

**New records of Caudofoveata**  
**(*Falcidens gutturosus*, *Prochaetoderma raduliferum*)**  
**and of Solenogastres**  
**(*Eleutheromenia carinata*, spec. nov.)**  
**from the eastern Mediterranean Sea**

(Mollusca)

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Salvini-Plawen, L. & B. Öztürk (2006): New records of Caudofoveata (*Falcidens gutturosus*, *Prochaetoderma raduliferum*) and of Solenogastres (*Eleutheromenia carinata*, spec. nov.) from the eastern Mediterranean Sea (Mollusca). – *Spixiana* **29/3**: 217–224

Samplings off the shores of Turkey and northern Cyprus between 1997 and 2004 were obtained from sandy and muddy bottoms down to 680 m. Among the Mollusca some stations contained the aplacophoran Caudofoveata *Falcidens gutturosus* (Kow.) and *Prochaetoderma raduliferum* (Kow.); they contribute to our knowledge on the distribution of the species. A single sample included a member of the aplacophoran Solenogastres, *Eleutheromenia carinata* spec. nov.; this species is described and systematically compared.

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### Introduction

Within the Mollusca, the Solenogastres (neomeniomorphs) and the Caudofoveata (chaetodermomorphs) represent two aplacophoran clades, both externally marked by a mantle with chitinous sclerites as well as unicellularly produced aragonitic sclerites and reflecting the conservative level of molluscan configuration (Salvini-Plawen 1985, 1988, 2003a, Salvini-Plawen & Steiner 1996, Haszprunar 2000). Though they long remained on the scientific sidelines, more intensive research during the last 35 years, however, has distinctly enlarged our knowledge on their organisation and evolutionary significance (summarised in Salvini-Plawen 1971, 1985, Scheltema et al. 1994). At present, the Caudofoveata (between 1.5 mm and 140 mm in length) include

about 120 named species, which generally live in depths below 50 m (records range between 3 m and 9000 m depth; Scheltema 1995, Belyaev 1966). The Solenogastres include about 250 nominal species (between 0.8 mm and 300 mm in length) with records between 1 m and 6850 m depth (predominantly below 50 m; Salvini-Plawen 2003b, Belyaev 1966).

Despite such increase in knowledge during recent decades, the presently known range of both the Caudofoveata and the Solenogastres by no means includes the true biodiversity; it is still fairly fragmentary not only with respect to biological, developmental and physiological features, but even regarding pure faunistics (diversity, biogeography, etc.). Worldwide, extensive geographical areas remain to be investigated, and stock-takings even within more intensively investigated regions reveal

that the true biodiversity is underestimated (e.g. Handl & Salvini-Plawen 2001, 2003, Salvini-Plawen 2003b). In the Eastern Mediterranean Sea only few samplings have also focused on aplacophoran molluscs; this is reflected in a poor knowledge of species biogeography and biodiversity (see Salvini-Plawen 1986). This contribution presents the records of Caudofoveata and of Solenogastres collected during research off the coast of Turkey and northern Cyprus. The examination and identification increased the known geographic distribution for two species of Caudofoveata and revealed a new species of Solenogastres.

Materials and methods

Samplings were made during various research projects between 1997 and 2004 on board the R/V “K. Piri Reis”, R/V “Egesuf” and R/V “Hippocampus”, along the Aegean Sea and Mediterranean Sea coasts of Turkey and of northern Cyprus. Specimens were obtained from sandy and muddy bottoms by grab, dredge and beam trawl at depths down to 680 m, and also from rocky biotopes and brown algae, red algae and *Posidonia oceanica* (L.) Delile, 1813 facies. The shallow shore samples were taken either by diving or by wading. The collected material was washed through a sieve with 0.5 mm mesh size and fixed in 4 % formalin. Specimens were sorted under a stereomicroscope in the laboratory. During the sorting process within the framework of a project supported by TUBITAK (The Scientific and Technical Research Council of Turkey, project code 103T154) representatives of the Caudofoveata and the Solenogastres were observed at some sampling stations (Fig. 1). These specimens were sampled from muddy substrates of various localities and depths

(Tab. 1). The materials collected are deposited in the ESFM museum (Ege University, Turkey).

1. Caudofoveata

The samples (Fig. 1 and Tab. 1) included 16 ex. of Caudofoveata whose shape is characterised by a slender, tail-like posterior body with a terminal knob or tassell. They belong, however, to two species of different families.

Prochaetodermatidae Salvini-Plawen, 1968

Caudofoveata with biserial radula, each pair supplemented by a basal reinforcement and lateral elements of the radula membrane.

Genus *Prochaetoderma* THIELE, 1902

Pedal shield divided/paired, pharynx with a pair of large spatulate elements; median denticulate portion of the radula teeth membranously enlarged; posterior body tapering, tail-like.

*Prochaetoderma raduliferum* (Kowalewsky, 1901)

Material: St. 7, 1 ex., Sandy mud with shell fragments, 69 m.

**Remarks.** Recent investigations (Scheltema & Ivanov 2000) show that Mediterranean representatives of *Prochaetoderma*, all measuring below 5 mm in length, belong to four different species: *P. raduliferum* (Kow.), *P. allenii* (Scheltema & Ivanov), *P. boucheti* Scheltema & Ivanov, and *P. iberogallicum* S.-Plawen. These are

Tab. 1. Coordinates, depths, dates and biotope characterisations of the samples.

Sta.	Date	Coordinates	Substrate	Depth (m)	Species
1	29.04.1997 25.04.1998	38°41'N–26°32'E	Mud	75	1 <i>Eleutheromenia</i> n. sp. 1 <i>F. guttuosus</i>
2	02.09.1998	38°41'N–26°35'E	Mud	77	1 <i>F. guttuosus</i>
3	22.01.1998 08.06.2004	38°41'N–26°37'E	Mud	71	2 <i>F. guttuosus</i> 2 <i>F. guttuosus</i>
4	15.04.1997	38°35'N–26°35'E	Mud	67	1 <i>F. guttuosus</i>
5	02.07.1997 14.10.1998	38°35'N–26°37'E	Mud	70	2 <i>F. guttuosus</i> 1 <i>F. guttuosus</i>
6	11.02.2000 19.03.2000	36°34'N–34°24'E	Mud	149	4 <i>F. guttuosus</i> 1 <i>F. guttuosus</i>
7	14.07.1998	35°10'N–32°50'E	Sandy mud with Shell fragments	69	1 <i>P. raduliferum</i>

newly described in part below new, poorly defined genera (Scheltema 1985), regarded at most as subgenera (Salvini-Plawen 1992). The present specimen was a juvenile with an atypical body shape, resembling *Prochaetoderma boucheti* Scheltema & Ivanov, 2000. Yet, its distally keeled elongate mantle scales and its pedal shield sclerites in two lateral rows of 6 and 4 scales, respectively, confirm the identity with *P. raduliferum* (Kow.), which is the type species originally described as *Chaetoderma radulifera* from the Sea of Marmara. In contrast to the distribution given earlier (Salvini-Plawen 1972, 1977, 1986, 1997) before separation into several species, this species is restricted to the eastern Mediterranean Sea (including the Adriatic), where it is well-documented from off Palestine at 65–238 m and from southern as well as western Cyprus at 90–180 m (unpubl. obs. S.-P.: Tel Aviv samples 1967–1968). The western-most record comes from off Malta (Mifsud 1996; the figure, however, erroneously shows a broken specimen of *Falcidens guttuerosus*). There is in part geographic overlap or even co-existence with *Prochaetoderma* (*Spathoderma*) *alleni* (Scheltema & Ivanov, 2000), such as in the central Adriatic, off Corfu and off Malta (Mifsud 2000: figure labeled as *P. raduliferum*).

#### **Chaetodermatidae Ihering, 1876 (Opinion 764, 1966)**

Radula membrane forming a basal cone or basal plate, on top of which only one or two pairs of true teeth are located or these are lacking; radula apparatus flanked by one or two pairs of cuticular scales or plates; midgut with cuticular stomach shield.

#### **Genus *Falcidens* Salvini-Plawen, 1968**

Radula represented by one pair of sickle-shaped teeth or pincers, which proximally are in contact or possess a symphysis; pedal shield unitary.

#### ***Falcidens guttuerosus* (Kowalewsky, 1901)**

The new records include 15 ex. from 6 sampling sites (Fig. 1 and Tab. 1).

**Material:** St. 1, 1 ex.; st. 2, 1 ex.; st. 3, 2 ex. (1998) and 2 ex. (2004) st. 4, 1 ex.; st. 5, 2 (1997) and 1 (1998) ex.; st. 6, 4 ex. (11.02.2000) and 1 ex. (19.03.2000).

**Remarks.** Thirty-three *Falcidens* species are described, only two of which inhabit – endemically – the Mediterranean Sea. *F. guttuerosus* is up to 15 mm long with a slender, tail-like posterior body and is char-

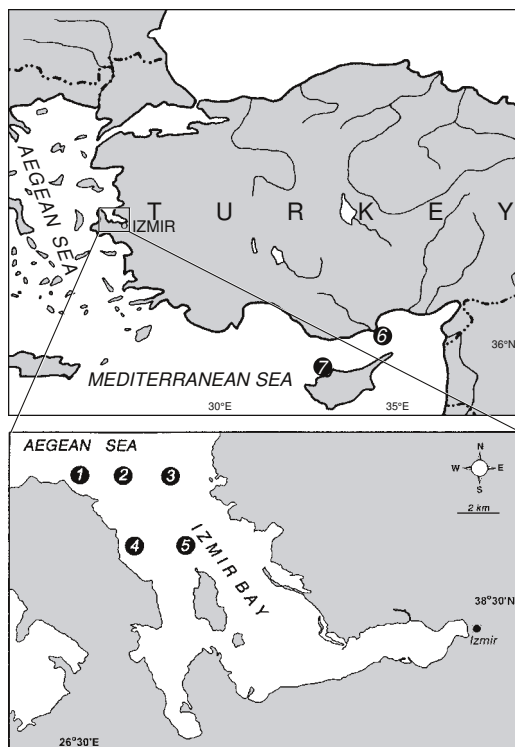


Fig. 1. Map of studied area with locations of stations where the specimens were sampled.

acterised by the particular shapes of its mantle scales (Salvini-Plawen 1972, 1996). It is a fairly common species, recorded at depths of 40–866 m from the Sea of Marmara, the Aegean Sea, from off western Cyprus and off Palestine (unpubl. obs. S.-P.: Tel Aviv samples 1967–1968), the Adriatic and Ionic Seas, as well from the western Mediterranean to off Málaga/Spain (Salvini-Plawen 1977, 1997).

#### **2. Solenogastres**

There was one record with a single specimen of Solenogastres. It belongs to the Pararrhopaliidae within the order Cavibelonia and represents a species new to science.

#### **Ordo Cavibelonia Salvini-Plawen, 1978**

Solenogastres with acicular, generally hollow mantle sclerites (spicules) in one or several layers, cuticle mostly thick with enclosed epidermal papillae; or with solid sclerites and moderately thick cuticle, but with a biserial radula and latero-ventral foregut

glandular organs not of ducts with subepithelially arranged glandular cells.

**Remarks.** The main character of this taxon, the hollow acicular sclerites, exhibits a variety of different patterns; this, however, has no bearing on the monophyletic status of Cavibelonia (Salvini-Plawen 2003a, 2004). The developmental arrangement of these spicules differs in being either (1) in a radial or (2) a tangential alignment. The latter may be arranged (2a) in a single, obliquely oriented layer, or (2b) they are arranged in two or more fairly rectangularly intercrossing layers almost embedded within the cuticle (and also termed "skeletal"). Another criterion exists with respect to the enclosed cavity: the spicules may be either thick-walled or thin-walled. Distally, spicules may be hooked (or barbed), asymmetrically flattened and serrate, or asymmetrically axe-like enlarged (also termed "capitate").

#### Pararrhopaliidae Salvini-Plawen, 1972

Parameniidae Simroth, 1893; Parameniidae Pruvot, 1902; Perimeniidae Nierstrasz, 1909; Pruvotiniidae Heath, 1911; Pruvotinidae Scheltema, 1998.

Solenogastres-Cavibelonia with distichous radula and ventral foregut glandular organs generally as subepithelially arranged follicles opening into a paired duct; with hooked mantle sclerites and/or a middorsal papillous pharyngeal gland and/or respiratory organs; see Salvini-Plawen 1978.

#### Genus *Eleutheromenia* Salvini-Plawen, 1967

*Paramenia* Pruvot, 1890, partim [non Brauer & Bergens-tamm, 1889]; *Pruvotina* Cockerell, 1903, partim; *Perimenia* Nierstrasz, 1909, partim).

**Definition.** Solenogastres with hollow spicules in more than one layer, also including hooked ones; with common atriobuccal opening; radula distichous; paired ventral foregut glands each as subepithelial follicles with common outleading duct (type A); no dorsal papillous foregut gland, no receptacula seminis, unpaired secondary genital opening; no copulatory stylets, but with a paired bundle of abdominal spicules; with dorsoterminal sense organ, with respiratory organs.

**Type species.** *Paramenia sierra* Pruvot, 1890; Costa Brava/Spain.

#### *Eleutheromenia carinata*, spec. nov.

Figs 2-5

**Diagnosis.** Body 9 mm × 0.5 mm with 0.2 mm high middorsal carina; cuticle moderate, no epidermal papillae; spicules upright, tangential and intercrossed, as well as hooked, all hollow; elongate scales along the pedal groove. Abdominal spicules in a paired bundle of hollow straight elements. Radula teeth with distal hook and at most one median denticle, radula support with some small turgescer cells; ventral foregut glandular follicles with paired duct; midgut with rostral caecum, without serial pouches. Paired portion of the spawning ducts very short and curving dorsally, unpaired portion straight and wide with central outlet within ventral pallial cavity. Respiratory organs as densely arranged papillae. Aegean Sea, Bay of Izmir; 75 m.

**Holotype:** One ex. with elongate shape and distinct middorsal keel (Fig. 2; preserved 9 mm long, with keel 0.7 mm high) from the Bay of Izmir (Fig. 1 and Tab. 1: Station 1), 38°41'N, 26°32'E, at 75 m on mud (collected 29.04.1997). Ribbons of semithin serial sections (cs 1-2 µm) were made with glassknives and stained with toluidine-blue. The material (sclerites and series sections on slides, midbody in alcohol) deposited at ESFM museum (Ege University, Faculty of Fisheries, Turkey) no. ESFM-SOL/98-1.

#### Description

**Body wall.** The body is distinctly marked by a sharp middorsal carina which varies somewhat in its height along its course and shows, in the midbody, 10 slight lobulations. In this keel, most prominently in the anteriormost body, the loose circular musculature is split into a small subepithelial fraction (below the epidermis of the carina); the main fibres traverse the base of the keel and, in front of the midgut caecum, thus as usual delimit the body cavity. The space between this split musculature is filled by mesenchyme and groups of granulated (gland) cells. Elsewhere, the epidermis is likewise underlain by loose circular and longitudinal fibres. In the ventral body half, the longitudinal fibres are increasingly condensed into groups and there is a not very compact but distinct lateroventral pair of (occasionally bipartite) bundles.

The 5-10 µm high epidermis includes numerous gland cells but there are no epidermal papillae. The cuticle is on the average only 25-30 µm thick. The overall mantle includes six types of sclerites (Fig. 3). (a) The main type consists of straight to slightly bent, hollow spicules (80-150 µm × Ø 7-9 µm), somewhat varying in their proximal portion and lying fairly parallel to the surface, arranged in two to three in-



Fig. 2. Solenogastres: *Eleutheromenia carinata*, spec. nov. (9 mm; anterior end above).

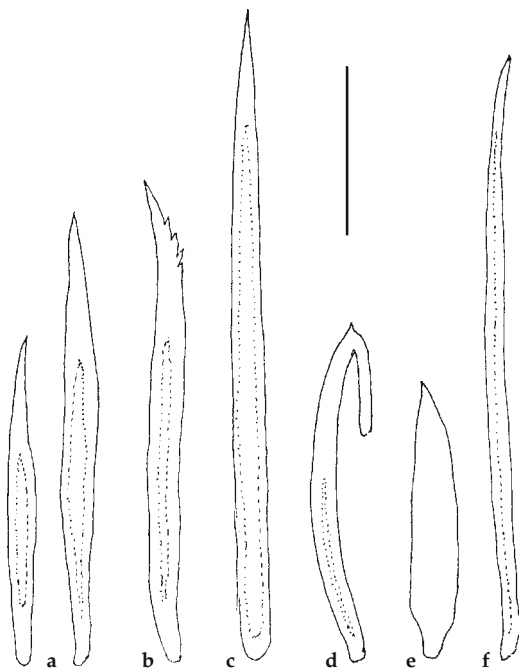


Fig. 3. *Eleutheromenia carinata*, spec. nov. (Solenogastres): mantle sclerites (see text); bar = 50  $\mu$ m.

tercrossing layers. (b) A similar acicular type with a serration at one side of the solid distal portion (120-160  $\mu$ m) is radially arranged in the anterior body only and extends beyond the cuticle. (c) Long and straight, thin-walled acicular spicules (150-250  $\mu$ m  $\times$   $\varnothing$  9-11  $\mu$ m) obliquely exceeding the cuticle towards dorsal and thus resulting in a somewhat rough body surface. (d) The characteristic type of curved bent spicules (80-110  $\mu$ m) with the solid distal portion forming a hook with a tip at the turn are present at the dorsal body and densely arranged on the keel. (e) Along the pedal groove, elongate scales (75-90  $\mu$ m  $\times$  14-15  $\mu$ m) are present. In addition (f), lateral to these scales, there is a dense longitudinal arrangement of slender needles (175-200  $\mu$ m  $\times$   $\varnothing$  5-6  $\mu$ m), extending obliquely towards posterior.

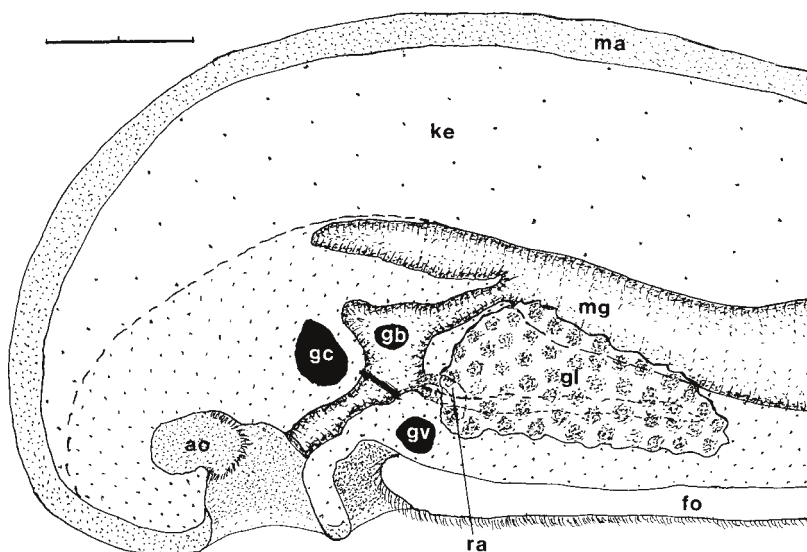
In front of the opening of the mantle cavity protrudes a paired bundle each of 15-20 ventromedially directed abdominal spicules (Fig. 5). They are about 150  $\mu$ m long and apparently hollow. At each side the sheath intrudes between the body wall musculature and the dorsoventral bundles and is laterally accompanied by its own longitudinal musculature.

**Foot and Mantle cavity.** The ciliated pedal pit forms, with its lateral rims, the single longitudinal fold

which runs through the pedal groove. The foot ends with the opening of the abdominal spicules and does not enter the mantle cavity. The pedal gland is voluminous, filling with its cell follicles the entire space in the cerebral and preradular foregut region. There are two types of intermixed gland cells, (1) pale-staining ones with net-like fibrous content opening frontally and laterally into the pedal pit, and (2) cells with dense, dark-staining content opening dorsally into the pit. Only the dark staining cells continue as small sole gland follicles along the foot.

The mantle or pallial cavity possesses a 6-8  $\mu$ m high epithelium which is protruded to numerous respiratory papillae (rather than plicae), filling the cavity also in front of its opening. They are densely packed; in cross sections, up to 19 radially arranged papillae are visible. The dorsofrontal transition from the hindgut is continuous; the unpaired ventral outlet of the spawnings ducts (secondary genital opening) is continuous with a groove of the mantle cavity bottom flanked by respiratory papillae.

**Sensory system.** The cerebral ganglia are fused and there are at least two pairs of small laterofrontal ganglia immediately adjacent to it, innervating the atrial region. The lateral body cords are loosely, the ventral ones more densely provided with nuclei. The (first) lateral ganglia lie close to the cerebral gan-



**Fig. 4.** *Eleutheromenia carinata*, spec. nov. (Solenogastres): organisation of anterior body (in preserved state); bar = 200  $\mu$ m. Abbreviations: ao = atrial sense organ; fo = pedal fold (foot); gb = buccal ganglion; gc = cerebral ganglion; gl = ventral foregut glandular organ; gv = (first) ventral ganglion; ke = body keel; ma = mantle; mg = midgut; ra = radula sheath.

gion and are elongate ( $\varnothing$  30  $\mu$ m); the (first) ventral ganglia ( $\varnothing$  50  $\mu$ m) are located above the end of the pedal pit. The buccal ganglia ( $\varnothing$  40  $\mu$ m) are located fairly dorsolateral at the foregut, in front of the radula apparatus (Fig. 4). The suprarectal commissure interconnecting the ganglia posteriora superiora (alongside the curving pericardioducts) is differentiated far anterior to the anal opening; it is medullary and 120  $\mu$ m long ( $\varnothing$  25  $\mu$ m).

The atrial or vestibular sense organ differentiates papillae which are bundled into groups up to four with a common trunk. As usual, the sensory area is bordered by a horseshoe-shaped ciliary fold, the dorso-posterior incurve excluding the buccal space which is continuous with the mouth. The dorsal folds end at half of the extension of the atrial roof in a common plate.

The single dorsoterminal sense organ is prominently differentiated close to the body end (Fig. 5).

**Alimentary tract.** The mouth opening is separated from the sensory region in the dorsoposterior area of the common, longitudinal atrio-buccal cavity (Fig. 4). A buccal space with folds leads into the pharyngeal foregut whose epithelium appears to be moderately cuticularised (microvilli?) and whose anterior is partly ciliated; the foregut is provided with weak musculature. A sphincter separates the widened portion between the cerebral ganglion and the radula apparatus; no subepithelial pharyngeal

glands are discernible and there is no compacted (papillous) dorsal foregut gland. The (protruded) radula is very small, distichous, each tooth (15–20  $\mu$ m high) with a distal hook and (probably) one median denticle. The radula support shows some small turgescent cells, as well as muscular and connective tissue. The ventral foregut glandular organs consist of cells packed into follicles which empty at each side into a distinct duct that opens lateroventrally of the radula. Dorsal and lateral subepithelial gland cells open into the anterior portion of the longitudinally folded, narrowed postradular foregut (esophagus); the latter opens without a sphincter into the ventral midgut. The midgut possesses a flat rostral caecum, paired in its anteriormost portion. The dorsoventral muscle bundles are not very compact and the inner ones already insert on the body wall at half height of the animal. They do not constrict the gut, which is well separated from the body wall. The midgut represents an unusual structure due to the differentiation of irregularly, dorso- and/or ventrolaterally arranged bulges with high, glandular (and deeply staining) epithelium that includes also nematocysts; the remaining epithelium is moderately high and bears a middorsal ciliary tract. In the region of the pericardium the midgut narrows and its ciliation spreads from the middorsal tract towards ventral. The hindgut lacks any visible demarcation against the dorsofrontal mantle cavity.



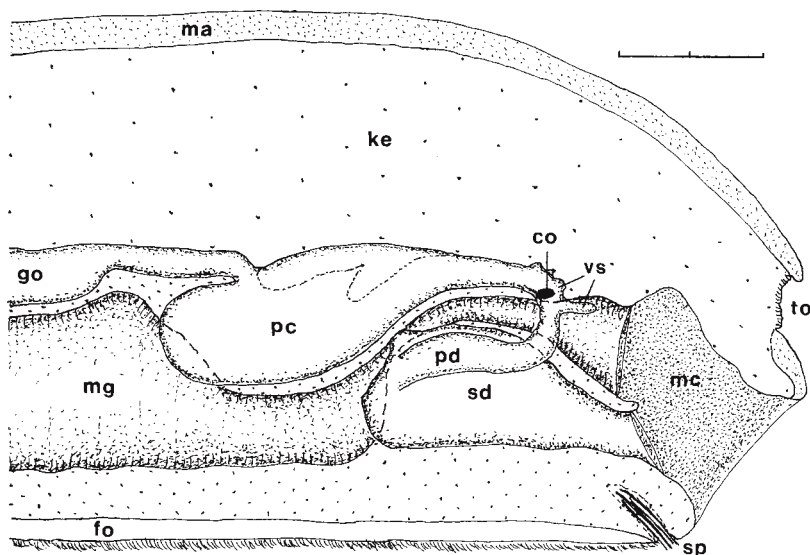


Fig. 5. *Eleutheromenia carinata*, spec. nov. (Solenogastres): organisation of posterior body (in preserved state); bar = 200  $\mu$ m. Abbreviations: co = suprarectal commissure; fo = pedal fold (foot); go = gonad; ke = body keel; ma = mantle; mc = mantle cavity; mg = midgut; pc = pericardium; pd = pericardioduct; sd = spawning duct; sp = abdominal spicules; to = terminal sense organ; vs = vesiculae seminales.

**Gonopericardial system.** The two gonads in the present specimen are not yet fully developed and a paired lumen alongside the dorsal sinus is only sporadically visible. In the posterior body, however, the two gonadal tubes are present and show lateral sacks filled with sperm; these represent some kind of vesiculae seminales of the strongly protandric animals. The paired gonopericardial ducts are distinct and open dorsally into the pericardium which shows a paired anterior beginning. This voluminous cavity exhibits a paired dorsal ciliary tract. The heart is a mediadorsal invagination of the pericardial roof. The fused atrium is elongate and opens from ventral into the ventricle. There are two kinds of blood cells: round to oval, homogeneous ones ( $\varnothing$  5–9  $\mu$ m) with distinct nucleus, and oval to irregularly elongate, vacuolated or differently granulated cells (10–15  $\mu$ m).

Posteriorly, the pericardium is a tube with paired dorsolateral ciliary tract; these tracts form by separation the ciliation of the pericardioducts. Close to and in the ventro-anterior curve of each duct, some small sacculations and a distinct, posteriorly directed vesicula seminalis are formed. The pericardioducts possess a cylindrical epithelium without longitudinal ridge or fold and are surrounded by musculature; in their anteriormost portion they widen and represent the laterodorsally curved continuation of the respective spawning duct. There are no receptacula seminis. The spawning ducts are fused along almost their entire extension; only the anteriormost portion

is paired. The unpaired organ is voluminous and highly glandular; merely its central portion (flanked by the short blind endings of the lateral portions) becomes the short outlet. This outlet is continuous with the ventral wall of the mantle cavity and forms here a groove. There are no copulatory stylets.

## Discussion

Referring to the definition of the genus *Eleutheromenia* (Salvini-Plawen 2003b, and above), the organisation described here is clearly congeneric. Presently, only the type species *E. sierra* (Pruvot, 1890) is known, geographically ranging from off the Costa Brava (northeastern Spain) to the Trondheim area (Norway) at 40–218 m depth (Salvini-Plawen 2003b). This species (length to height ratio approximately 6:1) is particularly characterised by a series of 15 prominent middorsal lobes forming a discontinuous keel (Pruvot 1891, Salvini-Plawen 2003b), whereas the current specimen (ratio 13:1) exhibits a continuous middorsal carina that does, however, vary somewhat in height. With regard to the remaining organisation, the general configuration straddles that of *E. sierra* and *E. carinata* spec. nov.

The particular organisation, however, includes several species-specific differences: With respect to the sclerites, there are no acicular spicules with a distal, harpoon-like indentation such as in *E. sierra*.

The mantle cavity forms numerous respiratory papillae. The midgut is at a distance to the body wall and therefore not serially constricted to form ventrolateral pouches (as in *E. sierra*). The ciliary tracts in the pericardium run dorsally and the atrium/auricle of the heart is unpaired (lateral tracts and paired atrium in *E. sierra*). Apart from the keel, the configuration of the spawning ducts is the most obvious difference: in the present not yet fully animal they form an almost fused organ – only the anterior-most portion is paired and dorsally curved as a continuation of the pericardioducts. In *E. sierra* the spawning ducts are subdivided into a paired and an unpaired section which overlap somewhat and are not axially continuous (but interconnect dorsoventrally), whereas the pericardioducts clearly open without enlargement from laterodorsal into the paired section. The fused spawning duct opens by means of a central outlet at the bottom within the anterior mantle cavity, whereas in *E. sierra* the unpaired spawning duct narrows and the outlet opens into the anterior-most area of the cavity.

### Acknowledgements

This study was supported by TÜBITAK (Project No TBAG 103T154). The authors are very grateful to Dr. Michael Stachowitsch (Vienna) for polishing the English text.

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