



Unraveling a 70-Year-Old Taxonomic Puzzle: Redefining the Genus *Ikedosoma* (Annelida: Echiura) on the Basis of Morphological and Molecular Analyses

Authors: Tanaka, Masaatsu, Kon, Takeshi, and Nishikawa, Teruaki

Source: Zoological Science, 31(12) : 849-861

Published By: Zoological Society of Japan

URL: <https://doi.org/10.2108/zs140155>

BioOne Complete (complete.BioOne.org) is a full-text database of 200 subscribed and open-access titles in the biological, ecological, and environmental sciences published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Complete website, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Complete content is strictly limited to personal, educational, and non - commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Unraveling a 70-year-old Taxonomic Puzzle: Redefining the Genus *Ikedosoma* (Annelida: Echiura) on the Basis of Morphological and Molecular Analyses

Masaatsu Tanaka*, Takeshi Kon, and Teruaki Nishikawa

Faculty of Science, Toho University, 2-2-1, Miyama, Funabashi, Chiba 274-8510, Japan

After a long-standing taxonomic confusion, the echiurid genus *Ikedosoma* Bock, 1942, endemic to Japan and surroundings, is redefined on the basis of morphological and molecular analyses of many new Japanese materials and some museum specimens. The re-examination of a syntype of *I. elegans* (Ikeda, 1904), the type species of the genus, first revealed that its oblique muscle layer is continuous throughout and never fasciculate between longitudinal muscle bands, unlike those described in the definitions that have prevailed for ca. 70 years, making this genus indistinguishable from *Listriolobus* Spengel, 1912. Two Japanese species of *Ikedosoma*, *I. elegans* and *I. gogoshimense* (Ikeda, 1904), which were thus redefined, had also been poorly defined in the past to the point of being nearly indistinguishable from each other, largely due to incomplete descriptions and poor collections. Molecular phylogenetic analyses using 18S and 28S ribosomal RNA, histone H3, and cytochrome c oxidase subunit I (COI) genes clearly confirmed the distinction between these two species, their monophyletic origin, and their distinction from *L. sorbillans* (Lampert, 1883). The genus *Ikedosoma* thus validated is morphologically distinguishable from *Listriolobus* by the absence of a rectal caecum. *Ikedosoma elegans* and *I. gogoshimense* also differ in the disposition of gonoduct pairs. The third known species, *I. qingdaoense* Li, Wang and Zhou, 1994, from Qingdao, North China, lacks information on oblique muscle layers, which makes even its generic affiliation uncertain.

Key words: Annelida, Echiura, Echiuridae, Thalamematinae, *Ikedosoma*, revision, taxonomy, molecular phylogeny

INTRODUCTION

For taxonomists, solving taxonomic puzzles is often more interesting than simply describing new species, although both processes undoubtedly contribute to our better understanding of biodiversity. Taxonomic puzzles, or *incertae sedis*, include uncertain taxonomic identities caused by various factors, ranging from incomplete original descriptions, to lack of name-bearing types, to subsequent misidentifications, to cryptic species issues. In the present study, we resolved a taxonomic puzzle in echiurans, mainly caused by incomplete descriptions and misinterpretations that have prevailed for ca. 70 years.

Echiurans (spoon worms) are a group of marine coelomate invertebrates, which present a cylindrical trunk and a nonretractable proboscis. There are ca. 165 known species of echiurans (Biseswar, 2012). This group has been ranked as a phylum since 1939 (for further details, see Fisher, 1946); however, recent molecular phylogenetic and phylogenomic analyses strongly indicate that these organisms belong to the phylum Annelida (McHugh, 1997; Struck et al., 2007, 2011; Kvist and Siddall, 2013; Weigert et al., 2014).

Echiurans are still awaiting taxonomic revision, as

exemplified in the revision by Nishikawa (2002) in which the order Heteromyota Fisher, 1946 and its only family Ikedidae Bock, 1942 were abolished for being established on misunderstood morphological peculiarities. Thus, echiurans are now divided into two orders: Echiuroinea Bock, 1942 (with two families: Echiuridae Quatrefages, 1847 and Bonelliidae Lacaze-Duthiers, 1858) and Xenopneusta Fisher, 1946 (with a single family: Urechidae Monro, 1927). *Ikeda taenioides* (Ikeda, 1904), the type species of the still valid genus *Ikeda* Wharton, 1913, is now included in the family Echiuridae; however, Nishikawa (2002) suggested its possible relationship with the family Bonelliidae. This suggestion has been validated using molecular methods (Lehrke, 2012; Goto et al., 2013), giving new insights into overall echiuran systematics.

Another taxonomic problem is related to the still less-known echiurid genus *Ikedosoma* Bock, 1942, with three described species, endemic to Japanese and adjacent waters. As described below in the Historical Background section, this problem arises from the fact that this genus was established exclusively on the basis of incomplete descriptions of the species concerned.

Here, we revise the definition of the genus *Ikedosoma* and its two Japanese species on the basis of detailed examination of a syntype and many newly collected specimens. We also conducted molecular phylogenetic analyses using nuclear 18S ribosomal RNA (hereafter, 18S), 28S ribosomal RNA (28S), histone H3 (H3), and the mitochondrial

* Corresponding author. Tel. : +81-47-472-5491;
Fax : +81-47-472-5491;
E-mail : echiura.sipuncula@gmail.com
doi:10.2108/zs140155

cytochrome *c* oxidase subunit I (COI) genes. Molecular information has been shown to be a powerful tool for the delimitation of species and a reliable support for phylogenetic hypotheses. This did hold in our present taxonomic studies of echiurans with fewer diagnostic morphological characters.

HISTORICAL BACKGROUND AND TAXONOMIC PROBLEMS

Three species belong to the genus *Ikedosoma*: *I. elegans* (Ikeda, 1904) and *I. gogoshimense* (Ikeda, 1904) (so far recorded from the Japanese coast) as well as *I. qingdaoense* Li, Wang and Zhou, 1994 (from Qingdao, North China). On the other hand, *I. pirotansis* Menon and DattaGupta, 1962 from Pirotan Island, Gulf of Kutch, India, is now included in the genus *Ikeda* (Nishikawa, 2002).

Ikeda's (1904) original descriptions of *I. elegans* (originally described as *Thalassema elegans*) and *I. gogoshimense* (as *T. gogoshimense*) were brief; however, the syntypes of the former were redescribed in detail by Ikeda (1907). Since its original and subsequent descriptions, *I. elegans* has not been fully described taxonomically, mainly due to a lack of further specimens. On the other hand, the internal morphology of *I. gogoshimense* remains uncertain; its original description only mentioned that the species "shows... an essential agreement with *Thalassema elegans*...", the agreement may be said to be complete... It therefore seems unnecessary to give a description of the anatomy" (Ikeda, 1904, p. 67); however, this description also noted the tendency to present more gonoducts in males than in females. Some differences in the habitus and ecology between these two species, mentioned in the original descriptions, will be considered below.

In his comprehensive taxonomic revision of echiurans, Bock (1942) established the genus *Ikedosoma* for *T. elegans* Ikeda, 1904 and placed it within the subfamily *Thalassematinae* Forbes and Goodsir, 1841 of Echiuridae. This reclassification was based on peculiarities regarding gonoduct number and arrangement in *T. elegans*. According to Ikeda's (1904, 1907) descriptions, up to 27 gonoducts could be observed; males usually had more gonoducts than females, and they were often clustered (e.g., two or more gonoducts gathering together). Soon afterward, Fisher (1946) considered it as a valid genus, and his "key to genera" explicitly described the genus *Ikedosoma* as having an oblique muscle layer fasciated between longitudinal muscle bands (LMB), typically like that observed in the genus *Ochetostoma* Rüppell and Leuckart, 1828. At that time, Fisher (1946) cited Ikeda's (1907, p. 50) description that "the circular muscle fibers form more or less regularly arranged transverse bundles," followed by the sentence that "This structure of the body wall closely approximates that of *Ochetostoma*..." (Fisher, 1946, p. 224). Therefore, it seems clear that Fisher regarded Ikeda's "transverse bundles" as oblique muscle fascicles, which we show to have been a misunderstanding in the present study. Fisher (1946) also transferred *T. gogoshimense* to the genus *Ikedosoma* on the basis of some similarities in the internal morphology between *T. gogoshimense* and *I. elegans*, as stated above. Following this, Fisher (1946) distinguished *Ikedosoma* from *Ochetostoma* mainly by the more and often clustered gonoducts (at least in male) in the former. Fisher also noted

the difference between the two genera in the position of the vascular ring vessel; however, the validity of this character remains uncertain to distinguish between the two genera. His amended definition of the genus *Ikedosoma*, as often lacking the vessel feature, has been followed by subsequent authors till date (Stephen and Edmonds, 1972; DattaGupta and Menon, 1976; Nishikawa, 1992; Edmonds, 2000).

Very recently, our re-examination of the *T. elegans* syntype deposited in the Zoological Collection of the University Museum, University of Tokyo (UMUTZ), has revealed that its oblique muscle layer is rather continuous, even between LMB, and never fasciculate, in contrast to Fisher's amended definition. Furthermore, according to Sato (1934), all the 18 specimens of *I. gogoshimense* he examined showed no sexual difference in the gonoduct number. Subsequently, *Ikedosoma* may not be distinguishable from *Listriolobus* Spengel, 1912, which also has a banded longitudinal muscle layer and a continuous oblique muscle layer and does not present sexual dimorphism in the gonoduct number (Fisher, 1949; Nishikawa, 2004). Therefore, the validity of *Ikedosoma* needs to be re-examined.

The brief original description of *I. gogoshimense* also remains contentious. In addition, the absence of name-bearing type specimens makes the existence of this species uncertain, despite which it has often been used for embryological and cytological studies (Sawada and Ochi, 1962; Ochi, 1963, 1976; Sawada and Noda, 1963; Sawada et al., 1975). In summary, the total number of gonoducts, if considered as a presumptive diagnostic feature, cannot be used for distinction between *I. gogoshimense* and *I. elegans* (six to 32 in the former and 13 to 27 in the latter); thus, the taxonomic distinction between these two species remains doubtful.

MATERIALS AND METHODS

Materials

From the UMUTZ echiuran collection, we examined a specimen of *T. elegans*, labeled as "Type specimen," which we assume corresponds to the "Specimen D" of the syntypes in Ikeda (1907), judging from its sex (female) and characteristic number and arrangement of gonoducts. The specimen was helpful for identifying the other five specimens of *I. elegans*, including two specimens long kept at our laboratory (one from the Takasu sandy flat, Okayama Pref., Seto Inland Sea and the other from a sandy flat of Ikarise Islet at the entrance of the Lake Hamana, Shizuoka Pref., Enshūnada Sea) and three newly collected specimens from the Ikarise in July 2012 and 2013 for morphological and molecular analyses (Fig. 1).

As described above, the taxonomic identity of *I. gogoshimense* remains unclear. Therefore, we collected a total of 41 individuals for morphological and molecular analyses during 2010 to 2013 from the type localities, Gogoshima Island in the Seto Inland Sea and Moroiso Inlet of Misaki in Sagami Bay, as well as from three other localities in the Seto Inland Sea (Ushimado and Takasu, Okayama Pref. and Hachi-no-higata, Hiroshima Pref.; Fig. 1). No inconsistencies were found after careful comparisons of their external appearance, including living coloration, ecology (particularly the size and shape of fecal pellets), and their internal structure, with the original description. These specimens were then identified as *I. gogoshimense*. We also examined 14 specimens deposited in the Toyama Science Museum (TOYA), Tohoku University Museum (TUM), National Museum of Nature and Science, Tsukuba (NSMT), as well as the ones long kept at our laboratory.

We also collected an individual of *Ochetostoma erythrogrammon* Rüppell and Leuckart, 1828 and two individuals of *Listriolobus*

sorbillans (Lampert, 1883) from Sesoko, Okinawa Island (26°38'N, 127°52'E) and Kabira Bay, Ishigaki Island (24°27'N, 124°08'E), Ryukyu Islands, respectively, for molecular analyses.

The collected individuals were first anesthetized with menthol. Small pieces were then taken from the proboscis and fixed with 99.5% ethanol for molecular analyses. The rest of the specimen

was fixed in ca. 10% seawater formalin and stored in 70% ethanol. All *Ikedosoma* specimens are deposited in NSMT and the remains at the Laboratory of Taxonomy, Toho University (LTTU).

We also aimed to examine the name-bearing type and other specimens of *I. qingdaoense*, which were described to be deposited in the Qingdao Marine Product Museum, China by Li et al.

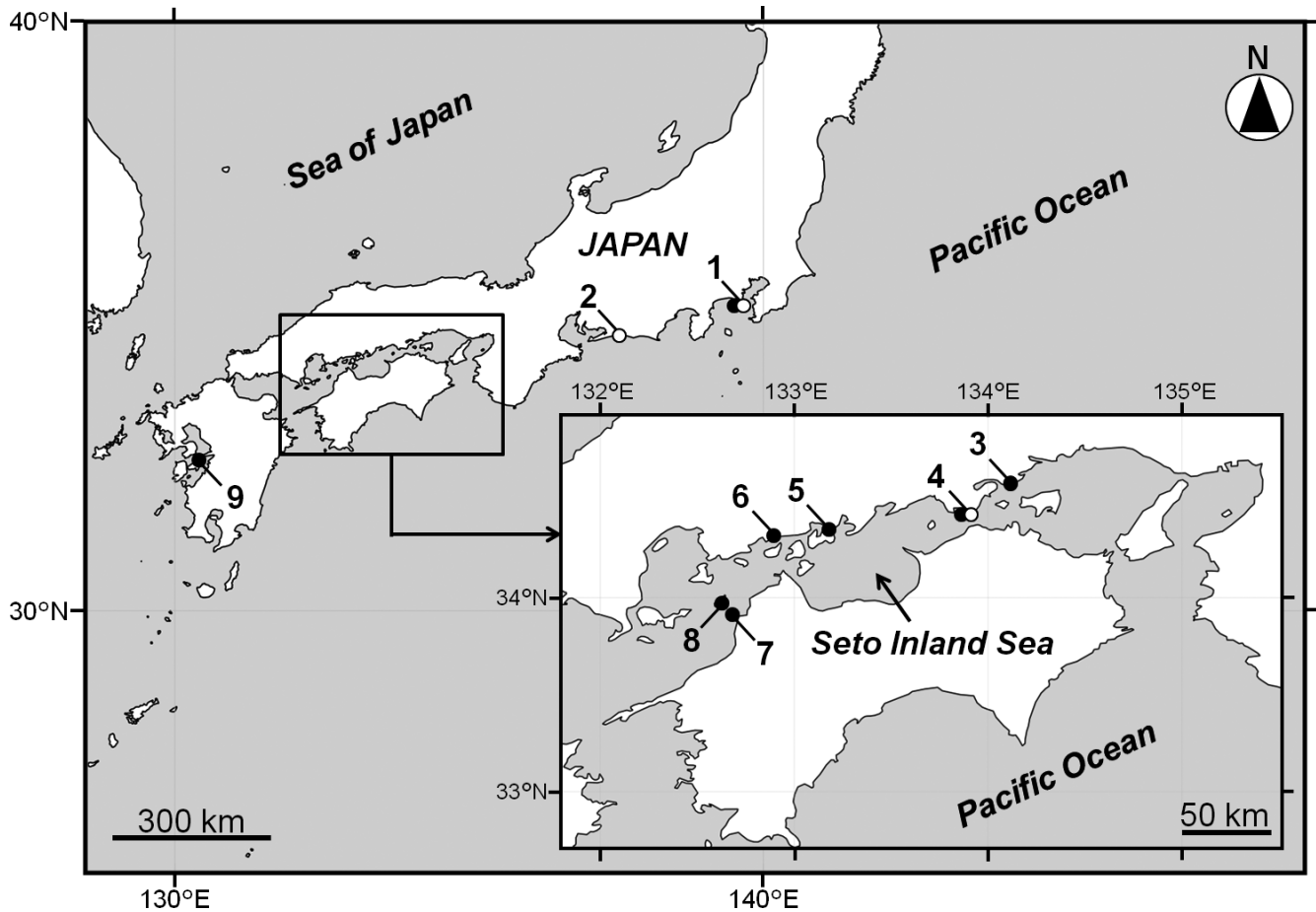


Fig. 1. Localities of *Ikedosoma elegans* (indicated by open circles) and *I. gogoshimense* (solid circles) used in the present study. Both species were recorded from Misaki (locality 1) and Takasu (4). Numbers indicate the localities as follows: 1, Misaki, Kanagawa Pref.; 2, Ikarise Islet, Shizuoka Pref.; 3, Ushimado, Okayama Pref.; 4, Takasu, Okayama Pref.; 5, Onomichi Bay, Hiroshima Pref.; 6, Hachi-no-higata, Hiroshima Pref.; 7, Gogoshima Island, Ehime Pref.; 8, Nakajima Island, Ehime Pref.; and 9, Ôikejima Island, Kumamoto Pref.

Table 1. List of PCR and cycle sequencing (CS) primers used in the present study for 18S, 28S, H3, and COI genes.

| Gene | Primer name | Primer sequence (in 5'–3' direction) | Direction | Reaction | Sources |
|------|-------------|--------------------------------------|-----------|----------|---------------------------|
| 18S | G01 | CACCTGGTTGATCCTGCCAG | Forward | PCR & CS | Saunders and Kraft (1994) |
| | G07 | AGCTTGATCCTTCTGCAGGTTACCTAC | Reverse | PCR & CS | Saunders and Kraft (1994) |
| | Echi_18S-1R | ACKACGAGCTTTTTRACTGCARC | Reverse | PCR & CS | Present study |
| | Echi_18S-2F | GGTAATWCCAGCTCCARTAG | Forward | PCR & CS | Present study |
| | Echi_18S-2R | GAGDTTYCCCGYGTGAGTC | Reverse | PCR & CS | Present study |
| 28S | Echi_18S-3F | GCTGAAACTTRAAGGAATTGACGGA | Forward | PCR & CS | Present study |
| | 28S D1F | ACCCSCTGAAYTTAAGCAT | Forward | PCR & CS | Colgan et al. (2003) |
| | 28S D3 | GACGATCGATTTGCACGTC | Reverse | PCR & CS | Vonnemann et al. (2005) |
| | 28S D2F | CCCGTCTTGAAACACGGACCAAGG | Forward | CS | Vonnemann et al. (2005) |
| | 28S C2R | ACTCTCTTCAAGTTCTTTTC | Reverse | CS | Vonnemann et al. (2005) |
| H3 | H3F | ATGGCTCGTACCAAGCAGACVGC | Forward | PCR & CS | Colgan et al. (1998) |
| | H3R | ATATCCTTRGGCATTRATRGTGAC | Reverse | PCR & CS | Colgan et al. (1998) |
| COI | Echi_cox1L | ACTCAACAAACCACAAGACATTGG | Forward | PCR & CS | Present study |
| | Echi_cox1H | TAKACYTCWGGRTGSCCAAARAATCA | Reverse | PCR & CS | Present study |
| | COI-E | TATACTTCTGGGTGTCCGAAGAATCA | Reverse | PCR & CS | Bely and Wray (2004) |
| | polyLCO | GAYTATWTTCAACAAATCATAAAGATATTGG | Forward | PCR & CS | Carr et al. (2011) |
| | polyHCO | TAMACTTCWGGGTGACCAAARAATCA | Reverse | PCR & CS | Carr et al. (2011) |

(1994) and Zhou et al. (2007). However, we have not succeeded in finding such a specimen, and its present whereabouts are unknown (H. Zhou, pers. comm.).

Morphological examination

Observations, dissections, and drawings were made using a stereoscopic microscope. The trunk length (TL) and proboscis length (PL) were measured using a digital caliper, and the number of LMB was counted. Trunk musculature was examined with the aid of a light box. The type of gametes found in the gonoducts was used to identify the specimens' sex. The general terminology used here follows that of Stephen and Edmonds (1972) and Nishikawa (2004).

DNA extraction, amplification, and sequencing

Total genomic DNA was extracted from the tissue samples using NucleoSpin Tissue (Macherey-Nagel) following the manufacturer's protocol. 18S (ca. 1800 bp), 28S (ca. 1000 bp), H3 (ca. 350 bp), and COI (ca. 700 bp) partial genetic sequences were amplified by polymerase chain reaction (PCR) with the primers listed in Table 1. Each PCR was performed in a 10- μ l reaction volume containing 2.2 μ l of distilled H₂O (Millipore), 5 μ l 2 \times Gflex Buffer (TaKaRa), 0.8 μ l of each primer (5 μ M), 0.2 μ l of Tks Gflex DNA polymerase (TaKaRa), and 1 μ l of template on LifeTouch Thermal Cycler (Bioer Technology) for 30–35 cycles, with the following thermal cycle profile: preheating at 94°C for 1 min, denaturing at 98°C for 10 s, annealing from 48°C to 54°C for 15 s, and extension at 68°C for 30 s. To confirm that amplifications were successful, 2- μ l aliquots of PCR products were visualized with electrophoresis on 1.5% TAE agarose gel stained with ethidium bromide for 30 min or more. Before sequencing, successful PCR products were cleaned using ExoStar (GE Healthcare), consisting of exonuclease I and alkaline phosphatase. Direct sequencing of the purified DNA products was performed using

the BigDye Terminator v3.1 Cycle Sequencing Kit in a 3130xl Genetic Analyzer (Life Technologies) or by Fasmac (Atsugi, Kanagawa, Japan). The obtained sequences were assembled and edited using ATGC (GENETYX). All sequences were deposited in DDBJ/EMBL/GenBank (accession nos. AB967985–968034).

Phylogenetic analyses

Additional Echiuridae and Urechidae sequences were obtained from DDBJ/EMBL/GenBank. Nearly all sequences extracted from GenBank were described by Goto et al. (2013). A total of 13 echiuran species were used for the present analyses: nine species of Thalassematinae of Echiuridae [*Arhynchite* (one species), *Listriolobus* (one species), *Thalassema* (one species), *Ikedosoma* (two species), *Ochetostoma* (four species)], and four species [Echiurinae of Echiuridae (one species) and Urechidae (three species)] as outgroups following Goto et al.'s (2013) tree topology. For further information, refer to Table 2.

The H3 and COI sequences were aligned using Mesquite Version 2.75 (Maddison and Maddison, 2011) taking into account each codon position. 18S and 28S sequences were aligned using MAFFT version 7 with L-INS-i (Kato et al., 2005; Kato and Standley, 2013) and subsequently trimmed using Gblocks ver. 0.91b with "With Half" allowed gap positions (Castresana, 2000). The final length of the aligned sequences was 1736 bp for 18S, 972 bp for 28S, 327 bp for H3, and 579 bp for COI.

We prepared five datasets (individual 18S, 28S, H3, and COI sequences, and a concatenated sequence of all of them) for analyses and set three partitions (first, second, and third codon positions) for H3 and COI or eight partitions (18S, 28S, and codon-specific positions of H3 and COI) for the concatenated sequence. Phylogenetic trees were constructed using maximum likelihood (ML) and Bayesian inference (BI). ML phylogenies were obtained

Table 2. List of species used for phylogenetic analyses in the present study with the registration number of the voucher specimens, collection locality or sources, and DDBJ/EMBL/GenBank accession numbers.

| Species | Abbreviation | Voucher | Locality or Sources | Accession no. | | | |
|-----------------------------------|--------------|-------------|----------------------------------|---------------|----------|----------|-----------|
| | | | | 18S | 28S | H3 | COI |
| <i>Arhynchite pugettensis</i> | — | — | Passamaneck and Halanych (2006) | AY210441 | AY210455 | — | — |
| <i>Ikedosoma elegans</i> | le-1 | NSMT-Ec 112 | Ikarise Islet, Shizuoka Pref. | AB967985 | AB967998 | AB968009 | AB968022 |
| <i>Ikedosoma elegans</i> | le-2 | NSMT-Ec 113 | Ikarise Islet, Shizuoka Pref. | AB967986 | AB967999 | AB968010 | AB968023 |
| <i>Ikedosoma elegans</i> | le-3 | NSMT-Ec 114 | Ikarise Islet, Shizuoka Pref. | AB967987 | AB968000 | AB968011 | AB968024 |
| <i>Ikedosoma gogoshimense</i> | lg-1 | NSMT-Ec 130 | Ushimado, Okayama Pref. | AB967988 | AB968001 | AB968012 | AB968025 |
| <i>Ikedosoma gogoshimense</i> | lg-2 | NSMT-Ec 133 | Takasu, Okayama Pref. | AB967989 | AB968002 | AB968013 | AB968026 |
| <i>Ikedosoma gogoshimense</i> | lg-3 | NSMT-Ec 154 | Gogoshima Island, Ehime Pref. | AB967990 | AB968003 | AB968014 | AB968027 |
| <i>Ikedosoma gogoshimense</i> | lg-4 | NSMT-Ec 131 | Takasu, Okayama Pref. | AB967991 | AB968004 | AB968015 | AB968028 |
| <i>Ikedosoma gogoshimense</i> | lg-5 | NSMT-Ec 138 | Hachi-no-higata, Hiroshima Pref. | AB967992 | — | AB968016 | AB968029 |
| <i>Ikedosoma gogoshimense</i> | lg-6 | NSMT-Ec 139 | Hachi-no-higata, Hiroshima Pref. | AB967993 | AB968005 | AB968017 | AB968030 |
| <i>Ikedosoma gogoshimense</i> | lg-7 | NSMT-Ec 116 | Misaki, Kanagawa Pref. | AB967994 | — | AB968018 | AB968031 |
| <i>Ikedosoma gogoshimense</i> | lg-8 | — | Goto et al. (2013) | AB771456 | AB771470 | AB771481 | AB771491 |
| <i>Listriolobus sorbillans</i> | Ls-1 | LTTU-Y098 | Kabira Bay, Ishigaki Island | AB967995 | AB968006 | AB968019 | AB968032 |
| <i>Listriolobus sorbillans</i> | Ls-2 | LTTU-Y099 | Kabira Bay, Ishigaki Island | AB967996 | AB968007 | AB968020 | AB968033 |
| <i>Listriolobus sorbillans</i> | Ls-3 | — | Goto et al. (2013) | AB771470 | AB771471 | AB771482 | AB771492* |
| <i>Ochetostoma erythrogrammon</i> | Oe-1 | LTTU-Y100 | Sesoko, Okinawa Island | AB967997 | AB968008 | AB968021 | AB968034 |
| <i>Ochetostoma erythrogrammon</i> | Oe-2 | — | Goto et al. (2013) | AB771458 | AB771472 | AB771483 | AB771493 |
| <i>Ochetostoma</i> sp. 1 | — | — | Goto et al. (2013) | AB771459 | AB771473 | AB771484 | — |
| <i>Ochetostoma</i> sp. 2 | — | — | Goto et al. (2013) | AB771460 | — | AB771485 | — |
| <i>Ochetostoma</i> sp. 3 | — | — | Goto et al. (2013) | AB771461 | — | AB771486 | AB771494 |
| <i>Thalassema owstoni</i> | — | — | Goto et al. (2013) | AB771462 | AB771474 | AB771474 | AB771495 |
| Outgroups | | | | | | | |
| <i>Echiurus echiurus</i> | — | — | Goto et al. (2013) | AB771455 | AB771469 | — | — |
| <i>Urechis caupo</i> | — | AToL000328 | Andrade et al. (2012) | JF509727 | JF509731 | JF509712 | JF509718 |
| <i>Urechis unicinctus</i> | — | — | Goto et al. (2013) | AB771464 | AB771476 | — | AB771497 |
| <i>Urechis</i> sp. 1 | — | — | Goto et al. (2013) | AB771465 | AB771477 | — | AB771498 |

* This sequence has been registered under the bivalve name of "*Basterotia* sp. RG-2012" in DDBJ/EMBL/GenBank, but it obviously came from *Listriolobus sorbillans* (see Goto et al., 2013, Table S1).

using the partitioned method as implemented in RAxML-VI-HPC (Stamatakis, 2006) and its graphical interface raxmlGUI version 1.3 (Silvestro and Michalak, 2012). As recommended in the RAxML-VI-HPC manual (Stamatakis, 2006), the general time reversible model with sites following a discrete gamma distribution (GTR + Γ ; Tavaré, 1986; Yang, 1993) for each partition was used without incorporating a proportion of invariant sites. Rapid bootstrap (BS) analysis was conducted with 1000 replicates ($-f$ a option). BI and Bayesian posterior probabilities (BPP) were estimated using MrBayes version 3.2.2 (Altekar et al., 2004; Ronquist et al., 2012). The substitution models for each partition were calculated on the basis of the Bayesian Information Criterion (Schwarz, 1978), as implemented in Kakusan4 (Tanabe, 2011). The selected models were as follows: for 18S, K2P model (Kimura, 1980) + Γ ; for 28S and the third codon of COI, GTR + Γ ; for the first and second codon of H3, JC69 model (Jukes and Cantor, 1969) + homogeneous; for the third codon of H3, HKY85 model (Hasegawa et al., 1985) + Γ ; for the first codon of COI, SYM model (Zharkikh, 1994) + Γ ; for the second codon of COI, F81 (Felsenstein, 1981) + Γ . Two independent runs for four Markov chains were performed over 10 million generations. The trees were sampled every 100 generations. Based on the parameter estimates and convergence estimated using Tracer version 1.5 (Rambaut and Drummond, 2009), the first 10,001 trees were discarded as burn-in. A consensus of sampled trees was computed, and the posterior probability for each interior branch was obtained. Pairwise genetic distances [\pm standard deviation (SD)] were calculated on the basis of the COI sequence using uncorrected p -distance and Kimura's two parameter (K2P) model (Kimura, 1980), as implemented in MEGA5.2 (Tamura et al., 2011).

RESULTS

Morphological examination

Detailed examination of the internal morphology of the present materials clearly revealed that both *I. elegans* and *I. gogoshimense* had a continuous oblique muscle layer, instead of forming distinct fascicules, even between LMB. In addition, they completely lacked the interbasal muscle and rectal caecum. Tables 3 and 4 show the anomalies found in the number and arrangement of gonoducts from the usual patterns (six postsetal pairs for *I. elegans* and three postsetal pairs for *I. gogoshimense*): e.g., the six usual pairs present plus two additional gonoducts, one added to the left of the fourth pair and another added to the right of the fifth pair, without the left one of the sixth gonoduct [indicated as "L4(2)R5(2)L6(0)"]. The three usual postsetal pairs were

also often present, but with one additional gonoduct posterior to the third pair on the right [as "R4(1)"]. Occasionally, the three usual pairs were present with three additional gonoducts, two paired and situated anterior to the first pair and the remaining added to the right one of the first pair, without the left one of the third pair [as "L0(1)R0(1)R1(2)L3(0)"]. As shown in these tables, the number of gonoduct pairs varied from five to six in *I. elegans* and from three to five in *I. gogoshimense*. The total number of gonoducts ranged from 10 to 13 in the former and six to 13 in the latter. The number of gonoducts and variability considerably overlapped between the two species; therefore, these numbers have been proved useless to distinguish these species. Instead, we found a new stable difference in the distribution of gonoduct pairs between these two: the longitudinal distance between the adjacent pairs was almost constant, with all pairs occupying the anterior one-third of the trunk in *I. gogoshimense*, while the distance became longer toward the posterior section, with the posterior-most pairs being located in the middle of the trunk in *I. elegans*.

Phylogenetic analyses

The 18S, 28S, H3, and COI alignments contained 99, 226, 53, and 258 variable sites, of which 56, 157, 31, and 243 sites were parsimony-informative. The mean base composition was 23.1% (A), 27.2% (C), 26.2% (G), and 23.5% (T).

We found a remarkable difference in the COI sequence of *I. gogoshimense* between the data of Goto et al. (2013) (see above) and our own data. The obtained trees (Fig. 2, only ML trees are shown) revealed that in each of the 18S,

Table 3. Variation in the number and disposition of gonoducts in *Ikedosoma elegans* in the present study; for further details, see text.

| Specimen (sex) | Disposition of gonoducts |
|------------------------|--------------------------|
| UMUTZ-Echi-15 (female) | R1(2) (= 13 in total) |
| NSMT-Ec 111 (unknown) | L6(0)R6(0) (= 10) |
| NSMT-Ec 112 (male) | L4(2)R5(2)L6(0) (= 13) |
| NSMT-Ec 113 (male) | L5(2) (= 13) |
| NSMT-Ec 114 (male) | R6(0) (= 11) |
| NSMT-Ec 115 (unknown) | Usual* (= 12) |

* Usual pattern is indicated as L1(1)R1(1)L2(1)R2(1)L3(1)R3(1)L4(1)R4(1)L5(1)R5(1)L6(1)R6(1).

Table 4. Variation in the number and disposition of gonoducts in *Ikedosoma gogoshimense* in the present study; for further details, see text.

| Sex | Disposition pattern of gonoducts | | | | | | | | | |
|---------|----------------------------------|------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------------|
| | Usual* (= 6 in total) | L0(1)L1(0) (= 6) | L0(1) (= 7) | L1(2) (= 7) | L2(2) (= 7) | L4(1) (= 7) | R1(2) (= 7) | R2(2) (= 7) | R4(1) (= 7) | L0(1)R0(1) (= 8) |
| Male | 8 | | 2 | | 1 | 1 | | | 2 | 1 |
| Female | 6 | 1 | | | 1 | | | 1 | 1 | |
| Unknown | 17 | | | 1 | 1 | | 1 | | 1 | |
| Total | 31 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 4 | 1 |

| Sex | Disposition pattern of gonoducts | | | | | | | | Total |
|---------|----------------------------------|-------------------------|-------------------------|-----------------------------------|------------------------------|------------------------------|------------------------------------|---|-------|
| | L0(1) L4(1) (= 8) | L2(2) L4(1) (= 8) | R0(1) R2(2) (= 8) | L0(1)R0(1) R1(2)L3(0) (= 8) | L0(1)R3(2) R4(1) (= 9) | R1(2)L4(1) R4(1) (= 9) | L0(1)R0(1) R1(2)L2(2) (= 10) | L0(1)R0(1) L1(2)R1(2) L2(2)R2(2)R4(1) (= 13) | |
| Male | | | 1 | | | 1 | | 1 | 18 |
| Female | 1 | | | | | | 1 | | 12 |
| Unknown | | 1 | | 1 | 1 | 1 | | | 25 |
| Total | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 55 |

* Usual pattern is indicated as L1(1)R1(1)L2(1)R2(1)L3(1)R3(1).

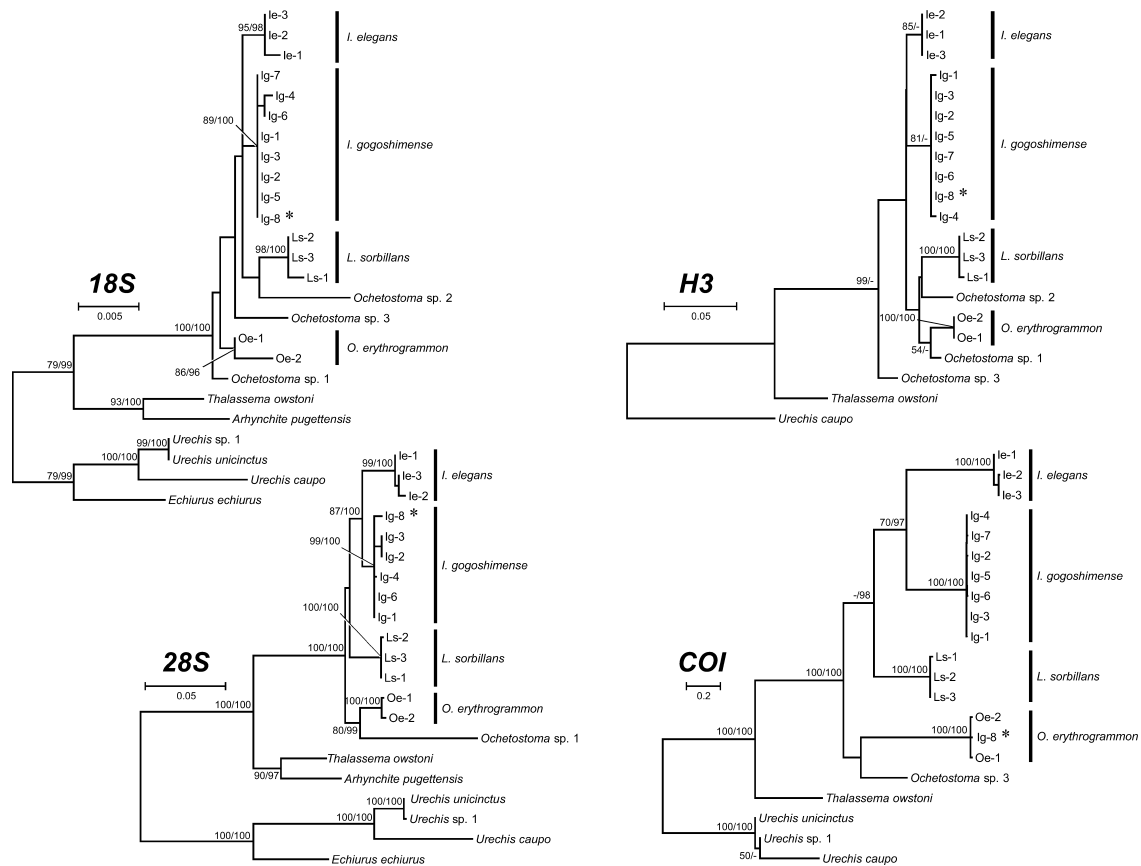


Fig. 2. Maximum-likelihood (ML) tree based on nuclear 18S, 28S, H3, and mitochondrial COI sequences. Numbers above branches represent the level of bootstrap support (BS) for ML analysis and Bayesian posterior probabilities (BPP). BS higher than 50% and BPP higher than 95% are shown. Data from Goto et al. (2013) of *Ikedosoma gogoshimense* (abbreviated as Ig-8) are marked with an asterisk.

28S, and H3 data sets, the downloaded sequence (AB771456, AB771470, and AB771481, respectively) was nested within our newly determined ones (AB967988–967994, AB968001–968005, and AB968012–968018, respectively), while the COI sequence (AB771491) was nested within those of *O. erythrogrammon* (AB771493 and AB968034) instead of *I. gogoshimense*. This discrepancy may be attributable to mitogenomic introgression or to human errors such as contamination or lack of quality control. Therefore, we excluded the COI sequence registered as AB771491 from our concatenated dataset.

The gene-concatenated ML tree demonstrated that the ingroup taxa could be divided into two major clades: A and B (Fig. 3). BI analysis produced an identical tree topology (data not shown). Clade A was composed of seven taxa (*I. elegans*, *I. gogoshimense*, *L. sorbillans*, *O. erythrogrammon*, and *Ochetostoma* species1–3) supported by 100% probabilities in BS and BPP. In Clade A, *I. elegans* and *I. gogoshimense* formed reciprocal monophyletic branches with high probabilities (BS = 100%, BPP = 100%). Furthermore, the monophyletic nature of these two *Ikedosoma* species was recovered with high support values (BS = 85%, BPP = 99%); however, *L. sorbillans* was not included therein. The average genetic divergence of the COI sequence between two *Ikedosoma* species, *I. elegans* and *I. gogoshimense* (excluding AB771491, shown above), was $23 \pm 0.3\%$ in *p*-distance ($27.9 \pm 0.5\%$ in K2P). The average genetic diver-

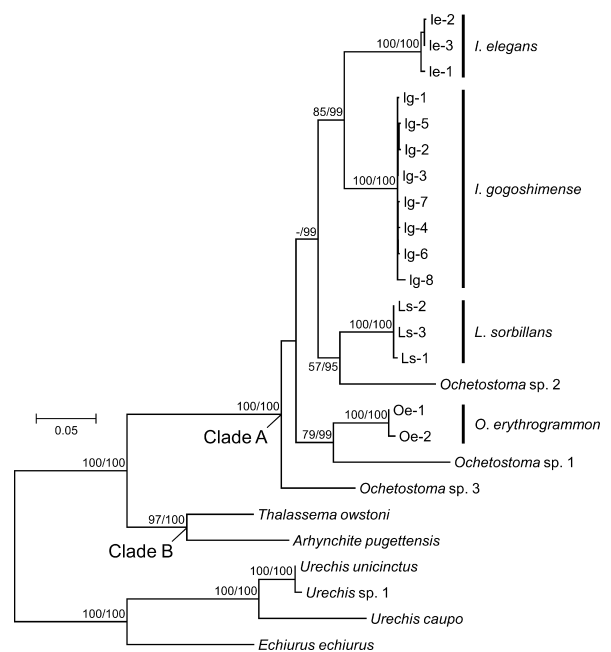


Fig. 3. Maximum-likelihood (ML) tree based on concatenated sequences of nuclear 18S, 28S, H3, and mitochondrial COI genes. Numbers above branches represent the level of bootstrap support (BS) for ML analysis and Bayesian posterior probabilities (BPP). BS higher than 50% and BPP higher than 95% are indicated.

gences within *I. elegans* and *I. gogoshimense* were 1.9 ± 1.3 and $0.8 \pm 0.2\%$ in *p*-distance (1.9 ± 1.4 and $0.8 \pm 0.2\%$ in K2P), respectively. Within the four *Ochetostoma* species used here, only *Ochetostoma* sp. 2 was contained in a subclade composed of *Ikedosoma* spp. and *L. sorbillans* with high BI support (BPP = 99%). On the other hand, internal relationships were not resolved by ML. Thus, the genus *Ochetostoma* was not shown to be monophyletic. Clade B was composed of *Arhynchite pugettensis* and *Thalassema owstoni* supported by high probabilities (BS = 97%, BPP = 100%).

DISCUSSION

Our molecular analyses revealed that *I. elegans* and *I. gogoshimense* form a distinct monophyletic clade, which does not include *L. sorbillans*. Furthermore, these two *Ikedosoma* species are morphologically distinguishable from all known species of *Listriolobus* owing to the absence of a rectal caecum. Table 5 shows a comparison of all known genera currently assigned to the subfamily Thalassematinae of Echiuridae, with some character states and authorships updated since Stephen and Edmonds (1972). Thus, *Ikedosoma* Bock, 1942 is regarded as a valid genus with the amended diagnosis shown below. A rectal caecum is a small blind sac of unknown function, projected from the end of the postsiphonal part of the intestine (Stephen and Edmonds, 1972). The caecum has often been ill described, chiefly owing to its vulnerability. The present study may show the significance of this organ in generic diagnosis; therefore, more attention should be paid to it.

Our molecular and morphological analyses also revealed the validity of both *I. elegans* and *I. gogoshimense*. Unfortunately, we were unable to examine the third species of this genus, *I. qingdaoense*. Its previous descriptions lack any information regarding the oblique muscle layer; therefore, even its generic affiliation remains unclear. Hence, this species is treated as "Species of uncertain status" in the Taxonomy section below.

Our molecular analyses did not provide evidence of monophyly in the genus *Ochetostoma*, despite its fasciculation of the innermost oblique muscle layer between LMB, unique among Thalassematinae (Stephen and Edmonds,

1972; Biseswar, 1988a; see also Table 5). Thus, the generic assignment of the *Ochetostoma* species 1–3 specimens requires reconfirmation for further discussion.

TAXONOMY

Ikedosoma Bock, 1942

(Japanese name: Yume-yumushi-zoku)

Ikedosoma Bock, 1942: 10–18 (type species by original designation: *Thalassema elegans* Ikeda, 1904).

Amended diagnosis

PL as or longer than its TL, without bifurcation at tip. Longitudinal muscle layer of trunk wall showing regular thickening into LMB. Oblique muscle layer continuous and never fasciculate between LMB. Gonoducts three to seven pairs, often with some anomalies. Interbasal muscle absent. Rectal caecum undetectable.

Ikedosoma elegans (Ikeda, 1904)

(Japanese name: Yume-yumushi)

(Figs. 4A–B and 5; Table 3)

Thalassema elegans Ikeda, 1904: 65–66; Ikeda, 1907: 47–55, pl. 1, fig. 4, pl. 4, figs. 48–49; Sato, 1935: 15, fig. 16; Satō, 1939: 356.

Ikedosoma elegans: Bock, 1942: 10–18; Fisher, 1946: 224; Stephen and Edmonds, 1972: 461–462, figs. 57D–E.

Anelassorhynchus mucosus: Nishikawa, 2007: 180 (partim).

Material examined

Syntype: UMUTZ-Echi-15, one female, TL ca. 215 mm, PL ca. 180 mm, LMB 11, Moroiso Inlet, Misaki, Kanagawa Pref., Sagami Bay, Japan, 21.vi.1902, coll. I. Ikeda, corresponding to the "Specimen D" of Ikeda (1907, p. 54).

Nontype specimens: NSMT-Ec 111, one of unknown sex, TL 70 mm, PL 130 mm, LMB eight, intertidal sandy or muddy flat of Ikarise Islet at the entrance of Lake Hamana, Shizuoka Pref., Enshūnada Sea (34°41'04"N, 137°35'59"E), 12.v.2002, coll. T. Nishikawa (TN), S. Kimura, and T. Kimura, referred to as *Anelassorhynchus mucosus* (Ikeda,

Table 5. Comparison of all known genera currently assigned to the subfamily Thalassematinae.

| Genus | Longitudinal musculature | Oblique musculature | Gonostomal lips | Number of gonoduct pairs | Rectal caecum | Position of gonostome | Sources |
|--|--------------------------|---------------------|------------------------------|--|-------------------|-----------------------|------------------------------------|
| <i>Ikedosoma</i> Bock, 1942 | banded | continuous | spirally coiled | 3–7 | absent | basal | Present study |
| <i>Listriolobus</i> Spengel, 1912 | banded | continuous | spirally coiled | 2–4 | present | basal | Nishikawa (2004) |
| <i>Ochetostoma</i> Rüppell and Leuckart, 1828* | banded | fasciculate | spirally coiled | 2–7 | present or absent | basal | Biseswar (1988a) |
| <i>Lissomyema</i> Fisher, 1946 | banded | continuous | fan-shaped | 2–3 | unknown | basal | Fisher (1946) |
| <i>Anelassorhynchus</i> Annandale, 1922 | continuous | continuous | spirally coiled | 1–5 | present or absent | basal | DattaGupta (1974); Biseswar (1984) |
| <i>Thalassema</i> Pallas, 1774 | continuous | continuous | not spirally coiled | 1–3 | present or absent | basal | Biseswar (1988b); Nishikawa (1998) |
| <i>Arhynchite</i> Satō, 1937 | continuous | continuous | leaf-like | 1 | present or absent | basal | Tanaka and Nishikawa (2013) |
| <i>Ikeda</i> Wharton, 1913 | continuous or banded | continuous | simple, without modification | unpaired and numerous (up to 400 in total) | absent | distal | Nishikawa (2002) |

* Authorships of the genus *Ochetostoma* and its type species *O. erythrogrammon* have been wrongly attributed to "Leuckart and Rüppell."

1904) by Nishikawa (2007). NSMT-Ec 112, one male, TL 160 mm, PL > 65 mm (25 mm + a 40 mm fragment), LMB 11, intertidally from Ikarise (see above), 1.vii.2012, coll. T. Unagami and M. Tanaka (MT). NSMT-Ec 113, one male, TL 100 mm, PL > 105 mm (55 mm + a 50 mm fragment), LMB 12, do., 7.vii.2013, coll. T. Unagami and MT. NSMT-Ec 114, one male, TL 103 mm, PL > 57 mm (only an anterior fragment), LMB 12, same collection data as above. NSMT-Ec 115, one of unknown sex, TL 120 mm, PL 90 mm, LMB 10, Takasu sandy flat, off Ohjigatake, Okayama Pref., Seto Inland Sea (34°27'N, 133°52'E), 28.v.1975, coll. TN.

Description

Trunk colored deep wine red, when alive, with white narrow longitudinal lines corresponding to LMB (Fig. 4A). Proboscis yellow to orange with green pigment distally (Fig. 4A, B). These colorations faded to pale yellow or beige after fixation with formalin.

In preserved specimens, TL ranging from 70 to 215 mm ($n = 6$) and PL ranging from 90 to 180 mm ($n = 3$). Proboscis elongated and truncated in its anterior extremity (Figs. 4A, B, 5A). Trunk wall rather thin and covered with numerous papillae, particularly prominent (up to ca. 700 μm in height) at posterior end. Trunk musculature composed of outermost circular, middle longitudinal, and innermost continuous oblique layers (Fig. 5B, C). LMB variable from eight to 12 ($n = 6$). When contracted, circular layer often weakly fasciculate to form transverse bands. Paired ventral setae of usual form, without interbasal muscle. Five to six pairs of gonoducts, all situated posterior to the setae. Each pair often clustered; total number of gonoducts ranging from 10 to 13 ($n = 6$) (Table 3). Longitudinal distance between adjacent pairs increasing toward posterior section, with posterior-most gonoducts being located in middle of trunk. Gonostome proximal, with its lips elongated and spirally coiled.

Alimentary canal long and convoluted, filled with sand

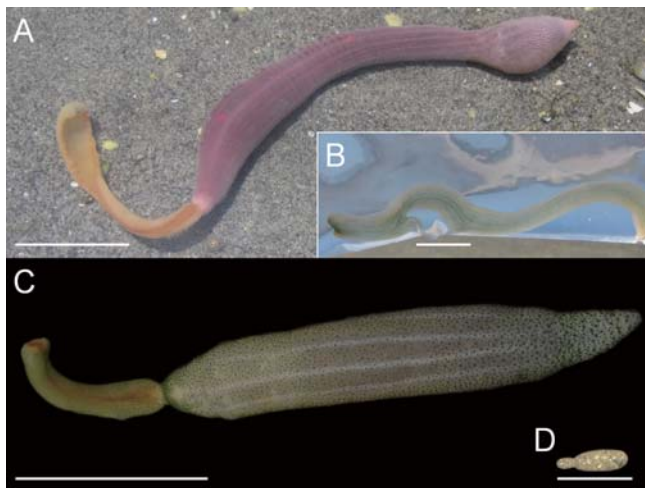


Fig. 4. Photographs of two *Ikedosoma* live specimens. (A) *I. elegans* (NSMT-Ec 113) from Ikarise Islet, proboscis incomplete, ventral view. (B) Anterior fragment of the proboscis of the specimen in (A) showing greenish pigmentation, ventral view. (C) *I. gogoshimense* (NSMT-Ec 116) from Moroiso Inlet, ventral view. (D) A fecal pellet of *I. gogoshimense* immediately after evacuation from the specimen in (C). Scales: (A) and (C), 5 cm; (B) and (D), 1 cm.

grains. Anterior part, or foregut, fastened to ventral trunk wall by sheet-like mesentery, almost straight along ventral nerve cord, and divided into pharynx, esophagus, gizzard, and crop. Behind foregut, intestine fastened to trunk wall through numerous thread-like mesenteries and divided into presiphonal, siphonal, and postsiphonal parts. Presiphonal and postsiphonal parts covered with ciliated groove. Rectal caecum absent.

Vascular system composed of dorsal, neurointestinal, ventral, and ring vessels. Dorsal vessel attached throughout entire length of crop and connected to dorsomedian part of ring vessel. Ring vessel incompletely encircling posterior end of crop. Ventral vessel running along almost entire length of ventral nerve cord and terminating at posterior end of postsiphonal intestine near anus. Neurointestinal vessel linked to ventral vessel at level of first pair of gonoducts, bifurcated into large loop, and terminating on each side of ring vessel.



Fig. 5. A syntype (UMUTZ-Echi-15) of *Thalassema elegans* Ikeda, 1904. (A) Whole body with the label probably written by Dr. Iwaji Ikeda. (B) Dorsal view of the opened trunk showing the musculature, using a light box. (C) Magnified trunk wall showing the two longitudinal muscle bands (marked by an asterisk) and the continuous oblique muscle layer in between. Scales: (A) 5 cm; (B) 3 cm.

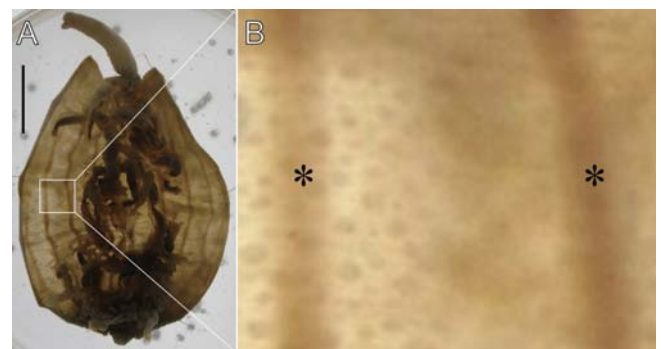


Fig. 6. A dissected specimen of *Ikedosoma gogoshimense* (NSMT-Ec 116), collected intertidally from Moroiso Inlet. (A) Opened trunk, using a light box, dorsal view. (B) Magnified trunk wall showing the two longitudinal muscle bands (indicated with an asterisk) and the continuous oblique muscle layer in between. Scale: (A), 3 cm.

Paired simple anal vesicles, ca. one-third of TL in well-preserved specimens, basally fastened to trunk wall by a few mesenteries, and entirely covered in numerous microscopic ciliated funnels.

Biological notes

Ikedosoma elegans was recorded to inhabit a deep (up to ca. 1.2 m), vertical, or somewhat oblique burrow, similar to the description of *Ikeda taenioides*, by Ikeda (1904, 1907). In the sandy flat in the Ikarise Islet in 2012 and 2013, we collected few specimens of *I. elegans* from burrows reaching ca. 50 cm in depth; however, the openings and the shape could not be ascertained. Similar to the results of the surveys by Ikeda (1907) in Moroiso, no proboscises or traces were found protruding or radiating from burrows. No symbionts have been found in the burrows (Ikeda, 1904, 1907; present study).

Remarks

The original and subsequent syntype descriptions were reported nearly 100 years ago. We managed to collect five new specimens of *I. elegans* from two new localities: one from the Pacific coast in central Japan and the other from the Seto Inland Sea; however, we did not succeed in collecting specimens from the type locality (Misaki) and its vicinity.

Ikeda (1907) examined four syntypes (three males and one female) and concluded that this species exhibits a sexual difference in the total number of gonoducts, i.e., up to 27 in males versus 13 in females. In the present study, however, we found only 11 or 13 gonoducts in total in the three newly collected males (Table 3). Consequently, it is highly probable that the number is much variable among individuals and this variation is unrelated to sexual dimorphism.

According to Ikeda's (1907) subsequent description of *I. elegans*, "in Specimen A, the first pair of segmental organs [gonoducts] lies just behind the ventral hooks [setae]; whereas in all the other specimens I have found it situated in front of the hooks" (p. 55). However, Ikeda's "Specimen D," re-examined in the present study, showed an anterior-most pair of gonoducts actually behind the ventral setae, similar to "Specimen A." Ikeda's description cited above may possibly represent an individual variation in the arrangement of gonoducts, although the pair was invariably located behind the setae in all the examined specimens in the present study.

Distribution

This species is thought to be endemic to the Japanese coast (Fig. 1). It is found on intertidal sandy to muddy flats of Moroiso Inlet, Misaki, Kanagawa Pref., Sagami Bay (type locality: Ikeda, 1904, 1907), of Ikarise Islet, Lake Hamana, Shizuoka Pref., Enshûnada Sea (present study), and of Takasu, Okayama Pref., Seto Inland Sea (present study).

Ikedosoma gogoshimense (Ikeda, 1904)

(Japanese name: Gogoshima-yumushi)

(Figs. 4C–D, 6, and 7; Table 4)

Thalassema gogoshimense Ikeda, 1904: 66–67, pl. 1, fig. 19; Sato, 1934: 251–252, figs. 7 and 8; Sato, 1935: 16, figs. 17 and 18; Satô, 1939: 356.

Ikedosoma gogoshimense: Fisher, 1946: 224; Stephen and

Edmonds, 1972: 462.

Anelassorhynchus mucosus: Nishikawa, 1992: 307, pl. 62, fig. 4.

Material examined

Nontype specimens: NSMT-Ec 116, one female, TL 89 mm, PL 26 mm, LMB 11, Moroiso Inlet, intertidal flat near Misaki Marine Biological Station (MMBS), The University of Tokyo, Kanagawa Pref., Sagami Bay (35°09'28"N, 139°36'44"E), 4.vi.2012, coll. H. Kohtsuka. NSMT-Ec117–118, two females, TL 37 and 54 mm, PL 12 and 18 mm, LMB 9 and 10, Moroiso Inlet, 4 m deep, near MMBS (do.),

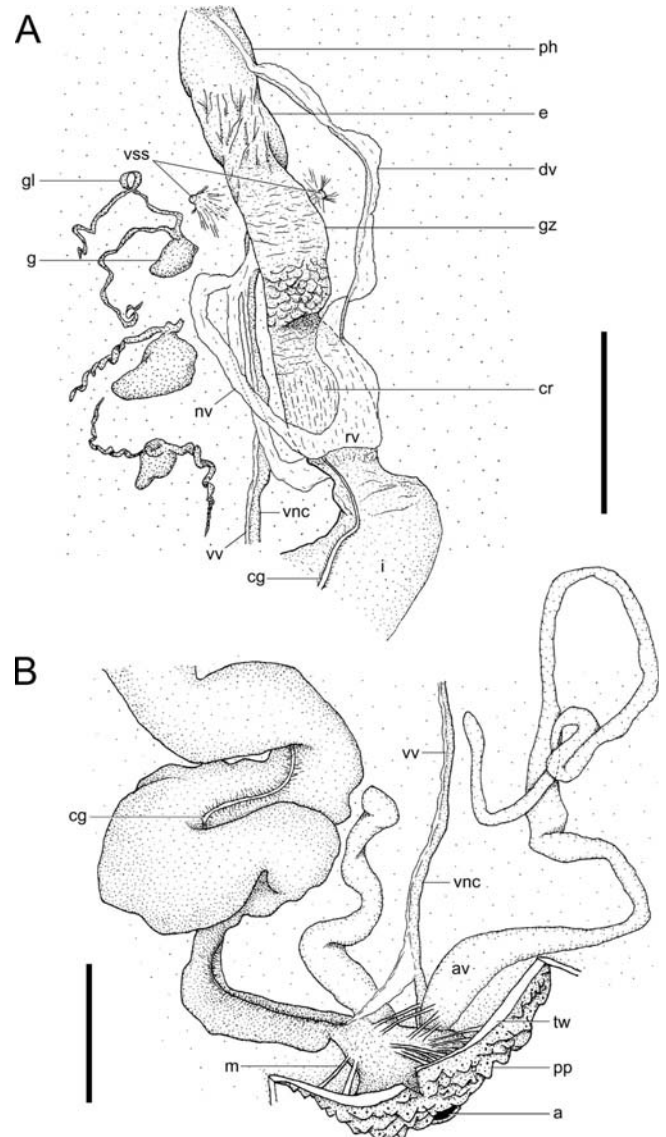


Fig. 7. A dissected trunk of *Ikedosoma gogoshimense* (NSMT-Ec 136), unknown sex, collected from Hachi-no-higata sandy flat, dorsal view, with right gonoducts and most of mesenteries omitted for clarity. **(A)** Anterior part. **(B)** Posterior part. Abbreviations: a, anus; av, anal vesicle; cg, ciliated groove; cr, crop; dv, dorsal vessel; e, esophagus; g, gonoduct; gl, gonostomal lip; gz, gizzard; i, intestine; m, mesentery; nv, neurointestinal vessel; ph, pharynx; pp, papillae; rv, ring vessel; tw, trunk wall; vnc, ventral nerve cord; vss, ventral setal sac; and vv, ventral vessel. Scale: 5 mm.

24.iv.2013, coll. H. Kohtsuka and M. Sekifuji. NSMT-Ec 119, one female, TL 41 mm, PL 15 mm, LMB 10, Ushimado, Okayama Pref., Seto Inland Sea, 5.vi.1985, coll. K. Ito, the photographed specimen of *Anelassorhynchus mucosus* (Ikeda, 1904) in Nishikawa (1992, pl. 62, Fig. 4). NSMT-Ec 120–130, three males + one female + six of unknown sex, TL 44–67 mm, PL 15–26, LMB 9 to 10, intertidal, near Ushimado Marine Laboratory, Okayama University, Okayama Pref., Seto Inland Sea (34°36′34″N, 134°08′33″E), 21.v.2011, coll. MT and TN. NSMT-Ec 131–133, one male + two specimens of unknown sex, TL 40–63 mm, PL 1.5–2.4 mm, LMB eight to nine, Takasu sandy flat, off Ohjigatake, Okayama Pref., Seto Inland Sea (34°27′N, 133°52′E), 20.v.2011, coll. MT and TN. NSMT-Ec 134, one specimen of unknown sex, TL 58 mm, proboscis absent, LMB nine, Kagawa Pref. (exact locality unknown), vii.1975, collector unknown. TUM Echiurida 2-9, one male + one specimen of unknown sex, TL 35 and 50 mm, PL 10 and 13 mm, LMB 9 and 10, Onomichi Bay, Hiroshima Pref., Seto Inland Sea, 7.iii.1931, coll. Takashi Gamô. NSMT-Ec 135, one female, TL 72 mm, PL 26 mm, LMB 9, Hachi-no-higata sandy flat at the mouth of Kamogawa River, Hiroshima Pref., Seto Inland Sea (34°19′25″N, 132°53′53″E), 28.vi.2010, coll. TN. NSMT-Ec 136–147, three males + one female + eight specimens of unknown sex, TL 31–50 mm, PL 11–23 mm, LMB eight to nine, do., 18.v.2011, coll. MT and TN. NSMT-Pol R58, one male + three specimens of unknown sex, TL 33–64 mm, PL 10–21 mm, LMB 9 to 10, Funakoshi, Gogoshima Island, Ehime Pref., Seto Inland Sea, 19.iii.1950. NSMT-Ec 148–158, five males + four females + one specimen of unknown sex, TL 43–87 mm, PL 13–44 mm, LMB 8 to 10, intertidal, Gogoshima Island, Ehime Pref., Seto Inland Sea (33°55′N, 132°41′E), coll. MT and K. Shibata. NSMT-Ec 159–163, two males + three specimens of unknown sex, TL 33–47 mm, PL 8–14 mm, LMB 8–10, Nakajima Island, Ehime Pref., Seto Inland Sea, 10.iii.2005, coll. G. Itani. TOYA-IV-IV2118, one female, TL 56 mm, proboscis absent, LMB 10, Ôikejima Island, Kumamoto Pref., Yatsushiro Sea, coll. N. Nunomura.

Description

Trunk colored pale reddish green, when alive, with white narrow longitudinal lines corresponding to LMB (Fig. 4C). Proboscis yellow to orange. Trunk and proboscis covered with dark green spots. These colorations faded to pale yellow or beige after fixation with formalin; however, dark green spot often remained unfaded.

In preserved specimens, TL ranging from 31 to 89 mm ($n = 55$) and PL from 8 to 44 mm ($n = 50$). Proboscis elongated and truncated in its anterior extremity (Fig. 4C). Trunk wall thick and covered with numerous papillae, particularly prominent (up to ca. 1 mm in height) at posterior end (Fig. 7B). Trunk musculature composed of outermost circular, middle longitudinal, and innermost continuous oblique layers (Fig. 6A, B). LMB variable from eight to 11 ($n = 55$). Paired ventral setae of usual form, without interbasal muscle (Fig. 7A). Gonoducts usually in three pairs and situated behind ventral setae (Fig. 7A) but with some anomalies in number (up to 13 in total) and disposition (up to five pairs, rarely with anterior-most pair in front of ventral setae) (Table 4). Longitudinal distance between adjacent pairs almost constant with all pairs

occupying anterior one-third of trunk (Fig. 7A). Gonostome proximal with its lips elongated and spirally coiled (Fig. 7A).

Alimentary canal long and convoluted, filled with sand grains and spheroidal fecal pellets, ca. 10 mm long (Fig. 4D, 7A–B). Anterior part, or foregut, fastened to ventral trunk wall by sheet-like mesentery, almost straight along ventral nerve cord, and divided into pharynx, esophagus, gizzard, and crop (Fig. 7A). Behind foregut, intestine fastened to trunk wall through numerous thread-like mesenteries and divided into presiphonal, siphonal, and postsiphonal parts (Fig. 7A, B). Presiphonal and postsiphonal parts covered with ciliated groove (Fig. 7A, B). Rectal caecum absent (Fig. 7B).

Vascular system composed of dorsal, neurointestinal, ventral, and ring vessels (Fig. 7A, B). Dorsal vessel attached half to entire length of crop and connected to dorsomedian part of ring vessel (Fig. 7A). Ring vessel incompletely encircling posterior end of crop (Fig. 7A). Ventral vessel running along almost entire length of ventral nerve cord and terminating at posterior end of postsiphonal intestine near anus (Fig. 7A, B). Neurointestinal vessel linked to ventral vessel at level of first or second pair of gonoducts, terminating on each side of ring vessel usually in bifurcation with large loop (Fig. 7A). In two specimens (NSMT-Ec 124 and 139), however, neurointestinal vessel not bifurcated.

Paired simple anal vesicles, only one-sixth of TL to more than twice TL, probably depending on fixed conditions, basally fastened to trunk wall by a few mesenteries (Fig. 7B), and entirely covered in numerous microscopic ciliated funnels.

Biological notes

Ikedosoma gogoshimense inhabits an L-shaped burrow, the vertical part of which is ca. 10 cm in depth (Kawaguti, 1971; Goto et al., 2011; Nishikawa, 2012). The burrow entrance is scattered with many fecal pellets (Ikeda, 1904; Kawaguti, 1971; Arakawa, 1971; Goto et al., 2011; Nishikawa, 2012). The fecal pellets are spheroidal, ca. 1 cm in length, each with a small, twisted protrusion (Fig. 4D; Arakawa, 1971; Nishikawa, 2012). *Basterotia gouldi* (Bivalvia: Sportellidae), *Macromphalus tornatilis* (Gastropoda: Vanikoridae), and *Pinnixa* sp. (Malacostraca: Pinnotheridae) have been found in burrows of this species and reported as symbionts (Goto et al., 2011).

This species was once abundantly found and collected in great numbers to be used as fish bait in the Seto Inland Sea (Satô, 1939), called by local people as “Inuyu,” “Inui,” “Inukouju,” or “Modoki” (Mori et al., 1932; Sato, 1934; Ishikawa, 1938). However, its density has largely declined recently, mostly because of overexploitation as fish bait (Nishikawa, 2007, 2012), as in the case of *Arhynchite hayaoi* (Tanaka and Nishikawa, 2013).

Remarks

Table 6 shows a comparison between two species of *Ikedosoma*: *I. gogoshimense* and *I. elegans*. *Ikedosoma gogoshimense* can be distinguished from *I. elegans* by the following: (1) presence of dark green spots over the trunk and proboscis in living specimens, (2) the constant longitudinal distance between the two adjacent pairs of gonoducts, and (3) the gonoducts occupying the anterior one-third of the trunk. In addition, *I. gogoshimense* shows some ecological peculiarities such as the spheroidal large fecal pellets

Table 6. Comparison between the two Japanese species of the genus *Ikedosoma*.

| Species | Maximal length of trunk (mm) in life | Maximal length of proboscis (mm) in life | Number of longitudinal muscle bands | Coloration in life | | Gonoducts | | | | Sources |
|------------------------|--------------------------------------|--|-------------------------------------|--|--|-----------------|--------------|--|-----------------------------|--|
| | | | | Trunk | Proboscis | Number of pairs | Total number | Longitudinal distance between adjacent pairs | Occupying | |
| <i>I. elegans</i> | ca. 350 | ca. 400 | 8–12 | Deep wine red | Yellow to orange with green pigment distally | 5–7 | 10–27 | Longer in a more posterior position | Anterior half of trunk | Ikeda (1907); present study |
| <i>I. gogoshimense</i> | ca. 150 | ca. 105 | 8–11 | Pale reddish green with dark green spots | Yellow to orange with dark green spots | 3–5 | 4–32 | Almost invariable | Anterior one-third of trunk | Ikeda (1904); Sato (1934); present study |

scattered around the openings of the burrows (no such pellets are found in *I. elegans* burrows) and the shallower burrows (up to 15 cm instead of up to 1.2 m in *I. elegans*).

In the original description, Ikeda (1904) noted that the number of gonoducts in *I. gogoshimense* markedly differed between sexes: three pairs (six in total) in females and three to four pairs in males. Male gonoducts are also often clustered, resulting in up to 32 gonoducts in total. In our examination of 55 specimens, the total number varied from six to 13 in three to five pairs. More than half of these 55 specimens showed a constant number of gonoducts (three pairs, six in total) regardless of sex (Table 4). The same observation was already described by Sato (1934) for the specimens from Onomichi Bay and Gogoshima Island, the Seto Inland Sea. Consequently, it is highly probable that the number of gonoducts is variable among individuals but unrelated to sexes, similar to *I. elegans*, as described above. In this context, Ikeda's (1904) male with 32 gonoducts, invariably clustered in each position of four pairs, may represent extreme intraspecific variation, possibly even different species. Further materials will help solve this problem.

Distribution

This species is thought to be endemic to the Japanese coast (Fig. 1). It is found mainly on intertidal sandy to muddy flats of Moroiso Inlet, Misaki, Kanagawa Pref. in Sagami Bay (one of the type localities: Ikeda, 1904; present study), in the Seto Inland Sea of Ushimado, Okayama Pref. (Nishikawa, 1992; present study), of Takasu, Okayama Pref. (present study), of Onomichi Bay, Hiroshima Pref. (Sato, 1934); of Hachi-no-higata, Hiroshima Pref. (present study), of Gogoshima Island, Ehime Pref. (the other type locality: Ikeda, 1904; present study), of Nakajima Island, Ehime Pref. (present study); and of Kagawa Pref., details unknown (present study), and in Yatsushiro Sea of Ôikejima Island, Kumamoto Pref. (present study).

Species of uncertain status

Ikedosoma qingdaoense Li, Wang and Zhou, 1994

Ikedosoma qingdaoense Li, Wang and Zhou, 1994: 207–208, fig. 2; Wang et al., 1995: 31; Zhou et al., 2007: 149–151, fig. 86.

Remarks

Ikedosoma qingdaoense was first described on the basis of six specimens collected from Huiquan Bay, Qingdao. It seems natural that the original description fol-

lowed Fisher's (1946) definition of the genus *Ikedosoma*. However, if the oblique muscle layer of *I. qingdaoense* can be regarded to be fasciculate, the species may belong to *Ochetostoma*. Unfortunately, the description lacked any references to the muscle layer, and the original and other specimens of *I. qingdaoense* are no longer available for re-examination. Therefore, the generic affiliation of the present species remains unknown.

Besides its doubtful generic affiliation, according to the original description of *I. qingdaoense* this species was distinguishable from *I. elegans* by the number of LMB (12 instead of 10) and by the position of gonoducts (behind the ventral setae in the former instead of only the anterior-most pair in front of the setae in the latter). However, the original or subsequent descriptions and the present studies of *I. elegans* clearly show that the number of LMB in *I. elegans* ranges from eight to 12, covering the number found in *I. qingdaoense*. Furthermore, Ikeda's (1907) subsequent description of *I. elegans* also shows that the anterior-most pair of gonoducts may be located in front of the ventral setae, although it was never detected in the material referred to in the present study. Therefore, *I. qingdaoense* appears to be also similar to most, if not all, specimens of *I. elegans* in that all gonoducts are situated behind the setae.

Thus, the abovementioned differences between these two species cannot be validated. Moreover, they also resemble each other in the variable longitudinal distance between adjacent gonoduct pairs (see fig. 2 of Li et al., 1994 for *I. qingdaoense*). Future comparisons are required between Japanese and Chinese populations to clarify their species identities.

Distribution

Known only from Qingdao, China, on intertidal sandy to muddy flats of Huiquan Bay (type locality: Li et al., 1994) and Xuejiadao, Jiaozhou Bay (Wang et al., 1995; Zhou et al., 2007).

ACKNOWLEDGMENTS

Our cordial thanks to Hiroshi Namikawa (NSMT), Noboru Nunomura (TOYA), Shin'ichi Sato (TUM), and Rei Ueshima (UMUTZ) for loan of specimens and permission to dissect; Shoichi Kimura (Aichi Pref.), Taeko Kimura (Mie University), Kazuki Okada (Hiroshima Pref.), Yoshitaka Saito (Hamamatsu City Office), Kaoru Saotome (Toho University), Kensuke Shibata (Ehime Pref.), and Tomo'o Unagami (Center for Environmental Studies) for field work; Gyo Itani (Kochi University), Katsutoshi Ito (Shizuoka Pref.), and Hisanori Kohtsuka and Mamoru Sekifuji (MMBS) for specimens; MMBS (The University of Tokyo), Tropical Biosphere Research

Center, Sesoko Station (University of the Ryukyus), Takehara Marine Science Station (Hiroshima University), and Ushimado Marine Laboratory (Okayama University) for facilities; Hong Zhou (Ocean University of China) for information on *Ikedosoma qingdaoense*; Junji Okuno (Coastal Branch of Natural History Museum and Institute, Chiba) for advice on the authorship of *Ochetostoma*; and Shinsuke Fukino (Chiba Pref.), Kaoru Kuriwa (University of the Ryukyus), and Kaoru Saotome and Yusuke Yamanoue (Toho University) for technical assistance and/or helpful discussion. This study was partly supported by a Grant-in-Aid for Field Research from Faculty of Science, Toho University to TN.

REFERENCES

- Altekar G, Dwarkadas S, Huelsenbeck JP, Ronquist F (2004) Parallel metropolis coupled markov chain monte carlo for bayesian phylogenetic inference. *Bioinformatics* 20: 407–415
- Andrade SCS, Strand M, Schwartz M, Chen H, Kajihara H, von Döhren J, et al. (2012) Disentangling ribbon worm relationships: multi-locus analysis supports traditional classification of the phylum Nemertea. *Cladistics* 28: 141–159
- Annandale N (1922) The marine element in the fauna of the Ganges. *Bijdr Dierkd* 22: 143–154
- Arakawa KY (1971) Studies on the faecal pellets of marine invertebrates (excluding molluscs) I. *Publ Seto Mar Biol Lab* 19: 231–241
- Bely AE, Wray GA (2004) Molecular phylogeny of naidid worms (Annelida: Clitellata) based on cytochrome oxidase I. *Mol Phylogenet Evol* 30: 50–63
- Biseswar R (1984) A key to species of *Anelassorhynchus* (Echiura) with a description of a new species from the east coast of southern Africa. *S Afr J Zool* 19: 16–21
- Biseswar R (1988a) *Ochetostoma* (Echiura) from southern Africa with a description of a new species. *Ann S Afr Mus* 98: 29–75
- Biseswar R (1988b) *Thalassema* (Echiura) from southern Africa with the description of a new species. *S Afr J Zool* 23: 81–91
- Biseswar R (2012) Zoogeography of the echiuran fauna of the East Pacific Ocean (Phylum Echiura). *Zootaxa* 3479: 69–76
- Bock S (1942) On the structure and affinities of “*Thalassema*” *lankesteri* and the classification of the group Echiuroidea. *Göteborgs Kungl Vetensk Samhälles Handl serB* 2: 1–94
- Carr CM, Hardy SM, Brown TM, Macdonald TA, Hebert PDN (2011) A tri-oceanic perspective: DNA barcoding reveals geographic structure and cryptic diversity in Canadian polychaetes. *PLoS ONE* 6: e22232
- Castresana J (2000) Selection of conserved blocks from multiple alignments for their use in phylogenetic analysis. *Mol Biol Evol* 17: 540–552
- Colgan DJ, McLauchlan A, Wilson GDF, Livingston SP, Edgecombe GD, Macaranas J, et al. (1998) Histone H3 and U2 snRNA sequences and arthropod molecular evolution. *Aust J Zool* 46: 419–437
- Colgan DJ, Ponder WF, Beacham E, Macaranas JM (2003) Gastropod phylogeny based on six segments from four genes representing coding or non-coding and mitochondrial or nuclear DNA. *Molluscan Res* 23: 123–148
- DattaGupta AK (1974) A new species of the genus *Anelassorhynchus* Annandale (Echiura), and a key to the species of the genus. *Proc Zool Soc Calcutta* 27: 29–33
- DattaGupta AK, Menon PKB (1976) The status of the species *Ikedosoma pirotansis* Menon and DattaGupta and a possible rearrangement of the genera under families. In “Proceedings of the International Symposium on the Biology of the Sipuncula and Echiura, Vol 2” Ed by ME Rice, M Todorović, Naučno Delo Press, Belgrade, pp 135–141
- Edmonds SJ (2000) Phylum Echiura. In “Polychaetes & Allies: The Southern Synthesis. Fauna of Australia. Vol 4A Polychaeta, Myzostomida, Pogonophora, Echiura, Sipuncula” Ed by PL Beesley, GJB Ross, CJ Glasby, CSIRO Publishing, Melbourne, pp 353–374
- Felsenstein J (1981) Evolutionary trees from DNA sequences: maximum likelihood approach. *J Mol Evol* 17: 368–376
- Fisher WK (1946) Echiuroid worms of the North Pacific Ocean. *Proc US Natl Mus* 96: 215–292
- Fisher WK (1949) Additions to the echiuroid fauna of the North Pacific Ocean. *Proc US Natl Mus* 99: 479–497
- Forbes E, Goodsir J (1841) On the natural history and anatomy of *Thalassema* and *Echiurus*. *Edinb New Philos J* 30: 369–378
- Goto R, Hamamura Y, Kato M (2011) Morphological and ecological adaptation of *Basterotia* bivalves (Galeommatoida: Sportellidae) to symbiotic association with burrowing echiuran worms. *Zool Sci* 28: 225–234
- Goto R, Okamoto T, Ishikawa H, Hamamura Y, Kato M (2013) Molecular phylogeny of echiuran worms (Phylum: Annelida) reveals evolutionary pattern of feeding mode and sexual dimorphism. *PLoS ONE* 8: e56809
- Hasegawa M, Kishino H, Yano T (1985) Dating of the human-ape splitting by a molecular clock of mitochondrial DNA. *J Mol Evol* 22: 160–174
- Ikeda I (1904) The Gephyrea of Japan. *J Coll Sci Imp Univ Tokyo* 20: 1–87
- Ikeda I (1907) On three new and remarkable species of echiuroids (*Bonellia miyajimai*, *Thalassema taenioides* and *T. elegans*). *J Coll Sci Imp Univ Tokyo* 21: 1–64
- Ishikawa H (1938) Jikken Ouyou Tsuriesamushi Riyou no Kenkyu [Studies on the worms used for fish bait]. *Tsuri-shiryō Kenkyūkai* [Association for fish bait studies], Fukuoka (in Japanese)
- Jukes TH, Cantor CR (1969) Evolution of protein molecules. In “Mammalian Protein Metabolism” Ed by HN Munro, Academic Press, New York, pp 21–132
- Katoh K, Standley DM (2013) MAFFT multiple sequence alignment software version 7: improvements in performance and usability. *Mol Biol Evol* 30: 772–780
- Katoh K, Kuma K, Toh H, Miyata T (2005) MAFFT version 5: improvement in accuracy of multiple sequence alignment. *Nucl Acids Res* 33: 511–518
- Kawaguti S (1971) Electron microscopy on blue-green algae in the body-wall of an echiuroid, *Ikedosoma gogoshimense*. *Biol J Okayama Univ* 14: 67–74
- Kimura M (1980) A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequences. *J Mol Evol* 16: 111–120
- Kvist S, Siddall ME (2013) Phylogenomics of Annelida revisited: a cladistic approach using genome-wide expressed sequence tag data mining and examining the effects of missing data. *Cladistics* 29: 435–448
- Lacaze-Duthiers H (1858) Recherches sur la Bonellie (*Bonellia viridis*). *Ann Sci Nat Zool* 10: 49–110
- Lampert K (1883) Über einige neue Thalassemen. *Z Wiss Zool* 39: 334–342
- Lehrke J (2012) Phylogeny of Echiura (Annelida, Polychaeta) inferred from morphological and molecular data-implications for character evolution. Ph. D, thesis, Mathematisch-Naturwissenschaftlichen Fakultät, Rheinischen Friedrich-Wilhelms-Universität Bonn, Germany
- Li F, Wang W, Zhou H (1994) Studies on the echiurans (Echiura) of the Yellow Sea (Huanghai) and Bohai Sea. *J Ocean Univ Qingdao* 24: 203–210
- Maddison WP, Maddison DR (2011) Mesquite: a modular system for evolutionary analysis. Version 2.75. <http://mesquiteproject.org>
- McHugh D (1997) Molecular evidence that echiurans and pogonophorans are derived annelids. *Proc Natl Acad Sci USA* 94: 8006–8009
- Menon PKB, DattaGupta AK (1962) On a new species of *Ikedosoma* (Echiuridae). *Ann Mag Nat Hist ser13* 5: 305–309
- Monro CCA (1927) On the families and genera of the class Echiuroi-

- dea. *Ann Mag Nat Hist ser9* 20: 615–620
- Mori T, Tamura S, Makino K (1932) Hiroshima-ken San Syuyou Esa-mushi Rui ni Kansuru Chousa-houkokusyo [Research report on animals used for fish bait in Hiroshima Prefecture]. Hiroshima-ken Suisan Shiken-jou Houkoku [Bull Hiroshima Fisheries Exp Sta] 1932: 1–45 (in Japanese)
- Nishikawa T (1992) The Phylum Echiura. In “Guide to Seashore Animals of Japan with Color Pictures and Keys, Vol 1” Ed by S Nishimura, Hoikusha, Ōsaka, pp 306–309 (in Japanese)
- Nishikawa T (1998) Nomenclatural remarks on the family-group names of the Phylum Echiura. *Proc Biol Soc Wash* 111: 249–256
- Nishikawa T (2002) Comments on the taxonomic status of *Ikeda taenioides* (Ikeda, 1904) with some amendments in the classification of the phylum Echiura. *Zool Sci* 19: 1175–1180
- Nishikawa T (2004) Synonymy of the West-Pacific echiuran *Listriolobus sorbillans* (Echiura: Echiuridae), with taxonomic notes towards a generic revision. *Spec Divers* 9: 109–123
- Nishikawa T (2007) Yumushi-doubutsu Mon [Phylum Echiura]. In “Dai Nana-kai Shizen-kankyō Hozen Kiso-chousa: Senkai-iki Seitaikei-chousa (Higata-chousa) Houkokusyo [The 7th National Survey on the Natural Environment: Shallow Sea Survey (Tidal Flats)]” Ed by A Ijima, Biodiversity Center of Japan, Nature Conservation Bureau, Ministry of the Environment, Fujiyoshida, pp 177–181 (in Japanese)
- Nishikawa T (2012) *Ikedosoma gogoshimense* (Ikeda, 1904). In “Threatened Animals of Japanese Tidal Flats: Red Data Book of Seashore Benthos” Ed by Japanese Association of Benthology, Tokai University Press, Hatano, p 237 (in Japanese)
- Ochi O (1963) Hemoglobin crystals of some invertebrates, *Urechis*, *Ikedosoma* and *Travisia*. *Mem Ehime Univ sectII serB* 4: 515–523
- Ochi O (1976) The erythrocyte and its pigment in echiurans *Urechis uncinatus* and *Ikedosoma gogoshimense*. In “Proceedings of the International Symposium on the Biology of the Sipuncula and Echiura, Vol 2” Ed by ME Rice, M Todorović, Naučno Delo Press, Belgrade, pp 197–204
- Pallas PS (1774) *Spicilegia zoologica quibus novae imprimis et obscurae animalium species iconibus, descriptionibus atque commentariis illustrantur*. Fasciculus 10, Gottlieb August Lange, Berolini
- Passamaneck Y, Halanych KM (2006) Lophotrochozoan phylogeny assessed with LSU and SSU data: evidence of lophophorate polyphyly. *Mol Phylogenet Evol* 40: 20–28
- Quatrefages A de (1847) Étude sur les types inférieurs de l’embranchement des Annelés: Mémoire sur l’Echiure de Pallas (*Echiurus Pallasii*, Nob.). *C R Hebd Séanc Acad Sci Paris* 24: 776–779
- Rambaut A, Drummond AJ (2009) Tracer Ver. 1.5. <http://tree.bio.ed.ac.uk/software/tracer/>
- Ronquist F, Teslenko M, van der Mark P, Ayres DL, Darling A, Höhna S, et al. (2012) MrBayes 3.2: efficient bayesian phylogenetic inference and model choice across a large model space. *Syst Biol* 61: 539–542
- Rüppell E, Leuckart FS (1828) Atlas zu der Reise im nördlichen Afrika von Eduard Rüppell: Neue wirbellose Thiere des rothen Meers[sic]. H. L. Brönnner, Frankfurt am Main
- Sato H (1934) On the sipunculids and echiurids of Onomichi Bay, Japan. *Dobutsugaku Zasshi* 46: 245–253 (in Japanese with English abstract)
- Sato H (1935) Fauna Nipponica, Vol VI: Class Echiuroidea, Class Sipunculoidea, Class Priapulioidea, Sanseido, Tokyo (in Japanese)
- Satō H (1939) Studies on the Echiuroidea, Sipunculoidea and Priapulioidea of Japan. *Sci Rep Tohoku Imp Univ 4th ser Biol* 14: 339–460
- Saunders GW, Kraft GT (1994) Small-subunit rRNA gene sequences from representatives of selected families of the Gigartinales and Rhodymeniales (Rhodophyta). 1. Evidence for the Plocamiales ord. nov. *Can J Bot* 72: 1250–1263
- Sawada N, Noda Y (1963) Studies on the fertilization in eggs of echiuroid, *Ikedosoma gogoshimense* (Ikeda) II. Electron microscope studies on the egg. *Mem Ehime Univ sectII serB* 4: 551–561
- Sawada N, Ochi O (1962) Studies on the fertilization in eggs of echiuroid, *Ikedosoma gogoshimense* (Ikeda) I. An outline of the fertilization and the development. *Mem Ehime Univ sectII serB* 4: 437–443
- Sawada N, Ochi O, Kubo M (1975) Electron microscope studies on sperm differentiation in marine annelid worms. I. Sperm formation in *Ikedosoma gogoshimense*. *Dev Growth Differ* 17: 77–87
- Schwarz G (1978) Estimating the dimension of a model. *Ann Stat* 6: 461–464
- Silvestro D, Michalak I (2012) raxmlGUI: a graphical front-end for RAxML. *Org Divers Evol* 12: 335–337
- Spengel JW (1912) Über den hautmuskelschlauch gewisser *Thalassema*-Arten und seine Bedeutung für die Systematik dieser Tiere. *Verh Deut Zool Ges* 22: 309–317
- Stamatakis A (2006) RAxML-VI-HPC: maximum likelihood-based phylogenetic analyses with thousands of taxa and mixed models. *Bioinformatics* 22: 2688–2690
- Stephen AC, Edmonds SJ (1972) The Phyla Sipuncula and Echiura. Trustees of the British Museum (Natural History), London
- Struck TH, Schult N, Kusen T, Hickman E, Bleidorn C, McHugh D, et al. (2007) Annelid phylogeny and the status of Sipuncula and Echiura. *BMC Evol Biol* 7: 57
- Struck TH, Paul C, Hill N, Hartmann S, Hösel C, Kube M, et al. (2011) Phylogenomic analyses unravel annelid evolution. *Nature* 471: 95–98
- Tamura K, Peterson D, Peterson N, Stecher G, Nei M, Kumar S (2011) MEGA5: molecular evolutionary genetics analysis using maximum likelihood, evolutionary distance, and maximum parsimony methods. *Mol Biol Evol* 28: 2731–2739
- Tanabe AS (2011) Kakusan4 and Aminosan: two programs for comparing nonpartitioned, proportional and separate models for combined molecular phylogenetic analyses of multilocus sequence data. *Mol Ecol Resour* 11: 914–921
- Tanaka M, Nishikawa T (2013) A new species of the genus *Arhynchite* (Annelida, Echiura) from sandy flats of Japan, previously referred to as *Thalassema owstoni* Ikeda, 1904. *Zookeys* 312: 13–21
- Tavaré S (1986) Some probabilistic and statistical problems in the analysis of DNA sequences. In “Some Mathematical Questions in Biology—DNA Sequence Analysis” Ed by RM Miura, American Mathematical Society, Rhode Island, pp 57–86
- Vonnemann V, Schrödl M, Klussmann-Kolb A, Wägele H (2005) Reconstruction of the phylogeny of the Opisthobranchia (Mollusca: Gastropoda) by means of 18S and 28S rRNA gene sequences. *J Mollus Stud* 71: 113–125
- Wang W, Zhou H, Li F (1995) A check list of echiurans (Echiura) from the China coasts. *J Oceanogr Huanghai Bohai Seas* 13: 30–35
- Weigert A, Helm C, Meyer M, Nickel B, Arendt D, Hausdorf B, et al. (2014) Illuminating the base of the annelid tree using transcriptomics. *Mol Biol Evol* 31: 1391–1401
- Wharton LD (1913) A description of some Philippine thalassemae with a revision of the genus. *Philippine J Sci sectD* 8: 243–270
- Yang Z (1993) Maximum-likelihood estimation of phylogeny from DNA sequences when substitution rates differ over sites. *Mol Biol Evol* 10: 1396–1401
- Zharkikh A (1994) Estimation of evolutionary distances between nucleotide sequences. *J Mol Evol* 39: 315–329
- Zhou H, Li F, Wang W (2007) Fauna Sinica, Invertebrata Vol 46: Sipuncula, Echiura. Science Press, Beijing

(Received June 30, 2014 / Accepted August 15, 2014)