

DESCRIPTION OF *Arculus hyllebergi* n. sp. (BIVALVIA: GALEOMMATOIDEA: LASAEIDAE), A COMMENSAL ON *Dolicholana porcellana* (Barnard, 1936) (CRUSTACEA: ISOPODA: CIROLANIDAE) FROM THE ANDAMAN SEA, THAILAND

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**ABSTRACT:** A second member of the monotypic genus *Arculus* Monterosato 1909 (type species *Lepton sykesi* Chaster 1895) is described. The new species, *Arculus hyllebergi* n. sp. was collected at Panwa Cape, Phuket, Thailand, attached to the pereopods (walking legs) of the burrowing isopod *Dolicholana porcellana* (Barnard 1936). The justification for placement in *Arculus* is provided based on anatomy and shell morphology.

**Keywords.** Bivalvia, Galeommatoidea, *Arculus*, taxonomy, Cirolanidae, *Dolicholana*, commensalism, Thailand

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## INTRODUCTION

Galeommatoideans are known to live either free or in commensal relationships with various invertebrates (see Goto *et al.* 2012; Li *et al.* 2012 for review of associations). Some of the most intimate commensal associations involve the bivalve directly attached to the host while the most simple involve the bivalve co-inhabiting in the crustacean's burrow or a gallery.

Several galeommatoideans are found associated with crustaceans including species of *Ehippodonta* and allies (Middelfart 2005) or yoyo clams (see *e.g.*, Goto *et al.* 2018) that occupy the crustacean burrow. Species that attach themselves to the host crustacean include among others *Arculus*, *Arthritica*, *Borniopsis*, *Neaeromya*, *Parabornia*, *Pseudopythina*, *Perigrinamor* (Warén and Carrozza 1994; Li *et al.* 2012; Goto *et al.* 2012; Goto *et al.* 2018). In some cases, direct attachment to a host is hard to document. For example, in the case of *Vasconiella* where dislodgement due to benthic sampling methodology is the reason a suspected host and the bivalve are never found attached to each other, although adaptations of bivalve anatomy suggest direct attachment (Coney 1990)

While collecting isopods from baited traps near Phuket Marine Biological Centre, Thailand, Dr. S. Keable (Australian Museum, Sydney) (see Keable 1999) came across some small bivalves

attached to the pereopods (walking legs) of the isopod *Dolicholana porcellana* (Barnard, 1936).

The species is closely similar to *Arculus sykesii* (Chaster, 1895), known from British waters, and the taxonomy of that species and the new species is compared in this study.

## MATERIAL AND METHODS

The bivalves were caught together with the host, *D. porcellana*, in a baited trap placed on a muddy bottom at 9 m depth at Khao Khat (approximately 100 m west of an oyster farm), Panwa Cape, Phuket, Thailand, 7°47.5'N, 98°23'E, 23–24 November 1995 (collector S.J. Keable). Five host specimens had a total of 33 commensal bivalves, however most had fallen off the host specimens, so the actual attached number for each host specimen remains unknown. The specimens were preserved in 5% sea water formalin and stored in 70% ethanol.

Specimens attached to the host were mounted whole on an aluminum stub with silver dag, gold coated and examined in a Scanning Electron Microscope (Leica LEO) at the Australian Museum, Sydney. Shells were dissected away from the animals and mounted, as previously outlined, on stubs and examined by SEM as well. The holotype was selected from the material examined in the SEM and is here illustrated (see Fig. 1).

Bivalves to be sectioned were decalcified in Bouin's fluid. Three specimens were embedded in paraplast and cut into 8 µm thick serial sections stained with hematoxylin and eosin (H+E). Two other specimens were embedded in araldite and representative transversal 2 µm thick sections were stained with toluidine blue. A decalcified bivalve (SL x SH 2.3 x 1.8 mm) had the left mantle and tenidium removed to display the arrangement of the mantle cavity and soft anatomy (see Fig. 2).

## SYSTEMATICS

### *Arculus* Monterosato, 1909

*Arculus* Monterosato, 1909: 254. Type species: *Lepton sykesii* Chaster, 1895. Original designation. Recent. UK.

**Diagnosis.** Shells oval, very small, under 1 to a few millimeters, equivalve, inequilateral with anterior end broadly rounded, opisthogyrous, thin, transparent to whitish. Cardinal hinge teeth consist of sigmoid lamellar anterior cardinal in the right valve (I) and a short straight lamellar cardinal in the left valve (II). One lateral tooth present posteriorly in right and left valves (PI and PII).

**Remarks.** *Arculus* has variously been placed in Cyamioidea (Geuze, 1995) and Leptonacea (=Galeommatoidea) (Warén and Carrozza, 1994). However, no justification for the choice of superfamilial grouping was presented in these earlier studies. It is clear from the present study that *Arculus* should be positioned in Galeommatoidea *sensu* Ponder (in Beesley *et al.* 1998). The lack of a posterior inhalant siphon is the main character that justifies this new placement (see description below).

### *Arculus sykesii* (Chaster, 1895)

*Lepton sykesii* Chaster, 1895: 248. Syntypes (one whole, 0.9 mm long, and one broken shell), NHM 96.8.6.32-3. Type locality: 27–37 m, off Guernsey, UK.

*Lepton (Neolepton) sykesii* - Marshall, 1895: 36, 37, fig. 2.

*Neolepton sykesi* - Phorson, 1988a: 106; 1988b: 117, figs. 1–3 (incorrect name emendation, ICZN, art. 33.4)

*Arculus sykesi* - Light and Killeen, 1990: 317; -

Keukelaar-Van Den Berge, 1991: 19; Smith, 1991: 428; - Warén and Carrozza, 1994: 303, figs. 1, 2; - van Aartsen, 1996: 46, fig. 32L, 32R (reproduced from Warén and Carrozza 1994). (incorrect name emendation, ICZN, art. 33.4).

**Description.** See description under genus.

**Distribution.** Keukelaar-Van Den Berg and Hoeksema (1991) noted the distribution from NW Ireland to the western Mediterranean. *A. sykesii* was additionally recorded in the Gulf of Genova (Warén and Carrozza 1994).

**Biology.** This species was recorded attached by byssus between the walking legs of the apseudid tanaid *Tuberapseudes echinatus* (Sars, 1886) in 40–50 m in the Gulf of Genova, Italy.

**Remarks.** Since its original introduction, *A. sykesii* has been historically emended to '*sykesi*', an incorrect emendation according to the ICZN, art. 33.4 (see <http://www.iczn.org/iczn/index.jsp>).

The records of *A. sykesii* listed in the cressonymy are doubtful. The records are only illustrated in four instances and of those, only Warén and Carrozza (1994: 303, figs 1, 2) is useful, and here the conspecificity with the type of *A. sykesii* is questionable. From a small drawing and photographs of the only remaining whole shell in the syntype series, taken by Dr. W.F. Ponder in the NHM (see reference above), the outline does not correspond well with that illustrated by Warén and Carrozza (1994). The outline of the type is more rounded and particularly the ventral margin is convex, not straight or bordering concave as in the species illustrated by Warén and Carrozza (1994). Although the species illustrated might not be conspecific with *A. sykesii*, a new name will not be erected herein until further collecting and studies are carried out on *A. sykesii*, preferably from around Guernsey, UK (the type locality). We have not been able to ascertain whether the host species (*Tuberapseudes echinatus* (Sars, 1886)) has a distribution that includes Guernsey, UK.

Despite these issues, it seems very probable that *A. sykesii* and Warén and Carrozza's (1994) species are congeneric and therefore, the illustrations provided by Warén and Carrozza (1994) will here be used as a baseline for the genus *Arculus*.

***Arculus hyllebergi n. sp.*****Figs. 1–2****Material examined**

**Holotype** (shell pair Fig. 1C, D), AM C. 546858 (2.5 mm long and 2.0 mm high) and paratypes (including Figs 1A and B) AM C. 430789. Baited trap placed on a muddy bottom at 9 m depth at Khao Khat (approximately 100 m west of an oyster farm), Panwa Cape, Phuket, Thailand, 7°47'5 N, 98°23'E, 23–24 November 1995. Attached to *D. porcellana* (collector S.J. Keable).

**Description***Shell*

Shell length (SL) and height (SH) of five specimens were 1.8 x 1.4 mm, 2.2 x 1.8 mm, 2.3 x 1.8 mm, 2.3 x 1.8 mm, and 2.8 x 2.2 mm. SL of the largest specimen was 2.9 mm. The prodissoconch II is just over 200 µm rounded with commarginal ribs, simple, with a clear prodissoconch I with rugose surface indicating shell gland deposition. The dissoconch is irregular with slight ventral notch, close to equilateral, flared posterior margin and incurved anterior margin. Shell surface of commarginal ribs. Pallial line entire, isomyarian.

Cardinal teeth in the right valve consisting of a curved Cardinal Anterior 3a, b (CA3a, b) element, while left valve has a CA2 and CA4b (see extensive discussion of the hinge teeth notations in Middelfart 2002). Both right and left valve with a posterior lateral.

*Animal anatomy*

No animals were studied alive.

The inner folds of the two mantle edges have fused along a relatively short distance separating the mantle gap into a long inhalant-pedal opening and a short posterior exhalant opening. The inner mantle edge is thickened and bears small, scattered papillae along the anterior part of the inhalant opening (Fig. 2, arrowheads). These features suggest that the live animal may extend this part as a short siphon.

The foot is indistinctly divided into anterior and posterior parts. There is a well-developed byssus gland, and the bivalves were attached by byssus to the host. Anterior and posterior pedal retractors are relatively large. A small protractor muscle arises in front of the anterior adductor muscle.

There is a single complete (inner) demibranch on each side consisting of a descending and an ascending lamella. Not even a vestigial outer demibranch is present. The suprabranchial chamber serves as a brooding chamber. The labial palps are long and slender and provided with more than a dozen ridges. The alimentary tract was not studied.

The species is a hermaphrodite. The gonad is an ovotestis, but the male and female parts are relatively independent. The ovary is mainly concentrated in the central and anterior part of the visceral mass, but extends into the base of the foot. It is mostly embedded into the digestive gland and therefore almost invisible from outside. The testis is more dorsally placed and extends backwards to the level of the pericardium and kidney. The genital openings could not be detected, but are presumably located far posterior in the ovotestis where it is supposed that the ova must pass through the testis when spawned. Behind the testis there is a pair of ovoid seminal receptacles, placed very close together but each with its own lateral and distinct opening into the suprabranchial chamber. The receptacles are about 150 µm long and 90–110 µm in diameter. They border on the pericardium and, more posteriorly, are partly surrounded by the kidney. Within each receptacle, the sperm are packed tightly together and strictly oriented with the head towards the epithelial wall. Because of the insufficient fixation, the nature of this epithelium could not be made out. Only one type of spermatozoa could be recognized in the testis and the receptacle. Observed in the light microscope, the sperm head is filiform, slightly pointed anteriorly and ca. 11 µm long and 0.4–0.5 µm in diameter (Fig. 2B). We could not distinguish the acrosome from the nucleus, but a small midpiece is present.

Of five studied bivalves, four (SL 2.2, 2.6, 2.7, and 2.9 mm) were brooding early embryos or larvae and all had the receptacles filled with sperm. A fifth, 2.3 mm long specimen, also contained stored sperm, but was non-ovigerous. Early and almost spherical embryos were 48–50 µm in diameter, while the full-grown D-larvae (present in a 2.7 mm long bivalve) measured 130 µm in length. Smaller specimens exist on the host exoskeleton which might be dwarf males or juveniles (see Fig. 1).

*Host relations*

The bivalves are byssally attached to the coxae of the pereopods or directly to the sternum of the

host. Each of three male hosts still had two bivalves attached on the ventral side of the thorax near or directly upon pereopods 6 or 7. One female had a single bivalve placed within the brood pouch. Another female had a small bivalve (the smallest, but not measured) attached to the ventral side between or on the left and right second pereopods, plus three other ones located on the outside of the oostegites.

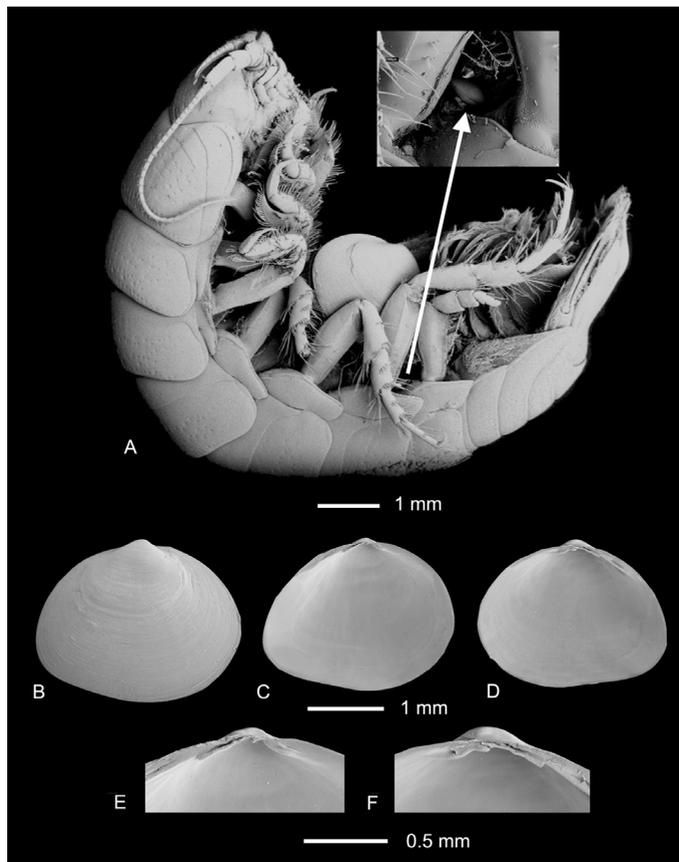
The host lives in burrows and is a scavenger. It reaches a maximum length of 21 mm and is distributed in the Bay of Bengal and Gulf of Thailand (Keable 1999).

**Etymology.** We describe the species in honour of Jørgen Hylleberg, who provided tireless mentoring

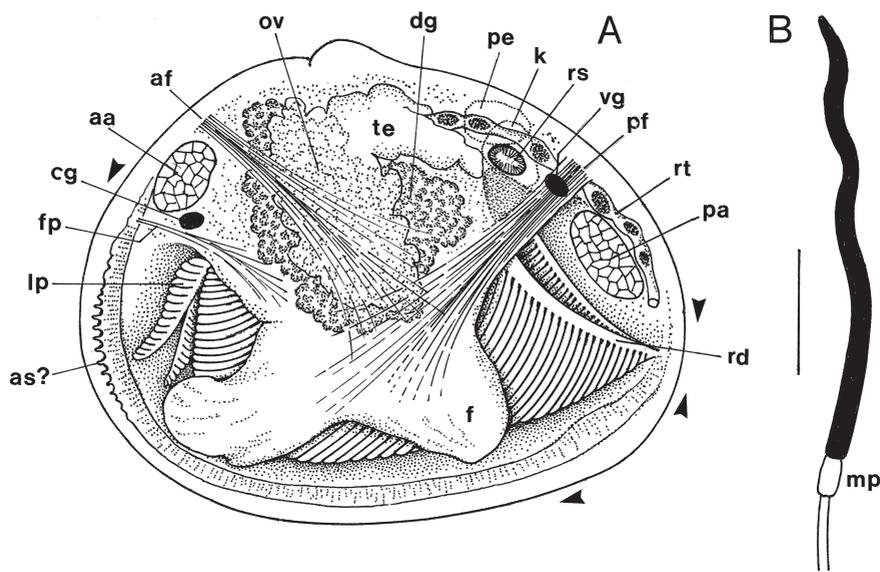
of the first author at Aarhus University, Denmark as well as in his beloved setting at the Phuket Marine Biological Center, Thailand. He inspired students and scientists across many nations to come together for the better good of people and for the enhancement of marine biological research.

This paper and the species described were registered with ZooBank (Species registration: urn:lsid:zoobank.org:act:748C064D-4643-4E66-9877-6066F42A002C) (Paper registration: urn:lsid:zoobank.org:pub:EB30445B-6253-4862-9E1F-0C85EE8 F7EF0).

All names were checked against WoRMS (<http://www.marinespecies.org/>).



**Figure 1.** *Arculus hyllebergi* n. sp. A. Specimen of *D. porcellana* with *A. hyllebergi* attached. Insert show possibly dwarf male or juvenile. B. Part of paratype series AM C. 430789, external view right valve. C–F holotype AM C. 546858, C. internal view left valve. D. internal view right valve. E. close-up hinge left valve. F. close-up hinge right valve.



**Figure 2.** *Arculus hyllebergi* n. sp. A. Left valve, mantle and ctenidium removed to show the organization of the soft parts and viscera. B. Sperm cell. aa, anterior adductor; af, anterior foot retractor; as? anterior siphon; cg, cerebral ganglion; dg, digestive gland; f, foot; fp, foot protractor; k, kidney; lp, labial palp; mp, midpiece; ov, ovary (mostly covered by digestive gland); pa, posterior adductor; pe, pericardium; pf, posterior foot retractor; rd, right demibranch; rs, seminal receptacle; rt, rectum; te, testis; vg, visceral ganglion. The two pairs of arrowheads indicate the length of the inhalant-pedal opening and the exhalant opening. Scales represent 1.0 mm (A) and 3  $\mu$ m (B)

## DISCUSSION

The filiform spermatozoa of *A. hyllebergi* belongs to the ent-aquasperm type of Rouse and Jamieson (1987). Franzén (1983) suggested that an elongated sperm head is often correlated with large, yolk-rich eggs. However, judging from the size of early embryos, the ova of the present species hardly surpasses 50  $\mu$ m in diameter. Long and slender sperm heads in galeommatoideans are an adaptation for the deposition of sperm in seminal receptacles, since this allows a large amount of sperm to be tightly packed in a confined area (Jespersen *et al.* 2002).

Some of the bivalve species live in the burrows of the hosts, while other, such as *A. hyllebergi*, are byssally attached to the host's exoskeleton. The latter are therefore confronted with the problem of maintaining contact with the host when it moults. Itani *et al.* (2002) showed that as soon as its upogebiid host starts moulting, the normally totally stationary *Peregrinamor ohshimai* Shôji, 1938

suddenly becomes active and within a few minutes moves to the newly emerged body of the host. *Borniopsis macrophthalmensis* (Morton and Scott, 1989), when removed from its crab host, is able to re-attach, and because of this, it was supposed that the bivalve is able to move to the same host after having been sloughed off with the host exuvium (Kosuge and Itani 1994). Lützen and Takahashi (2003) suggested the possibility that small-sized bivalves commensal with crustaceans may complete their entire life cycle within the inter-moult period of grown-up host individuals and that they are left to perish together with the cast exuvium.

While we place *A. hyllebergi* in *Arculus* with *A. sykesii*, there is still some uncertainty that these two species are congeners. More data, specifically better images and/or drawings, are needed to diagnose *Arculus sykesii*. The associations, further anatomy and morphology as well as molecular tools, will be important pieces of information in characterizing the phylogenetic relationship in this group, which will in turn inform better taxonomy.

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We would like to first of all thank the collector Steve Keable from the Australian Museum (AM) for pointing out the coexistence of *A. hyllebergi* with *D. porcellana* during the first authors searches of commensal relationships in the Galeommatoidea.

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