



## Recording of *Procamallanus (Procamallanus) annulatus* and *Procamallanus (Procamallanus) elatensis* from Red Sea Fishes in Egypt

Nermean M. Hussein<sup>1\*</sup>, Refaat M. A. Khalifa<sup>2</sup> and Zeinab T. M. Abdel-Ghaffar<sup>1</sup>

<sup>1</sup>Department of Zoology, Faculty of Science, South Valley University, Qena 83523, Egypt

<sup>2</sup>Department of Medical Parasitology, Faculty of Medicine, Assiut University, Egypt

\*Corresponding author: [nermeanmohu@yahoo.com](mailto:nermeanmohu@yahoo.com)

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### ABSTRACT

Previous studies of *Procamallanus* species in marine fishes in Egypt recorded only *Procamallanus (Procamallanus) elatensis* Fusco and Overstreet, 1979 from siganid fishes. The present research examined Red Sea fishes at Hurghada and Safaga, Egypt for *Procamallanus* nematodes Family: Camallanidae Railliet and Henry, 1915. The investigation used standard methods of collection and examination for marine fishes, for processing and illustrating of specimens, for study of morphometric characteristics of the parasites by light and scanning electron microscopy (SEM), and taxonomic identification. Nematode specimens display smooth continuous buccal capsules without special ridges. Esophagi are divided into anterior muscular and longer posterior glandular sections. Male caudal alae are present. Female posterior extremities are conical and end in short blunt processes. Vulvae are located in front of the middle of the body, and females are viviparous. The first species from *Caranx sexfasciatus* (Perciformes: Carangidae) are similar in all features and most body dimensions in both genders to *Procamallanus (Procamallanus) annulatus*, Yamaguti, 1955. Notable features include the presence of deirids; six crescent-shaped elevations surrounding the mouth; presence of three protuberances on the female tail tip and three pairs of pre-cloacal papillae on males; five pairs of post-cloacal papillae and one pair of posterior lateral phasmids; and an additional two pairs of small transversely elongate sessile ventral papillae surrounding the cloacal opening. This species differs from *Procamallanus (Procamallanus) elatensis* Fusco and Overstreet, 1979 described from *Parupeneus forsskali* and *Mulloidichthys flavolineatus* (Perciformes: Mullidae) where the male displays four pre-cloacal papillae, four post-cloacal papillae and four lateral papillae, and female tail tip ends with two protuberances.

### INTRODUCTION

In Egypt, parasitic diseases represent about 80% of fish diseases; many of which can be of importance for fish eating animals, birds and humans (Eissa, 2006). Nematodes are usually considered the most economically important helminth parasites of fishes in the world due to nematodes are motile than other helminthes and therefore one could anticipate more exports on their effects on fish health (Woo, 1995). Nematodes of the

family Camallanidae Railliet et Henry, 1915, characterized by a well-developed, usually orange-coloured buccal capsule and a life cycle involving a copepod intermediate host, are mostly gastrointestinal, blood-sucking parasites of marine, brackish-water and fresh-water fishes (Ivashkin *et al.*, 1971; Anderson *et al.*, 2009; Rigby and Rigby, 2014). The genus *Procamallanus* was divided into two subgenera, *Procamallanus* and *Spirocamallanus*, *Procamallanus* is restricted to species with a smooth buccal capsule lining and *Spirocamallanus* is characterized by a spiral thickening on the inner wall of the buccal capsule (Olsen, 1952). Five subgenera: *Procamallanus* Baylis, 1923; *Spirocamallanus* Olsen, 1952; *Spirocamallanoides* (Moravec and Sey, 1988); *Punctocamallanus* (Moravec and Scholz, 1991) and *Denticamallanus* (Moravec and Thatcher, 1997) were identified (Moravec and Thatcher, 1997). This taxonomy is exactly the most recent structuring adapted by Gibson (2017). The genus *Procamallanus* Baylis, 1923 (Nematoda: Camallanidae) includes species that parasitize freshwater, brackish and marine fishes (Sood, 1989). *Procamallanus spiculastratus* sp. n., a nematode of the genus *Procamallanus* Baylis, 1923 (Camallanida, Procamallaninae) was described from freshwater fish *Astronotus ocellatus* (Oscar fish) in Brazil by Raul *et al.* (2018). *Procamallanus elatensis* was described from two siganid hosts, *Siganus rivulatus* (marbled spinefoot) and *S. luridus* (dusky spinefoot) from the northern Gulf of Aquaba in the northern Red Sea (Fusco and Overstreet, 1979). Also, this species was recorded from the same two fish species using light and scanning electron microscopy (SEM) (Abdou *et al.*, 1995), and it was recorded from *Siganus rivulatus* (Siganidae) in the Gulf of Aqaba, Red Sea according to Dzikowski *et al.* (2003). The distribution of *Procamallanus elatensis* Fusco and Overstreet, 1979 was discussed along the intestine of *Siganus rivulatus* (Hassanine and Al-Jahdali, 2007). Al-Jahdali (2011, 2012) studied factors affecting gastrointestinal nematode infra populations finding that, to a great extent, populations are density dependent in *Siganus rivulatus* from the Saudi coast of the Red Sea. *Siganus sutor* (shoemaker spinefoot) was reported as a new host record of *Procamallanus elatensis* from the Red Sea, Egypt (Khalifa *et al.*, 2019). This study reports *Caranx sexfasciatus* (Perciformes: Carangidae) (big eye trevally) as a new host record and locality for *Procamallanus (Procamallanus) annulatus* Yamaguti, 1955, and *Mulloidichthys flavolineatus* and *Parupeneus forsskali* (Perciformes: Mullidae) (yellowstripe and Red Sea goatfish) as new host records for *Procamallanus elatensis*.

## MATERIALS AND METHODS

### Sampling:

Sixty-one fish samples were collected along the coast of Hurghada and Safaga, Red Sea, Egypt from February 2016 to January 2017. They were transported as alive as possible to the Laboratory of Parasitology, Zoology Department, Faculty of Science, South Valley University at Qena Governorate, Egypt. Fishes were identified using different criteria (Randall, 1983; Lieske and Myers, 2004; Lieske *et al.*, 2004) and also confirmed through the fishbase website (<http://www.fishbase.org>). Gastrointestinal tracts were untangled with fingers (Justine *et al.*, 2012). The entire digestive system and other viscera were opened longitudinally. Macroscopic and microscopic examination of different organs was carried to detect of nematode parasites. Collected nematodes were

cleaned by washing several times with isotonic saline solution. Relaxed nematodes were preserved in bottles containing a mixture of 70% alcohol and 5% glycerin.

#### **LM examination:**

For microscopical examination, nematodes were mounted on slides with a few drops of lactophenol and covered with a cover slip. Identification nematodes used keys for nematode parasites of vertebrates (Yorke *et al.*, 1926; Yamaguti, 1963; Anderson *et al.*, 2009).

#### **SEM examination:**

For SEM studies, specimens were fixed for six hours at 4°C in 3% buffered glutaraldehyde, washed several times in 0.1 M sodium cacodylate buffer, dehydrated in ascending concentrations of ethanol and transferred to pure acetone. Samples were then processed in a critical point drier "Bomer - 900" with Freon 13. Samples were sputter-coated with gold in a Technics Hummer V (Lee, 1993) and examined with a JEOL JSM-5400LV SEM operated at 15 kV in the electron microscopy unit, Assiut University.

## **RESULTS**

Six of eight specimens of *Caranx sexfasciatus* Quoy and Gaimard, 1825, 25.5–26.5 cm in length, were infected with *Procamallanus (Procamallanus) annulatus* Yamaguti, 1955). One of 29 specimens of *Parupeneus forsskali* Fourmanoir Guézé, 1976, 18.5–24 cm, and two of 24 specimens of *Mulloidichthys flavolineatus* Lacepède, 1801, 16–28.5 cm (Mullidae) were infected with *Procamallanus (Procamallanus) elatensis* Fusco and Overstreet, 1979.

#### **Morphology of *Procamallanus (Procamallanus) annulatus* Yamaguti, 1955** (Figures 1–3)

Specimens were medium-sized nematodes, with finely and transversely striated cuticle. Live specimens are reddish. Mouth aperture is circular and surrounded by six flat, crescent-shaped elevations and four sub-median cephalic papillae. Buccal capsule is orange-brown, thick-walled, barrel-shaped, longer than wide, with a well-developed basal ring. The inner surface of the mouth capsule appears smooth, without any spiral ridges. The muscular esophagus is shorter than the glandular esophagus and both sections expand near their posterior ends. The intestine was brown and narrow. The excretory pore is located posterior to the junction of both sections of the esophagus. The tail of both sexes is conical with a blunt tip.

**Male:** Body measures 9.66–10.61 mm in length with a maximum width of 269–277 µm (Fig. 1). The buccal capsule, including the basal ring, is 96–100 µm in length and 64–67 µm in width; the basal ring measures 7–9 µm in length and 47–51 µm in width. Maximum width/length ratio of the buccal capsule is 1:1.49–1:1.5. Length of the muscular esophagus is 369–411 µm, with 65–77 µm maximum width; length of the glandular esophagus is 410–433 µm, with a maximum width of 53–62 µm; length ratio of muscular to the glandular esophagus is 1:1.05–1:1.1. Length of the entire esophagus and buccal capsule represents 8 % of body total length. The nerve ring is 217–230 µm from the anterior extremity. Excretory pore is located 590–600 µm from anterior end. The posterior end of body is ventrally bent and displays a wide, vesiculated caudal alae

supported by pedunculate papillae. Alae are anteriorly interconnected by a mound-forming pre-cloacal sucker, posteriorly reaching to the tail tip. Pre-cloacal papillae include three pairs of equally spaced sub-ventral pedunculate papillae; post-cloacal papillae: five pairs of anterior sub-ventral papillae and one pair of posterior lateral phasmids; an additional two pairs of small transversely elongate sessile ventral papillae surround the cloacal opening. Spicules are similar in shape, unequal, with sharp points. The large (right) spicule is 306–309  $\mu\text{m}$  length with a narrowed, ventral-bent, alate distal tip. The small (left) spicule less sclerotized, 138–160  $\mu\text{m}$  length. Length ratio of spicules is 1:1.93–1:2.21. Gubernaculum measures 83–96  $\mu\text{m}$  in length. Tail is conical, 65–81  $\mu\text{m}$  length (table 1), with a rounded tip.

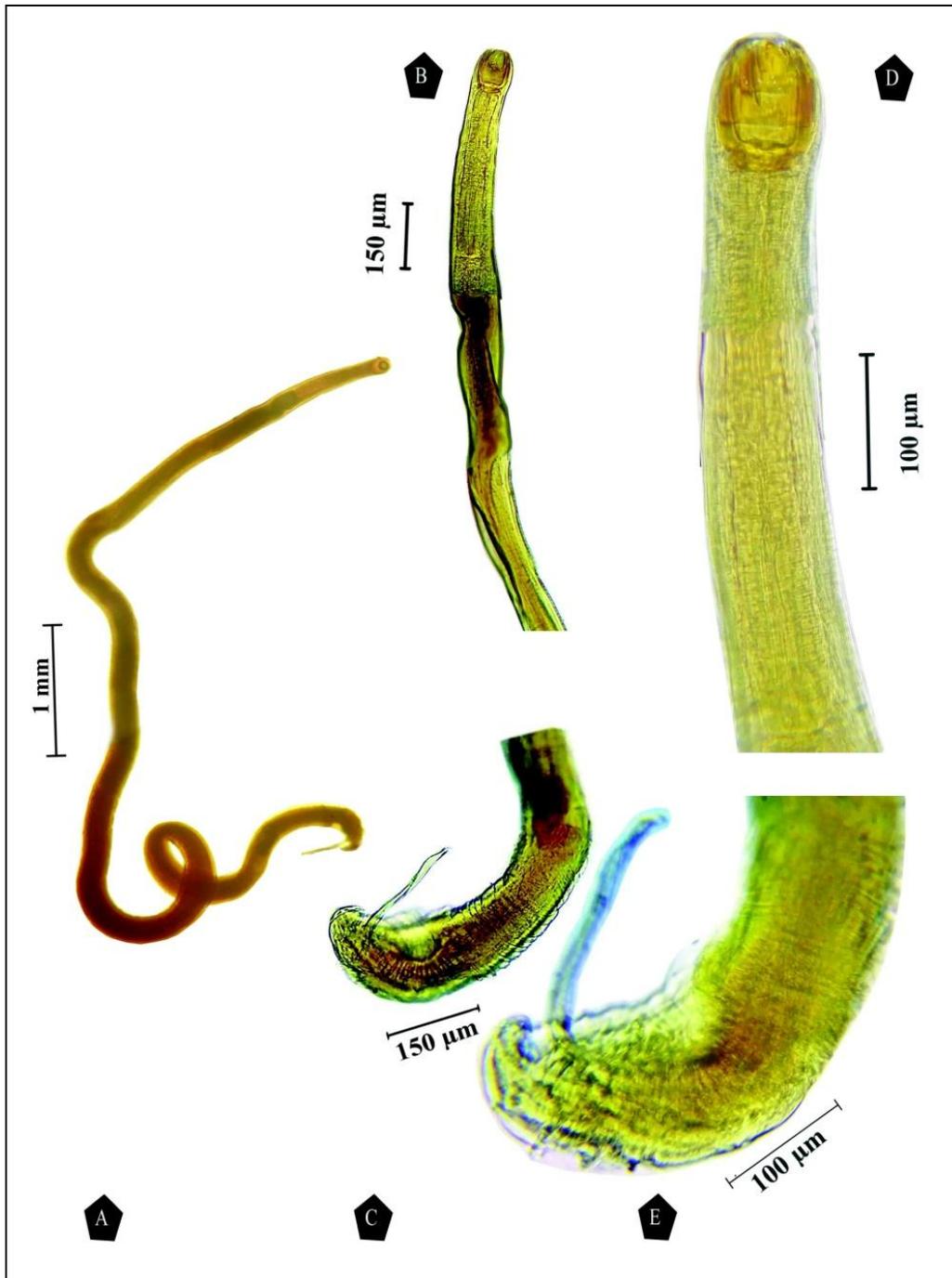
**Female:** Body length is 17.38–23.7 mm, with 431–529  $\mu\text{m}$  maximum width (Fig. 2). Buccal capsule including basal ring measures 107–223  $\mu\text{m}$  in length and 83–212  $\mu\text{m}$  in width; basal ring is 17–52  $\mu\text{m}$  in length and 63–135  $\mu\text{m}$  in width. Maximum width/length ratio of buccal capsule is 1:1.07–1:1.43. The length of the muscular esophagus is 467–822  $\mu\text{m}$ , and 81–202  $\mu\text{m}$  in width; length of glandular esophagus is 550–1,260  $\mu\text{m}$  and 113–303  $\mu\text{m}$  in maximum width; length ratio of muscular and glandular esophagus is 1:1.17–1:1.50. Length of the entire esophagus and buccal capsule represents 2–13% of body length. The nerve ring is 279–319  $\mu\text{m}$  from anterior extremity. Excretory pore is located 779–950  $\mu\text{m}$  from the anterior end. Pre-equatorial vulvae are located 3.901–11 mm from the anterior extremity at 22–46 % of body length. Uterus filled with larvae. The tail is conical, measures 211–302  $\mu\text{m}$  length (table 1), the tail has a blunt tip, with three outlined protuberances.

**Ultrastructure:** (Fig.4).

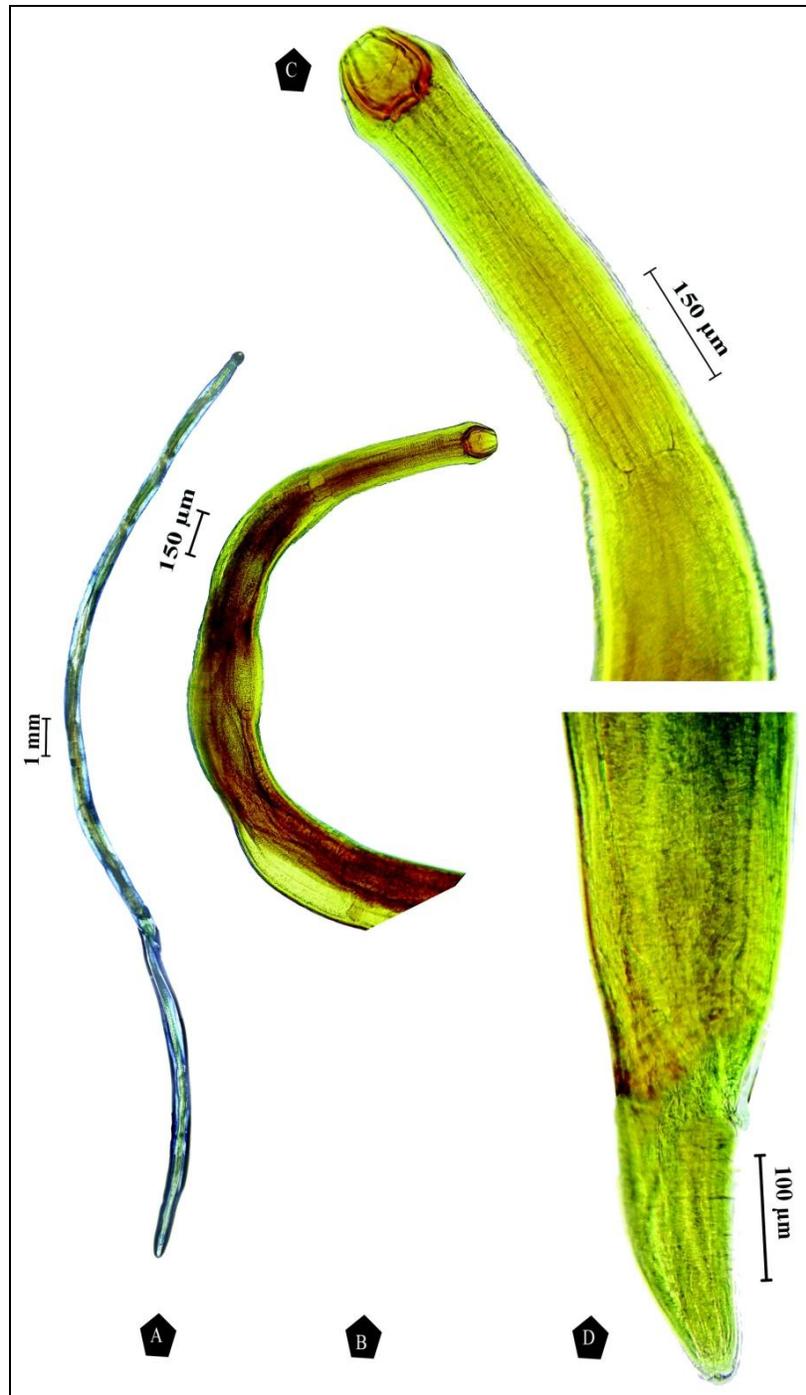
The cephalic head (anterior extremity) is bulb-like in both genders, with a large circular mouth opening provided with a cephalic collar with a hexagonal peripheral margin and supported with six flat, crescent-shaped cephalic plates. Four large cephalic papillae are situated in the external circle inside the cephalic plate with a pair of small lateral amphids. The inner surface of the buccal capsule is smooth, without any spiral ridges, and measures 135  $\mu\text{m}$  in length and 157  $\mu\text{m}$  in width. Deirids are small, simple, with rounded ends, situated mid-way between the posterior end of the buccal capsule and nerve ring, 170  $\mu\text{m}$  from the anterior extremity. Cuticle displays transverse striations extending from the posterior region of the cephalic head to the posterior extremity of the body.

The male posterior extremity is curved and provided with wide caudal alae supported on each side by a series of pre-cloacal and post-cloacal papillae; pre-cloacal group represents three pairs of equally spaced sub-ventral pedunculate papillae; the post-cloacal group is five pairs of anterior sub-ventral papillae and two pairs of small transversely elongate sessile ventral papillae surrounding the cloacal opening and one pair of posterior lateral phasmids. The tail is conical, with a rounded tip.

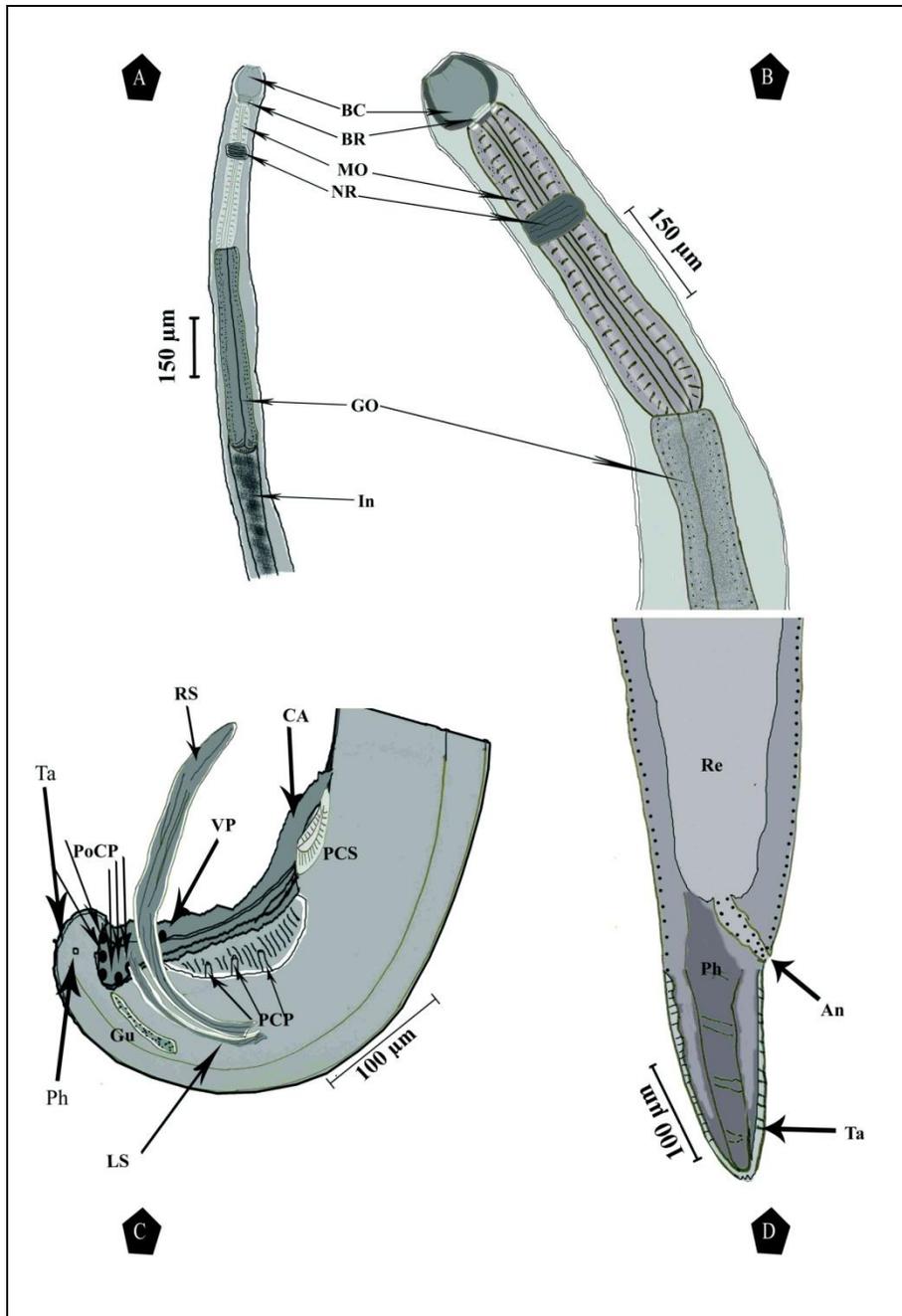
The female posterior extremity is straight, with a conical tail ending with a blunt tip, and displays three slightly outlined protuberances. The anus is represented by a narrow transverse slit-like opening.



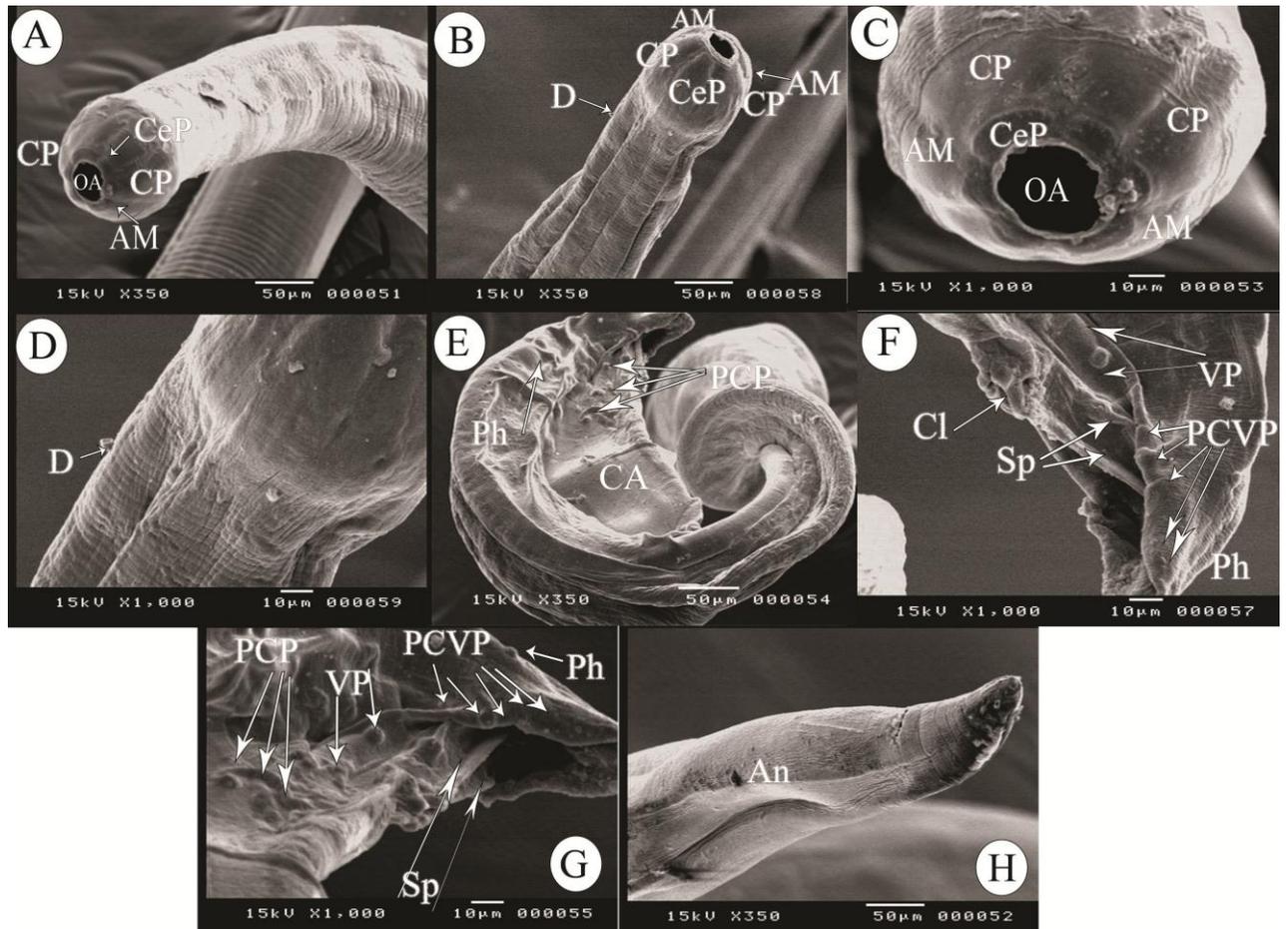
**Fig. 1** Light microscopic images of adult male of *Procamallanus* (*Procamallanus*) *annulatus* from the intestine of *Caranx sexfasciatus*, **A** Whole nematode, **B** Ventrolateral view of anterior extremity, **C** Lateral view of posterior extremity, **D** Enlarged ventrolateral view of anterior extremity showing the buccal capsule and muscular esophagus, **E** Lateral view of enlarged posterior extremity.



**Fig. 2** Light microscopic images of adult female of *Procammallanus (Procammallanus) annulatus* from the intestine of *Caranx sexfasciatus*, **A** Whole nematode. **B** Ventrolateral view of the anterior extremity. **C** Enlarged ventrolateral view of anterior extremity. **D** Lateral view of enlarged posterior extremity.



**Fig. 3** Line drawings of *Procamallanus* (*Procamallanus*) *annulatus* from *Caranx sexfasciatus*, **A** Ventrolateral view of the male anterior extremity. **B** Ventrolateral view of enlarged the female anterior extremity; note buccal capsule BC, basal ring BR, nerve ring NR, muscular esophagus MO, glandular esophagus GO, narrow intestine In. **C** Enlarged lateral view of the male posterior extremity, notice rectum Re, anus An, phasmids Ph, tail Ta, wide caudal alae CA, right spicule RS, left spicule LS, pre-cloacal papillae PCP, post-cloacal papillae PoCP, gubernaculum GU, ventral papillae VP, pre-cloacal sucker PCS. **D** Enlarged lateral view of the female posterior extremity.



**Fig. 4** SEM micrographs of *Procamlanus (Procamlanus) annulatus* from *Caranx sexfasciatus*. **A & B** Anterior extremity of the male, lateral view. **C** High magnification of the male buccal capsule, apical view depicting a four large Cephalic Papillae CP, crescent shaped Cephalic Plates CeP, circular Oral Aperture OA, small lateral Amphid Am, small Deirid D. **D** Deirid D, sub-lateral view. **E** Posterior extremity of the male, Lateral view; note Phasmid Ph, wide Caudal alae CA, Pre-caudal Papillae PcP. **F** Posterior extremity of the male, ventro-lateral view. **G** Posterior extremity of the male, ventro-lateral view notice Cephalic collar Cl, Sensory Papillae SP, Post-cloacal Ventral Papillae PcVP, ventral papillae VP, phasmid Ph. **H** Posterior extremity of the female, ventral view, anus An.

**Table 1.** Comparison of the collected *Procammallanus (Procammallanus) annulatus* specimens with the previously described forms

Reference		Yamaguti (1955)	Moravec and Justine (2011)	Present study
Fish host (s)		<i>Siganus</i> sp. (Perciformes: Siganidae)	<i>Siganus lineatus</i> (Perciformes: Siganidae)	<i>Caranx sexfasciatus</i> (Perciformes: Carangidae)
Locality		Celebes	New Caledonia (off Nouméa; Nouméa fish market)	Hurghada, Egypt in the Red Sea
Parasite number		7 ♂ and 5 ♀	6,1juvenile ♂, 5gravid and 2 subgravid ♀	4 ♂ and 6 ♀
Site of infection		Small intestine	Intestine and pyloric caeca	Intestine
<b>Parameters</b>				
Body length (mm)	Male	10–20	16.99–19.94	9.66–10.61
	Female	28–43	37.97–46.76	17.38–23.7
Maximum body width (µm)	Male	260–390	367–490	269–277
	Female	500–840	707–938	431–529
Buccal capsule length (µm)	Male	120–150	105–111	75–90
	Female	140–165	123–132	89–181
Buccal capsule width (µm)	Male	105–130	99–108	51–61
	Female	120–130	126–132	83–212
Muscular esophagus length (µm)	Male	420–510	408–490	369–411
	Female	460–620	517–639	467–822
Muscular esophagus width (µm)	Male	90–123	69–90	65–77
	Female	120–140	102–122	81–202
Glandular esophagus length (µm)	Male	500–740	530–680	410–433
	Female	740–1,050	707–911	550–1,260
Glandular esophagus width (µm)	Male	90–140	63–78	53–62
	Female	120–140	81–122	113–303
Nerve ring from anterior extremity (µm)	Male	230–350	272–354	217–230
	Female	320–380	326–449	279–319
Excretory pore from anterior extremity (µm)	Male	490–610	558–734	590–600
	Female	600–750	748–1142	779–950
Deirids from anterior extremity (µm)	Male	Not mentioned	228–270	170–190
Large (Right) spicule length (µm)	Male	370–420	321–387	306–309
Small (left) spicule length (µm)	Male	210–250	231–299	138–160
Small spicules:large spicule Length (µm)	Male	Not mentioned	1:1.07–1.47	1:1.93–1:2.21
Gubernaculum length (µm)	Male	140–150	135–165	83–96
Tail length (µm)	Male	240–300	153–300	065–081
	Female	350–420	408–558	211–302
Vulva from anterior extremity ( mm)	Female	10–18	15.40–17.50	3.901–11
Vulva from anterior extremity: body length(µm)	Female	1:1.4–1.8	Not mentioned	1:2.15–4.61

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**Morphology of *Procamallanus (Procamallanus) elatensis* Fusco and Overstreet, 1979**  
(Figures 5–7).

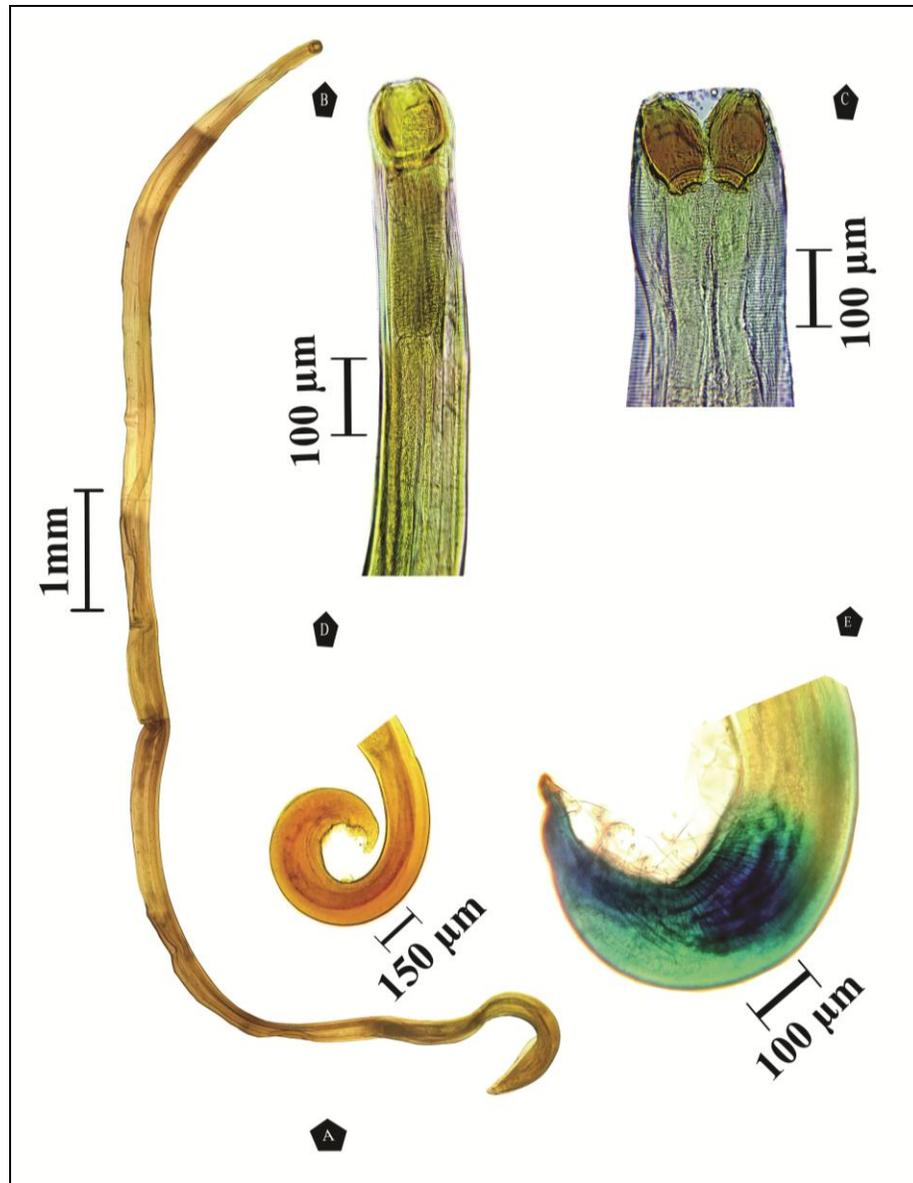
Live specimens are characterized by reddish color and medium size. Cuticle is provided with transverse striations extending from the posterior region of the buccal capsule to the posterior extremity of the body. The greatest width is at the midbody level. The mouth opening is circular, dorso-ventrally elongated and surrounded by a thin translucent membrane with six flat crescent-shaped elevations and four sub-median cephalic papillae. Lateral amphids present with origins external to origins of papillae. Lips are lacking, and small anterior deirids are situated some distance anterior to the level of the nerve ring. The buccal capsule is yellow-orange, sclerotized, without spiral bands, thick-walled, and barrel-shaped. The anterior portion bears six sclerotized lobes, with a well-developed basal ring and conspicuous ledge anterior to the basal ring. Esophagus is composed of two parts, a short anterior muscular club-shaped and a long posterior glandular portion enlarged posteriorly and ending with paired bilobed valves. Nerve ring is within the level of the second quarter of the muscular esophagus. The intestine is narrow. Excretory pore is located anterior to the nerve ring. Tails of both sexes are conical.

**Male:** Body length is 9.354–25.5 mm; body width is 235–563  $\mu\text{m}$  (Fig. 5). The buccal capsule measures 102–191  $\mu\text{m}$  in length, and 90–160  $\mu\text{m}$  in width. Esophagus measures 1,111–1,757  $\mu\text{m}$  in length, and is 6.9–11.8 % of body length; length of the muscular portion is 448–751  $\mu\text{m}$ , and its width is 81–160  $\mu\text{m}$ ; the glandular portion is 663–1,006  $\mu\text{m}$  in length by 75–163  $\mu\text{m}$  in width. The nerve ring: 85–315  $\mu\text{m}$  from the cephalic end, and 62–126  $\mu\text{m}$  in breadth. Excretory pore is located 275–407  $\mu\text{m}$  from anterior end, 44–114  $\mu\text{m}$  anterior to the nerve ring. Testes are straight with anterior tip blunt near the region of the upper intestine. Spicules gradually taper posteriorly, unequal; right spicule is 258–583  $\mu\text{m}$  length; left spicule is 158–261  $\mu\text{m}$ ; spicule-ratio is 1:1.6–1:2.2. The gubernaculum is 43–88 at greatest length, v-shaped with a weakly sclerotized plate joining on the right side with a shorter left side. Caudal alae length is 183–650  $\mu\text{m}$ , with anterior portions not contiguous, and supported by eight pairs of ventro-lateral, elongate, stalked and symmetrical papillae. Four pairs are pre-cloacal, decreasing in size posteriorly; four pairs are post-cloacal; the fourth pair is short, not supporting alae, on the lateral edge of the tail dorsal to the third pair. Phasmids are slightly smaller than and immediately posterior to the last pair of post-cloacal papillae. Prominent transverse muscular bands are present ventrally in the anal region, extending anteriorly from cloaca to large spicule. The tail is conical, measuring 129–372  $\mu\text{m}$  length (table 2); the posterior end of the body displays up to two coils.

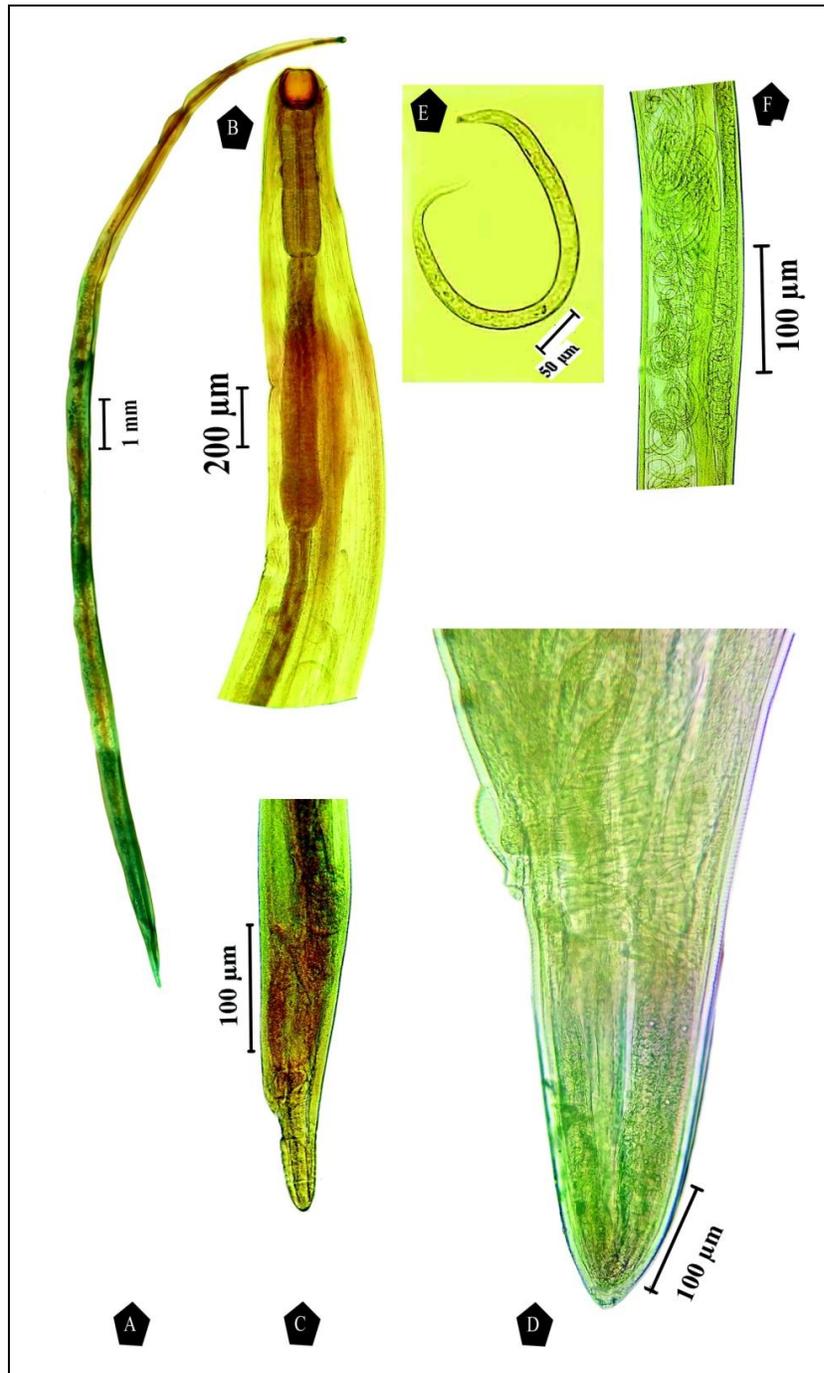
**Female:** Body is 11.48–36.71 mm x 308–886  $\mu\text{m}$  (fig. 6). The buccal capsule is 82–230  $\mu\text{m}$  in length and 75–217  $\mu\text{m}$  width. Esophagus is 931–2,839  $\mu\text{m}$  in length, and 3.9–7.6% of body length; the muscular portion is 370–1,031  $\mu\text{m}$  in length and 75–256  $\mu\text{m}$  in width; the glandular portion is 561–1,808  $\mu\text{m}$  in length and 73–392  $\mu\text{m}$  in width. The nerve ring measures 135–594  $\mu\text{m}$  from the cephalic end, 67–245  $\mu\text{m}$  in breadth. Excretory pore is located 339–452  $\mu\text{m}$  from the anterior end, 37–407  $\mu\text{m}$  anterior to the nerve ring and 159–424  $\mu\text{m}$  posterior to the buccal capsule. The vulva is pre-equatorial. The vagina is muscular, straight, extending posteriorly from the vulva. The uterus is J-shaped, and saccular, filled with larvae with a posterior oviduct at base of the J. Oviducts are usually

straight, directed posteriorly; anterior oviduct is longer than posterior. Ovaries straight, directed posteriorly, the posterior ovary is short, the anterior cylindrical. Larvae measure 296–310  $\mu\text{m}$  in length and 11–13  $\mu\text{m}$  in width. Rectum measures 166–501  $\mu\text{m}$ , surrounded with four rectal glands arranged into two columns of two along the length of the rectum. The tail is conical, with a blunt tip and measures 208–594  $\mu\text{m}$  length (table 2).

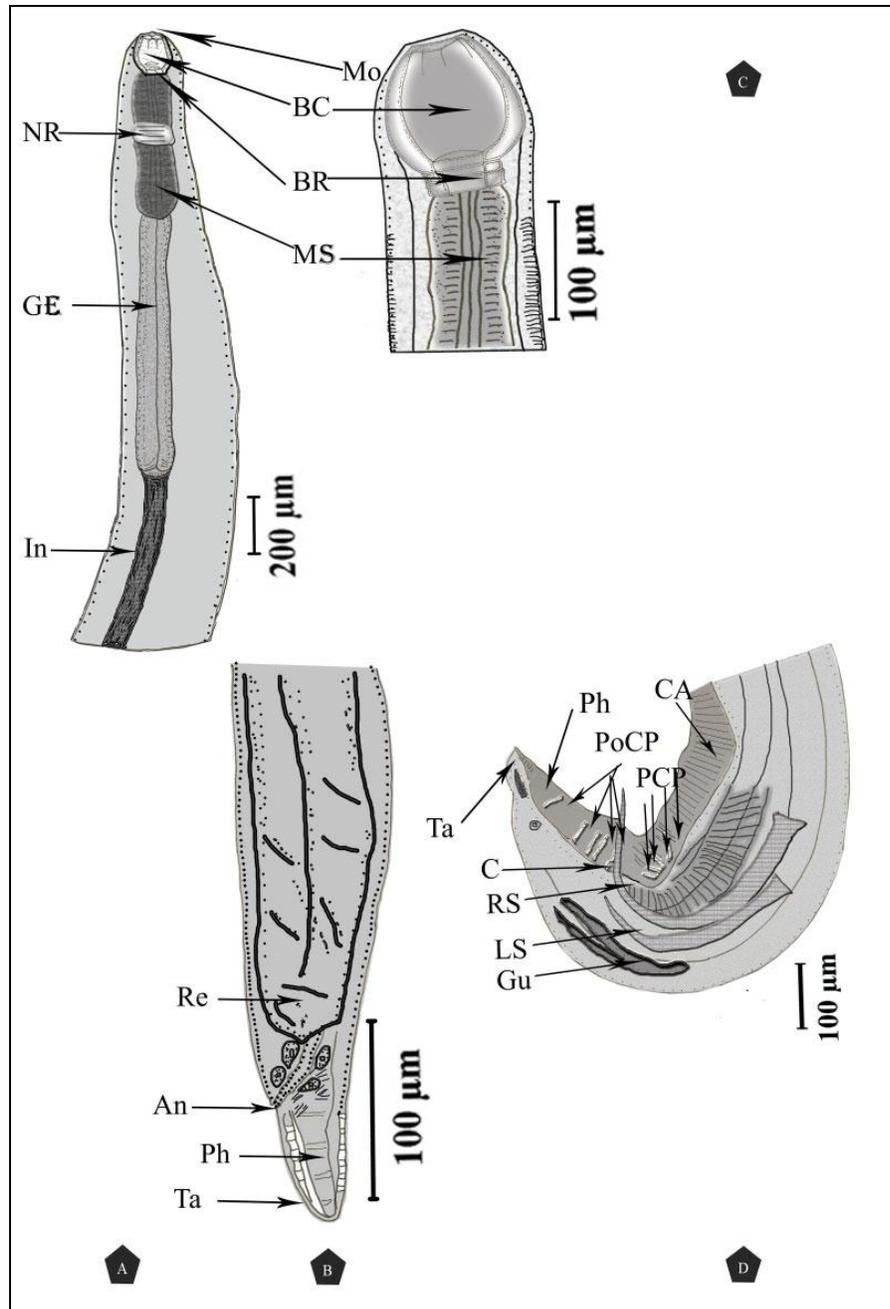
**Ultrastructure:** (Fig.8). The cephalic head (anterior extremity) is bulb-like in both genders, mouth opening is large, circular, and provided with a cephalic collar with a hexagonal peripheral margin and supported with six flat, crescent-shaped cephalic plates. Two lateral cervical papillae are located on both lateral sides of the first third of the body. Four large cephalic papillae are situated in the external circle inside the cephalic plate. Very minute pores are present on the cephalic plate. Cuticle displays transverse striations extending from the posterior region of the cephalic head to the posterior extremity. Several longitudinal wavy thickenings from the cuticle extend from the beginning of transverse striations anteriorly and ramify to several smaller branches near the base of the cephalic plates. The male posterior extremity is curved ventrally and provided with two lateral thickened alae which are more distinct in the lateral view and connected anteriorly; the right alae is curved and pointed. The pre- and post-cloacal ventral papillae are found on the thickened lateral edges of the alae; eight pairs with symmetrical spherical ends are differentiated into two groups. The pre-cloacal group is represented by four pairs, distributed in one and three with the last three equally spaced; the post-cloacal group includes the other four pairs. SEM distinguishes four pairs of small papillae; varying in size, located on the lateral surfaces of the male tip near its posterior extremity. A pair of lateral phasmids slightly smaller than and immediately posterior to the last pair of post-cloacal papillae. The tail is conical, with a rounded tip. The female posterior extremity is straight with a conical tail ending with a blunt tip and two slightly outlined protuberances. The anal opening is represented by a narrow transverse slit-like opening (Fig. 8). A slit-like vulval opening is found on the top of a small elevation, situated on the mid-ventral surface, approximately at the middle of the body. The uterus is filled with larvated eggs and free larvae.



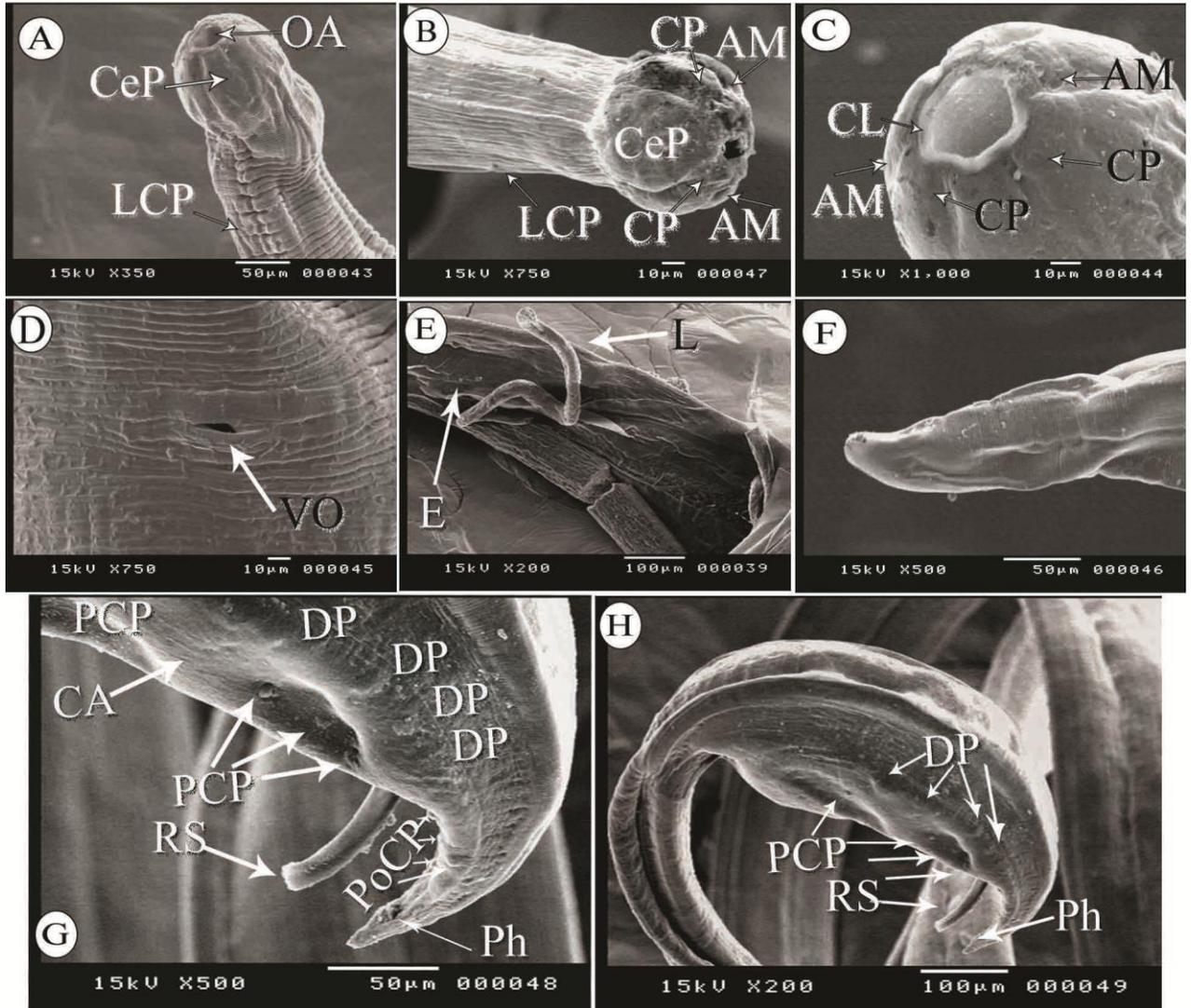
**Fig. 5** Light microscopic image of adult male of *Procamlanus (procamlanus) elatensis* from the intestine of *Siganus rivulatus*, *Parupeneus forsskali* and *Mulloidichthys flavolineatus*. **A** Whole nematode. **B** Ventral view of the anterior extremity. **C** Ventral view of enlarged cephalic end, **D** Lateral view of the posterior extremity. **E** Enlarged ventrolateral view of posterior extremity.



**Fig. 6** Light microscopic images of female of nematode parasite *Procamallanus (procamallanus) elatensis* from *Parupeneus forsskali* and *Mulloidichthys flavolineatus*; **A** Whole nematode. **B** Ventrolateral view of the anterior extremity. **C** Lateral view of the posterior extremity. **D** Enlarged lateral view of posterior extremity. **E** First-stage larva from uterus. **F** Ventral view of uterus filled with larvae.



**Fig. 7** Line drawings of *Procammallanus (Procammallanus) elatensis* from *Siganus rivulatus*, *Parupeneus forsskali* and *Mulloidichthys flavolineatus*; **A** Ventral view of female anterior extremity; note the large circular mouth Mo, buccal capsule BC, well-developed basal ring BR, nerve ring NR, short muscular esophagus MS, long glandular esophagus GE, intestine In. **B** Lateral view of female posterior extremity; note rectum Re, anus An, phasmids Ph, conical tail Ta. **C** Enlarged ventral view of male buccal capsule. **D** Enlarged lateral view of male posterior extremity; notice caudal alae CA, cloaca C, long right spicule RS, left spicule LS, pre-cloacal papillae PCP, post-cloacal papillae PoCP, Gubernaculum GU.



**Fig. 8** SEM micrographs of *Procamallanus (Procamallanus) elatensis* from *Parupeneus forsskali* and *Mulloidichthys flavolineatus*; **A&B** Anterior extremity of the male, lateral view notice Cephalic Plate CeP, Oral Aperture OA, Lateral Servical Papillae LCP, lateral Amphid Am, four sub-median Cephalic Papillae CP. **C** High magnification of the female buccal capsule, apical view depicting Cephalic Collar CL. **D** Ventral view of the middle part of the female note Vulval Opening VO. **E** Section of the uterus of gravid female contains larvae L and eggs E. **F** Ventral view of the posterior extremity of the female revealing transverse anus. **G** Lateral view of the posterior extremity of the male note caudal alae CA, pre-cloacal papillae PCP, post-cloacal papillae PoCP, right spicule RS, phasmids Ph, Dorsal Papillae DP. **H** Apical view of the posterior extremity of male.

**Table 2.** Comparison of the collected *Procamallanus (Procamallanus) elatensis* specimens with the previously described forms

Reference		Fusco and Overstreet (1979)	Abdou et al. (2001a)	Khalifa et al. (2019)	Present study
Fish host (s)		<i>Siganus rivulatus</i> and <i>Siganus luridus</i>	<i>Siganus rivulatus</i> and <i>Siganus luridus</i>	<i>Siganus rivulatus</i> , <i>Siganus luridus</i> and <i>Siganus sutor</i>	<i>Parupeneus forsskali</i> and <i>Mulloidichthys flavolineatus</i>
Locality		Northern Gulf of Aqaba	Hurghada, Egypt	Sharm EL-Naga, Egypt	Hurghada and Safaga, Egypt in the Red Sea
Parasite number		29; 11 ♂ and 18 ♀	10; 5 ♂ and 5 ♀	14; 5 ♂ and 9 ♀	5; 4 ♂ and 9, 3 ♀
Site of infection		Intestine, Abdominal cavity	Intestine	Intestine	Intestine
<b>Parameters</b>					
Body length (mm)	Male	12.6–15.8	8–10	13.91–14.37	9.35–25
	Female	20.4–27.7	20.0–25.0	27.49–31.26	11.48–36.71
Maximum body width (µm)	Male	216–309	200–250	189–239	235–563
	Female	358–445	460–580	376–427	308–886
Buccal capsule length (µm)	Male	111–137	100–120	101–106	102–191
	Female	136–173	130–150	115–133	82–230
Buccal capsule width (µm)	Male	87–111	90–100	70–82	90–160
	Female	113–136	110–140	91–101	75–217
Muscular esophagus length (µm)	Male	337–525	370–450	356–396	448–751
	Female	488–593	460–540	378–411	370–1,031
Muscular esophagus width (µm)	Male	93–117	60–90	73–77	81–160
	Female	74–130	100–120	105–114	75–256
Glandular esophagus length (µm)	Male	662–946	506–780	555–600	663–1,006
	Female	772–1, 214	730–910	599–804	561–1,808
Glandular esophagus width (µm)	Male	96–155	60–90	77–94	75–163
	Female	680–1,360	Not mentioned	1,190–1,320	730–3,920
Nerve ring from anterior cephalic end (µm)	Male	253–321	120	188–195	85–315
	Female	309–396	140–160	227–291	135–594
Nerve ring breadth (µm)	Male	36–48	90	61–77	62–126
	Female	240–340	120–140	112–132	67–245
Total esophagus length (µm)	Male	1,086–1,255	950–1,190	911–996	1,111–1,757
	Female	1,292–1,807	1,040–1,300	990–1,215	931–2,839
Total esophagus length L%*	Male	8–9%	Not mentioned	6.5–6.9 (6.7) %	6.9–11.8 (8.3)%
	Female	6–8%	Not mentioned	3.2–4.4 %	3.9–7.6 %
Large (Right) spicule length(µm)	Male	420–486	290–570	204–336	258–583
Small (left) spicule length (µm)	Male	138–195	200–220	69–189	158–261
Small spicules:large spicule Length (µm)	Male	1:2.4–1:3.3	Not mentioned	1:1.78–1:2.96	1:1.6–1:2.2
Caudal alae length(µm)	Male	Not mentioned	290–400	395–412	183–650
Gubernaculum length (µm)	Male	41–63	Not mentioned	31–86	43–88
Tail length (µm)	Male	143–205	500–550	112–115	129–372
	Female	297–389	220–350	248–282	208–594
Rectum length (µm)	Female	204–315	Not mentioned	188–211	166–501
*= of body length					

## DISCUSSION

The incidence of infection of *Caranx sexfasciatus* Quoy and Gaimard, 1825, with *Procamallanus* (*Procamallanus*) *annulatus* Yamaguti, 1955) in the present study indicates that this parasite is a very common inhabitant of this host in Red Sea at Hurghada. But the rate of infection of *Parupeneus forsskali* Fourmanoir Guézé and *Mulloidichthys flavolineatus* Lacepède, 1801 (Mullidae) with *Procamallanus* (*Procamallanus*) *elatensis* Fusco and Overstreet, 1979 is very low comparing with siganid fishes that was recorded by **Khalifa et al. (2019)**. The present nematodes were identified as belonging to the family Camallanidae Railliet and Henry, 1915 based the following criteria: Worms were usually red, displayed a characteristic buccal capsule and esophagus divided into muscular and glandular portions (**Stromberg and Crites, 1974**). **Yeh (1960)** divided the family Camallanidae into two subfamilies, Camallaninae Railliet & Henry, 1915, for species with the buccal capsule divided into two halves, and Procamlaninae Yeh, 1960, for those with a single, cup-like buccal capsule, mouth opening was slit-like, and the buccal capsule well developed and orange-brown, spicules were unequal. Parasites were recovered from alimentary tracts of fishes (**Arai and Smith, 2016**). Also, the mouth was without lips, the male posterior extremity is curved ventrally, caudal alae are present, papillae are mostly pedunculated and spicules unequal, female vulva lies near the middle of the body, parasites were recovered from the stomach and intestine of fishes (**Yamaguti, 1963**). Specimens were identified as belonging to the genus *Procamallanus* Baylis, 1923 based on the following criteria: The buccal capsule was continuous with a smooth wall, and not separated into paired lateral valves (**Yamaguti, 1963**). Also, tridents in the buccal capsule were absent and the esophagus was divided into an anterior muscular and a longer posterior glandular section, male caudal alae were present, and the female posterior extremity was conical and ending in three very short blunt processes; the vulva was in front of the middle of the body and females were viviparous (**Yorke et al., 1926**). The two present species differ from *Procamallanus spiculastratus* sp. n. of the genus *Procamallanus* Baylis, 1923 (Camallanidae, Procamlaninae) from the freshwater fish *Astronotus ocellatus* in Brazil (**Raul et al., 2018**) and *P. annipetterae* Petter, 1990 in that the latter species display tooth-like structures on the basal ring of the buccal capsule and the sclerotized gubernaculum are absent. The present species are similar to *P. annulatus* Yamaguti, 1955 (Indonesia), *P. elatensis* Fusco & Overstreet, 1979 (Israel), *P. laeviconchus* Wedl, 1861 (Egypt), *P. planoratus* Kulkarni, 1935 (India) and *P. pseudolaeviconchus* Moravec & Van As, 2015 (Botswana) by the presence of a sclerotized gubernaculum, and absence of teeth. The two species (*Procamallanus spiculastratus* and *P. annipetterae*) may represent a distinct genus. A formal phylogenetic analysis is required to confirm this possibility.

The smooth and continuous buccal capsules without differentiation into paired lateral valves indicate that the present specimens belong to the genus *Procamallanus* Baylis, 1923 (**Sahay and Narayan, 1967**) and the absence of internal spiral thickenings from the buccal capsule places the specimens in the subgenus *Procamallanus* Baylis, (**Sahay, 1966; Moravec and Thatcher, 1997**). The first species specimens are similar in overall features and most body dimensions in both genders with the original description given by **Yamaguti (1955)** indicating that specimens belong to *Procamallanus*

(*Procamallanus*) *annulatus* Yamaguti, 1955. However, they are differentiated from the original description in some features, such as the presence of deirids, six crescent-shaped elevations surrounding the mouth, three poorly developed protuberances on the female tail tip and phasmids on the male tail. These features were observed by SEM, that can image some of features which are difficult to see by light microscopy in that of **Yamaguti (1955)**. The specimens for the first species differed in some measurements compared with the previous description of **Yamaguti (1955)** and that of **Moravec and Justine (2011)**. All mentioned differences may be due to the parasite infecting a different fish host and living under different ecological conditions. Moreover, the redescription of **Moravec and Justine (2011)** was from eight specimens of different ages; five gravid females; two subgravid females and one juvenile male, which may lead to some alternations in measurements compared with the present worms. Still, the present SEM result for the first species was more or less similar to that presented by **Moravec and Justine (2011)** in the presence of derides, six crescent-shaped elevations surrounding the circular mouth, the presence of three protuberances on the female tail tip, a pair of phasmids on the male tail and two pairs of ventral papillae surrounding the cloacal opening. **Yamaguti (1955)** originally described *Procamallanus (Procamallanus) annulatus* from *Siganus* sp. fish host from Celebes; **Moravec and Justine (2011)** re-described the parasite from Golden-lined spinefoot, *Siganus lineatus* (Siganidae, Perciforms) from New Caledonia, while the present specimens were recorded from another fish host; *Caranx sexfasciatus* (Perciformes: Carangidae) from Hurghada, Egypt in the Red Sea. This species is a new host at a new locality for species records. Moreover, the present redescription added many light and SEM ultrastructural details in the morphometry of the parasite documented by many photos and camera lucida diagrams.

The second species specimens were similar to the original description given by **Fusco and Overstreet (1979)** and **Abdou *et al.* (2001a)** in overall appearance and almost body dimensions in both genders and all allometric measurements of both male and female, indicating that the present specimens belong to *Procamallanus (Procamallanus) elatensis* Fusco and Overstreet, 1979.

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