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A new Cardiodectes Wilson, 1917 (Hexanauplia: Copepoda: Siphonostomatoida) parasitic on a scarid teleost (Perciformes: Scaridae) from Roatan Island, Central America

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Abstract Members of the parasitic copepod family Pennellidae are highly transformed ecto- or mesoparasites infecting a wide array of marine teleosts. Currently, this family contains more than 20 valid genera. The pennellid genus *Cardiodectes* Wilson, 1917 is currently known to contain 15 nominal species. Some pennellids exhibit a complex life cycle involving an intermediate host; it is known that planktonic pteropod molluscs are intermediate hosts for *Cardiodectes*. Pennellid mesoparasites can be detected by the conspicuous female egg-carrying trunk on the host external surface. The copepod cephalothorax is deeply embedded in the host muscle tissue. Members of *Cardiodectes* have been reported from several teleost families, mainly Myctophidae and Engraulidae. From the parasitological examination of a juvenile individual of a scarid teleost collected in a reef lagoon of Roatan Island, Honduras, Central America, several ovigerous female individuals of a mesoparasitic pennellid copepod were found; these specimens were recognized as representative of an undescribed species of *Cardiodectes* Wilson, 1917. The new species, *C. roatanensis* **n. sp.**, differs from its known congeners in several respects, including the presence of neck lobes, paired posterior protuberances of the trunk, trunk shape and proportions, structure of cephalothorax lobes, cephalothorax relative size, and number of legs. The new species from Roatan is the second member of this copepod genus to be reported from the Caribbean region, after *C. boxshalli* Bellwood, 1981 from off Jamaica (Bellwood 1981). It is also the second report of *Cardiodectes* on a parrotfish.

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The siphonostomatoid copepod family Pennellidae includes highly transformed ecto- and mesoparasitic copepods infecting marine teleost hosts, including some commercially important species (Kabata, 1981; Yumura et al., 2022). The genus *Cardiodectes* Wilson, 1917 is currently known to contain 15 nominal species; the type species is *C. bellottii* (Richiardi, 1882) (Walter & Boxshall, 2022). Because development and mating occur in the plankton or on an intermediate planktonic host, there is little information available on the pennellid mating process and developmental stages. It is known that planktonic pteropod molluscs (*i. e.*, species of *Limacina*, *Creseis*) can be intermediate hosts for *Cardiodectes* and other pennellids (Ho, 1966; Perkins, 1983; Ismail et al., 2013: Ohtsuka et al., 2018a, 2018b). An infective free-swimming copepodid enters the planktonic intermediate host; once inside it, the copepod goes through three distinct chalimus stages, followed by mating between adult males and preadult females in the water column. Males die after mating and postmated females

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leave the gastropod to infect the final fish host. Females of pennellid copepods undergo an extreme transformation during their postmating metamorphosis stage (Kabata, 1979; Boxshall & Halsey, 2004) The naupliar stage of some pennellids is absent and directly hatches as an infective copepodid (Ohtsuka et al., 2018a, 2018b). Pennellid mesoparasitic forms can be easily detected on their teleost host by the presence of the egg-carrying trunk on the host external surface. The cephalothorax, comprising the cephalic appendages and the uni- or biramous legs, is embedded in the host muscle tissue. Members of *Cardiodectes* have been reported from up to 23 species of different teleost families mainly including Myctophidae (13 species), Engraulidae (3), Apogonidae (1), Gobiidae (1), Scaridae (2), Anthiadinae (1) (Izawa, 1970; Bellwood, 1981; Uyeno & Nagasawa, 2010; Uyeno. 2013; this survey). Species of *Cardiodectes* have been reported from widely different geographic areas including the Indian Ocean (Brian & Gray, 1928; Markevich, 1936), the Caribbean Sea (Bellwood, 1981), and the Celebes Sea (Leigh-Sharpe, 1934), but mainly the Pacific waters adjacent to Japan (Izawa, 1970; Uyeno & Nagasawa, 2010; Uyeno, 2013). Several ovigerous female individuals of a mesoparasitic pennellid copepod were recorded from a juvenile parrotfish found in a reef area of Roatan Island, Central America. They were recognized as an undescribed species of *Cardiodectes* Wilson, 1917. The new species differs from its known congeners in several respects, including the trunk shape and proportions, cephalothorax lobes size and structure, number of thoracic appendages, trunk posterior processes, and neck region structure. The new species from Honduras is the second member of this copepod genus to be reported from the Caribbean region, after *C. boxshalli* Bellwood, 1981 from off Jamaica (Bellwood, 1981).

From the parasitological examination of teleosts collected as part of a project to study the connectivity of the Mesoamerican Reef System (ECOME) in Roatan Island, Honduras, Central America, Northwestern Tropical Atlantic (NWTA), we found several postmetamorphic female individuals of mesoparasitic copepods attached to a juvenile parrotfish (Perciformes: Scaridae) tentatively identified as the emerald parrotfish *Nicholsina ustis* (Valenciennes, 1839). After the taxonomic examination of these specimens, we recognized that they represent an undescribed species of the pennellid genus *Cardiodectes*. In this contribution we describe a new *Cardiodectes* and compare it with its known congeners.

Materials and Methods

The parasitized juvenile parrotfish host was collected from the reef lagoon of Sandy Bay West End Marine Reserve (16° 20'8.09"N; 86° 34'2.68 W), Roatan Island, Honduras, Central America, on September 9, 2021 during a biological connectivity survey in the Mesoamerican Reef System (ECOME). Roatan Island is located about 52 km off the northern Honduran coast. The parasitized teleost was captured using a water column collector (Steele et al., 2002) placed in the reef lagoon at a depth of 2.5 m, following Malca et al.'s (2015) field methodology. Salinity (35.85PSU) and temperature (28.5°C) were measured at the sampling site. The parasitized host is a postlarval individual (total body length SL = 2.05 cm) of the emerald parrotfish *Nicholsina ustis* (Valenciennes, 1839); the host was identified by following Jones et al.'s (2006) keys and descriptions of North Atlantic immature fish species. Infection by these mesoparasitic copepods can be detected by the presence of the egg-carrying trunk on the host external surface. The attached copepods were completely removed from the host by dissection (Bellwood, 1981). The holotype specimen was immersed in a solution of Methylene-Green and glycerol. By carefully removing the host tissues from the copepod cephalothorax with a pair of sharpened needles, we were able to obtain and observe the main features of the cephalothorax of three individuals for further taxonomic evaluation; one of them was preserved in ethanol and the other two were processed for SEM examination with a JEOL JSM-6010LA microscope at facilities of ECOSUR in Chetumal, Mexico. The process included dehydration of specimens in progressively higher ethanol solutions (70, 96, 100 %), critical point drying, and gold coating following standard methods.

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Systematics

Class Copepoda Milne Edwards, 1840
Superorder Podoplea Giesbrecht, 1882
Order Siphonostomatoida Burmeister, 1835
Pennellidae Burmeister, 1835
***Cardiodectes* C. B. Wilson, 1917**

***Cardiodectes roatanensis* n. sp.**
(Figs 1–3)

Type host: Parrot fish identified as the emerald parrotfish *Nicholsina ustis* (Valenciennes, 1839) (Perciformes, Scaridae).

Type locality: Sandy Bay reef lagoon, Roatan Island, 52 km from northern coast of Honduras, western Caribbean (16°20'8.09"N; 86°34'2.68 W).

Type-material: Holotype ovigerous female (trunk length = 1.44 mm) from a juvenile parrotfish (Perciformes: Scaridae) collected in coastal areas of Roatan Island, Honduras, Central America (16°20'8.09"N;

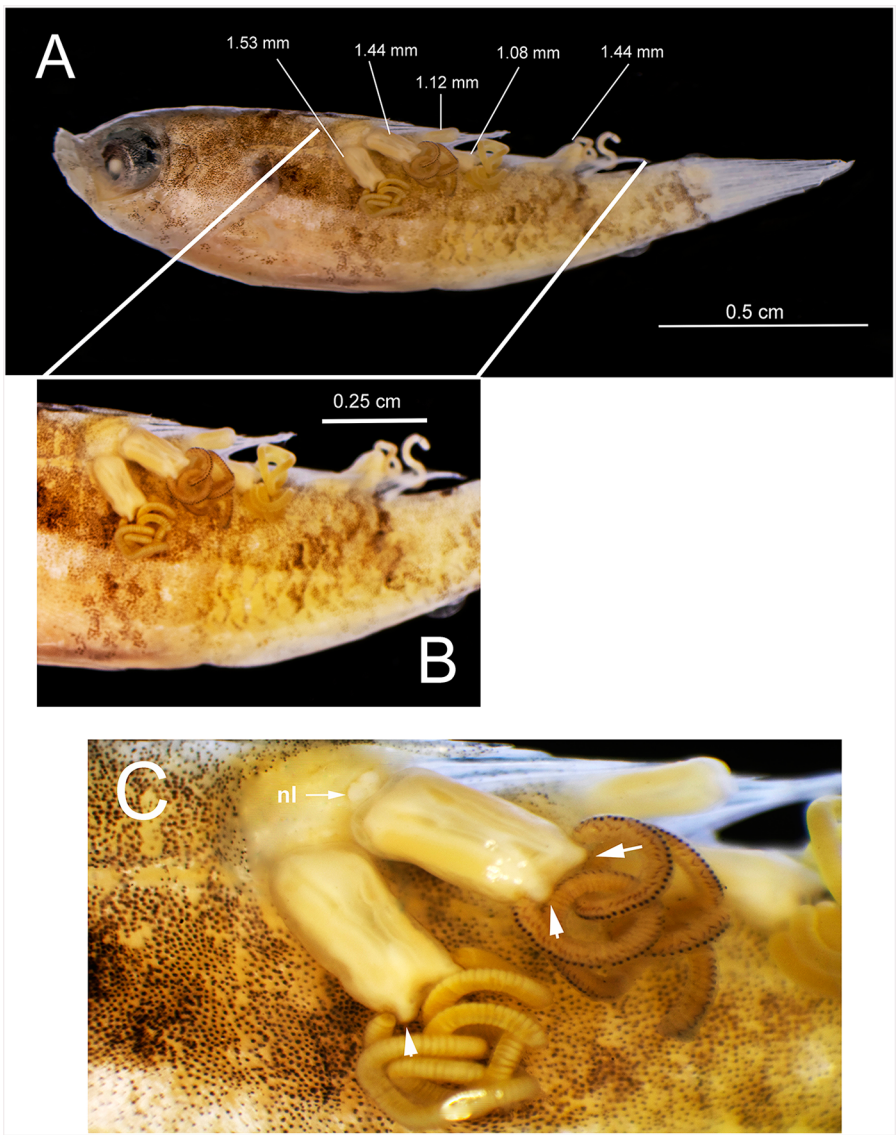

Fig. 1 Ovigerous females of *Cardiodectes roatanensis* **n. sp.** attached to juvenile individual of the emerald parrotfish *Nicholsina ustis* from Roatan Island, Honduras. B, C. details on attachment area, trunk length, and general view of *C. roatanensis* females anchored to host, arrowheads pointing at posterior protuberances (nl = neck lobe).

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86°34'2.68 W), coll. 09 September, 2021 by E. Vidotto. Holotype female deposited in the collection of zooplankton held at El Colegio de la Frontera Sur (ECOSUR), Chetumal, Mexico (ECO-CHZ). Type host deposited in the collection of Ichthyoplankton at ECOSUR (ECO-CH-LP 26738). Two paratype individuals (trunk length: 1.12mm x 0.67; 0.73 mm x 0.25 (average paratype length = 0.92 mm; *n*= 2) from same site and host, partially dissected, ethanol-preserved, vial (ECO-CHZ-10608), one additional undissected paratype (ECO-CHZ-10609). Two more ovigerous paratype females (trunk length = 1.44, 1.40 mm, respectively) processed for SEM analysis.

Attachment site: on both sides of pectoral fin base (Fig. 1).

Type host: *Nicholsina ustis* (Valenciennes, 1839)

Differential diagnosis: Based on six female specimens available. Adult female trunk roughly subrectangular, with pair of prominent posterodistal protuberances separated by concave distal margin. Genital openings located subdistally on posterolateral position, trunk integument regular on dorsal and ventral surfaces. Egg strings uniseriate, loosely coiled, with regular pattern of pigment spots, revealing naupliar eyes of unhatched copepodites, most likely CI, the active infective stage of most pennellids (see Ohtsuka et al., 2018a, 2018b) (Fig. 2). Strings carrying between 80 and 125 unhatched eggs or copepodites. Neck region with pair of conspicuous, asymmetrical lobes. Cephalothorax and trunk connected by thick neck with pair of asymmetrical lobular processes. Cephalothorax short, about 0.3 times as long as trunk, with single pair of thin, wing-like anterior lobes. Cephalothorax with three legs indicated by inconspicuous transverse tergal plates on ventral surface; antennules and antennae not observed. Anterior margin of wing-like lobes with pair of digitiform, distally branched processes.

Description

Adult female: Body consisting of external trunk with attached egg strings, neck region, and embedded cephalothorax (Fig. 2A–D). Trunk robust, sack-like, subrectangular, between 2.3 and 3.0 times as long as wide, maximum trunk length 1560 µm, width = 659 µm (holotype), 1400 µm long x 608 µm wide, 1440 µm x 478 µm wide (two paratypes); trunk with smooth surface, proximal margin slightly asymmetrical. Posterior margin bearing pair of prominent posterodistal protuberances, symmetrical; protuberances separated by concave gap of 300–350 µm (Fig. 3A, B, D). Trunk with attached egg strings on posterolateral surface adjacent to large posterior protuberances; egg strings loosely coiled, with regular pattern of dark spots (arrowheads in Fig. 2C, D) representing naupliar eyes of unhatched CI copepodites. Cephalothorax and trunk connected by thick cylindrical neck with pair of conspicuous, slightly asymmetrical lobular processes or neck lobes (nl in Fig. 2 A–D), visible externally even in attached individuals (nl in Fig. 1C). Cephalothorax short, about 0.3 times as long as trunk, with single pair of wing-like anterior lobes; wing- like lobes flattened, thin, translucent (ct in Fig. 2A–D). Cephalothorax with three legs indicated by transverse tergal plates on ventral surface; antennules and antennae not observed. Anterior margin of wing-like lobes with pair of digitiform, distally branched processes possibly representing antennule lobes.

Etymology: The species is named in reference to the type locality, Roatan Island, Honduras, Central America, Northwestern Tropical Atlantic. Noun in genitive case. Gender is feminine.

Distribution: Roatan Island, Honduras, Central America.

Remarks

The new species was identified as a member of the genus *Cardiodectes* by the presence of the main generic diagnostic characters detailed by Bellwood (1981) and Boxshall & Halsey (2004). The genus *Cardiodectes* currently comprises 15 species, which are separated into two morphological groups, '*medusaeus*' and '*rubosus*' (Izawa, 1970; Bellwood, 1981). The former contains 6 species, *C. anchorellae* Brian & Gray, 1928, *C. bellottii* (Richiardi, 1882), *C. cristatus* Shiino, 1958, *C. frondosus* Schuurmans-Stekhoven, 1937, *C. longicervicus* Shiino, 1958, and *C. medusaeus* (Wilson, 1908), subsequently referred to as *C. bellottii* (Hogans, 2017); the group is recognized by possessing a urosome. The second group comprises the remaining nine species: *C. asper* Uyeno & Nagasawa, 2010, *C. bertrandi* Uyeno & Nagasawa, 2010, *C. bellwoodi* Uyeno, 2013, *C. boxshalli* Bellwood, 1981, *C. hardenbergi* Markevich, 1936, *C. krishnai* Sebastian, 1968, *C. rotundicaudatus* Izawa, 1970, *C. rubosus* Leigh-Sharpe, 1934, *C. shini*

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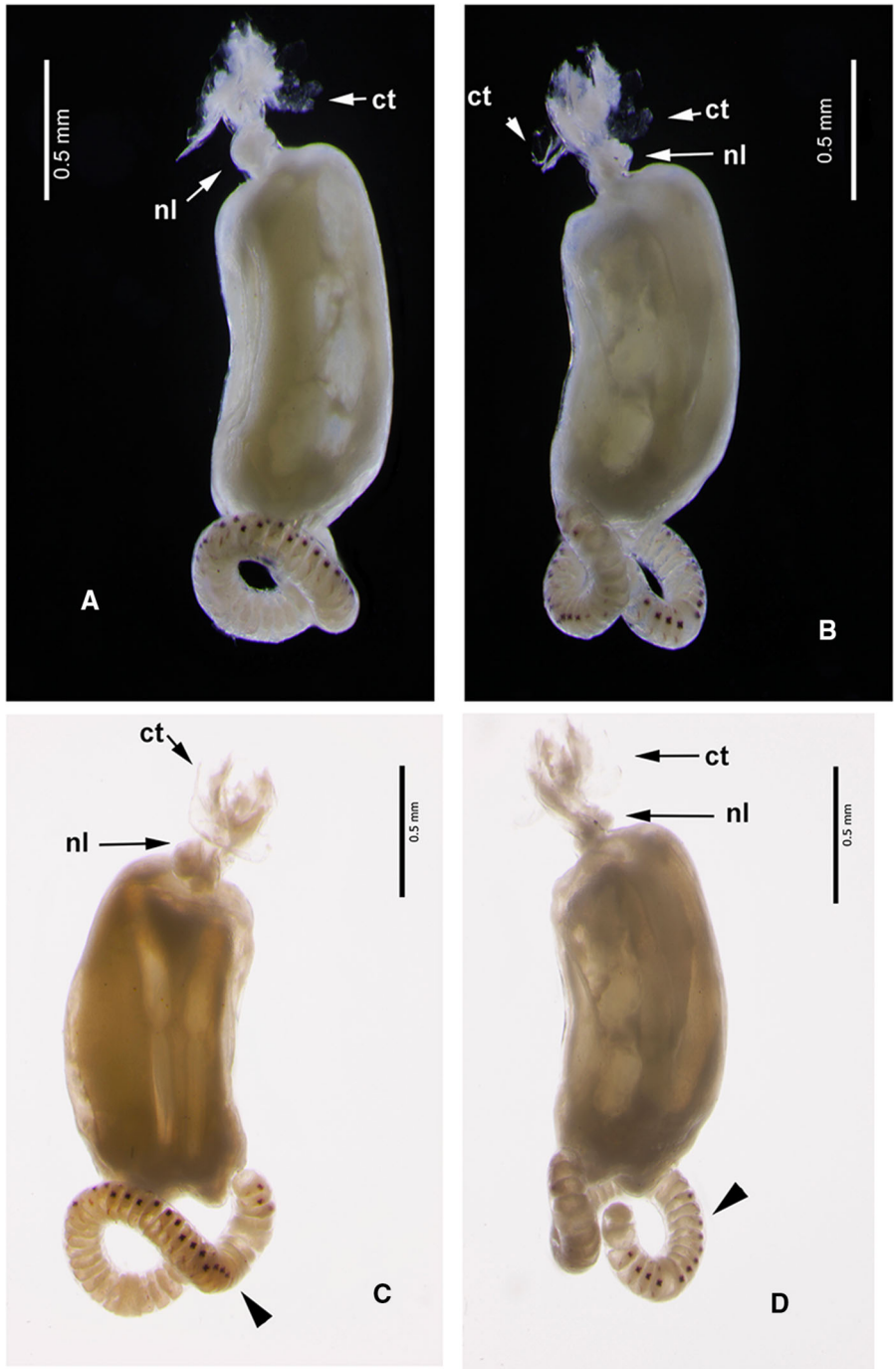

Fig. 2 *Cardiodectes roatanensis* **n. sp.**, from *Nicholsina ustis* from Roatan Island, Honduras. Ovigerous paratype female (ECO-CHZ-10608). A–D. semi-lateral view showing body shape, size, and general proportions of trunk, neck, and cephalothorax regions. (ct = cephalothorax wing-like lobes, nl = neck lobes).

Uyeno, 2013, *C. spiralis* Bellwood, 1981, and *C. roatanenis* **n. sp.**, lacking a urosome. Izawa (1970) recognized a further divergence between these two groups, stating that members of the *medusaeus* group tend to parasitize primitive teleosts like myctophids and some engraulids, whereas species of the *rubosus*

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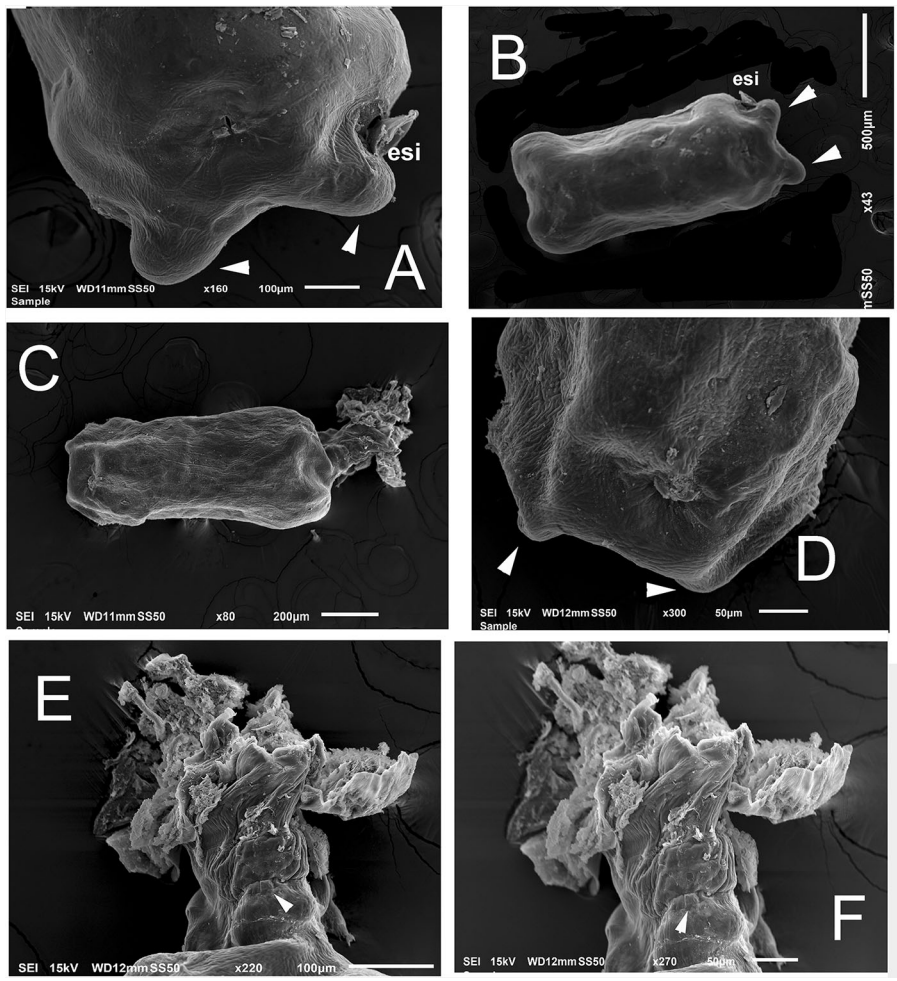

Fig. 3 *Cardiodectes roatanensis* **n. sp.**, from *Nicholsina ustis* from Roatan Island, Honduras. SEM-prepared non-type individuals. A. trunk posterior margin showing strong protuberances (arrowheads) separated by concave margin. B. trunk showing protuberances and insertion of egg strings (esi), another specimen. C. habitus of complete body showing. D. same specimen showing protuberances (arrowhead) and integument ornamentation. E. F. detail of cephalothorax region showing cuticularized ridge (sensu Bellwood, 1981).

group are found in less primitive families (i.e., Apogonidae, Scaridae, Gobiidae, Phosichthyidae) (see Yumura et al., 2022, this survey). *Cardiodectes bellottii* (= *C. medusaeus*) is known to exhibit low host-specificity, infecting a wide range of fish families or genera (Ohtsuka et al., 2018a, 2018b). Infection of the parrotfish *N. ustis* by both *Cardiodectes boxshalli* (Bellwood, 1981) in Jamaica and *C. roatanensis* **n. sp.** in the Caribbean suggests a regional preference of *Cardiodectes* for scarid fish as hosts, although the emerald parrotfish is relatively scarce in the western Caribbean.

The new species clearly belongs to the "*rubosus*" species group as it lacks an abdomen and it was found on a non-myctophid family (see Izawa, 1970). Following the only available key to the known species of *Cardiodectes* (Bellwood, 1981), the new species keys down to a couplet including *C. boxshalli* and *C. krishnai* Sebastian, 1968 because of its possession of a single pair of cephalothoracic lobes and a trunk that is either 2 (*C. boxshalli*) or 5 (*C. krishnai*) times as long as wide. The trunk length/width ratio of the new species (2.33–3.1) falls between these two species. Overall, *C. roatanensis* most closely resembles *C. boxshalli*, with which it shares the same host species, trunk shape, and the presence of neck lobes; neck lobes have been described also in *C. spiralis* Bellwood, 1981, only known from New Guinea; this

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character separates these three species (*C. spiralis*, *C. boxshalli*, and *C. roatanensis* **n. sp.**) from the other known members of the "*rubosus*" group.

There are several differences between the new species and its closest congener *C. boxshalli*: 1) in *C. boxshalli* the neck region is narrow (Bellwood, 1981, fig. 3A) vs. a thick, wide neck present in *C. roatanensis* **n. sp.** (Fig. 3C, E, F); 2) *Cardiodectes boxshalli* has three cuticularized ridges on the cephalothorax dorsal surface (Bellwood 1981, fig. 3A); only one such processes are found in *C. roatanensis* **n. sp.** (arrowhead in Fig. 3E, F); 3) in *C. boxshalli* the trunk shows an irregular posterior surface (Bellwood, 1981, fig. 1D), whereas the same surface is smooth in the new species (Fig. 2A–D); 4) in *C. boxshalli* the cephalothoracic lobes are thick, fleshy (Bellwood, 1981, fig. 3B) whereas in *C. roatanensis* **n. sp.** these lobes are thin, flattened, translucent (ct in Fig. 2A, B, D); 5) in *C. boxshalli* the cephalothorax is large, being 0.9 times as long as trunk (Bellwood, 1981, fig 1B), vs. a clearly smaller cephalothorax (only 0.3 times as long as trunk) in the new species (Figs. 2A–D, 3C). 6) in *C. boxshalli* the trunk posterior margin is straight or weakly convex, lacking strong adjacent processes (Bellwood, 1981, fig. 1B–D) vs. a posterior margin with strong, prominent rounded processes separated by a convex margin present in *C. roatanensis* (Figs. 1C, 2C, D, 3A, B, D). Overall, the new species differs from its known congeners by its possession of a unique combination of characters: 1) a robust, sack-like trunk about 2.3–3 times as long as wide, with pair of prominent rounded processes on the posterior margin separated by a concave margin (arrowheads in Figs. 1C, 3A, B, D); 2) trunk surface regular, surface with pattern of shallow wrinkles (Fig. 3C, D); 3) neck thick, short, with pair of weakly asymmetrical neck lobes (nl in Figs. 1C, 2A–D). 4) cephalothorax short, about 1/3 the trunk length, with flat, wing-like lobes. A combination of these characters has not been observed in any other known congener.

Remarks on host: The host specimen is a juvenile (Fig. 1A); there are no previous reports of *Cardiodectes* parasitizing immature individuals (Izawa 1970). This scarid species is absent from Bermuda, Bahamas, and West Indies, but it is common in the Lesser Antilles, eastern Caribbean. It can be abundant in reef areas, usually in shallow water but has been recorded at depths of over 80 m. Also found in estuaries, reef slope and reef lagoon zones.

Ecology: Among other pennellids, species of *Cardiodectes* are known to utilize planktonic pteropod molluscs as intermediate hosts (Ho, 1966; Perkins 1983; Ismail et al., 2013; Ohtsuka et al. 2018a, 2018b). Zooplankton surveys in the westernmost areas of the Caribbean, adjacent to the northern Honduran coast, show that pteropod molluscs are most diverse and abundant in this area, where *Limacina inflata* (52.5%) and *L. trochiformis* are the dominant species (Suárez-Morales 1994; Parra-Flores & Gasca 2009) and thus, widely available intermediate hosts for *Cardiodectes* in the western Caribbean (Perkins 1983).

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Author contributions E.S. and L.V wrote the main manuscript text and prepared figures 1-3, E.V. obtained financial support for field work and subsequent collection of the material examined.

Data availability Data sharing not applicable to this article as no formal datasets were generated or analysed during the current study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable institutional, national and international guidelines for the care and use of animals were followed.

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