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(Acanthocephala: Rhadinorhynchidae)
from Marine Fish off the Pacific Coast of
Vietnam*

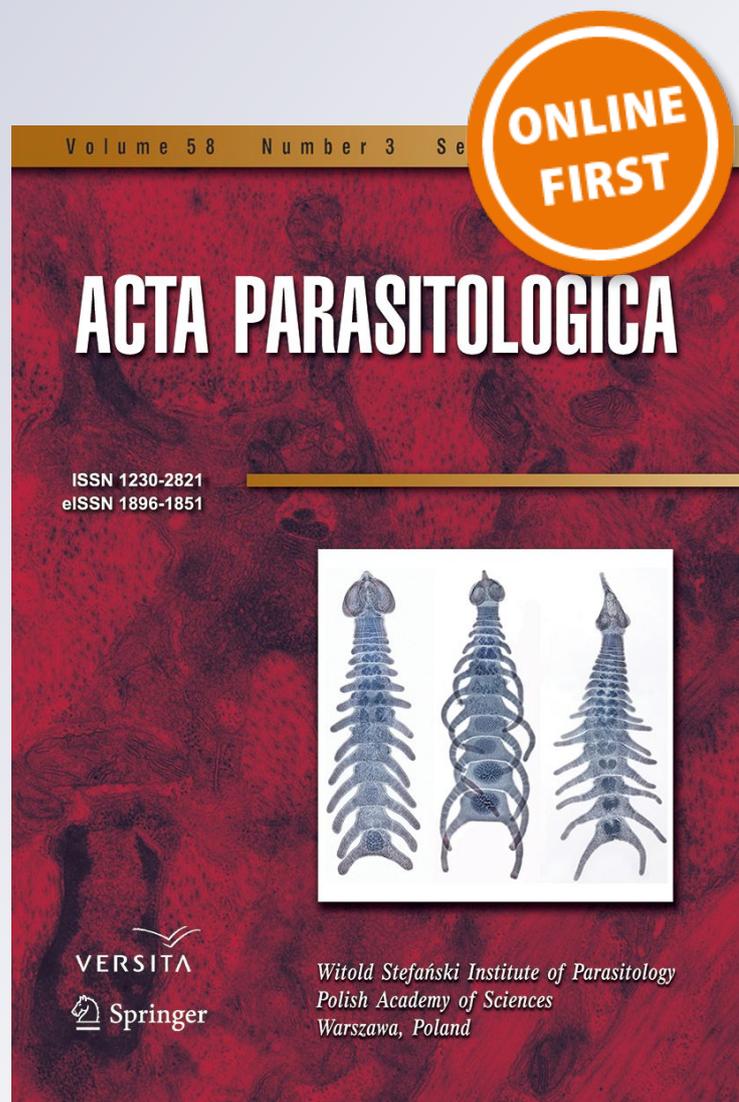
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Acta Parasitologica

ISSN 1230-2821

Acta Parasit.

DOI 10.2478/s11686-019-00092-2



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Description of Three New Species of *Rhadinorhynchus* Lühe, 1911 (Acanthocephala: Rhadinorhynchidae) from Marine Fish off the Pacific Coast of Vietnam

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Received: 26 April 2019 / Accepted: 3 June 2019

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Abstract

Background Of the 43 valid species of *Rhadinorhynchus* Lühe, 1911, 20 species are now known from the Pacific Ocean off Australia, Japan, and Vietnam. We have already described over 50 species and higher taxa from the Pacific Ocean off Vietnam over the last 15 years.

Purpose The present research is a continuation of our efforts to taxonomically map new acanthocephalan taxa, especially from Vietnam. Some of our collections in 2016 and 2017 revealed the presence of new species of the genus *Rhadinorhynchus* from various species of marine fish off the Pacific coast of Vietnam. We provide descriptions of these new species here.

Methods Standard methods of collection and examination of marine hosts, processing and illustrating of specimens, and taxonomic identification of parasites using the extensive collections of the lead author were used. Type specimens were deposited at the Harold W. Manter Lab. collection, Lincoln, Nebraska.

Results Three species *Rhadinorhynchus* are described from marine fish off the Vietnamese coast. *Rhadinorhynchus circumspinus* n. sp. with fusiform trunk, 1 field of anterior trunk spines, and anteriorly globular proboscis with up to 21 dorsoventrally differentiated hooks in 17–18 rows is described from *Triacanthus biaculeatus* Bloch (Triacanthidae) off Hai Phong. *Rhadinorhynchus pacificus* n. sp. with cylindrical trunk and proboscis with up to 25 dorso-ventrally similar hooks in 14–18 rows and trunk spines in 2 fields of dorsal, ventral and lateral spines is described from *Auxis thazard* (Lacepède) and *Auxis rochei* (Lacepède) (Scombridae) off Nha Trang. *Rhadinorhynchus multispinosus* n. sp. with cylindrical trunk and proboscis with up to 32 dorso-ventrally differentiated hooks in 12 rows, and many trunk spines in 2 fields of dorsal, ventral and lateral spines is described from *Decapterus maruadsi* (Temminck and Schlegel) (Carangidae) also off Hai Phong. *Rhadinorhynchus polynemi* Smales, 2014 of Australia is not the Indian species (with smallest basal hooks) as the basal hooks are largest and is now named *Rhadinorhynchus australis* nom. nov. (= *Rhadinorhynchus polynemi* Smales, 2014). *Rhadinorhynchus trivandricus* George and Nadakal, 1978 with smallest basal hooks and 8 pyriform cement glands is relegated to genus *Indorhynchus* Golvan, 1969.

Conclusions With the description of these 3 new species, the number of valid species of *Rhadinorhynchus* has now increased to 46. We include a new generic diagnosis to accommodate the increased knowledge of variability within this genus.

Keywords Acanthocephala · Descriptions · *Rhadinorhynchus circumspinus* n. sp. · *R. multispinosus* n. sp. · *R. pacificus* n. sp. Marine fish · Vietnam

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Introduction

Most of the recent taxonomic work on the Acanthocephala from Vietnam was reported by the Amin—Heckmann—Ha team since 2000. We have described about 50 acanthocephalan species and higher taxa from freshwater and marine fish, amphibians, reptiles, birds, and mammals in Vietnam. A complete listing of this taxonomic literature can be found in Amin et al. [3]. Three other species of *Rhadinorhynchus*

were otherwise previously reported from marine fishes in Vietnam by Arthur and Te [4]. Eighteen species of acanthocephalans in 5 families were more recently collected from fishes in the Pacific and amphibians in central Vietnam in 2016 and 2017. In the present report, we describe 3 new species of *Rhadinorhynchus* covering the full spectrum of variations in trunk spines.

Materials and Methods

Collections

Three species of rhadinorhynchid acanthocephalans were collected from marine fishes along the coast of Vietnam. Three female specimens of *R. circumspinus* were found in 2 of 5 individuals of short-nosed tripod fish *Triacanthus biaculeatus* Bloch (Triacanthidae) off Hai Phong (20°51'54.5"N 106°41'01.8"E) on April 14, 2016. Of 10 females of *R. pacificus* collected, 8 were found in the frigate tuna *Auxis thazard* (Lacepède) (Scombridae) in January, 2016 (7 specimens) and October, 2017 (1 specimen) and 2 specimens in the bullet tuna *Auxis rochei* (Lacepède) (Scombridae) in October, 2017, off Nha Trang (12°15'N 109°11'E). Two male and 4 female specimens of *R. multispinosus* were collected from 3 of 5 Japanese scads, *Decapterus maruadsi* (Temminck and Schlegel) (Carangidae) also off Hai Phong on April 14, 2016.

Methods

Worms were initially stored in cold water, then fixed in cold 70% ethanol. They were subsequently punctured with a fine needle then stained in Mayer's acid carmine, destained in 4% hydrochloric acid in 70% ethanol, dehydrated in ascending concentrations of ethanol (24 h each), and cleared in 100% xylene then transferred in 50% Canada balsam and 50% xylene (24 h. each). Whole worms were mounted in Canada balsam. Measurements are in micrometers, unless otherwise noted; the range is followed by the mean values between parentheses. Width measurements represent maximum width. Trunk length does not include proboscis, neck, or bursa.

Line drawing were created using a Ken-A-Vision micro-projector (Ward's Biological Supply Co., Rochester, N.Y.) which uses cool quartz iodine 150 W illumination. Color-coded objectives, 10×, 20×, and 43× lenses, are used. Images of stained whole mounted specimens were projected vertically on 300 series Bristol draft paper (Starthmore, Westfield, Massachusetts), then traced and inked with India ink. Projected images were identical to the actual specimens being projected. The completed line drawings were subsequently scanned at 600 pixels on a USB and subsequently

downloaded on a computer. Microscope images were created using 10× and 40× objective lenses of a BH2 light Olympus microscope (Olympus Optical Co., Osachi-shibamiya, Okaya, Nagano, Japan) attached to an AmScope 1000 video camera (United Scope LLC, dba AmScope, Irvine, California), linked to an ASUS laptop equipped with HDMI high-definition multimedia interface system (Taiwan-USA, Fremont, California). Images from the microscope are transferred from the laptop to a USB and stored for subsequent processing on a computer.

Type specimens were deposited in the University of Nebraska's State Museum's Harold W. Manter Laboratory (HWML) collection in Lincoln, Nebraska, USA.

Results and Discussion

Amin [1] and Amin et al. [2] recognized 38 valid species of *Rhadinorhynchus* and invalidated 30 others. Only 5 more species of *Rhadinorhynchus* were described since, 4 from marine fishes off Australia [9] and *Rhadinorhynchus oligospinosus* Amin and Heckmann, 2017 off the Peruvian Pacific coast.

The increasing awareness of the variability in species of *Rhadinorhynchus*, especially since the detailed study of Amin et al. [2], and the additional variations presented by the 3 new species described herein called for the need to provide a new expanded diagnosis of the genus. Modifications and additions not presented in previous diagnoses are bolded.

Generic diagnosis: Rhadinorhynchidae, Rhadinorhynchinae: Trunk long, cylindrical, slightly dilated anteriorly, with small, numerous hypodermic nuclei. Lacunar system with lateral main vessels and reticular anastomoses. Trunk spines anterior, **in one** or two fields separated by aspinose area **or connected by lateral spines**. Anterior spines in complete circles and **larger posterior spines either dorsal, ventral, or both. Spines more numerous and larger in females than in males**. Proboscis usually very long, claviform **or more bulbous anteriorly, with 8–26 rows of 17–48 hooks each**. Hooks usually dorsoventrally differentiated **with dorsal hooks being more slender than robust ventral hooks but occasionally similar. Posterior hooks smaller, spine-like with undeveloped roots but abruptly** becoming distinctly larger and projecting at right angle to proboscis basally. **Hook roots simple, directed posteriorly, of similar or slightly smaller length than hook blades**. Proboscis receptacle long, double-walled, with **ganglion usually** at middle but **seldom posteriorly**. Lemnisci usually long and slender. Testes elongate, tandem. Cement glands usually long, tubular, **usually 4 but occasionally 2, 7 or 8**. Female reproductive system very long. Eggs **fusiform elongate** with polar

prolongation of fertilization membrane. Gonopore terminal in males and **often** subterminal in females. **Bursa with or without sensory papillae or plates.** Parasites of marine and occasionally freshwater fish.

The 43 valid species of *Rhadinorhynchus*, include 21 species from the Pacific ocean especially off Australia, Japan, and Vietnam, not including the 3 species described herein. These species are:

1. *Rhadinorhynchus australis* nom. nov. (= *R. polynemi* [9]) from NE Australia.
2. *Rhadinorhynchus bicircumspinus* Hooper, 1983 from New South Wales, Australia.
3. *Rhadinorhynchus biformis* [9]. From Heron Island, Australia.
4. *Rhadinorhynchus carangis* Yamaguti, 1939 from Japanese Inland Sea.
5. *Rhadinorhynchus chongmingnensis* Huang, Zheng, Deng, Fan et Ni, 1988 from Chongming, China.
6. *Rhadinorhynchus cololabis* Laurs et McCauley, 1964 from Oregon, USA.
7. *Rhadinorhynchus decapteri* Parukhin et Kovalenko, 1976 from Hawaii.
8. *Rhadinorhynchus ditrematis* Yamaguti, 1939 from Japanese Inland Sea.
9. *Rhadinorhynchus dorsoventrospinosus* Amin, Heckmann, Ha 2011 from Halong Bay, Vietnam.
10. *Rhadinorhynchus johnstoni* Golvan, 1969 from South Australia.
11. *Rhadinorhynchus laterospinosus* Amin, Heckmann, Ha, [2] from Halong Bay, Vietnam.
12. *Rhadinorhynchus oligospinosus* n. sp. from Port of Chicama, La Libertad, Peru.
13. *Rhadinorhynchus ornatus* Van Cleave, 1918 from the Atlantic coast of the USA, Japan, and the Pacific Ocean off South America.
14. *Rhadinorhynchus pichelinae* [9] from Point Peron, West Australia.
15. *Rhadinorhynchus polydactyli* [9] from Moreton Bay, Queensland, Australia.
16. *Rhadinorhynchus pomatomi* [9]. New Brighton, New South Wales, Australia.
17. *Rhadinorhynchus pristis* (Rudolphi, 1802) from Gulf of Tonkin, South China Sea.
18. *Rhadinorhynchus selkirki* Van Cleave, 1920 from Juan Fernandez Island, Chile.
19. *Rhadinorhynchus seriolae* (Yamaguti, 1963) Golvan, 1969 from Japan and Australia.
20. *Rhadinorhynchus trachuri* Harada, 1935 from a Tokyo market, Japan.
21. *Rhadinorhynchus zhukovi* Golvan, 1969 from the Kuril Islands, Japan–Russia.

Three new species are added to this list and described below.

***Rhadinorhynchus circumspinus* n. sp. (Figs. 1–3, 7–16)**

The following description is based on the only 3 female specimens found in 2 of 5 individuals of short-nosed tripod fish *Triacanthus biaculeatus* off Hai Phong in the north of the country on April 14, 2016. The host species is native to the Indian Ocean and the West Pacific [8]. The acanthocephalan may be more common in the tripod fish elsewhere within its range or in other species of fish. The worms had ripe eggs suggesting that the tripod fish is a natural host.

Description

General: With characters of the genus *Rhadinorhynchus*. Trunk fusiform elongate markedly narrowing anteriorly and gradually tapering posteriorly, spinose anteriorly in 1 undivided field of complete circles of irregularly alternating 22–24 spines each extending posteriorly to about half length of receptacle (Fig. 1). Spines similar dorsoventrally, fewer dorsally, with prominent core, smaller posteriorly than anteriorly and dorsally than ventrally (Figs. 13, 14). Proboscis globular anteriorly but truncated apically (Figs. 2, 7) with 17–18 rows of 18–21 dorsoventrally dissimilar hooks with simple posteriorly directed roots becoming vestigial or discoid at posterior end (Figs. 8–11). Dorsal hooks shorter than ventral hooks apically and basally but longer and usually thinner throughout proboscis otherwise. Sub-apical hooks longest (Fig. 7). Basal hooks markedly longer than pre-basal hooks dorsally and ventrally (Fig. 11). Neck prominent (Fig. 7). Proboscis receptacle more than twice as long as proboscis, double-walled, with cephalic ganglion at its center. Lemnisci digitiform, slender, subequal, markedly longer than receptacle (Fig. 1).

Females (based on 3 specimens with eggs and ovarian balls) trunk 10.00–10.37 (10.21) mm long by 0.95–1.12 (1.02) mm wide anteriorly. Dorsal and ventral trunk spines in 15–18 (17) and 20–22 (21) circles. Trunk spines of similar size and shape dorsally and ventrally. Dorsal spines 37–42 (40) and 22–27 (24) long anteriorly and posteriorly, respectively. Ventral spines 38–43 (41) and smaller 25–30 (26) long anteriorly and posteriorly, respectively. Proboscis 1.00–1.04 (1.02) mm long by 0.25–0.27 (0.26) mm wide anteriorly. See Table 1 for hook measurements. Neck 312–416 (362) long by 260–291 (274) wide at base. Proboscis receptacle 2.13–2.80 (2.52) mm long by 0.37–0.42 (0.40) mm wide. Long lemnisci 3.75–4.16 (3.95) mm long by 0.08–0.13 (0.10) mm wide. Shorter lemnisci 2.70–3.74 (3.22) mm long by 0.07 mm wide. Reproductive system 875–975 (929) long

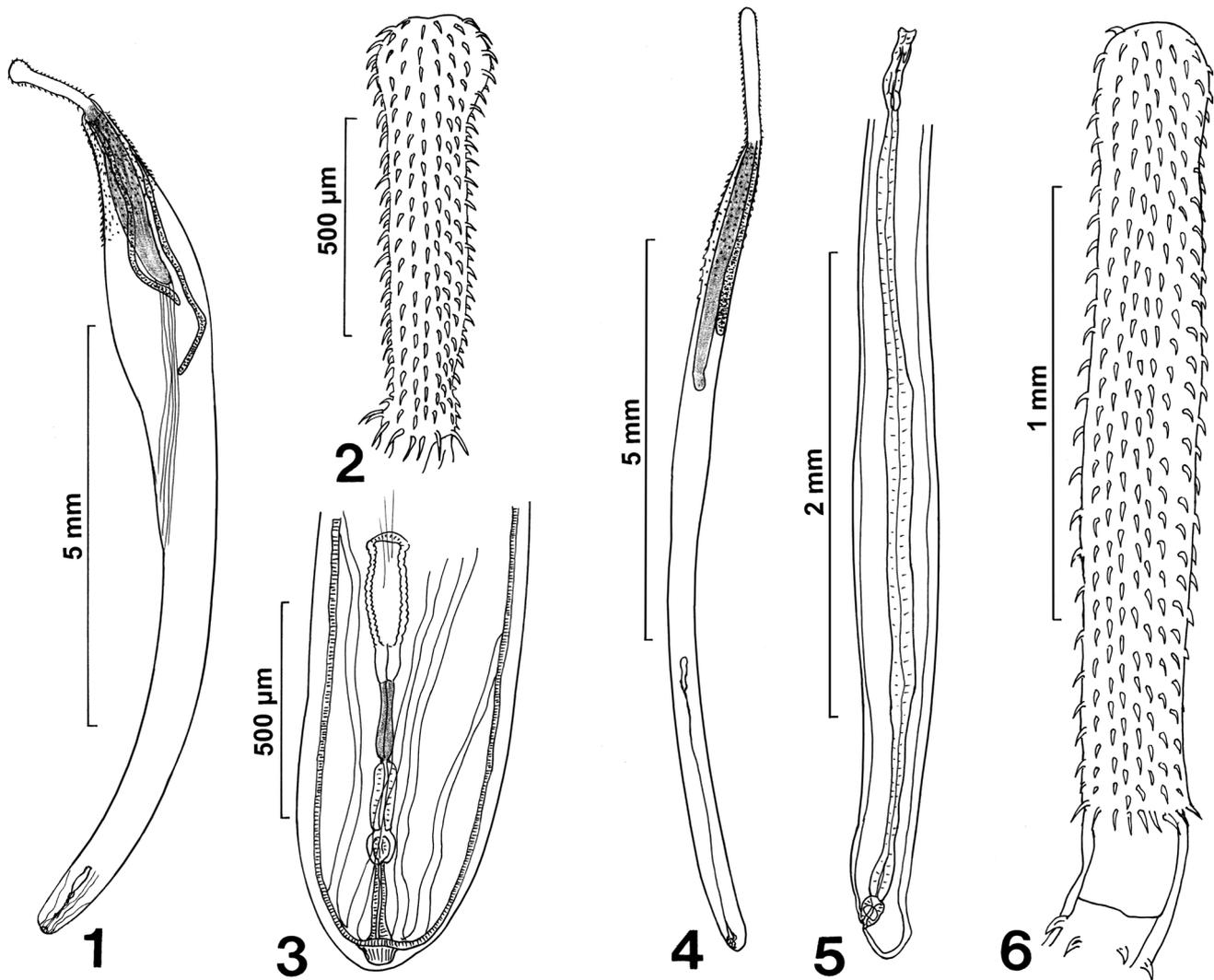


Fig. 1–6 Line drawings of female specimens of *Rhadinorhynchus circumspinus* n. sp. from *Triacanthus biaculeatus* (Figs. 1–3) and of *Rhadinorhynchus pacificus* n. sp. from *Auxis thazard* in Vietnam. **1** Holotype female of *R. circumspinus*. **2** Proboscis. Note globular anterior end. **3** Reproductive system. Note morphological differentiation

(only 9% of trunk length) with unusual specialized features. The vaginal sphincter reduced at orifice but ducted internally into first bulb at start of very short uterus (Figs. 3, 15). Uterine bell considerably long, about one-third length of whole reproductive system, with distal funnel-like opening into body cavity (Fig. 13), 302–354 (323) long. Posterior end of trunk with 2 dorsal and 2 ventral thick ligaments the outer of which attached to body wall. Eggs elongate fusiform with polar prolongation of fertilization membrane, 57–67 (62) long by 12–15 (13) wide.

Taxonomic Summary

Type host: short-nosed tripod fish *Triacanthus biaculeatus* Bloch (Triacanthidae).

of specialized parts. **4** Holotype female of *R. pacificus*. Note proportion of proboscis and receptacle to trunk length. **5** Reproductive system. Note subterminal gonopore, very long uterus and elongate uterine bell. **6** Proboscis of specimen in Fig. 4 showing similar dorsal and ventral spines

Type locality: Pacific Ocean off Hai Phong (20°51'54.5"N 106°41'01.8"E), Vietnam.

Site of infection: Intestine.

Type specimens: HWML collection no. (holotype female and 2 paratype females on 1 slide).

Etymology: the new species name describes the arrangement of the spine circles in the undivided anterior field of spines.

Remarks

Rhadinorhynchus circumspinus n. sp., like all valid species of the genus *Rhadinorhynchus*, has larger basal than

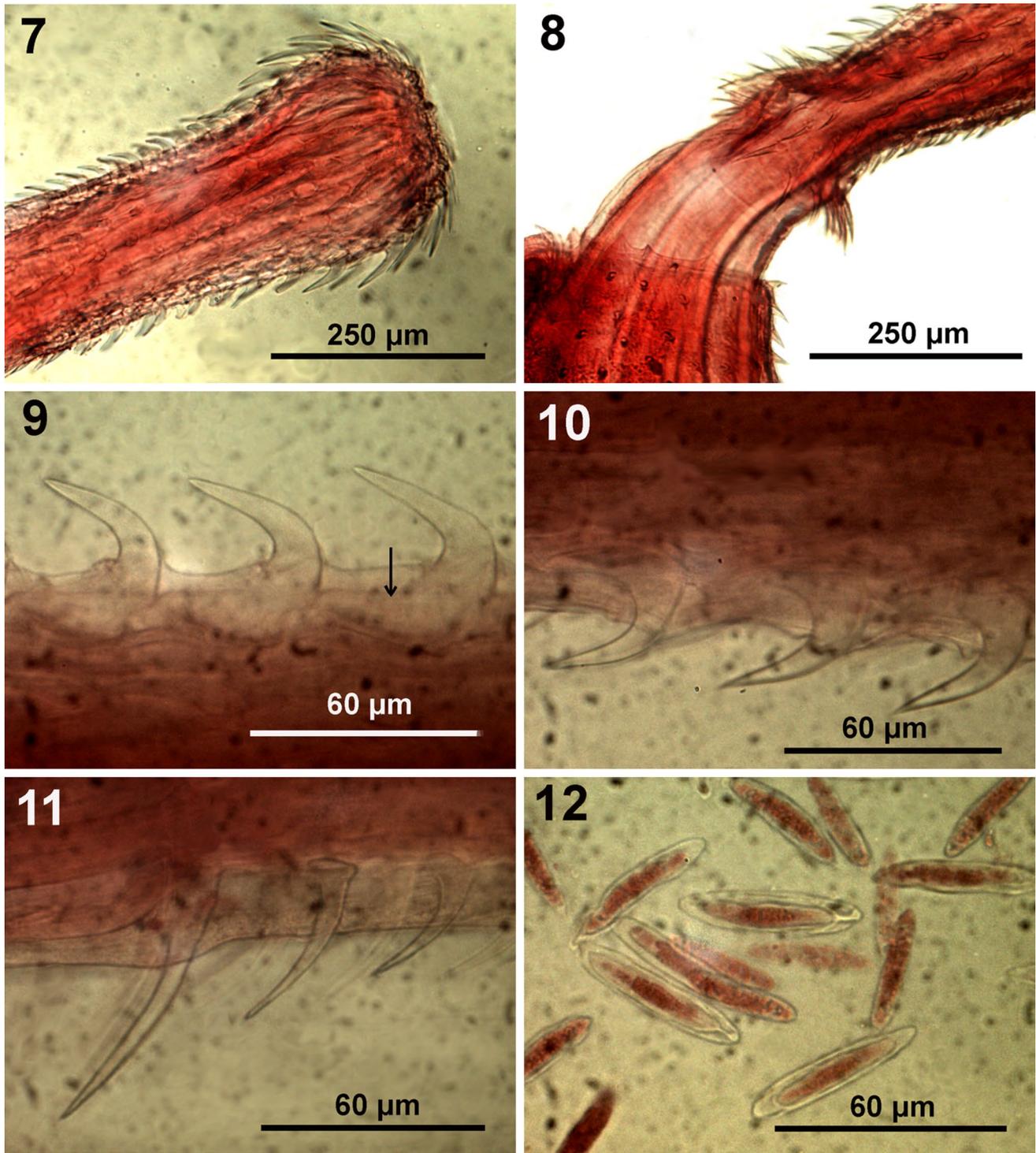


Fig. 7–12 Microscopic images of female specimens of *Rhadinorhynchus circumspinus* n. sp. from *Triacanthus biaculeatus* in Vietnam. **7** Proboscis. See globular anterior end and larger anterior hooks. **8** Posterior proboscis, neck, and anterior trunk of a paratype female. Note long basal hooks, prominent neck, and spines in anterior field. **9** Dorsal hooks at mid-proboscis. Note prominent simple roots (arrow)

about equal in length to blades. **10** Ventral proboscis hooks and roots about similar to dorsal hooks (Fig. 9) but somewhat shorter. **11** Posterior ventral hooks including the considerably longer basal hook. Note abbreviated or discoid roots. **12** Eggs. Note the polar prolongation of fertilization membrane

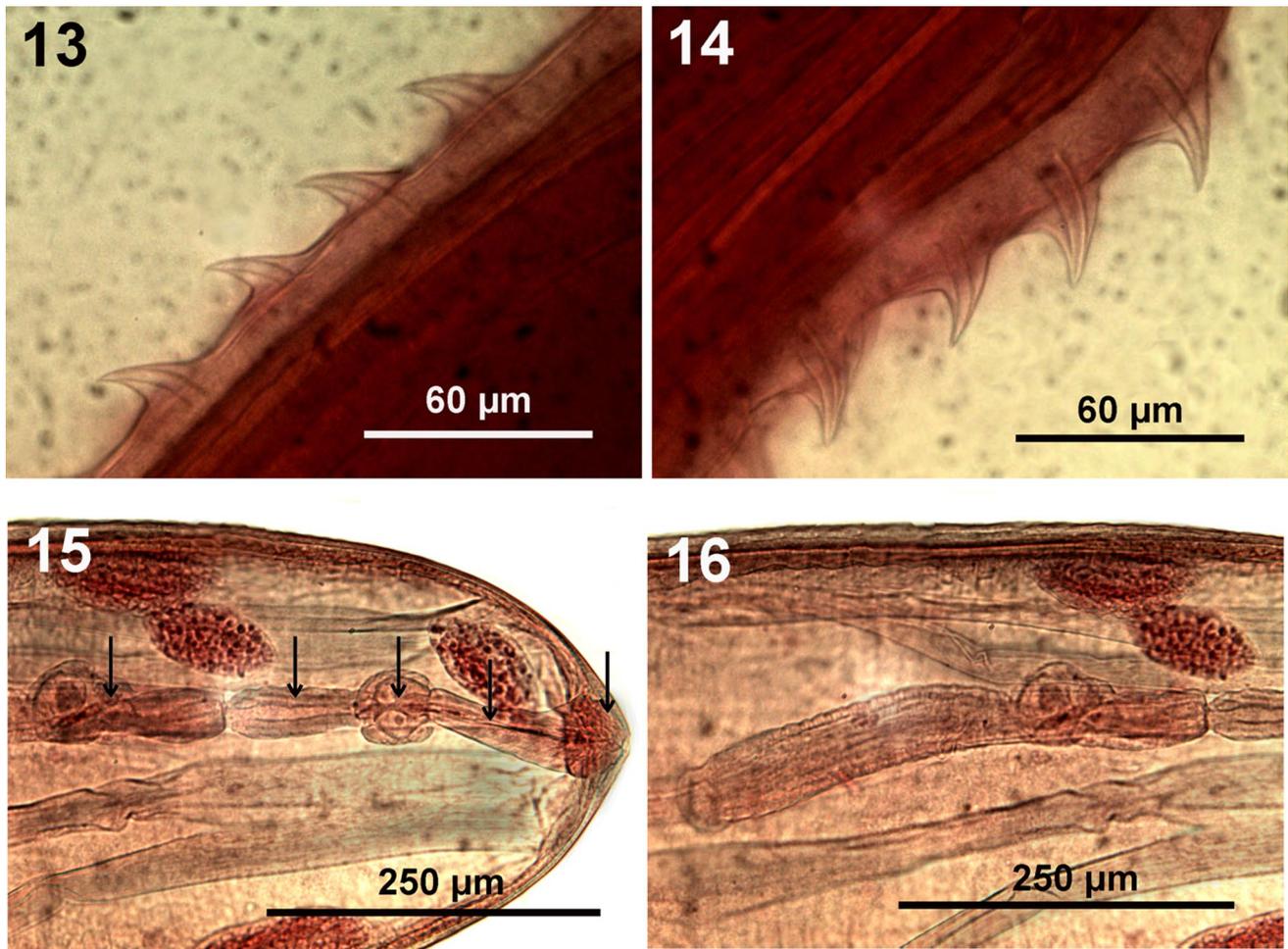


Fig. 13–16 Microscopic images of female specimens of *Rhadinorhynchus circumspinus* n. sp. from *Triacanthus biaculeatus* in Vietnam. **13** Dorsal spines with 1 internal rod support. **14** Similar but larger posterior ventral spines. **15** Detail of a female reproductive

system with arrows pointing to differentiating specialized structures. **16** The anterior part of the same reproductive system in Fig. **15** showing the long uterine bell with parallel sides and the funnel-like distal orifice

pre-basal proboscis hooks and anterior trunk spines. It is, however, unique compared to all species of the genus in having a small fusiform trunk and a globular apical proboscis end. In addition, it has 15–22 complete circles of anterior trunk spines in 1 field extending to about half the length of the receptacle. All other species of *Rhadinorhynchus* with 1 anterior field of trunk spines have cylindrical trunk and cylindrical proboscis, and variable patterns of trunk spine distribution. There are 13 known species with one field of anterior trunk spines from which *R. circumspinus* can be readily distinguished. An annotated list of these 13 species emphasizing trunk spine patterns appears below. For further species differentiation using proboscis hook patterns, among other characters, see the key to species in Amin et al. [2] and check Smales [9].

1. *Rhadinorhynchus africanus* (Golvan, Houin et Del-tour, 1963) Golvan, 1969 from Gabon with 1 triangular field of irregular small spines within range of receptacle.
2. *Rhadinorhynchus atheri* (Farooqi, 1981) Amin, 1985 from Lagos, Nigeria with uninterrupted field of minute spines extending to level of testes in males and mid trunk of females.
3. *Rhadinorhynchus australis* nom. nov. (= *R. polynemi* [9]) with 19–25 and 28–37 complete circles of spines extending past lemnisci and receptacle in males and females, respectively.
4. *Rhadinorhynchus biformis* [9] from Australia with 10 circles of numerous small spines overlapping irregular circles and rows of contrasting large spines extending to posterior end of receptacle and $\frac{1}{4}$ length of males and females, respectively.

Table 1 Length and thickness at base of dorsal and ventral proboscis hooks of 3 female specimens of *Rhadinorhynchus circumspinus* from *Triacanthus biaculeatus* in Vietnam

Hook no.	Hook length		Hook thickness	
	Dorsal hooks	Ventral hooks	Dorsal hooks	Ventral hooks
1	53–57 (55)*	60–63 (62)	7–10 (8)	9–12 (10)
2	87–88 (88)	82–90 (86)	23–27 (25)	27–30 (28)
3	82–87 (85)	75 (75)	27 (27)	25–27 (26)
4	72 (72)	62–65 (63)	25–27 (26)	20–25 (23)
5	60–62 (61)	52–55 (53)	22–23 (22)	19–22 (20)
6	55–60 (57)	50 (50)	20–22 (21)	20 (20)
7	42–50 (46)	42–50 (46)	15–17 (16)	15–20 (17)
8	40–47 (45)	40–48 (44)	13–15 (14)	15–20 (17)
9	45–52 (49)	42–50 (46)	12–15 (13)	15–17 (16)
10	45–55 (51)	50–53 (51)	15 (15)	15–19 (18)
11	45–55 (51)	50–53 (52)	15 (15)	15–19 (17)
12	55–57 (56)	45–55 (51)	15 (15)	15–19 (17)
13	52–62 (58)	50–52 (51)	12–15 (14)	14–17 (15)
14	60–62 (61)	45–50 (48)	10–15 (12)	15 (15)
15	55–62 (59)	42–50 (47)	12 (12)	14–15 (15)
16	55–60 (57)	40–47 (44)	10–12 (11)	13–17 (15)
17	55–65 (60)	45–52 (49)	12 (12)	8–11 (10)
18	65–70 (67)	40–62 (54)	9–12 (11)	8–10 (9)
19	75–92 (81)	90–102 (97)	10–12 (11)	10–13 (12)

* Range (mean) in μm

- Rhadinorhynchus capensis* Bray, 1974 from South Africa with small spines in 1 small ventro-lateral field of about 15 circles just posterior to the proboscis. The validity of this species is uncertain because of the vague questionable size of the basal proboscis hooks compared to others.
- Rhadinorhynchus carangis* Yamaguti, 1939 from Japanese Inland Sea with small spines in 1 field extending past the short lemnisci but short of the end of the long receptacle.
- Rhadinorhynchus decapteri* Parukhin and Kovalenko, 1976 from Hawaii with about 14–15 widely spaced circles of sparse spines extending to posterior end of receptacle.
- Rhadinorhynchus ganapatti* Chandra, Rao and Shyamasundari, 1985 from India with about 4–5 widely spaced circles of 5–8 spines each reaching the end of the receptacle.
- Rhadinorhynchus pichelinae* [9] from Australia with 21–24 irregular circles of spines extending to between the end of the lemnisci and the receptacle.
- Rhadinorhynchus plagioscionis* Thatcher, 1980 from Amazonia with many random spines in irregular cir-

cles extending past the posterior testis in males and to near the posterior end of female trunk.

- Rhadinorhynchus plotosi* Parukhin, 1985 from the Gulf of Oman with irregular circles of spines reaching the posterior end of the receptacle ventrally but shorter distance dorsally.
- Rhadinorhynchus polydactyli* [9] from Australia with large scattered spines in 26–42 irregular circles reaching testes in males and posterior receptacle in females.
- Rhadinorhynchus pomatomi* [9] from Australia with 25–30 large spines in 5–6 irregular incomplete circles.

Rhadinorhynchus polynemi Gupta and Lata, 1967 of India is not a *Rhadinorhynchus* as the basal hooks are smallest. *Rhadinorhynchus polynemi* [9] of Australia is not the Indian species as the basal hooks are largest and is now named *Rhadinorhynchus australis* nom. nov. (= *Rhadinorhynchus polynemi* [9]). Smales [9] used the same name of the Indian species for her Australian material for structural similarities but overlooked posterior hook vs. basal hook size, the extent of the distribution of posterior trunk spines, and differences in the proboscis hook counts. *Rhadinorhynchus trivandricus* George and Nadakal, 1978 with smallest basal hooks and 8 pyriform cement glands is relegated to genus *Indorhynchus* Glovan, 1969 that was erected for a similar species, *Rhadinorhynchus indicus* Tripathi, 1959. Both *Indorhynchus trivandricus* comb. nov. (= *Rhadinorhynchus trivandricus* George and Nadakal, 1978) and *Indorhynchus indicus* (Tripathi, 1959) Golvan, 1969 have anterior spines in 1 field similar to those of *R. circumspinus* but are disqualified from membership in the genus *Rhadinorhynchus* on the account of their 8 pyriform cement glands and small basal hook size.

Rhadinorehynchus pacificus n. sp. (Figs. 4–6, 17–26)

Specimens of this acanthocephalan were obtained from two related hosts off the south Pacific coast of Vietnam at Nha Trang in 2016 and 2017, *A. thazard* and *A. rochei*. Most of the examined hosts had mixed infections with other acanthocephalans mostly including *Rhadinorhynchus laterospinosus* Amin, Heckmann and Ha, 2011. Most of the specimens of *R. pacificus* were collected from *A. thazard*, a highly migratory marine pelagic–neritic oceanodromous fish native to the Indian and the Western Central Pacific Ocean. Many authors have used the name *A. thazard* to include *A. rochei* of the Atlantic Ocean in the belief that there was only a single world-wide species of *Auxis*. These tunas feed on small fish, squids, crustaceans, and stomatopod larvae [5]; Froese and Pauly [6]. Considering the range of distribution of these host species, it would not be unlikely to discover *R. pacificus* from the same or other hosts elsewhere upon more extensive collections.

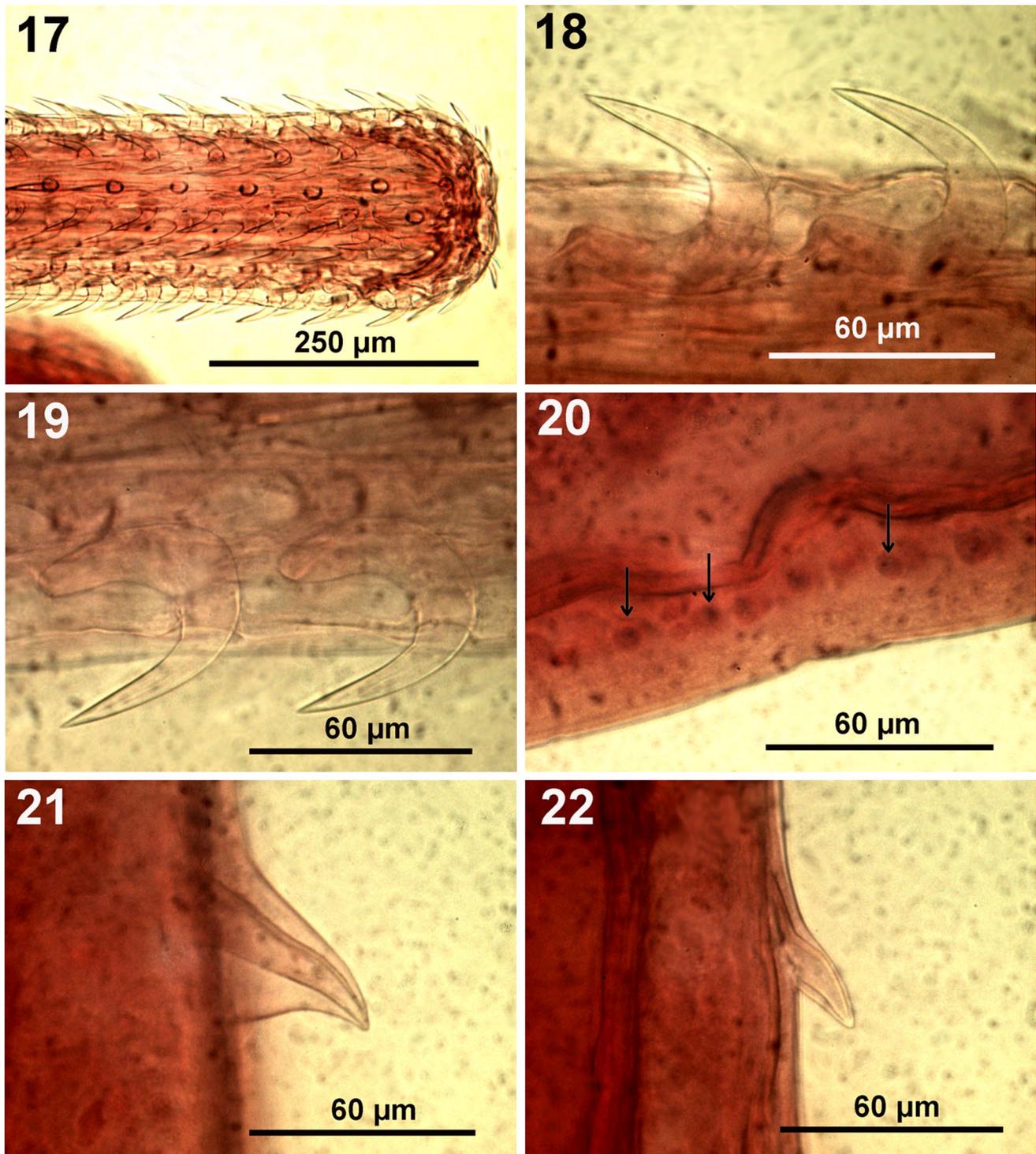


Fig. 17–22 Microscopic images of female specimens of *Rhadinorhynchus pacificus* n. sp. from *Auxis thazard* in Vietnam. **17** Anterior half of a proboscis showing its shape and similar dorsal and ventral hooks. **18** Dorsal hooks at mid-proboscis; note the prominent roots and their size compared to the hook blades. **19** Similar ventral hooks

and roots at mid-proboscis. **20** Part of the body wall showing many fragmented nuclei (arrows) in the sub-cuticular layer. **21** A posterior ventral spine with a single internal rod support. **22** An anterior ventral spine. Anterior spines are similar to posterior spines in this species but are considerably smaller

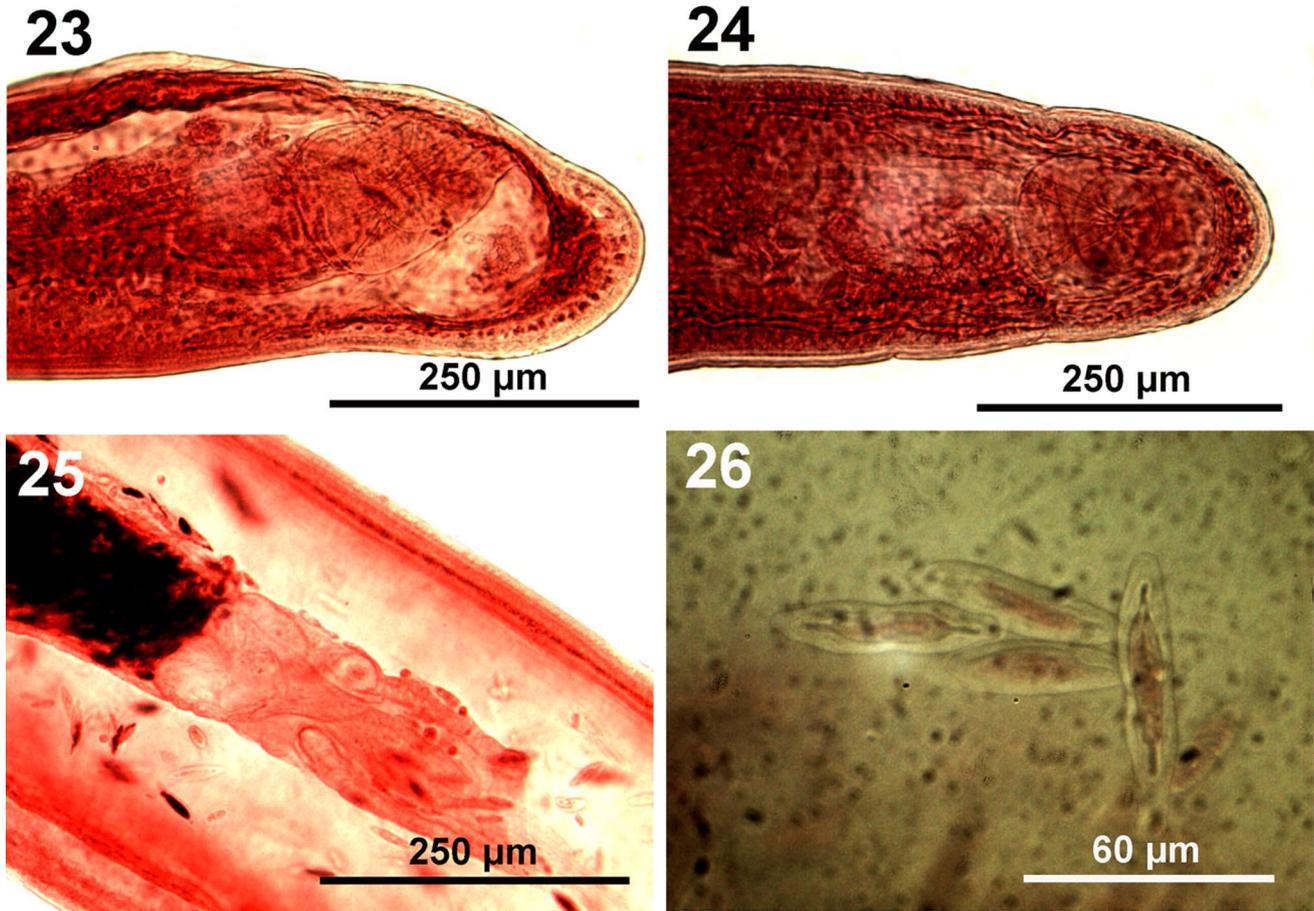


Fig. 23–26 Microscopic images of female specimens of *Rhadinorhynchus pacificus* n. sp. from *Auxis thazard* in Vietnam. **23** A lateral view of the posterior end of a paratype female showing the vagina and the subterminal gonopore. **24** A face view of the posterior end

of another female specimens showing a different perspective of the vagina. **25** Detail of the long uterine bell with parallel sides. **26** Eggs. Note the polar prolongation of fertilization membrane

With the description of *R. pacificus*, the number of species of acanthocephalans in the genus *Rhadinorhynchus* with trunk spines in 2 fields separated by an unarmed zone and with the posterior field of spines including dorsal, lateral, and ventral spines increases to 5. The other 4 members of this group are *Rhadinorhynchus cadenati* (Golvan and Houin, 1964) Golvan, 1969 from Senegal and Nigeria, *Rhadinorhynchus dorsoventrospinosus* Amin, Heckmann, and Ha, 2011 from Vietnam, *Rhadinorhynchus erumei* (Gupta and Fatima, 1981) Amin, 1985 from India, and *Rhadinorhynchus lintoni* Cable and Linderoth, 1963 from the Mediterranean and Atlantic Ocean. Those 5 species do not appear to be grouped together based on common ecological or host related factors.

Description

General with characters of the genus *Rhadinorhynchus*. Trunk cylindrical, spinose anteriorly in 2 fields separated

by unarmed zone (Fig. 4). Sub-cuticular layer with many fragmented nuclei (Fig. 20). Spines in anterior field in 1–6 complete irregular circles, similar dorsoventrally. Up to 12, 8, and 5 ventral, dorsal and lateral spines, respectively, in irregular circles in posterior field; larger anteriorly than posteriorly (Figs. 21, 22). Spines in posterior field extending to about half length of receptacle. Proboscis cylindrical, slightly wider anteriorly (Figs. 6–17), with 14–18 rows of 22–25 hooks each. Hooks of similar length and shape dorsoventrally but ventral hooks slightly thicker (Figs. 18, 19). Apical hooks smallest, becoming larger more posteriorly then gradually decrease in size till pre-basal hooks before becoming abruptly larger basally. Hook roots simple, posteriorly directed, about as long as blades and markedly thicker (Figs. 18, 19), becoming vestigial or discoid at posterior end. Neck prominent. Proboscis receptacle more than twice as long as proboscis, double-walled, with cephalic ganglion at its center. Lemnisci digitiform, equal, shorter than receptacle (Fig. 4).

Table 2 Length and distribution of trunk spines of 10 female specimens of *Rhadinorhynchus pacificus* from *Auxis thazard*, and *Auxis rochei* in Vietnam

	Anterior trunk spines			Posterior trunk spines		
	Dorsal	Ventral	Across	Dorsal	Ventral	Across
No.	3–4 (3.4)*	1–5 (3.4)	2–6 (3.6)	2–8 (4.2)	4–12 (8.3)	1–5 (3.2)
Length	50–62 (57)**	42–70 (57)	40–62 (55)	67–75 (70)	57–75 (67)	52–75 (65)
Length	–	–	–	45–52 (49)***	37–57 (48)	40–54 (46)

*Range of number of spines on one side (mean)

**Range (mean) length of spines in μm

***Range (mean) length of posterior-most trunk spines in μm

Table 3 Length and thickness at base of dorsal and ventral proboscis hooks of 5 female specimens of *Rhadinorhynchus pacificus* from *Auxis thazard* and *Auxis rochei* in Vietnam

Hook no.	Hook length		Hook thickness	
	Dorsal hooks	Ventral hooks	Dorsal hooks	Ventral hooks
1	37–47 (44)*	32–52 (43)	10–12 (11)	10–15 (12)
2	55–67 (60)	42–67 (57)	12–18 (15)	12–20 (16)
3	57–77 (68)	54–67 (62)	12–22 (18)	12–20 (17)
4	60–77 (68)	58–70 (64)	12–20 (18)	12–20 (18)
5	62–82 (70)	60–70 (66)	12–22 (17)	13–20 (18)
6	67–77 (70)	60–70 (66)	12–20 (17)	15–20 (18)
7	67–72 (69)	60–70 (66)	15–18 (17)	15–20 (19)
8	62–72 (68)	65–70 (69)	12–18 (16)	15–22 (19)
9	67–75 (71)	62–75 (69)	14–18 (16)	15–22 (19)
10	70–75 (72)	67–75 (72)	13–17 (15)	15–20 (19)
11	70–77 (73)	67–82 (73)	13–19 (16)	15–24 (20)
12	70–75 (73)	67–77 (72)	12–19 (15)	15–20 (19)
13	70–72 (71)	70–77 (73)	12–16 (15)	15–20 (19)
14	70–74 (72)	70–81 (74)	12–17 (14)	15–22 (19)
15	70–72 (71)	70–75 (72)	12–18 (14)	18–20 (19)
16	60–72 (67)	67–80 (72)	12–18 (14)	18–20 (19)
17	55–70 (65)	67–80 (71)	12–16 (13)	17–20 (18)
18	55–70 (65)	65–75 (70)	11–15 (12)	15–20 (16)
19	60–67 (63)	67–75 (71)	10–15 (12)	14–20 (17)
20	55–67 (60)	62–75 (69)	12 (12)	14–20 (17)
21	55–62 (60)	60–75 (66)	11–13 (12)	14–18 (16)
22	52–60 (56)	55–68 (63)	10–14 (11)	12–20 (15)
23	40–52 (47)	45–62 (54)	10–12 (11)	10–17 (13)
24	37–50 (44)	37–55 (46)	9–12 (11)	10–15 (12)
25	62–67 (64)	62–70 (67)	8–12 (11)	10–15 (12)

*Range (mean) in μm

Females (based on 10 mature adults with eggs and ovarian balls) trunk 9.12–21.62 (15.79) mm long by 0.37–0.85 (0.58) mm wide. See Table 2 for length and distribution of trunk spines. Body wall with many fragmented nuclei (Fig. 20). Proboscis 1.37–1.85 (1.59) mm long by 0.19–0.30 (0.25)

mm wide anteriorly. See Table 3 for length and thickness of dorsal and ventral hooks. Neck 312–364 (333) long dorsally by 208–281 (250) wide posteriorly. Proboscis receptacle 2.96–4.25 (3.47) mm long by 0.22–0.36 (0.28) mm wide. Lemnisci 2.35–3.00 (2.78) mm long by 0.13–0.18 (0.15) mm wide. Reproductive system 2.34–6.55 (4.35) mm long, 26%–36% (29%) of trunk length. Gonopore sub-ventral with well-developed vagina (Figs. 23, 24), 190–250 (216) long. Uterus long (Fig. 5) with elongate and prominent uterine bell with parallel sides (Fig. 25), 269–488 (352) long. Eggs elongate fusiform with polar prolongation of fertilization membrane (Fig. 26), 52–65 (59) long by 12–15 (13) wide.

Taxonomic Summary

Type host: Frigate tuna *Auxis thazard* (Lacepède) (Scombridae).

Other host: the bullet tuna *Auxis rochei* (Lacepède) (Scombridae).

Typy locality: Pacific Ocean off Nha Trang (12°15'N 109°11'E).

Site of infection: Intestine.

Type specimens: HWML collection no. (holotype female) and no. paratype females.

Etymology: The new species named for its known geographical distribution.

Remarks

Rhadinorhynchus pacificus n. sp. belongs in a group of 5 species of rhadinorhynchid acanthocephalans characterized by having trunk spines in 2 fields separated by an unarmed zone and with the posterior field of spines including dorsal, lateral, and ventral spines. It is distinguished from the other 4 members of this group as follows. Females of *R. cadenati* from Senegal and Nigeria

have longer proboscides (2.13 long) with extremely dorsoventrally differentiated hooks, unequal lemnisci, terminal gonopore, and larger eggs (80×17). In females of *R. dorsoventrospinosus* from Vietnam, the posterior trunk spines are more numerous reaching 27 dorsally and 43 ventrally and may extend well past the receptacle to about half the length of trunk, the proboscis has fewer rows (11, 12) each with more dorsoventrally differentiated hooks (30–31) with roots about half as long as blades, and larger eggs (100×20). *Rhadinorhynchus erumei* from India was described from only one 6.00-mm-long male specimen with small anterior trunk spines (22–25 long)

in 2 sets: more numerous (8, 9) tightly spaced anterior circles followed by fewer 5–6 widely separated circles posteriorly, and a short (0.75 mm long) proboscis with 12 rows of 26 very small hooks (22 long) each reaching only 26 in length basally. In females of *R. lintoni* from the Mediterranean and Atlantic Ocean, the trunk spines in the posterior field are variable, the proboscis has 14–16 rows of more (28–32) extremely dorsoventrally differentiated hooks, much longer receptacle (7.5 mm long), female reproductive system reaching 15 mm long, and larger eggs, 110×22 .

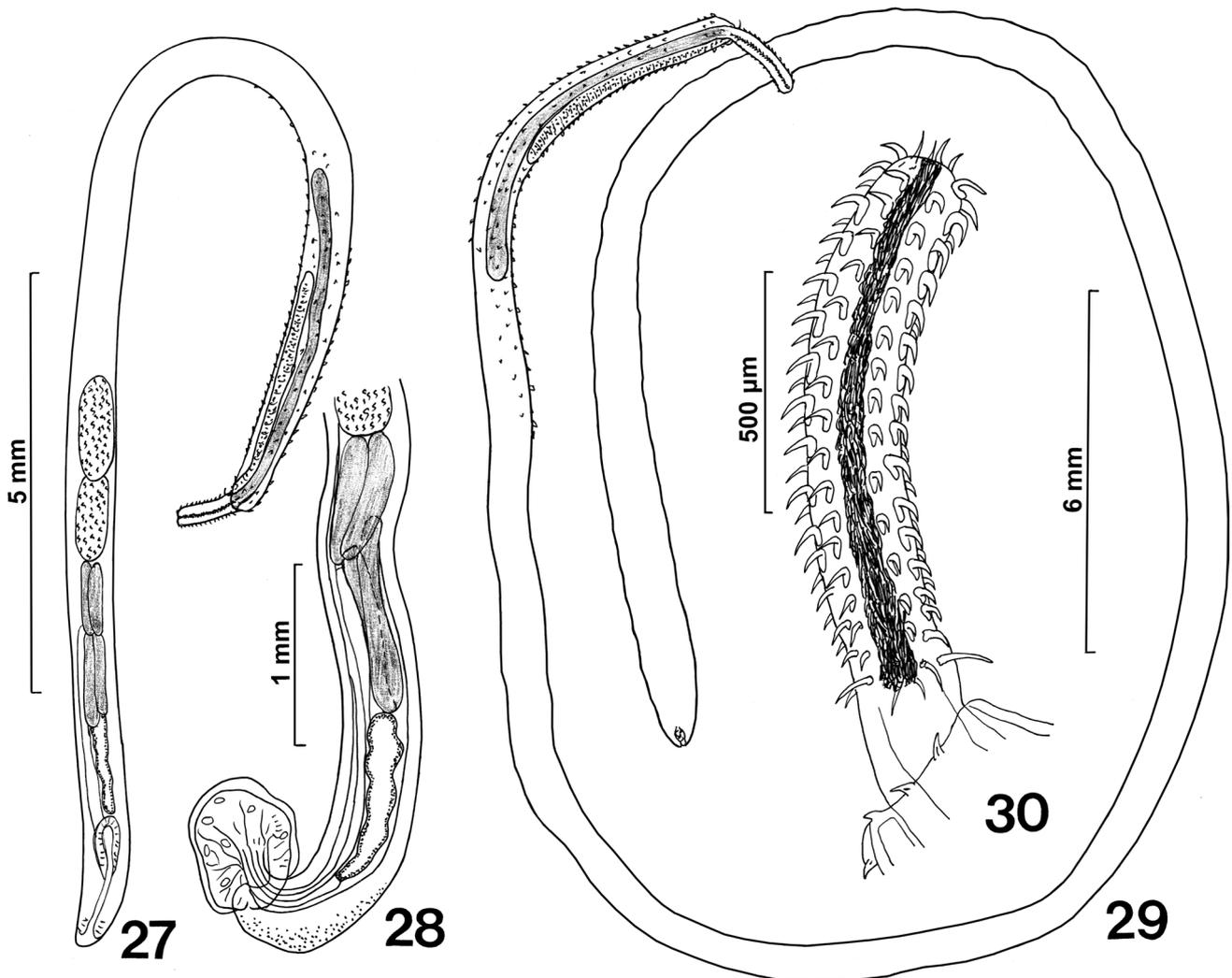


Fig. 27–30 Line drawings of male and female specimens of *Rhadinorhynchus multispinosus* n. sp. from *Decapterus maruadsi* in Vietnam. **27** Holotype male. Note the proportion of body cavity occupied by the reproductive system. **28** Detail of the reproductive system from a paratype male. Note the partially overlapping cement glands and the

undulating Saefftigen's pouch. **29** The long allotype female specimen also with a lemniscus markedly shorter than the receptacle. **30** The partially retracted proboscis of the allotype female in Fig. 29 showing the dorsoventrally differentiated hooks

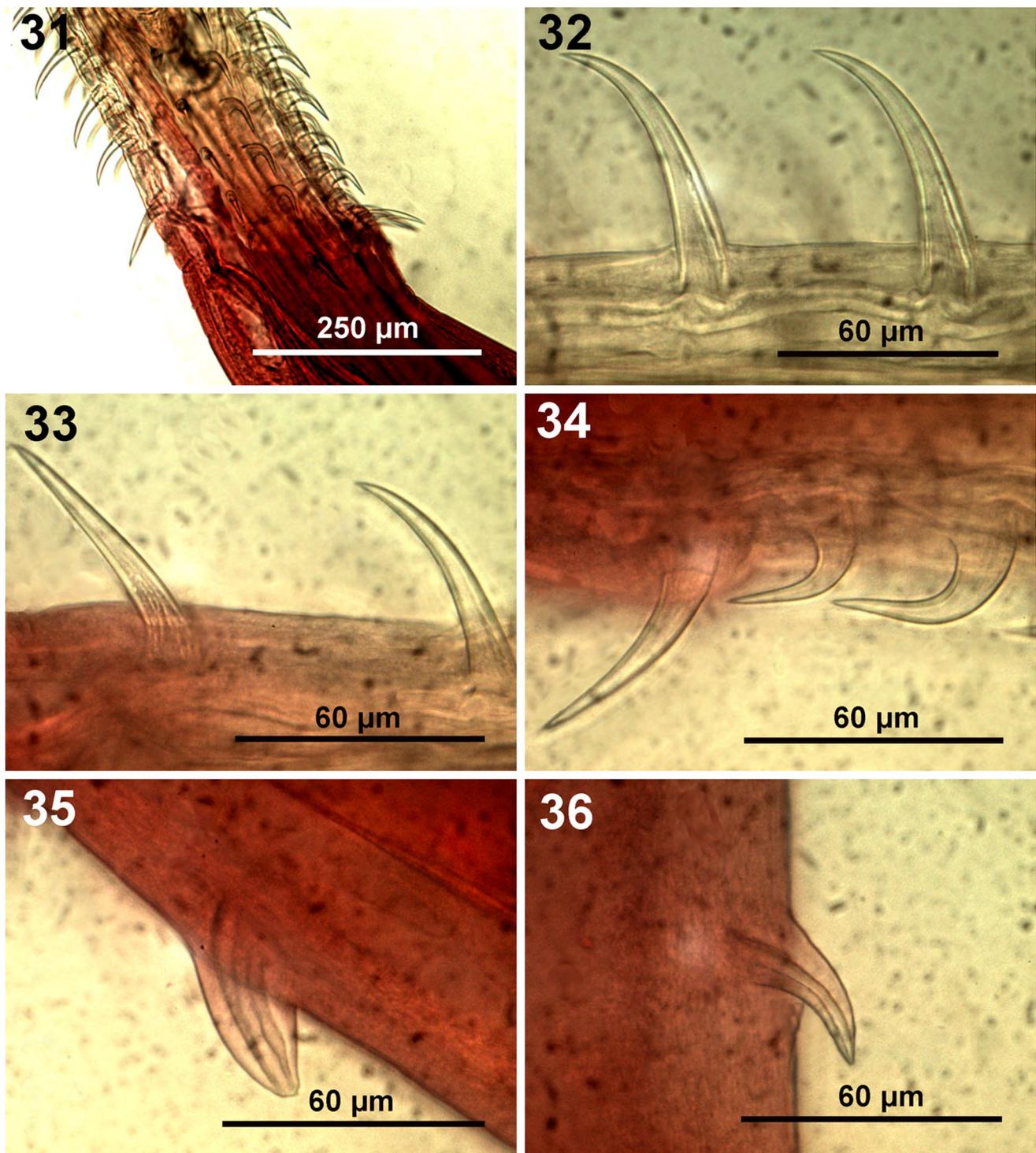


Fig. 31–36 Microscopic images of male and female specimens of *Rhadinorhynchus multispinosus* n. sp. from *Decapterus maruadsi* in Vietnam. **31** The posterior portion of a proboscis showing dorsal hooks to the left and ventral hooks to the right. Note the longer basal hooks. **32** Dorsal hooks at mid-proboscis. **33** Posterior dorsal hooks showing a basal hook at left and a smaller pre-basal hook to the right. Note that the smaller pre-basal hook is markedly smaller than the

other dorsal hooks in Fig. 32. The hook size gradually decreases in size posteriorly. **34** Posterior ventral hooks showing long basal hook compared to the considerably smaller pre-basal ventral hooks. **35–36** A comparison between a large anterior spine (with double internal rod supports) (Fig. 35) and a smaller posterior-most spine (with only a single internal rod support) (Fig. 36) which is characteristic of this species

Table 4 Length and distribution of trunk spines of 2 male and 4 female specimens of *Rhadinorhynchus multispinosus* from *Decapterus maruadsi* in Vietnam

	Anterior trunk spines			Posterior trunk spines		
	Dorsal	Ventral	Across	Dorsal	Ventral	Across
<i>Males</i>						
No.	2–3 (1.5)*	0–3 (1.5)	3–5 (4.0)	15–28 (21.5)	20–24 (22.0)	3–6 (4.0)
Length	57–67 (62)**	57–61 (59)	55–61 (58)	52–73 (62)	52–73 (62)	50–68 (59)
Length	–	–	–	30–50 (42)***	25–45 (33)	27–47 (37)
<i>Females</i>						
No.	2–3 (2.7)	0–2 (1.0)	5–7 (6.0)	18–29 (22.3)	32–43 (36.0)	5–7 (6.0)
Length	60–67 (65)	67–77 (72)	62–64 (63)	62–82 (70)	66–77 (72)	59–69 (64)
Length	–	–	–	55–62 (58)	52–70 (60)	51–60 (55)

*Range of number of spines on one side of worms (mean)

**Range (mean) length of spines in μm

***Range (mean) length of posterior-most trunk spines in μm

Table 5 Length and thickness at base of posterior dorsal and ventral hooks of 4 female and 2 male specimens of *Rhadinorhynchus multispinosus* from *Decapterus maruadsi* in Vietnam

Hook no.	Males				Females			
	Hook length		Hook thickness		Hook length		Hook thickness	
	Dorsal hooks	Ventral hooks	Dorsal hooks	Ventral hooks	Dorsal hooks	Ventral hooks	Dorsal hooks	Ventral hooks
16	88 (88)	84–85 (84)*	17 (17)	23–26 (25)	–	–	–	–
17	85–92 (89)	87 (87)	17 (17)	25–27 (26)	–	–	–	–
18	82–88 (86)	85–87 (86)	17 (17)	25–27 (26)	–	–	–	–
9	80–88 (86)	85–87 (86)	17 (17)	25–26 (26)	–	–	–	–
20	85–88 (87)	85–87 (86)	16–17 (17)	25 (25)	–	–	–	–
21	82–89 (87)	85–87 (86)	17 (17)	25 (25)	–	–	–	–
22	85–89 (88)	82–87 (85)	16–17 (17)	25–26 (26)	75 (75)	67 (67)	17 (17)	20 (20)
23	87–90 (89)	82–87 (84)	17 (17)	22–25 (24)	75 (75)	67 (67)	15 (15)	18 (18)
24	87–92 (90)	82–87 (85)	15–17 (16)	22–25 (24)	75 (75)	67 (67)	15 (15)	16 (16)
25	92–95 (93)	82–85 (83)	15–17 (16)	22–25 (23)	70 (70)	65 (65)	15 (15)	17 (17)
26	90–95 (92)	77–82 (79)	15–17 (16)	22–25 (23)	67 (67)	62 (62)	14 (14)	17 (17)
27	90–92 (91)	70–82 (76)	15–17 (16)	22–25 (23)	67 (67)	57 (57)	14 (14)	17 (17)
28	85–90 (87)	67–80 (72)	15–17 (16)	21–23 (22)	62 (62)	55 (55)	14 (14)	16 (16)
29	77–85 (81)	62–77 (68)	13–17 (15)	20–25 (22)	56–59 (58)	50–63 (56)	13 (13)	15–16 (16)
30	60–77 (68)	62–72 (67)	13–17 (15)	14–25 (19)	47–55 (51)	37–42 (39)	12–13 (12)	11–13 (12)
Basal	72–85 (81)	70–90 (82)	15–17 (16)	15–22 (18)	65–75 (70)	62–75 (68)	12–15 (13)	12–15 (14)

*Range (mean) in μm

**Harada (1935) reported the length of 11 dorsal and ventral “basal” hooks but numbered them HI to HXI. Based on their length, we placed them at the posterior part of the proboscis. His single measurements must have been made of posterior hooks of an anteriorly retracted proboscis

***Rhadinorhynchus multispinosus* n. sp. (Figs. 27–42)**

This is the second species of *Rhadinorhynchus* in this collection with 2 fields of trunk spines separated by a distinct unarmed zone and with the posterior field including dorsal, ventral and lateral spines. Four females and 2 males were found in 3 individuals of the Japanese scad *D. maruadsi* off Hai Phong in the north of Vietnam. The parasite distribution may parallel that of its Indo-West Pacific host in the South China Sea to Mariana Islands

[7] and perhaps elsewhere pending further investigations in these waters.

Description

General With characters of the genus *Rhadinorhynchus*. Shared structures considerably larger in females than in males, especially trunk size. Trunk long, uniformly cylindrical, spinose anteriorly in 2 fields separated by aspinose zone (Figs. 27, 29). Anterior field with 0–3 circles of 3–5

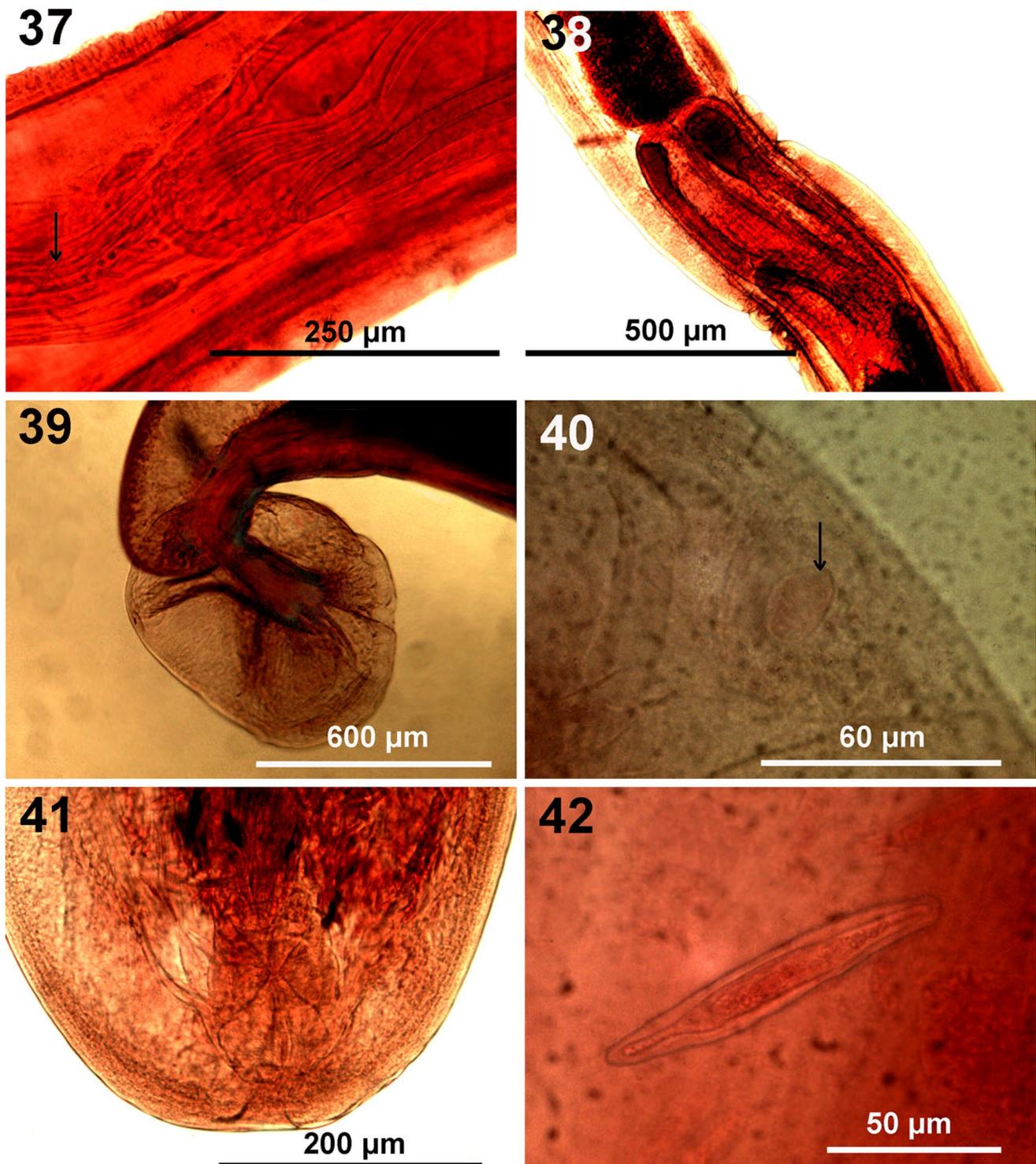


Fig. 37–42 Microscopic images of male and female specimens of *Rhadinorhynchus multispinosus* n. sp. from *Decapterus maruadsi* in Vietnam. **37** The posterior portion of a proboscis receptacle showing the extensive differentiation of proboscis retractor muscles extending outside of the receptacle (arrow). **38** Detail of the anterior pair of cement glands contiguous with the posterior testis. **39** The bursa of the paratype male specimen. **40** One of the few detected ovoid sen-

sory plates (arrow) enclosed in a rim-like ring near the periphery of the bursa in Fig. 39. **41** A view of the vagina and the terminal gonopore. The rest of the reproductive system was obscured by eggs in all specimens. **42** A ripe egg. Note the polar prolongation of fertilization membrane not identical in both poles which was a common observation

spines each in males and 5–7 spines each in females on 1 side. Posterior field with up to 28 dorsal and 24 ventral spine circles in males and 29 and 43 spines in females, respectively, and extending a short distance past the receptacle dorsally and longer distance ventrally. Spines more frequent and larger in females than in males. Spines in posterior field largest anteriorly with 2 skeletal support rods (Fig. 35) and smallest posteriorly with 1 support rod each (Fig. 36). Proboscis long, cylindrical, slightly widening anteriorly, with 12 rows of 31–32 dorsoventrally differentiated hooks each (Figs. 30, 31). Hooks longer and more slender with near vertical projection dorsally (Figs. 32, 33) but shorter and more recurved posteriorly ventrally (Fig. 34), increasing in size at middle then gradually decrease in size posteriorly except at basal ring when becoming abruptly longer. Hook roots simple, recurved posteriorly, about as long as blades, becoming discoid or vestigial at posterior end (Figs. 32–34). Neck prominent. Proboscis receptacle long, more than twice as long as proboscis, double-walled, with cephalic ganglion near its middle, and numerous proboscis retractor muscles. Lemnisci digitiform, equal, considerably shorter than receptacle (Figs. 27, 29). Gonopore terminal in both sexes.

Males (based on 2 mature adults with sperm). Trunk 17.75–18.12 (17.93) mm long by 0.50–0.57 (0.53) mm wide. See Table 4 for size and distribution of trunk spines. Proboscis 1.56–1.61 (1.58) mm long by 0.21–0.32 (0.26) wide anteriorly. See Table 5 for accessible measurements of distinct posterior 15 hooks. Proboscis receptacle 4.37–4.50 (4.43) mm long by 0.21–0.32 (0.26) wide. Lemnisci 2.50 mm long by 0.19 wide. Reproductive system in posterior 30–40% of trunk. Testes post-equatorial, oblong and contiguous (Fig. 27). Anterior testis 1.25–1.32 (1.28) mm long by 0.25–0.45 (0.35) mm wide, longer than posterior testis 0.80–1.05 (0.92) mm long by 0.30–0.45 (0.37) wide. Cement glands 4, in 2 pairs; contiguous with posterior testis Figs. 27, 28, 38). Anterior cement glands 0.75 mm long by 0.17–0.25 mm wide; posterior glands longer 1.12 mm long by 0.25 mm wide. Two cement gland ducts joining base of undulating Saeftigen's pouch (Fig. 28), 837 long by 177 wide. Bursa with prominent rim (Fig. 39), 875 long by 675 wide, with few ovoid sensory plates (Fig. 40), 30–33 long by 17–20 wide, in well-like rims.

Females (based on 4 adults with eggs and ovarian balls). Trunk much longer than in males, 45.00–67.50 (57.94) mm long by 0.82–1.20 (0.95) mm wide. Proboscis 2.00–2.32 (2.17) mm long by 0.24–0.25 (0.24) wide. Neck 500–520 (513) long dorsally by 312–475 (384) wide posteriorly. Proboscis receptacle 4.17–6.00 (5.06) mm long by 0.30–0.32 (0.31) mm wide. Lemnisci 3.32–3.67 (3.45) mm long by 0.14–0.21 (0.17) mm wide. Reproductive system obscured

by eggs. Vagina spheroid, well developed; gonopore terminal (Fig. 41). Ripe eggs elongate fusiform with polar prolongation of fertilization membrane (Fig. 42), 92–112 (103) long by 15–20 (18) wide.

Taxonomic Summary

Type host: Japanese scad, *Decapterus maruadsi* (Temminck and Schlegel) (Carangidae).

Typy locality: Pacific Ocean off Hai Phong (20°51'54.5"N 106°41'01.8"E).

Site of infection: Intestine.

Type specimens: HWML collection no. (holotype male), no. (allotype female), no. (paratypes).

Etymology: The name of new species describes the large number of trunk spines especially those in the posterior field.

Remarks

There are currently 5 other species of rhadinorhynchid acanthocephalans characterized by having trunk spines in 2 fields separated by an unarmed zone and with the posterior field of spines including dorsal, lateral, and ventral spines. *Rhadinorhynchus multispinosus* is distinguishable from the other 5 members of this group as follows. The proboscis in *R. cadenati* from Senegal and Nigeria has more proboscis hook rows (16) of less hooks (25–26) each, unequal lemnisci, considerably fewer trunk spines, and smaller eggs (80 × 17). In *R. dorsoventrospinosus* from Vietnam, the posterior trunk spines extend well past the receptacle and may reach half the length of the trunk, proboscis hook roots only about half as long as blades, and females are much shorter (17.5–37.75 mm long) with markedly smaller receptacle (3.87–4.75 mm long) and subterminal gonopore. Gonopore is terminal in *R. multispinosus*. *Rhadinorhynchus erumei* from India was described from only one 6.00-mm-long male specimen with much smaller anterior trunk spines (22–25 long) in 2 sets: 8–9 tightly spaced anterior circles followed by 5–6 widely separated circles posteriorly, and a considerably shorter (0.75 mm long) proboscis with fewer hooks per row (26) carrying much smaller hooks (22 long) each reaching only 26 in length basally. In specimens of *R. lintoni* from the Mediterranean and Atlantic Ocean, the trunk spines in the posterior field are variable, the trunk is shorter (42–44 mm) and the receptacle is longer (7.5 mm) in females, the proboscis has more rows of hooks (14–16), the lemnisci are always shorter than the receptacle, and the gonopore is subterminal. Specimens of *R. pacificus* from

Vietnam have more proboscis hook rows (14–18) of fewer dorsoventrally similar hooks (22–25) each, smaller receptacle (2.96–4.25 mm long), fewer trunk spines, subterminal gonopore, and much smaller eggs (52–65 × 12–15).

Discussion

Forty-three species of *Rhadinorhynchus* were known from marine fish throughout the world especially in the Pacific and the Atlantic. We add 3 more species from marine fish off the Pacific coast of Vietnam, 1 with 1 anterior field of continuous trunk spines, *R. circumspinus* n. sp., and 2 species with 2 fields of trunk spines separated by an unspined zone, *R. pacificus* n. sp., and *R. multispinosus* n. sp. Amin et al. [2] have also previously described two other species of *Rhadinorhynchus* from fishes off the Vietnamese Pacific coast, *R. dorsoventrospinosus*, and *R. laterospinosus*. Based on Russian sources, Arthur and Te [4] reported 3 other species of *Rhadinorhynchus* from Vietnamese marine fishes that we did not come across in our investigations in Vietnam. These are *R. carangis* and *R. pristis* from *Caranx malabaricus* and *R. ditrematus* from *Decapterus* sp. This increases the Vietnamese Pacific species of *Rhadinorhynchus* to 8 which is a considerable portion of world-wide species of this genus (17%). Most of these 8 species so far are known from fishes off the Vietnamese Pacific and will undoubtedly be found in other waters elsewhere in the same or other fish species.

There are currently 14 species of *Rhadinorhynchus*, including *R. circumspinus*, known to have trunk spines distributed in one anterior continuous field. Of particular interest is the finding of *R. circumspinus* n. sp. characterized by its unique body and proboscis forms not known before in any other species of *Rhadinorhynchus*. Regrettably, males of this species were not encountered and we hope that future collections from its host, the short-nosed tripod fish *T. biaculeatus*, may produce more specimens. Like most species of *Rhadinorhynchus*, the proboscis hooks of *R. circumspinus* and *R. multispinosus* have dorsoventrally differentiated proboscis hooks. In *R. pacificus*, however, dorsal and ventral hooks are similar in length and shape which is quite unusual in this genus. In all cases, the hook roots are of about equal size to the blades except for the basal and prebasal hooks where the roots are discoid or vestigial.

Considering the relatively large number of species of the *Rhadinorhynchus* in the East Asia Pacific, there appears to be a need to better understand their interspecific relationships as well as their phylogenetic associations with other groups of Acanthocephala. None of the Asian species of *Rhadinorhynchus* have been studied at the molecular level to date, except for our pioneering work on *R. laterospinosus* based on 18S rDNA and *cox1* genes confirming the paraphyly of the genus [3]. We demonstrated a strong relationship between *R. laterospinosus* and other representatives of

the genus like *R. pristis*. To date, genetic data have been provided for only 3 species of *Rhadinorhynchus*: *R. laterospinosus*, *R. pristis*, and *R. lintoni* [3]. The scarcity of molecular profiles available for this genus poses difficulties for correctly determining relationships among its members and with other genera, and adds significance to future molecular research. In our attempts to get a genetic perspective on this issue, we are currently undergoing research on the molecular profile of 2 other East Asian species of *Rhadinorhynchus* from Vietnam, *R. dorsoventrospinosus* and *R. hiansi* Soota and Bhattacharya, 1981.

Acknowledgements This project was supported by the Vietnam National Program No. 47 under Grant code VAST.DA47.12/16-19 and by an Institutional Grant from the Parasitology Center, Inc. (PCI), Scottsdale, Arizona.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflict of interest.

Ethical Standards Compliance with all relevant ethical standards.

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