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A new species of *Caulleryaspis* (Annelida: Sternaspidae) from the Sunda Strait, Indonesia, with a key to all known species in the genus

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Abstract. *Caulleryaspis sundaensis*, new species, is described from the Sunda Strait, Indonesia. A single specimen was collected off western Java at a depth of 1,060 m during the South Java Deep-Sea (SJADES) Biodiversity Expedition 2018 to the Sunda Strait and eastern Indian Ocean off southwest Java, Indonesia. This new species is distinguished from all other known sternaspid species by the unique features of its ventro-caudal shield, which has a deep anterior depression, and where the anterior margins of the shield are slightly convergent and deeply curved (U-shaped). A table comparing the shields of *Caulleryaspis* species, together with a key to identify all species in the genus, are also provided.

Key words. deep-water, Polychaeta, taxonomy, ventro-caudal shield

INTRODUCTION

Polychaetes in the family Sternaspidae have been poorly studied, until the recent reviews by Petersen (2000) and Sendall (2006), and revision by Sendall & Salazar-Vallejo (2013). In earlier studies, the characteristics of the ventro-caudal shield were not emphasised as diagnostic features and this led to difficulties in distinguishing different species, so much so that a few of them were even considered to be cosmopolitan species (Sendall & Salazar-Vallejo, 2013). For example, *Sternaspis scutata* (Renier in Ranzani, 1817) originally described from the Mediterranean Sea was recorded from many localities in the world oceans. However, most records were probably based on misidentifications, as demonstrated by a series of morphological studies (Salazar-Vallejo & Buzhinskaja, 2013; Salazar-Vallejo, 2014b; Wu et al., 2015; Díaz-Díaz & Rozbaczylo, 2017; Salazar-Vallejo, 2017; Zhadan et al., 2017), which confirmed that multiple records of *S. scutata* identified by various authors were actually several species. This conclusion was further supported by a recent phylogenetic study (Kobayashi et al., 2018).

The ventro-caudal shield of sternaspids, according to Bartolomaeus's (1992: 250) work on *S. scutata*, "…is so hard that it destroys razor blades when being trimmed for ultramicrotomy". As shown by Lowenstam (1972), these shields are impregnated with ferrous oxide and phosphorus pentoxide, rendering an amorphous ferric phosphate hydrogel. This explains the rigid but brittle shield found in many sternaspids, especially those belonging to *Sternaspis* Otto, 1821.

However, amongst specimens from Shamrock Canyon, Northeast Atlantic Ocean that were identified as *S. scutata* by Kirkegaard (1983), Petersen (2000) noticed that two specimens possessed soft and flexible shields when the material was re-examined. Later, Sendall (2006) in her master's thesis described a species from Iceland which possessed a flexible shield and referred it to '*S. gudmundi*'. This was formally named subsequently as *Caulleryaspis gudmundssoni* Sendall & Salazar-Vallejo, 2013, and was designated as the type species for a new genus, *Caulleryaspis* Sendall & Salazar-Vallejo, 2013. The possession of a flexible ventro-caudal shield, on which sediment particles are firmly attached (Sendall & Salazar-Vallejo, 2013) is a diagnostic feature of this genus. Later, this diagnosis was amended to include species with flexible shields free of sediment particles (Salazar-Vallejo & Buzhinskaja, 2013). To date, six species belonging to this genus are recognised (Salazar-Vallejo, 2017), of which two are described from the Southeast Asian region (Fig. 1): *Caulleryaspis laevis* (Caullery, 1944) from Indonesia, and *C. nana* (Zhadan, Tzetlin & Salazar-Vallejo, 2017) from Vietnam. Both species were originally placed in *Sternaspis* Otto, 1821, and later transferred to *Caulleryaspis* by Sendall & Salazar-Vallejo (2013) and Salazar-Vallejo (2017).

As detailed above, most sternaspid species collected were earlier identified as *S. scutata*, including those from East and Southeast Asia. Indeed, this species was recorded as the sole representative of the family Sternaspidae from the Andaman and Nicobar Islands (Aungtonya et al., 2002; Rajasekaran & Fernando, 2012), Malaysian waters (Idris &

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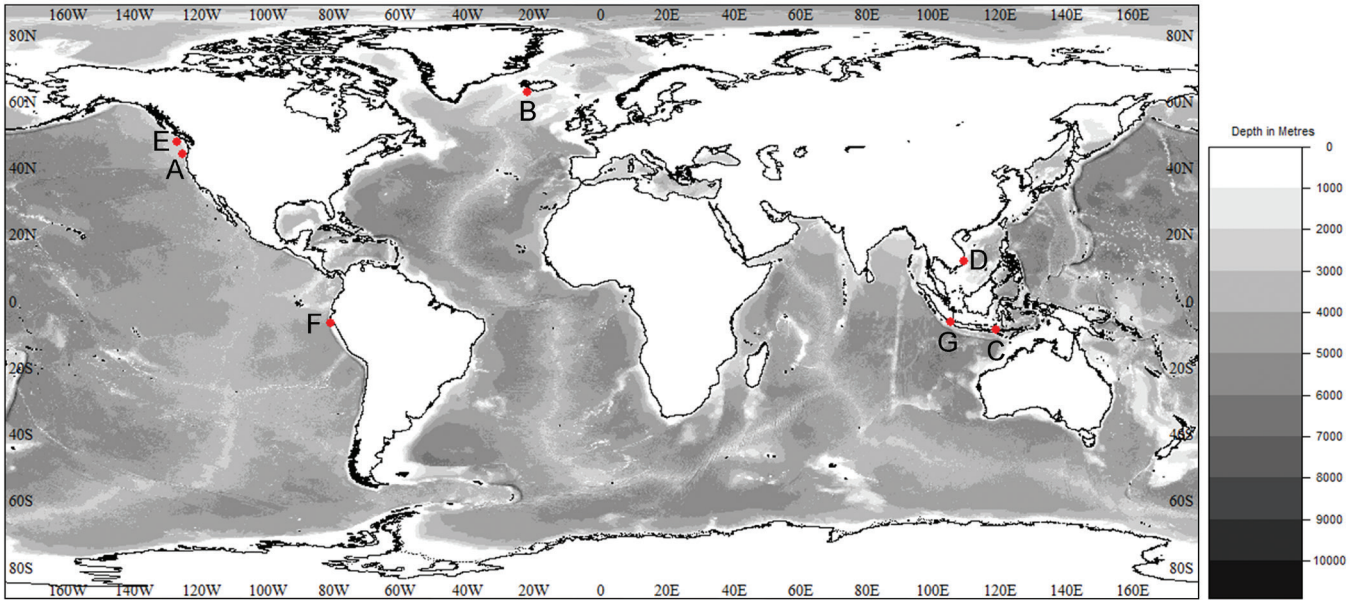

Fig. 1. Type localities of *Caulleryaspis* species. A, *C. fauchaldi*; B, *C. gudmundssoni*; C, *C. laevis*; D, *C. nana*; E, *C. nuda*; F, *C. villamari*; G, *C. sundaensis*, new species. Image based on bathymetry data from the GEBCO_2014 Grid (version 20150318), as displayed through the GEBCO Digital Atlas, published by the British Oceanographic Data Centre on behalf of the IOC and IHO, 2003.

Arshad, 2013), and South China Sea (Paxton & Chou, 2000). There are three sternaspid species previously described from Indonesian waters, namely *S. spinosa* Sluiter, 1882 (30 m, Bay of Batavia [Jakarta]), *S. rietschi* Caullery, 1944 (1,788 m, Wokam Island), and *C. laevis* (Caullery, 1944) (55 m, Sumbawa Island); the latter two were collected during the Siboga Expedition. After the revision by Sendall & Salazar-Vallejo (2013) and subsequent studies by Salazar-Vallejo (2014a), Wu et al. (2015), Wu & Xu (2017), and Zhadan et al. (2017), the number of sternaspids recorded from the East and Southeast Asian regions has increased to 17 species.

Scientific expeditions which involved the collection of polychaetes from the Indo-Malay-Philippines Archipelago (IMPA) were reviewed and summarised in Glasby & al-Hakim (2017), who showed that polychaete diversity in the IMPA is poorly recorded compared to neighbouring regions. A joint Indonesia–Singapore deep-sea biodiversity expedition to southwest Java, Indonesia (South Java Deep-Sea Biodiversity Expedition 2018) collected more than 900 polychaete specimens using either a beam trawl or dredge from 53 stations between Sunda Strait and Cilacap (8°19.850′S, 109°16.743′E) at depths ranging from 92 m to 1,796 m. We describe below the fourth sternaspid species from Indonesian waters.

MATERIAL AND METHODS

The single specimen was collected using a beam trawl, from a deep-water station in the Sunda Strait, Indonesia, during the South Java Deep-Sea (SJADES) Biodiversity Expedition 2018. The formalin-fixed specimen was examined using an Olympus SZX16 stereomicroscope. Photographs were taken using Nikon D7000 with 60 mm micro lens and Canon EOS 6D with MP-E 65 mm macro lens. Images taken at different focus distances were stacked using Adobe Photoshop software. The holotype is preserved in 80% ethanol and deposited in the Museum Zoologicum Bogoriense (MZB), Research Center for Biology, Indonesian Institute of Sciences, Cibinong, Indonesia. Classification and terminology used in this study follows Sendall & Salazar-Vallejo (2013); the key to species of *Caulleryaspis* was modified from Salazar-Vallejo (2017).

TAXONOMY

Order Terebellida Rouse & Fauchald, 1997

Family Sternaspidae Carus, 1863

Caulleryaspis Sendall & Salazar-Vallejo, 2013

Type species. *Caulleryaspis gudmundssoni* Sendall & Salazar-Vallejo, 2013, by original designation.

Diagnosis (from Salazar-Vallejo & Buzhinskaja, 2013). Sternaspids with introvert hooks falcate, tapered. Preshield region with 7 segments. Ventro-caudal shield flexible, usually with abundant sediment particles firmly adhered, rarely sediment particles loosely adhered; without well-defined radial ribs and concentric lines. Branchial filaments arranged in discrete branchial plates.

Remarks. The use of the ventro-caudal shield as a diagnostic character to distinguish sternaspid species was formalised by Sendall & Salazar-Vallejo (2013). Currently, there are two groups of *Caulleryaspis* species; those having sediment particles that are firmly adhered on the ventro-caudal shield (not removable), and those without sediment particles or having loosely adhering sediment particles which can be brushed off easily. The latter group includes *C. nuda* Salazar-Vallejo & Buzhinskaja, 2013 from the lower bathyal depth

of the northeastern Pacific, and two species from shallow tropical waters: *C. nana* (Zhadan, Tzetlin & Salazar-Vallejo, 2017) from Vietnam and *C. villamari* Salazar-Vallejo, 2017 from the eastern Pacific. Among these three species, *C. nana* is the smallest in size (holotype is 2.5 mm long). The holotype of *C. nuda* is 13 mm long, but smaller specimens were also examined. For *C. villamari*, the holotype is 32 mm long, and juveniles were collected from the same region.

A phylogenetic study by Kobayashi et al. (2018) showed that specimens they identified as *Caulleryaspis* cf. *nuda* from the Sea of Okhotsk, northwestern Pacific Ocean was an immediate sister clade to *Sternaspis* cf. *williamsae*. This is consistent with previous observations made by Salazar-Vallejo & Buzhinskaja (2013), where they noted that the two species shared morphological similarities. These included the overall shield outline and the presence of a thin layer of loosely attached sediment particles on the shield, although *C. nuda* differed in having a more convex, delicate and pliable shield margin. Kobayashi et al. (2018) thus suggested the need to include more *Caulleryaspis* species in phylogenetic analysis, to review the validity of this genus. Another study by Drennan et al. (2019) showed genetic connectivity between specimens identified as *Sternaspis* cf. *annenkovae* Salazar-Vallejo & Buzhinskaja, 2013, from off southeastern Australia and specimens identified as *Sternaspis* cf. *williamsae* Salazar-Vallejo & Buzhinskaja, 2013, from the northwestern Pacific. They also synonymised both Antarctic species, *Sternaspis monroi* Salazar-Vallejo, 2014, and *S. sendalli* Salazar-Vallejo, 2014, based on morphology and molecular studies on materials collected from the Southern Ocean and Antarctic Peninsula, which raised questions concerning the validity of the current morphological delimitation of Sternaspidae.

Smaller *Caulleryaspis* specimens, such as those identified as *Caulleryaspis* cf. *nuda* in Kobayashi et al. (2018), might be juveniles of *Sternaspis*. Upon further examination of their morphology, supported with evidence from molecular analysis, these specimens initially identified as *Caulleryaspis* sp. might actually be *Sternaspis* sp. instead. This also implies that describing new species using small-sized specimens should be treated with caution. However, their findings should not be used to include *Caulleryaspis* under *Sternaspis*, especially because specimens of the type species of *Caulleryaspis*, *C. gudmundssoni* Sendall & Salazar-Vallejo, 2013, have not been included in molecular studies. While it is entirely possible that ventro-caudal shield characters may turn out to be phylogenetically uninformative, this hypothesis will require further morphological analysis in conjunction with molecular studies. As of now, we opine that the shield is still the preferred diagnostic morphological character to distinguish species in the Sternaspidae until proven otherwise, given the very limited repertoire of taxonomic characters available. Further, the differences between *Caulleryaspis* and *Sternaspis* are sufficient to retain them as distinct genera.

***Caulleryaspis sundaensis*, new species**
(Fig. 2)

Material examined. Holotype: MZB.Pol.00224, Sunda Strait (between Sumatra and Java), Station CP18 (6°10.758′S; 105°05.589′E to 6°11.587′S; 105°05.735′E), beam trawl, depth 1,060–1,073 m, gravel with plastic trash and sunken wood pieces, coll. South Java Deep-Sea (SJADES) Biodiversity Expedition 2018, R/V BARUNA JAYA VIII, 26 March 2018.

Description. Holotype (MZB.Pol.00224) damaged, anterior region partially broken, almost detached from the posterior body region; integument variably eroded, most chaetae without tips. Body yellowish to brownish in alcohol. Introvert exposed, almost detached from abdomen, shield asymmetrical, dark reddish brown (Fig. 2A). Body 30 mm long, 7 mm wide, abdomen 22 mm long, about 30 segments; left shield plate 7 mm long, 7 mm wide, and right shield plate 8.4 mm long, 7.2 mm wide.

Prostomium hemispherical, smooth, light brown; peristomium oval. Mouth oval, covered by papillae, extending from base of prostomium to the anterior edge of second segment (Fig. 2B).

First three chaetigers with 15–18 neurohooks. Introvert neurohooks slightly falcate, thick, brass coloured, mostly with damaged tips; each with subdistal darker area.

Genital papillae slightly darker than body wall, cirriform, blunt; protruding ventrally between segment 7 and 8 from a distinct opening (Fig. 2A inset). Pre-shield region with 7 segments; 4 lateral bundles of short capillary chaetae.

Ventro-caudal shield flexible, some areas with a small quantity of sediment particles attached, but mostly appearing bare; colour dark reddish brown, median area darker (Fig. 2C). Dark concentric lines visible at the centre of the shield, less visible towards margins; main ribs distinct. Anterior margins deeply curved, anterior corners rounded, slightly convergent, anterior depression deep, U-shaped; anterior keels visible, barely exposed. Suture indistinct. Lateral margins expanded medially, especially on left shield plate, reduced posteriorly; margins markedly crenulated, with distinct posterolateral corners (Fig. 2D). Fan convex, raised, not projected beyond posterolateral corners, with deep median and lateral notches; posterior margins crenulated. Fan twice as wide as anterior margins.

Marginal chaetal fascicles golden to golden brown, include ten lateral ones, chaetae in oval arrangement, and six posterior fascicles, in offset and parallel arrangement. Bases for peg chaetae robust, observed near the last lateral chaetal fascicles, at the posterolateral corners. Peg chaetae formed by thin, short spines. Additional small fascicle of short capillary chaetae between peg chaetae and the outermost posterior shield chaetae, on both sides of shield. Most chaetal tips broken, except the first two lateral fascicles.

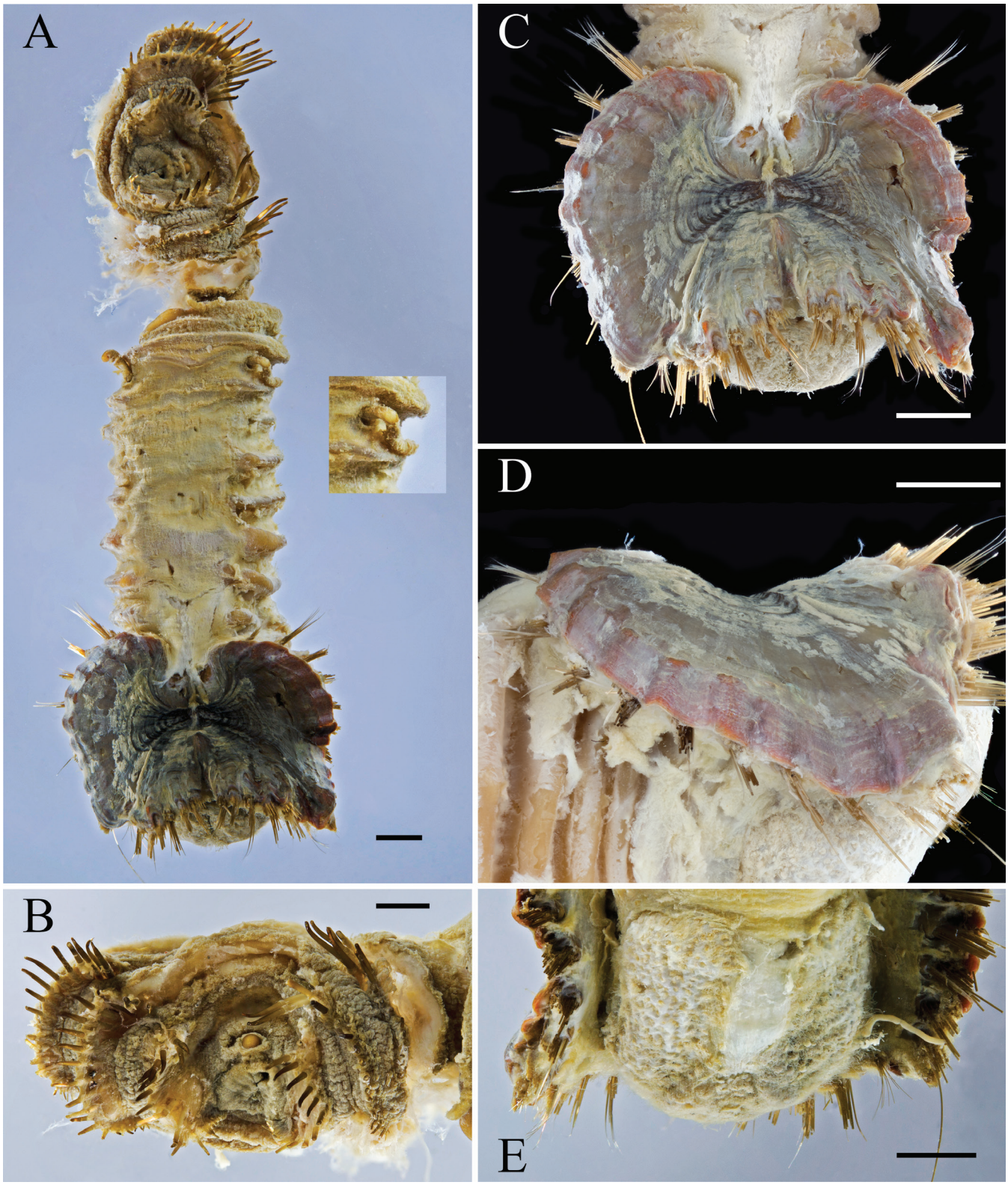

Fig. 2. *Caulleryaspis sundaensis*, new species, holotype (MZB.Pol.00224). A, entire specimen, abdomen in ventral view, damaged anterior end in frontal view (inset: close-up of left genital papilla); B, frontal view of anterior end; C, ventro-caudal shield, frontal view; D, ventro-caudal shield, lateral view; E, branchial plates. Scale bars: A–E = 2.0 mm.

Branchiae and interbranchial filaments damaged (lost). Branchial plates long, parallel, anteriorly slightly wider (Fig. 2E).

Etymology. The specific epithet refers to the Sunda Strait, the known geographical distribution of the species.

REMARKS AND DISCUSSION

The overall morphology of the flexible ventro-caudal shield, in combination with other non-shield characters, principally peg chaetae and branchial plate morphology, distinguishes the new species from all other known species in *Caulleryaspis* (Table 1). In particular, the anteromedial region of the shield has a deep anterior depression, and the anterior margins of the shield are deeply curved as well as slightly convergent, resulting in a U-shaped configuration. This is in contrast to the usually straight or mildly curved, widely divergent V-shaped forms seen in other congeners.

In *Caulleryaspis*, there are three described species (*C. laevis* [Caullery, 1944], *C. fauchaldi* Salazar-Vallejo & Buzhinskaja, 2013, and *C. gudmundssoni* Sendall & Salazar-Vallejo, 2013) which possess shields with sediment particles firmly adhering to the shield surfaces, thus masking the overall shield features (see Table 1). However, the shield surface of *C. sundaensis*, new species, is not masked by sediment and surface features of the shield are clearly visible. This sediment-free condition of the shield is similar to *C. nuda* Salazar-Vallejo & Buzhinskaja, 2013, *C. nana* (Zhadan, Tzetlin & Salazar-Vallejo, 2017), and *C. villamari* Salazar-Vallejo, 2017. While the shield anterior depression in the latter two species is shallow, those of *C. nuda* and the new species described in this paper have a deep anterior depression. In addition, *C. sundaensis*, new species, can be easily distinguished from *C. nuda* by the U-shaped anteromedial shield, in having distinct main ribs, with visible concentric lines on the shield surface and a fan that is convex, raised, and not projected beyond posterolateral corners. The new species also possesses robust peg chaetae and parallel branchial plates, in contrast to the absence of peg chaetae and convergent branchial plates in *C. nuda* (Table 1).

Despite the fact that the proposed new species is based on a single, slightly damaged specimen, we feel that the above mentioned unique morphological characters are sufficiently distinctive to be described as new to science. The area and depth from which the only specimen was obtained is poorly explored, and the polychaete fauna in the deeper areas of the Sunda Strait have not been documented to date. It is also apparently rare, as it is the only specimen amongst 900 polychaete individuals collected during the two-week long expedition which included 44 trawls and 9 dredges that sampled the seabed at depths between 92 m and 1,796 m. While we acknowledge that our current understanding of the extent of intraspecific morphological variation in closely related species is far from ideal, it seems unlikely that the variants of *C. nuda*, *C. nana*, and *C. villamari* would approach the likeness of the new species. Certainly this warrants a closer examination of a wider range of material to delineate the ontogenetic and geographical extent of morphological and molecular variation in the Sternaspidae, so that developmental plasticity and aberrations are taken well into account.

The asymmetric development of the shield in *C. sundaensis*, new species (Fig. 2C), is also worth noting. This is unusual as all the other sternaspids reported elsewhere have symmetrical shields. We speculate that the asymmetrical shape is a result of the head-down burrowing behaviour in heterogeneous substrata (e.g., sediment mixed with plenty of gravel or rock) and the species may be relatively sedentary in habit in order for the shield symmetry to be affected by the uneven sediment surface. This unexpected shield asymmetry also provides an insight into the plasticity of shield development in sternaspids. It seems unlikely that this shield shape is simply an artefact due to the method of collection. In any case, its burrowing behaviour is unknown. Future studies, preferably based on observations of living specimens, will be helpful in understanding the relationships between sediment type, burrowing posture, and shield symmetry in sternaspid species. Furthermore, since the few observations reported so far were only on *Sternaspis*, it will be very interesting to learn more about the burrowing and feeding behaviour of species belonging to the three other sternaspid genera, i.e., *Caulleryaspis* Sendall & Salazar-Vallejo, 2013, *Mauretanaspis* Fiege & Barnich, 2020, and *Petersenaspis* Sendall & Salazar-Vallejo, 2013.

Based on the limited observations of the trawled material, we suggest that this species may be living in a heterogeneous substratum, possibly with gravel. This is an uncommon habitat for the sternaspids which are often regarded as soft sediment infauna (e.g., Jumars et al., 2015). Most sternaspid species are known to inhabit mud and/or sand, although others were collected from coarser mixed sediment, i.e., silt or mud with rocks. Sternaspids have been observed to burrow head-down into sandy substrata with the posterior shield and branchial region above the sediment surface, supposedly to facilitate oxygen exchange (Sendall & Salazar-Vallejo, 2013). However, Dorgan et al. (2006) and Jumars et al. (2015) reported subsurface burrowing behaviour of *S. scutata* in mud. These animals would stay completely buried in the mud for months and rarely approached the water-sediment interface. Such burrowing behaviour was also observed in sand (Self & Jumars, 1988). Sendall & Salazar-Vallejo (2013) suggested the different burrowing behaviours could be induced by the type of substratum, although Jumars et al. (2015) surmised that due to the lack of extensible feeding appendages beyond the introvert, it seems more likely for them to adopt the motile-burrowing feeding behaviour rather than holding the sedentary partially-exposed posture for extended periods.

Table 1. Summary of morphological characters of the shield region of *Caulleryaspis* species. Abbreviations: n.v. = not visible; n.s. = not specified; *a* = Salazar-Vallejo & Buzhinskaja (2013); *b* = Sendall & Salazar-Vallejo (2013); *c* = Zhadan, Tzetlin & Salazar-Vallejo (2017); *d* = Salazar-Vallejo (2017).

	C. fauchaldi Salazar-Vallejo & Buzhinskaja, 2013	*C. gudmundssoni* Sendall & Salazar-Vallejo, 2013	*C. laevis* (Caullery, 1944)	*C. nana* (Zhadan, Tzetlin & Salazar-Vallejo, 2017)	*C. nuda* Salazar-Vallejo & Buzhinskaja, 2013	*C. villamari* Salazar-Vallejo, 2017	*C. sundaensis*, new species
Shield							
Surface features	n.v.	n.v.	n.v.	visible	visible	visible	visible
Colour	n.v.	n.v.	n.v.	reddish-brown	pale brown	grayish	dark reddish brown
Concentric lines	n.v.	n.v.	n.v.	n.v.	n.v.	n.v.	visible
Ribs	n.v.	n.v.	n.v.	n.v.	barely defined	faintly defined	main ribs distinct
Anterior margins	rounded	rounded	rounded	rounded	rounded	rounded	deeply curved; convergent
Anterior depression	deep	deep	shallow	very shallow	deep	shallow	deep
Anterior keels	not exposed	not exposed	n.s.	visible in some specimens	not exposed	n.v.	visible
Suture	n.v.	n.v.	n.v.	well defined	n.v.	n.s.	indistinct
Fan	truncate	truncate	truncate	concave, with median projections	projected	truncate	convex & raised
Median notch	n.v.	n.v.	shallow	absent	deep & wide	shallow	deep
Lateral notches	n.v.	n.v.	n.s.	n.s.	n.s.	shallow	deep
Posterior margins	n.v.	n.v.	smooth	smooth	n.s.	barely crenulated	crenulated
Lateral shield chaetae	9	10	10	8	10	10	10
Posterior shield chaetae	4–5	3	5	5–6	4–6	8	6
Peg chaetae	robust; thin, short spines	robust; base stout	long; base narrow	translucent; short & thin	n.v.	small, thick spines	robust; thin, short spines
Branchial plates	slightly divergent	roughly parallel	widely separated	almost parallel	convergent	parallel	parallel
References	*a*	*b*	*b*	*c*	*a*	*d*	present paper

Key to species of *Caulleryaspis* Sendall & Salazar-Vallejo, 2013 (modified from Salazar-Vallejo, 2017)

1. Shield with sediment particles firmly attached; shield surface not visible 2
– Shield without firmly attached sediment particles; shield surface visible..... 4
2. Shield with deep anterior depression; peg chaetae robust..... 3
– Shield with shallow anterior depression; peg chaetae indistinct ..... *C. laevis* (Caullery, 1944) (Indonesia)
3. Shield with anterior margins angular; peg chaetae forming thick, large spines..... *C. gudmundssoni* Sendall & Salazar-Vallejo, 2013 (North Atlantic, Iceland)
– Shield with anterior margins rounded; peg chaetae forming thin, small spines..... *C. fauchaldi* Salazar-Vallejo & Buzhinskaja, 2013 (Northeastern Pacific, Oregon to California)
4. Shield with lateral margins rounded, medially expanded..... 5
– Shield with lateral margins straight to slightly curved..... 6
5. Ribs barely visible; shield pale; anterior depression V-shaped..... *C. nuda* Salazar-Vallejo & Buzhinskaja, 2013 (Northeastern Pacific, off Oregon)
– Ribs distinct; shield dark; anterior depression U-shaped..... *C. sundaensis*, new species (Sunda Strait, Indonesia; this study)
6. Ribs indistinct, shield dark red to brownish ..... *C. nana* (Zhadan, Tzetlin & Salazar-Vallejo, 2017) (Vietnam)
– Ribs distinct, shield yellowish to pale brown..... *C. villamari* Salazar-Vallejo, 2017 (Eastern Pacific, Ecuador)

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