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A new interstitial genus and species of Acrocirridae from Okinawa-jima Island, Japan

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Abstract

A new interstitial acrocirrid, *Actaedrilus yanbarensis* **gen et. sp. nov.**, is described from Okinawa-jima Island, Japan. Individuals of the new genus and species were collected from the interstices of subtidal coarse sand (about 1 m depth). The new genus is comprised of the new species and *A. polyonyx* (Eliason, 1962) comb. nov. and it is characterized by the presence of two pairs of long branchiae, non-retractile head, minute body, and short club-shaped palps. We infer the phylogenetic position of *A. yanbarensis* gen. et sp. nov. within Acrocirridae using five gene markers (COI, 16S, 18S, 28S, Cyt B).

Keywords: *Acrocirrus*, Annelida, *Macrochaeta*, Pacific Ocean, Polychaeta, Ryukyu Islands

Introduction

Acrocirridae Banse, 1969 (suborder Cirratuliformia) includes nine genera and 43 described species distributed from the intertidal zone to the deep-sea (Magalhães and Bailey-Brock 2012; Martínez et al. 2019). Most acrocirrids are benthic, but some of the genera are known to be pelagic (Osborn and Rouse 2011). Previous molecular phylogenetic studies showed that acrocirrids are split into two main clades (*Acrocirrus–Macrochaeta* clade and *Flabelligena*–swimming acrocirrids clade) (Osborn and Rouse 2010, 2011).

The former clade comprised of *Acrocirrus* Grube, 1873 and *Macrochaeta* Grube, 1850 shares many characters such as the absence of the cephalic hood, nonretractile head, paired branchiae, nephridiopore papillae on segment 3, trunk divided into thoracic and abdominal regions, and spinous capillary notochaetae. On the other hand, the two genera are only distinguished by their combination of characters (See Table 1). These include the insertion and length of the palps, the size of the body, and the number of segments (Martínez et al. 2019). Because the definitions of these characters are not always clear and several species might possess intermediate combinations of these states, a revision of both genera is necessary in the future (Martínez et al. 2019). So far, thirteen *Acrocirrus* species and twelve *Macrochaeta* species are described but only four species, all belonging to *Acrocirrus* Grube, 1873, have been reported from Japanese waters (Okuda 1934; Imajima 2009).

During a joint survey to investigate the interstitial fauna at Okinawa-jima Island, the first author found individuals of *Macrochaeta*-like species. Our integrative approach combining morphology and molecular phylogenetics concludes that this species belongs to a new genus.

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Material and Methods

Coarse sand was sampled by hand in three sites in Okinawa-jima Island, Ryukyu Islands, Northwest Pacific Ocean (Fig. 1): Akasaki Beach (26.819 N, 128.315 E); Fukuchigawa Marine Park (26.630 N, 128.158 E); Okuma Beach (26.746 N, 128.171 E). The specimens were extracted using a 32 µm opening mesh net with seawater, and preserved in 70 % ethanol or fixed with a 10 % formalin solution in seawater. The specimens were sorted, photographed, and examined in detail with a Nikon SMZ18 dissecting microscope, and whole-mounted and observed by an OLYMPUS BX51 compound microscope. The specimens used for scanning electron microscope (SEM) observations were washed in deionized water or PBS buffer and dehydrated in a graded ethanol series, dried in a critical-point dryer (HITACHI HCP-1) using liquid CO_2, and coated with gold in an ion sputter (HITACHI E-1045). Observations were conducted using a HITACHI S-3000N scanning microscope. Materials have been deposited in the Tsukuba Research Departments of the National Museum of Nature and Science (**NSMT**) and Invertebrate Collection of the Hokkaido University Museum (**ICHUM**).

TABLE 1. A comparative table of three genera of Acrocirridae based on Okuda (1934)*, Imajima (1963)*, Banse (1978)*, Santos and Silva (1993)*, and Martínez et al. (2019). *These references include descriptions of longest or smallest species of the genera *Acrocirrus* and *Macrochaeta*.

	Actaedrilus **gen. nov.**	***Acrocirrus*** **Grube, 1873**	***Macrochaeta*** **Grube, 1850**
Body length	minute (< 0.5 cm)	large (1.5–7.8 cm)	minute (0.3–2.0 cm)
Palp bases	close together	separated	close together
Palps	short, club shaped	long, conical	short, conical or club shaped
Branchiae	2 pairs	4 pairs	3–6 pairs
Thoracic region	indistinct	segment 1–12	variable number of segments
Parapodia	reduced	developed	reduced
Notochaetae	spinous capillary	spinous capillary	spinous capillary
Neurochaetae	compound	compound or simple hook	compound, pseudo compound or simple hook
Eyes	absent	present or absent	present or absent

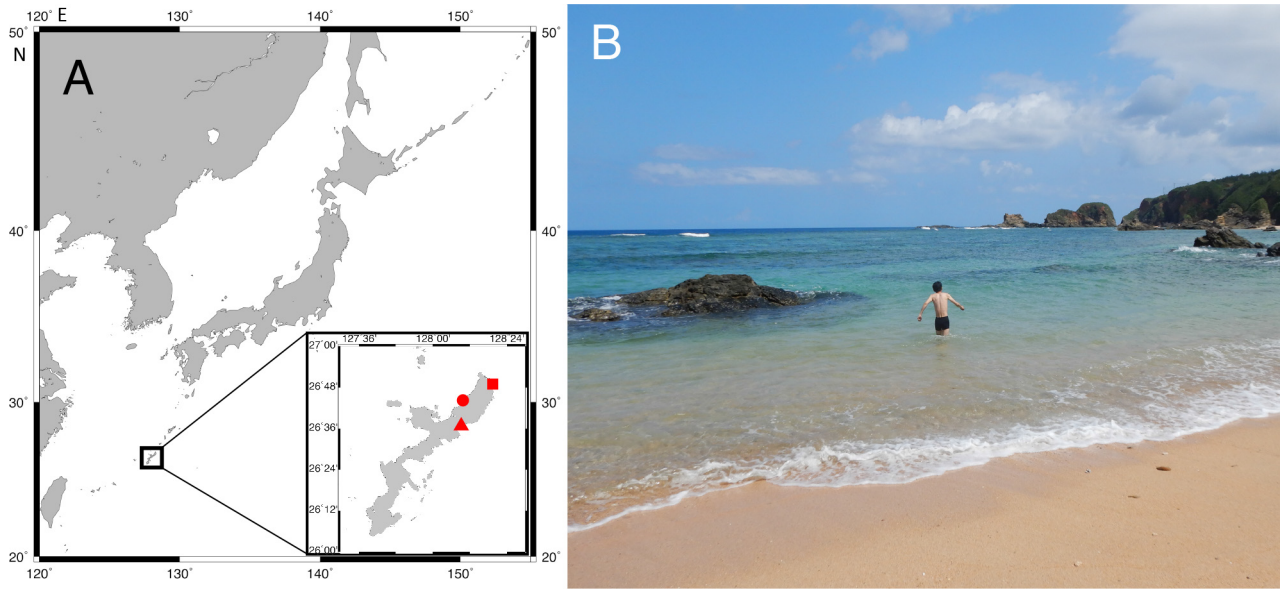

FIGURE 1. Sampling sites of *Actaedrilus yanbarensis* gen. et sp. nov. A, sampling locations. Symbols: a circle indicates Okuma Beach; a square indicates Akasaki Beach (type locality); a triangle indicates Fukuchigawa Marine Park. B, the landscape of a sampling site, Akasaki Beach (type locality).

Genomic DNA was extracted from a fragment of the paratype (approximately half of the body) (NSMT-Pol P-807) following the methods in Jimi & Fujiwara (2016). The cytochrome *c* oxidase subunit I (COI), 16S rRNA (16S), 18S rRNA (18S), 28S rRNA (28S), cytochrome b (Cyt B) genes were amplified and sequenced with the following primer sets: polyLCO (5'-GAYTATWTTCAACAAATCATAAAGATATTGG-3') and polyHCO (5'-TAMACTTCWGGGTGACCAAARAATCA-3') (Carr et al. 2011); 16SarL (CGCCGTTTATCAAAAACAT) and 16SbrH (CCGGTCTGAACTCAGATCACGT) (Palumbi et al. 1991); mitchA (CAACCTGGTTGATCCTGCCAGT) and mitchB (TGATCCTTCCGCAGGTTCACCTAC) (Medlin et al. 1988); and LsudiF (ACCCGCTGAATTTAAGCATA) and D3aR (ACGAACGATTTGCACGTCAG) (Lenaers et al. 1989); 424F (GGWTAYGTWYTWCCWTGRGGWCARAT) and 876R (GCRTAWGCRAAWARRAARTAYCAYTCWGG) (Boore & Brown 2000). The newly obtained sequences have been deposited in the DDBJ/EMBL/GenBank (LC543642, COI gene, 582 base pairs (bp); LC545955, 16S gene, 529 bp; LC545956, 18S gene, 1648 bp; LC545957, 28S gene, 1080 bp; LC545958, Cyt B gene, 404 bp). The comparative sequences were retrieved from Osborn and Rouse (2010). All sequences were aligned using MAFFT ver. 7.205 under the E-INS-i strategy (Katoh and Standley 2013). Alignment-ambiguous positions were removed using trimAL under the gappyout strategy (Capella-Gutiérrez et al. 2009). The trimmed sequences of the five genes, COI (576 bp), 16S (505 bp), 18S (1855 bp), 28S (999 bp), Cyt B (364 bp) were concatenated by using Kakusan (Tanabe 2007), which recommended a GTR+G evolutionary model for each of the genes. A phylogenetic tree was constructed using maximum likelihood (ML) method in the program RAxML-VI-HPC (Stamatakis 2006). The robustness of the ML tree was evaluated by 1,000 bootstrap pseudo-replicates (-f option). Bayesian Inference (BI) analysis was conducted using Mr.Bayes 3.2.2 (Ronquist et al. 2012), with Markov chains of 10 million generations. Model choice for each partition was also based on the Kakusan results. Run convergence was analyzed using Tracer v1.6 (Rambaut et al. 2018); the first 1 million generations trees were discarded as burn-in.

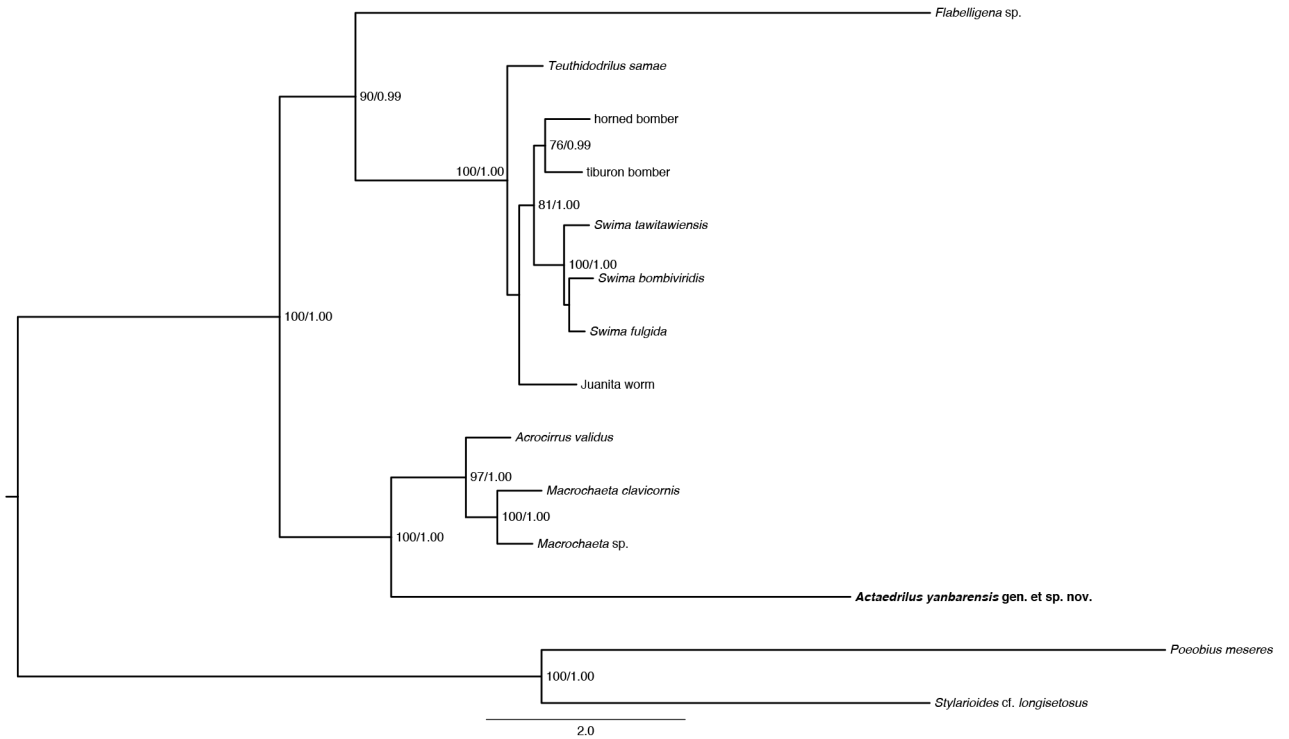

FIGURE 2. Maximum-likelihood phylogenetic tree of Acrocirridae based on COI, 16S, 18S, 28S, Cyt B sequences. *Stylarioides* cf. *longisetosus* and *Poeobius meseres* were used as an 'outgroup' for the rest of the acrocirrids. Bootstrap support values higher than 50% are indicated on each branch (left). Posterior probability values are also indicated (right).

Results

Molecular phylogenetic analysis

The topologies recovered by ML and BI analyses were identical. The monophyly of Acrocirridae was inferred with maximum support values (100% bootstrap support [BS], 1.00 posterior probability [PP]), and the two main clades, the *Acrocirrus-Macrochaeta* clade and the *Flabelligena*–swimming acrocirrids clade, were also inferred with high support values (97 % BS, 1.00 PP; 90% BS, 0.99 PP) as in the previous studies (Osborn and Rouse 2010,2011). The *Macrochaeta*-like species collected in this study, henceforth called *Actaedrilus yanbarensis* gen. et sp. nov., was sister to the *Acrocirrus-Macrochaeta* clade with maximum support values (100% BS; 1.00 PP) within Acrocirridae (Fig. 2).

Systematics

Family Acrocirridae Banse, 1969

Genus *Actaedrilus* gen. nov.
[New Japanese name: chibi-kumanoasituki-zoku]
(Figures 3–5)

Composition. *Actaedrilus yanbarensis* gen. et. sp. nov. (type species), *A. polyonyx* (Eliason, 1962).

Diagnosis. Benthic Acrocirridae. Body cylindrical with 25 segments, minimum (< 3.4 mm in length). Prostomium heart shaped, without eyes. Cephalic hood absent, head non retractile. Peristomial palps short, club shaped, with bases separated by at least the width of the palps. Branchiae two pairs, present on segments 2 and 3. Boundary between thoracic and abdominal segments indistinct. Epidermis with a variable coverage of papillae. Parapodia reduced, without associated papillae. Notochaetae spinous capillary. Neurochaetae compound.

Etymology. The new genus-group name (masculine) derives from the Latin *Acta* (seashore) + Greek *drilus* (worm), referring to the habitat of the type species.

Remarks. This genus closely resembles *Macrochaeta* in having a minute body, non-retractile head, short palps, spinous capillary notochaetae, and compound neurochaetae. However, the molecular analyses based on five genes (Fig. 2) clearly distinguishes it from the *Acrocirrus–Macrochaeta* clade. Morphologically, the new genus differs from *Acrocirrus* and *Macrochaeta* by having two pairs of branchiae (See Table 1). The type species of *Macrochaeta*, *M. clavicornis* (M. Sars, 1835), is contained in the molecular tree and has four pairs of branchiae. This justifies isolating the new species from the genus *Macrochaeta*. In addition to the new species, *Macrochaeta polyonyx* Eliason, 1962, the only species with two pairs of branchiae in the genus, should be attributed to *Actaedrilus* as *Actaedrilus polyonyx* comb. nov. However, the gene sequences of *A. polyonyx* have not been reported and no species form a clade with the new species in the molecular tree of the present study. A taxonomic revision of *Acrocirrus*, *Actaedrilus*, and *Macrochaeta* based on further molecular phylogenetic analysis is necessary to more accurately define the new genus.

***Actaedrilus yanbarensis* gen. et sp. nov.**
[New Japanese name: chibi-kumanoasitsuki]
(Figures 3–5)

Material examined. Holotype: NSMT-Pol H-806, Akasaki Beach, 1 m depth, 14 May 2019, collected by NJ, observed using a compound microscope. Paratypes: NSMT-Pol P-807, four specimens, collection data is the same as that of the holotype; ICHUM-6079, observed using a compound microscope, Akasaki Beach, 10 specimens, 18 March 2020, collected by NJ, observed using the SEM; NSMT-Pol P-808, four specimens, Fukuchigawa Marine Park, 1 m depth, 14 May 2019, collected by NJ, observed using the compound microscope; NSMT-Pol P-809, two specimens, Okuma Beach, 1 m depth, 14 May 2019, collected by NJ, observed using

the compound microscope; ICHUM-6080, two specimens, Okuma Beach, 1 m depth, 14 May 2019, collected by NJ, observed using the compound microscope and SEM.

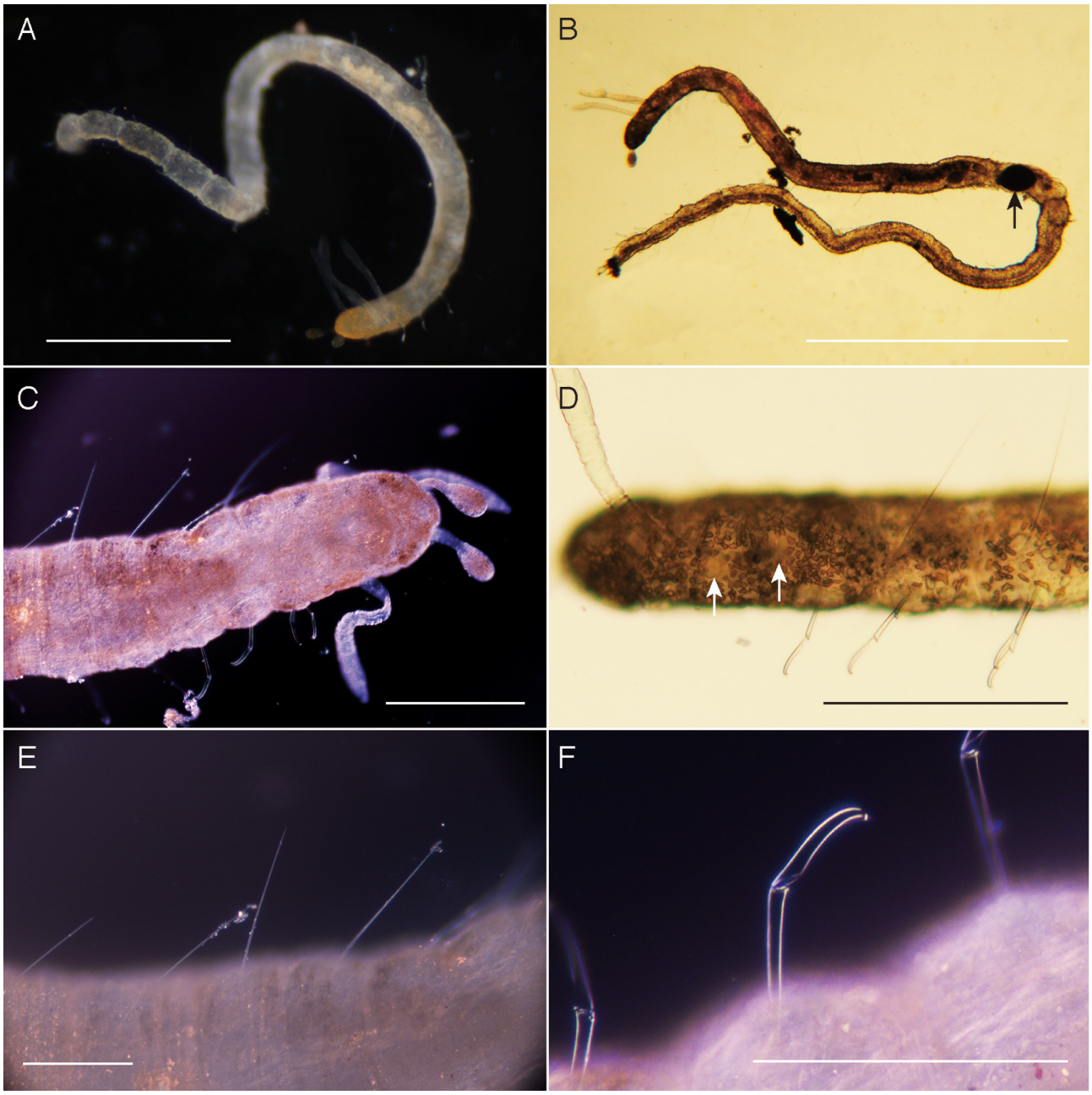

FIGURE 3. *Actaedrilus yanbarensis* gen. et sp. nov. A, C, E–F, paratypes (NSMT-Pol P-809); B, D, holotype (NSMT-Pol H-808). A, whole body, live specimen. B, whole body, live specimen. C, anterior end, dorsal side, live specimen. D, anterior end, lateral side, live specimen. E, notochaeta. F, neurochaeta. Scale bars: A, 500 µm; B, 1 mm; C–D, 200 µm; E–F, 100 µm. Black arrow indicates an egg. White arrows indicate position of branchiae.

Description of holotype (variation amongst paratypes indicated in parentheses). Posteriorly incomplete fragment, 3.3 mm in length (2.9–3.4 mm, n=4), 83 µm in width (without chaetae, at widest chaetiger) (80–82 µm, n=4), 21 chaetigers (not included 3 achaetous segments) (18–20 chaetigers, n=4, posterior end lost). Body small, cylindrical, yellowish in life (Fig. 3A–3D), whitish after fixation, surface papillated. Body papillae dispersed on entire body (Figs 4, 5), each papilla 5 µm long (5 µm, n=4, measured on SEM), not arranged in transverse rows, digitate, with presumably sensory terminal cilia (Fig. 5B). Pedunculate papillae absent. Prostomium heart shaped, dorsally covering part of the peristomium (= segment 1), eyes absent. Peristomium visible dorsally in part, visible ventrally. Palps on anterior margin of prostomium, one pair, club

shaped, arising 50 μm apart (49–50 μm, n=4), papillae concentrated around palp scar (Fig. 5D). Branchiae two pairs, present on achaetous segments 2–3 (Figure 4A–4C), anterior one as long as posterior one or slightly shorter (314 μm, n=1). Nuchal organs present dorsally (Fig. 4), one papilla present below. Frontally sensory ciliary pits present ventral side of prostomium. Nephridiopore papillae situated below of 2nd pair of branchiae on segment 3, rounded (Fig. 4A, 4B). Parapodia reduced, without associated papillae. Neurochaetae present from segment 4. Notochaetae present from segment 5.

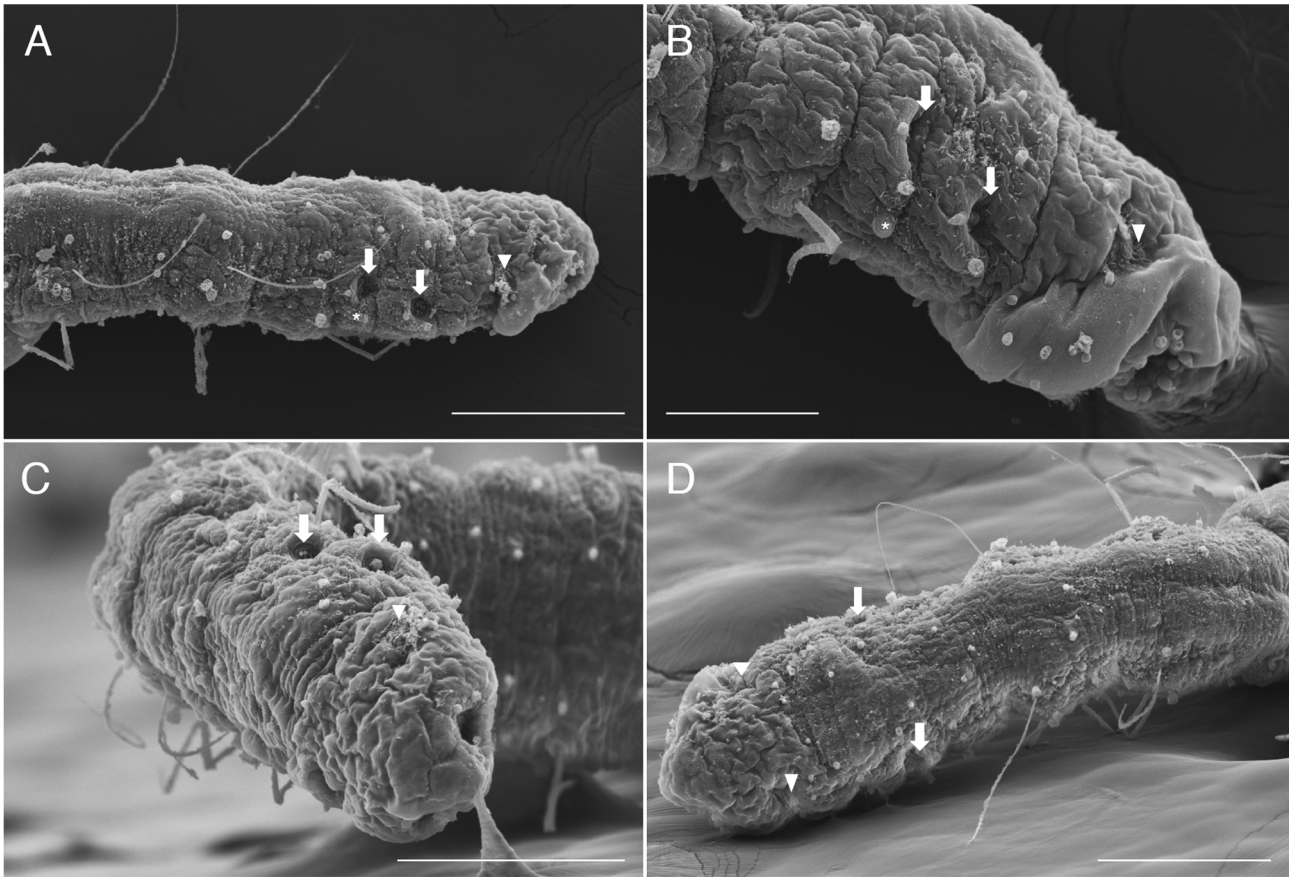

FIGURE 4. Scanning electron micrographs of *Actaedrilus yanbarensis* gen. et sp. nov., paratype (ICHUN-6079). A, anterior end, lateral side. B, same, lateral side. C, same, frontal side. D, same, dorsal side. White arrows indicate branchial scars. White arrows heads indicate nuchal organs. Asterisks indicate nephriodipore papillae. Scale bars: A, C–D, 100 μm; B, 50 μm.

Notochaetae capillaries appear smooth using compound microscope but show spine-like ridges using SEM (Figs 3E, 5E), one notochaeta per fascicle until last two chaetigers, two notochaetae per fascicle on last two chaetigers. Neurochaetae compound (Figs 3F, 5F), blades sickle shaped, one or two neurochaetae per fascicle. Posterior end unknown.

One egg (one, n=4) present in middle segment, 166 μm diameter (145–155 μm, n=4).

Etymology. This species is named after the type locality (yanbaru = north area of Okinawa-jima Island).

Variation. No morphological difference recognized among specimens of three localities.

Sequence. Determined from paratype (NSMT-Pol P-809): LC543642, COI gene, 582 base pairs (bp); LC545955, 16S gene, 529 bp; LC545956, 18S gene, 1648 bp; LC545957, 28S gene, 1080 bp; LC545958, Cyt B gene, 404 bp.

Remarks. The new species has one or two neurochaeta per bundle, in contrast to *Actaedrilus polyonyx* (Eliason, 1962) with more than two neurochaetae per bundle.

In addition, we also present the new species' morphological differences from the four *Acrocirrus* species known from Japan (Okuda 1934; Imajima 2009): (*A. heterochaetus* Annenkova, 1934, *A. muroranensis* Okuda, 1934, *A. uchidai* Okuda, 1934, *A. validus* Marenzeller, 1879): *i*) neurochaetae from chaetiger 1, *ii*) 1–2 neurochaetae per bundle, *iii*) upper face of prostomium is not ridged.

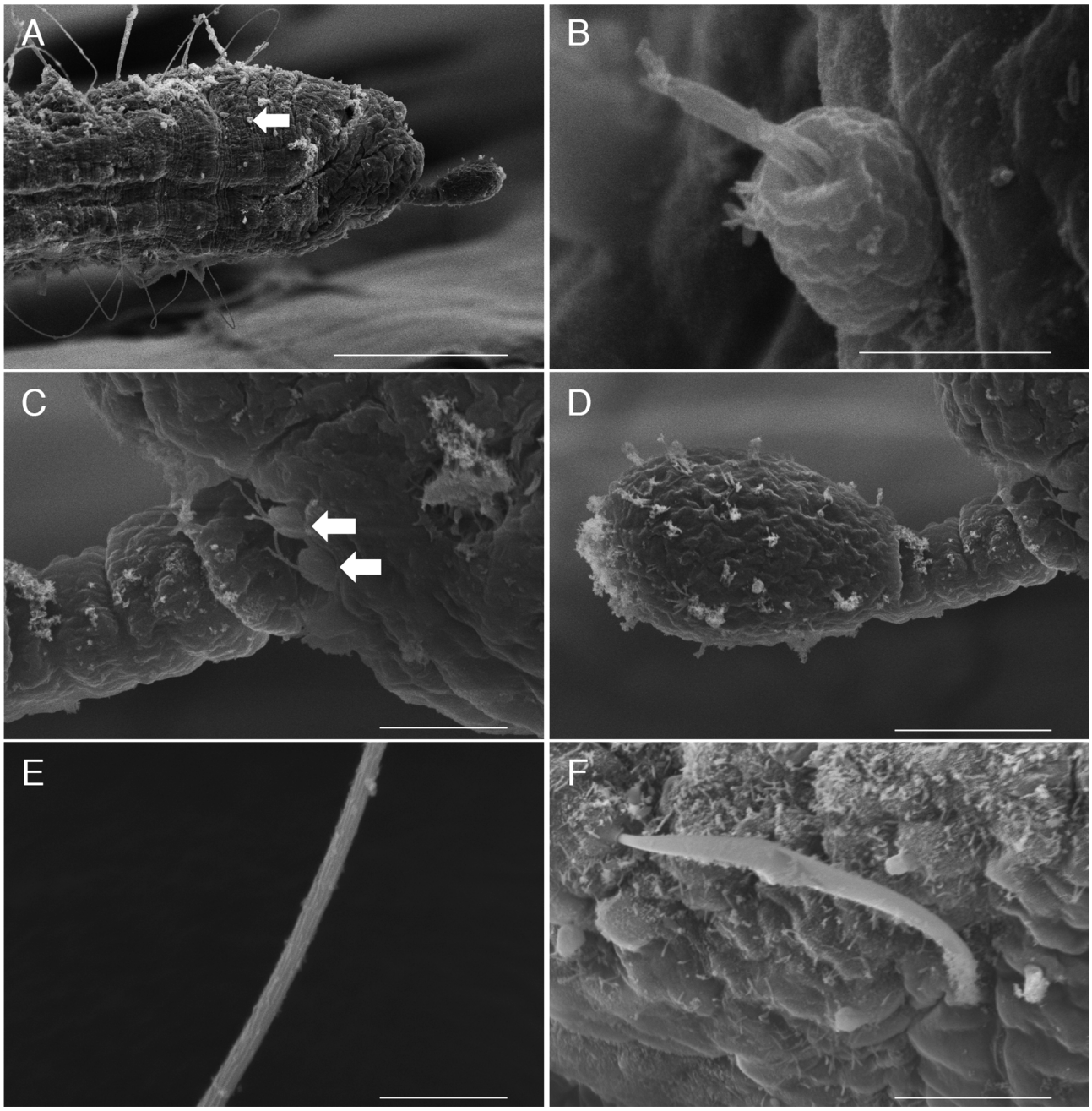

FIGURE 5. Scanning electron micrographs of *Actaedrilus yanbarensis* gen. et sp. nov., paratypes (ICHUM-6080). A, anterior end, dorsal side. B, body papilla. C, base of palp. D, palp. E, notochaeta. F, neurochaeta. White arrows indicate body papillae. Scale bars: A, 100 μm; B, 3 μm; C, 20 μm; D, 10 μm; E, 5 μm; F, 20 μm.

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