennule reaching to the last metasomal segment.

Sexual dimorphism is distinct in the setation of the antennary rami and mandibular palp of the new species in addition to the antennule and leg 5. The sexual difference in the mandibular palp is clearly illustrated in *N. caetanoi* without any comment in the text (see Figs. 8, 30: Alvarez, 1985).

The maxillipedal praecoxa is apparently separated from the coxa in *Neoscolecithrix* from New Zealand waters (Bradford-Grieve, 2001, pers. comm.), but in the new species we were unable to determine whether the incomplete suture lines located proximally on the syncoxa of the maxilliped represent a former segmental boundary.

Two ovoid phoronts of presumably, apostome ciliates were attached on the maxillary setae with a stalk as seen in *Vampyrophyry pelagica* (Chatton & Lwoff, 1930) on the body of epipelagic copepods (Fig. 2C) (cf. Grimes & Bradbury, 1992). Sewell (1951) also reported the presence of apostome phoronts on the body surface of a wide variety of deep-water calanoid copepods in the Arabian Sea.

Distribution. *Neoscolecithrix japonica* has hitherto been known only from the type locality. If the fifth copepodid stage reported as *O. bidentata* (=junior synonym of *N. koehlerii* Canu, 1896: see Hulsemann, 1985) from off Zhoushan, Zhejiang Province, in the East China Sea (Chen & Zhang, 1965) is identical to the new species, it seems to be widely distributed in the East China Sea.

From the neighboring waters of the type locality of *N. japonica*, two new species of a hyperbenthic scolecitrichid genus *Macandrewella* Scott, 1909 have been recently described, togeth-

er with several species of a phaennid genus *Xanthocalanus* (Ohtsuka *et al.*, 2002; Ohtsuka, unpublished data). It seems that a wide variety of calanoid copepods with sensoriform setae on the mouthparts are predominant in the hyperbenthic layer of these areas.

Etymology. The specific name is derived from the Latin *japonicus* meaning Japanese, and indicates the type locality of the new species.

Discussion

Five calanoid families have modified sensoriform setae on the maxilla: the Diaixidae, Parkiidae, Phaennidae, Scolecitrichidae, and Tharybidae. The validity and scope of these families are controversial. *Neoscolecithrix* has been tentatively assigned to the Phaennidae (Rose, 1933; Brodsky, 1950; Fosshagen, 1972) and to the Tharybidae (Bradford *et al.*, 1983). In addition, Fosshagen (1972) pointed out that, on the basis of the composition of the maxillary sensory setae, it is also related to the Scolecitrichidae.

Bradford (1973) attempted to distinguish between the Phaennidae and Scolecitrichidae, and provided definitions of both families. The Scolecitrichidae was distinguished from the Phaennidae primarily on the presence of 1 or 2 vermiform sensoriform setae on the basis and of 3 vermiform plus 5 brush-like setae on the endopod of the maxilla in scolecitrichids, as compared to none on the basis and 1 vermiform plus 7 brush-like sensoriform setae on the endopod in phaennids. In males the fifth legs are usually biramous in scolecitrichids but typically uniramous, although sometimes with rudimentary endopods, in phaennids. Bradford *et al.* (1983) commented that the details of these armature elements on the maxilla are sometimes difficult to observe and should be confirmed by very careful re-examination.

Although some aspects of the diagnosis of the Phaennidae are in doubt (Ohtsuka *et al.*, 1998), this family is more robustly defined as a result of Bradford's insight, and there is no longer any cause for confusion, other than inadequate or in-

accurate data, between phaennids and related families. The boundaries of the Scolecitrichidae, however, remain an unresolved problem. Even in 1973, Bradford noted that, according to published data, several species of Scolecitrichidae appeared not to conform to her new definition, including species of *Parascaphocalanus* Brodsky, 1955, *Racovitzanus* Giesbrecht, 1902 and *Scolecithricella* Sars, 1902. This problem is exacerbated by the poorly defined boundaries of related families, such as the Tharybidae and Diaixidae, and by the establishment of the Parkiidae, a family based on autapomorphies and proposed without due phylogenetic analysis. In addition, both the Scolecitrichidae and Tharybidae have served as receptacles for taxa excluded from other families, such as the Phaennidae.

The problem of the boundaries between these families is highlighted by taxa, such as *Xantharus* Andronov, 1981, *Rythabis* Schulz, 1995, *Cenognatha* and *Neoscolecithrix*, that apparently exhibit a mix of character states typical of two existing families. Andronov (1981) attributed *Xantharus* to the Phaennidae but Bradford *et al.* (1983) stated that the presence of only vermiform sensoriform setae on the endopod of the maxilla of *Xantharus* would preclude it from the family Phaennidae as they defined it. Vyshkvarzeva (1989) excluded *Xantharus* from the Phaennidae but Ferrari & Markhaseva (1996) retained it. Detailed re-examination of *Xantharus formosus* Andronov, 1981 by Ohtsuka *et al.* (1998) demonstrated errors in the original description, for example the presence of 3 vermiform and 5 brush-like sensoriform elements on the maxilla rather than 7 vermiform sensoriform elements as reported by Andronov (1981). In addition, a second species, *Xantharus renatehaasae* Schulz, 1998, was described as having 1 unmodified seta, plus 3 vermiform and 5 brush-like sensoriform elements on the maxillary endopod. *Xantharus* is not a phaennid. Schulz (1998) placed *Xantharus* in the Scolecitrichidae and we follow him here. The genus *Rythabis*, established in the Tharybidae (Schulz & Beckmann, 1995), is tentatively treated here as a member of the

Scolecitrichidae s.l. because it lacks robust synapomorphies with the core taxa of the Tharybidae (considered here to comprise only three genera, *Tharybis* Sars, 1902, *Undinella* Sars, 1900 and *Parundinella* Fleminger, 1957 which share an enlarged maxillulary arthrite plus a reduced maxillulary palp). The four families, Scolecitrichidae, Tharybidae, Diaixidae and Parkiidae, are in urgent need of comprehensive phylogenetic revision and actions taken here are temporary, pending such revision.

The first step in such a revision is the production of accurate morphological data on key taxa and the recent redescriptions of *Xantharus* (c.f. Schulz, 1998) and *Tharybis* (c.f. Ohtsuka *et al.*, 1998) have provided a new perspective. In particular, it is now clear that a total of nine setal elements on the maxillary endopod was probably the plesiomorphic state for the whole of the scolecitrichid/phaennid group of families. Species retaining all nine elements are present in a range of genera attributed to the Phaennidae, Scolecitrichidae and Tharybidae (including *Brachycalanus* Farran, 1905, *Grievella* Ferrari & Markhaseva, 2000, *Landrumius* Park, 1983, *Rythabis* and *Tharybis*) as well as in *Neoscolecithrix*. The families Diaixidae, Scolecitrichidae, Tharybidae and Parkiidae all share the apomorphic transformation of 8 of these 9 setal elements into 3 vermiform + 5 brush-like sensoriform setae. The ninth element may be modified into a small sensoriform seta or can remain unmodified, but most commonly it is lost. The presence of the 3+5 pattern is, therefore, of no value in distinguishing between members of this group of four nominal families, as it is symplesiomorphic to the group.

The family Scolecitrichidae contains a central core of eighteen genera, and the great majority of species belong to this recognisable crown group. The crown group can be defined on the basis of the following synapomorphies: (1) maximum of 4 setae on proximal praecoxal endite of maxilla (apomorphic state=fifth seta lost), (2) third syncoxal endite of maxilliped represented by a single setal element, usually a brush-like sensori-

form seta (apomorphic state=loss of other 2 setae). It comprises the following eighteen genera: *Amallothrix* Sars, 1925, *Archescocleithrix* Vyshkvartzeva, 1989, *Heteramalla* Sars, 1907, *Lophothrix* Giesbrecht, 1895, *Macandrewella* A. Scott, 1909, *Mixtocalanus* Brodsky, 1950, *Parascaphocalanus*, *Pseudoamallothrix* Vyshkvartzeva, 2000, *Puchinia* Vyshkvartzeva, 1989, *Racovitzanus*, *Scaphocalanus* Sars, 1900, *Scolecithri-cellula*, *Scolecithrix* Brady, 1883, *Scolecitrichopsis* Vyshkvartzeva, 2000, *Scolecocalanus* Farran, 1936, *Scopalatum* Roe, 1975, *Scottocalanus* Sars, 1905, and *Undinothrix* Tanaka, 1961. These character states are not shared by the genera *Neoscolecithrix*, *Cenognatha*, *Rythabis*, *Falsilandrumius* Vyshkvartzeva, 2001, *Grievella*, *Landrumius* and *Xantharus*. All seven of these genera, *Neoscolecithrix* included, may be considered as parts of the family Scolecitrichidae complex and they may represent early offshoots of the lineage leading to the crown group Scolecitrichidae.

Uncertainty over the classification of *Neoscolecithrix* and the other scolecitrichids is generated partly because the family, as currently defined, may be paraphyletic. The validity of the families Tharybidae, Diaixidae and Parkiidae and their phylogenetic relationships with the Scolecitrichidae are unresolved. One or more of these three families may have been derived from an ancestor within the Scolecitrichidae. The only way to resolve these relationships and to test the validity of the family level taxa is through a comprehensive phylogenetic analysis, which should include all genera currently attributed to these four families, plus the Phaennidae and one or more potential out-groups lacking modified sensoriform setal elements on the maxilla, from the superfamily Clausocalanoidea.

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