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Uropterygius cyamommatus, a new moray eel (Anguilliformes: Muraenidae) from anchialine caves in Christmas Island, Australia, and Panglao Island, the Philippines

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Abstract. *Uropterygius cyamommatus*, new species, is described based on nine specimens from limestone anchialine caves in Christmas Island and Panglao Island. This species is a small-sized, elongated moray eel belonging to the uniform brown-coloured species group of the genus. It differs from all congeners of *Uropterygius* in having very small eyes (3.0–4.6% of head length), a relatively long tail (56.3–61.1% of total length), and a comparatively large number of vertebrae (total vertebrae 141–149). The new species represents the first-recorded moray eel that inhabits anchialine caves.

Key words. eastern Indian Ocean, Elopomorpha, Uropterygiinae, western Pacific Ocean

INTRODUCTION

Nelson (1966) divided the family Muraenidae into two subfamilies, Muraeninae and Uropterygiinae, according to the absence and presence of hypobranchial in the former and the latter, respectively. More morphological characteristics were subsequently defined for recognising Uropterygiinae, in which the very short dorsal and anal fins that are restricted to the posterior portion of the caudal region are the most used diagnostic characters (Böhlke et al., 1989). Most moray eels in the subfamily Uropterygiinae are small-sized species (< 80 cm) that reclusively inhabit shallow waters (< 60 metres), and they usually possess either a reticulate (comprised of pale snowflake-like blotches) or uniform brown colouration pattern, leading to much difficulty in identification and a highly underestimated diversity (Smith et al., 2019). Compared to 188 valid species (22 were newly described in the last decade) in the subfamily Muraeninae, there are only 36 species within the Uropterygiinae, and it has been more than ten years since the most recent species was described (Reece et al., 2010; Fricke et al., 2022).

Uropterygius Rüppell, 1838 is the largest genus of the Uropterygiinae which contains 21 valid species (Smith, 2012). Among them, five species exhibit very similar external morphology with uniform brown colouration, including *U. concolor* Rüppell, 1838, *U. genie* Randall & Golani, 1995, *U. golanii* McCosker & Smith, 1997, *U. inornatus* Gosline, 1958, and *U. xenodontus* McCosker & Smith, 1997, in which *U. concolor* has been speculated as a widespread species complex in a recent study (Smith et al., 2019).

In this study, a uniform brown-coloured moray of the genus *Uropterygius* was collected from two limestone anchialine caves in Christmas Island, Australia, and one cave in Panglao Island, Bohol, the Philippines (Fig. 1). Eels were captured using baited traps set in the upper freshwater layers at a depth of less than two metres through terrestrial openings of the subterranean cave systems (Fig. 2). The specimens from Christmas Island have been reported by Tan et al. (2014), but listed as *Echidna unicolor* Schultz, 1953. It has very small eyes, a relatively long tail, and a comparatively large number of vertebrae, which make it distinct from all known species in *Uropterygius*. Herein we describe this as a new species, which represents the first-recorded moray eel that inhabits anchialine caves.

MATERIAL AND METHODS

Fresh specimens were photographed, then fixed in 10% formalin and gradually transferred to 70% ethanol solution for long term storage. Morphometric definitions followed Böhlke et al. (1989), presented as percentages of total length (TL) or head length (HL). Meristic counts include vertebrae, teeth, and cephalic sensory pores. Vertebrae were counted from radiographs and the formula was presented as pre-anus, pre-dorsal fin, pre-anal fin, and total vertebrae, which was modified from Böhlke (1982). Dentition and head pores were examined under a stereomicroscope, their

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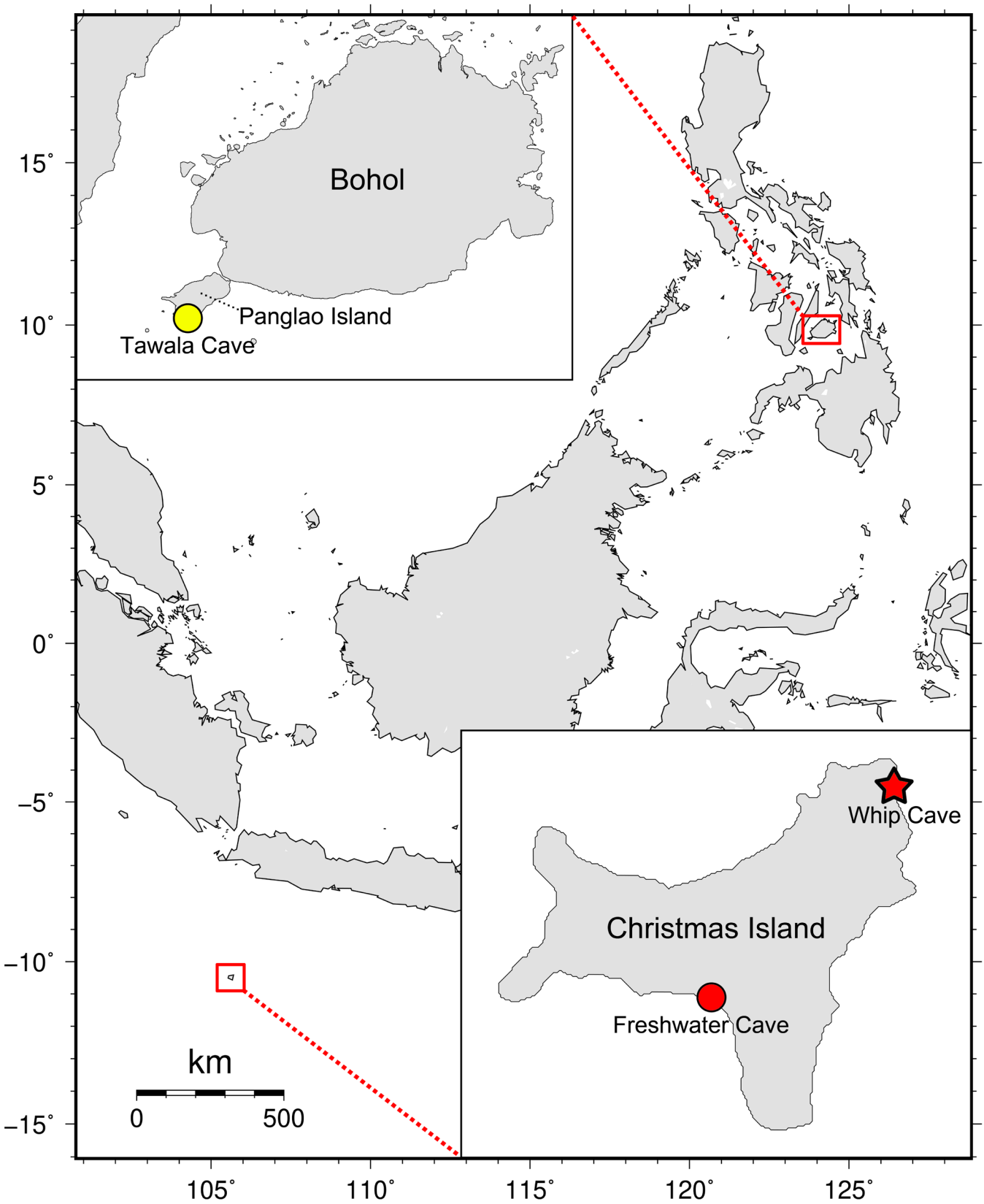

Fig. 1. Sampling map of *Uropterygius cyamommatus*, new species. Star for the holotype; circles for paratypes and non-type specimens; red symbols for specimens from Christmas Island; yellow symbol for specimens from Panglao Island.

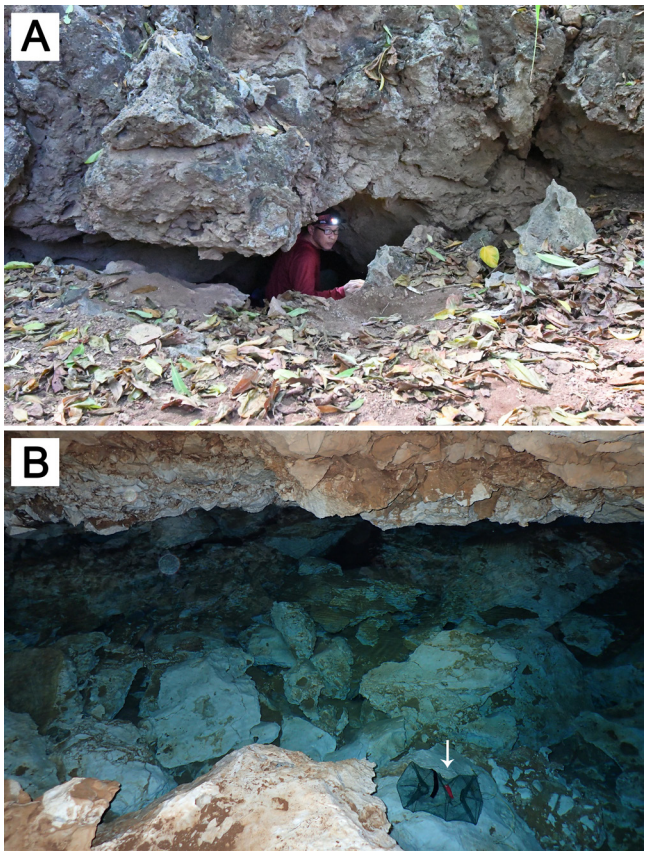

Fig. 2. Whip Cave. A, terrestrial entrance; B, internal view of the cave, arrow indicates the set-up fish trap. Photographs by HHT.

terminologies follow Smith et al. (2019). Specimens were deposited in the Western Australian Museum, Perth (WAM); Zoological Reference Collection, Lee Kong Chian Natural History Museum, National University of Singapore (ZRC); and National Museum of Marine Biology and Aquarium, Pingtung (NMMB-P).

TAXONOMY

Family Muraenidae

Subfamily Uropterygiinae

***Uropterygius cyamommatus*, new species**
Common name: Bean-eyed snake moray
(Figs. 3–7, Table 1)

Holotype. WAM P.35403.001 (361 mm TL, male); Christmas Island, Australia: Whip Cave (10°25.377′S 105°42.081′E), a cave system with a narrow cave mouth and lower chambers filled with anchialine water affected by tidal changes; baited fish trap, 01 February 2010, coll. H.H. Tan et al.

Paratypes. Four specimens (333–401 mm TL). NMMB-P37200 (380 mm, male), WAM P.35404.001 (390 mm, female), ZRC 56488-1 (401 mm, female), ZRC 56488-2 (333+ mm*, male; * for tail tip damaged but hypural plate intact); Christmas Island, Australia: Freshwater Cave (10°30.796′S 105°37.448′E), a cave with a large but steep entrance and links to several deep anchialine chambers; baited fish trap, 25 March 2011, coll. H.H. Tan et al.

Non-type material. Four specimens (291–352 mm TL). NMMB-P37201 (301 mm, female), ZRC 46849-1 (352 mm, female), ZRC 46849-2 (291 mm, female); Panglao Island, Bohol, Philippines: Tawala Cave; baited fish trap, 29 November 2001, coll. P.K.L. Ng et al. --- ZRC 63039 (333+ mm*, female); Panglao Island, Bohol, Philippines: Tawala Cave; baited fish trap, 28 July 2003, coll. H.H. Tan et al.

Diagnosis. A small-sized slender moray eel of genus *Uropterygius*. Tail long, 56.3–61.1% of TL. Eyes very small, 3.0–4.6% of HL, sometimes reduced and subcutaneous. One branchial pore. Maxillary teeth biserial. Dentary teeth 2–3 rows anteriorly, biserial posteriorly. Body uniform brown. Anterior nostril, gill opening, oral cavity, and head pores whitish. Pre-anus vertebrae 56–62, pre-dorsal fin vertebrae 130–138, pre-anal fin vertebrae 131–139, total vertebrae 141–149.

Description. Data is presented for holotype first, paratypes and non-type specimens in parentheses. Proportions in percentage of TL: tail length 59.0 (56.3–61.1), trunk length 31.0 (29.7–33.8), head length 10.0 (8.9–9.9), depth at gill opening 3.5 (3.2–5.2), depth at anus 3.2 (2.6–4.6). Proportions in percentage of HL: length of upper jaw 28.7 (26.8–33.1), length of lower jaw 28.3 (25.5–32.6), interorbital width 11.1 (12.1–14.4), snout length 13.1 (14.0–17.0), eye diameter 3.9 (3.0–4.6). Vertebral counts: Pre-anus vertebrae 58 (56–62), pre-dorsal fin vertebrae 137 (130–138), pre-anal fin vertebrae 138 (131–139), total vertebrae 146 (141–149).

A small-sized slender moray eel, anus well anterior to mid-point of body, tail long, body laterally compressed with depth nearly consistent throughout whole fish, tail tip blunt, caudal fin short (Fig. 3). Dorsal and anal fins inconspicuous, restricted to the posterior end of tail. Gill opening small, oval, below lateral midline of body, about same size with eye. Eyes very small, above mid-jaw (Fig. 4), two paratypes (NMMB-P37200 and WAM P.35404.001) with a reduced left eye embedded in skin (Fig. 5A). Snout blunt, nasal cavity somewhat enlarged. Jaws short, subequal in length, teeth not visible when mouth closed. Anterior nostril a stubby tube, shorter than eye diameter, its base in a depression close to tip of snout. Posterior nostril an oval hole located above anterior margin of eye, without a conspicuous raised rim.

Three supraorbital pores, first on tip of snout immediately above lip; second just next to upper base of anterior nostril, at the level of horizontal middle line of eye; third on upper margin of snout at the same level of posterior nostril, above and posterior to the first infraorbital pore. Four infraorbital pores arranging equidistantly, first just below base of anterior nostril; second on the midpoint between anterior nostril base and anterior margin of eye; third below middle point of eye; fourth below and posterior to eye. Second supraorbital and first infraorbital pores in depression of anterior nostril base. Typically six preoperculo-mandibular pores but with a variation from four to seven pores, all along lower jaw,

Fig. 3. *Uropterygius cyamommatus*, new species, holotype, WAM P.35403.001, 361 mm TL. A, fresh colouration (photographed by HHT); B, preserved colouration (photographed by WCH). Arrows indicate the position of anus.

Table 1. Morphometric measurements and meristic counts of *Uropterygius cyamommatus*, new species. The means of morphometric values and vertebral number are given in parentheses.

	Christmas Island		Panglao Island	Total
	Holotype	Paratypes (n = 4)	(n = 4)	(n = 9)
TL (mm)	361	333–401	291–352	291–401
% TL				
Tail length	59.0	57.7–61.1 (59.5)[a]	56.3–57.7 (56.9)[b]	56.3–61.1 (58.3)[a, b]
Preanal length	41.0	38.9–42.3 (40.5)[a]	42.3–43.7 (43.1)[b]	38.9–43.7 (41.7)[a, b]
Trunk length	31.0	29.7–33.3 (31.2)[a]	33.3–33.8 (33.6)[b]	29.7–33.8 (32.2)[a, b]
Head length	10.0	9.0–9.7 (9.3)[a]	8.9–9.9 (9.5)[b]	8.9–10.0 (9.5)[a, b]
Body depth at gill opening	3.5	3.2–5.2 (4.1)[a]	3.2–4.2 (3.6)[b]	3.2–5.2 (3.8)[a, b]
Body depth at anus	3.2	2.6–4.6 (3.5)[a]	3.5–3.8 (3.6)[b]	2.6–4.6 (3.5)[a, b]
% HL				
Length of upper jaw	28.7	30.3–33.1 (32.2)	26.8–30.1 (28.4)	26.8–33.1 (30.1)
Length of lower jaw	28.3	29.9–32.6 (31.5)	25.5–29.1 (27.3)	25.5–32.6 (29.3)
Snout length	13.1	15.3–17.0 (16.0)	14.0–15.2 (14.4)	13.1–17.0 (15.0)
Interorbital width	11.1	12.1–14.4 (13.4)	12.1–12.5 (12.2)	11.1–14.4 (12.6)
Eye diameter	3.9	3.0–4.6 (3.9)	4.0–4.3 (4.1)	3.0–4.6 (4.0)
Teeth				
Intermaxillary + Vomerine	38	39–44	30–45	30–45
Maxillary outer	20–22	22–26	20–24	20–26
Maxillary inner	11–12	9–13	8–13	8–13
Dentary outer	29–30	29–32	22–29	22–32
Dentary middle	2–5	0–6	0–7	0–7
Dentary inner	12	9–19	10–16	9–19
Cephalic sensory pores				
Supraorbital	3	3	3	3
Infraorbital	4	4	4	4
Preoperculo-mandibular	6	5–7	4–7	4–7
Branchial	1	1	1	1
Vertebrae				
Pre-anus	58	56–59 (57)	59–62 (60)	56–62 (59)
Pre-dorsal fin	137	132–137 (133)	130–138 (134)	130–138 (134)
Pre-anal fin	138	133–139 (135)	131–139 (135)	131–139 (135)
Total	146	144–146 (145)	141–149 (145)	141–149 (145)

[a]Data not including ZRC 56488-2 due to damaged tail.
[b]Data not including ZRC 63039 due to damaged tail.

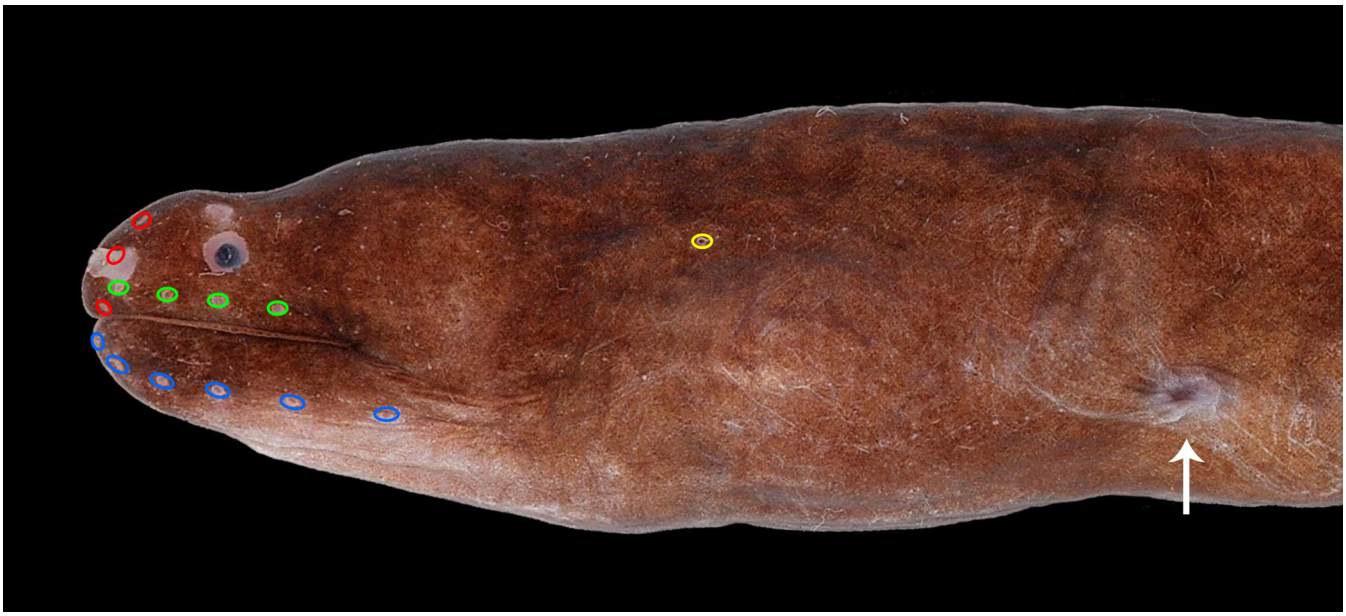

Fig. 4. *Uropterygius cyamommatus*, new species, lateral view of head marked with cephalic sensory pores: red for supraorbital pores; green for infraorbital pores; blue for preoperculo-mandibular pores; yellow for the branchial pore. Arrow indicates the gill opening. Photo of WAM P.35403.001, holotype, 361 mm TL (photographed by HHT).

last (generally sixth) pore posterior to corner of mouth. One branchial pore on posterior-dorsal area of head, closer to corner of mouth rather than gill opening (Fig. 4).

Teeth (Fig. 6) conical, slightly elongated, end pointed and slightly retrorse, edge smooth. Intermaxillary, maxillary, and vomerine teeth continuously; peripheral series small, numerous, and equal-sized; inner series longer, fewer, and spaced. Intermaxillary and vomerine plates with 30–45 teeth, approximately arranged in 7–8 rows on intermaxilla and becoming single row on vomerine, except for one paratype (NMMB-P37200) without teeth on vomerine. Maxilla with 20–26 teeth on outer row; 8–13 teeth on inner row, extending to posterior end of outer row. Dentary teeth arranging in 2–3 rows anteriorly and 2 rows posteriorly; teeth on outer row small and equal-sized, 22–32 in number; inner teeth 9–19, larger and more spaced than those of outer, decreasing in size posteriorly, extending to or slightly before the posterior end of outer row; most examined specimens with a middle row of 2–7 teeth on anterior part of dentary, except for two specimens (NMMB-P37200 and ZRC 46849-2) with only two rows of dentary teeth; one paratype (ZRC 56488-1) with an additional one row of two very small teeth on the anteriormost middle part of lower jaw.

Body uniform brown, slightly lighter ventrally, most pale on venter below lower jaw. Anterior nostril (including its base depression), posterior nostril opening, gill opening, oral cavity, and head pores whitish. Numerous small, inconspicuous whitish neuromasts arranged in irregular lines on anterior head region and in one row along lateral line (Fig. 4). Preserved colouration similar to fresh fish except faded (Fig. 3B).

Distribution. Currently, this species is only known from anchialine caves in Christmas Island and Panglao Island.

Etymology. From Greek words kúamos (a bean) and ómma (the eye), in reference to its tiny bean-shaped eyes.

Comparisons. The new species belongs to the genus *Uropterygius* according to a combination of the following characters: (1) three supraorbital pores (vs. four in *Anarchias* Jordan & Starks, 1906); (2) the anus anterior to the mid-point of body (vs. anus far behind mid-body in *Scuticaria* Jordan & Snyder, 1901); (3) jaws short and subequal in length (vs. gape very long, lower jaw longer than upper jaw in *Channomuraena* Richardson, 1848 and *Cirrimaxilla* Chen & Shao, 1995).

Uropterygius cyamommatus can be easily distinguished from the other five uniform brown-coloured species of the genus, viz. *U. concolor*, *U. genie*, *U. golanii*, *U. inornatus*, and *U. xenodontus*, by the combination of eye diameter, tail length, vertebrae count, and dentition (Table 2). In comparison, it has distinctively small eyes; its tail length is exclusively long except for *U. concolor* (56.3–61.1, vs. 52.4–60.0% of TL); and its total vertebral number is only overlapped with *U. golanii* (141–149, vs. 145–148).

DISCUSSION

Uropterygius cyamommatus, new species, is the first-recorded species of the Muraenidae that inhabits anchialine caves. It has exclusively small eyes among all species of *Uropterygius*, except for *U. oligospondylus* Chen, Randall & Loh, 2008 (eye diameter 3.9–7.1% of TL; Loh et al., 2008; Hibino et al., 2020; Koreeda et al., 2020). The latter inhabits the intertidal zone which comprises of boulders and is frequently hit by strong waves; thus, it is believed to lurk in the interstices of boulders and detect prey relying on its sensitive sense of smell instead of vision (Hibino et al.,

Table 2. Comparison of uniform brown-coloured species in the genus *Uropterygius* with selected characters.

	Eye diameter (% HL)	Tail length (% TL)	Total vertebrae	Maxillary teeth	Dentary teeth	Type locality	Sources
U. cyamommatus, new species	3.0–4.6	56.3–61.1	141–149	biserial	2–3 rows anteriorly, biserial posteriorly	Christmas Island	This study
*U. concolor**	7.7–11.0	52.4–60.0	117–124	biserial	biserial anteriorly and uniserial posteriorly	Red Sea	2, 6
U. genie	10.4–11.4	53.5–54.5	121–122	multiserial in about 4 rows	about 4 rows anteriorly and uniserial posteriorly	Red Sea	5, 6
U. golanii	8.0–9.2	50.7–51.4	145–148	uniserial	biserial anteriorly and uniserial posteriorly	Red Sea	4, 6
U. inornatus	7.7–10.0	52.4–54.5	116–133	uniserial	biserial anteriorly and uniserial posteriorly	Hawaiian Islands	1, 3
U. xenodontus	7.1–10.0	49.8–52.0	152–157	uniserial	uniserial or biserial anteriorly, uniserial posteriorly	Coral Sea	4, 7

*Data including its two synonyms, *Anarchias vermiformis* Smith, 1962 and *Gymnomuraena fusca* Peters, 1866.
1, Böhlke & Randall, 2000; 2, Böhlke & Smith, 2002; 3, Gosline, 1958; 4, McCosker & Smith, 1997; 5, Randall & Golani, 1995; 6, Smith et al., 2019; 7, Tashiro et al., 2018.

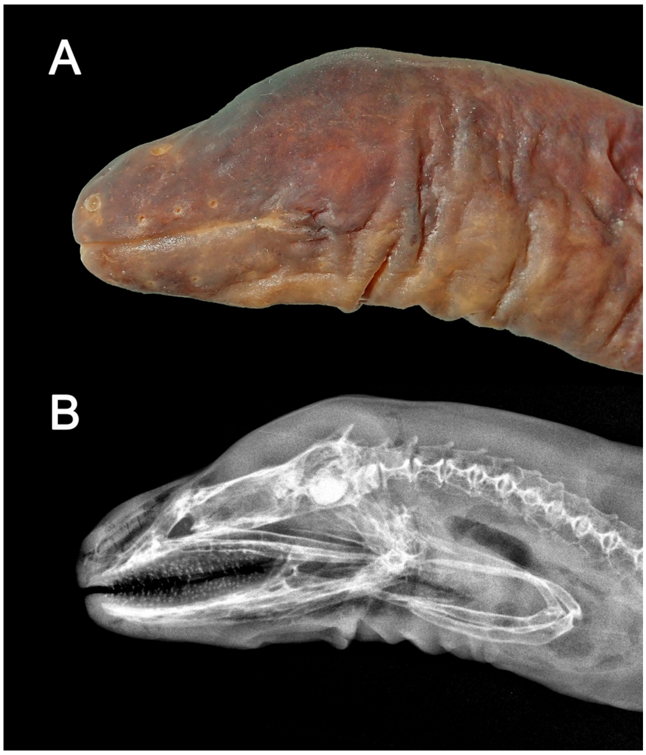

Fig. 5. *Uropterygius cyamommatus*, new species, lateral view of the head region of a specimen without the left eye. A, external view; B, radiograph showing the skeletal structure of orbital region. Photo of NMMB-P37200, paratype, 380 mm TL (photographed by HHT).

2020; Koreeda et al., 2020). Like many other cave-inhabiting aquatic creatures, the reduced eyes of *U. cyamommatus* may represent an adaptation to aphotic or low-light environments (e.g., Humphreys, 2001; Tan et al., 2014). It is interesting to note that no remarkable change is found in the skeletal structure of the orbital region in eyeless specimens (Fig. 5B). In addition, *U. cyamommatus* is one of the few species in this genus that possess vertebrae of more than 140 (Fig. 7) (along with *U. golanii* and *U. xenodontus*) and have a long tail reaching 60% of TL (along with *U. concolor* and *U. kamar* McCosker & Randall, 1977). Reece & Mehta (2013) proposed that burrowing moray eels, such as *Pseudechidna brummeri* (Bleeker, 1858) and *Rhinomuraena quaesita* Garman, 1888, tend to have extremely elongated bodies and more vertebrae, especially in the tail region. Given that this phenomenon has often been observed in other burrowing species, such as *Diaphenchelys pelonates* McCosker & Randall, 2007 and *Strophidon* McClelland, 1844 spp., *U. cyamommatus* may also exhibit a similar behaviour in anchialine caves.

Hydrological measurements for water layers around traps in the Whip and Freshwater Caves revealed very low salinities (0.8 and 0.6 psu, respectively), which can be considered freshwaters (Tan et al., 2014). To date, *Gymnothorax polyuranodon* (Bleeker, 1854) is the only moray eel that has been confirmed to inhabit freshwater habitats (Ebner et al., 2011; Tsukamoto et al., 2014). *Uropterygius cyamommatus* may represent the second recorded moray found in a freshwater environment. However, anchialine caves have several lower canals connected to the sea, and the water is affected by tidal changes, forming mixing zones of fresh

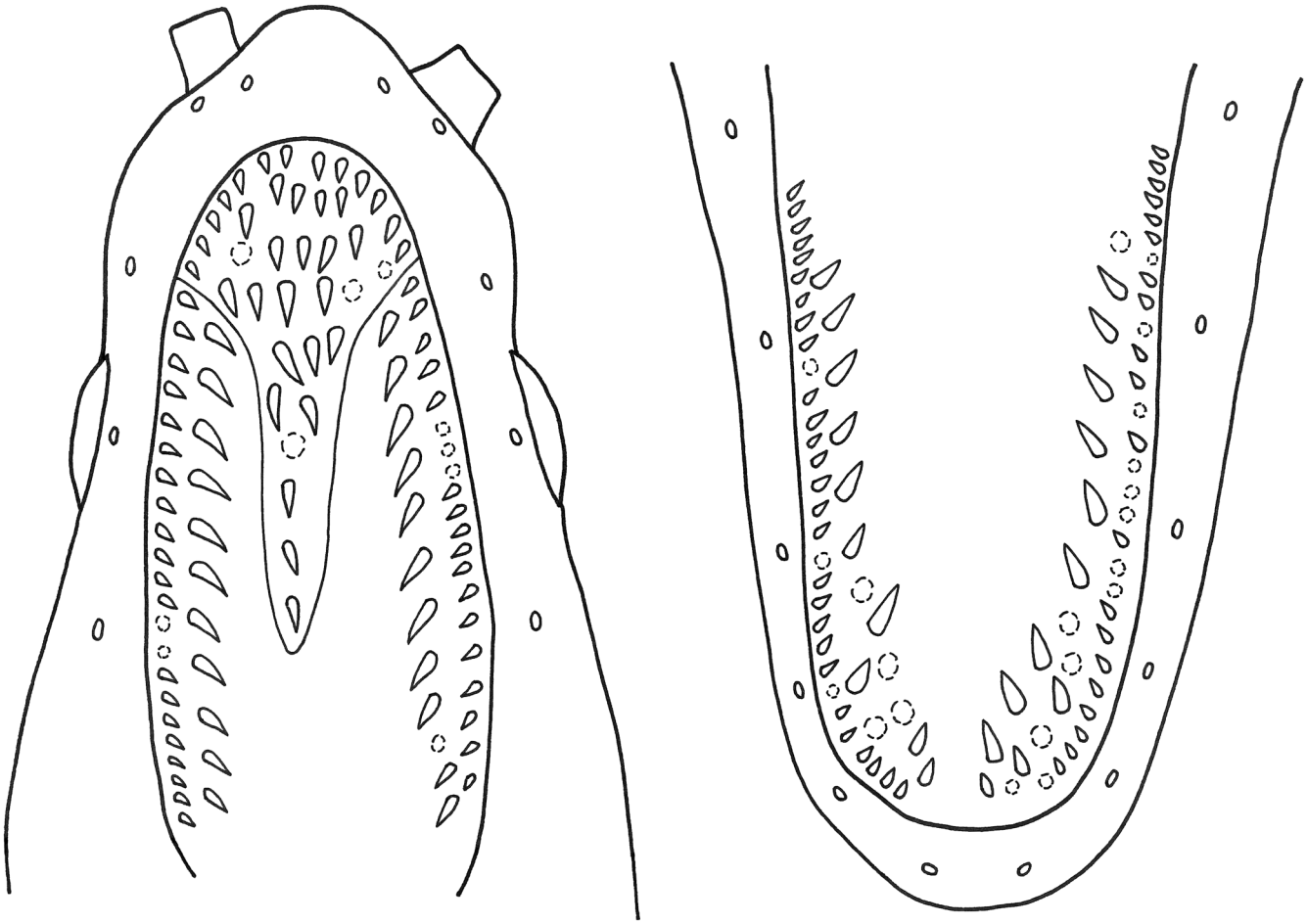

Fig. 6. Dentition of *Uropterygius cyamommatus*, new species, holotype, WAM P.35403.001. Upper jaw (left) and lower jaw (right). Dotted circles represent the sockets of missing teeth. Schematic drawings by WCH.

and seawater and vertical salinity gradients (Grimes, 2001). Although the exact inhabited water layer of *U. cyamommatus* cannot be determined, it is highly possible to inhabit the lower layer with saline water since another marine eel [an unidentified species of the Chlopsidae, listed as *Congresox talabonoides* (Bleeker, 1852b) in Tan et al. (2014)] was co-captured in the trap from the Whip cave. *Uropterygius cyamommatus* may have detected the bait in the trap and swum from the lower saline layer into the upper freshwater layer, which indicates it can at least tolerate low salinity for a certain period or even withstand long-term freshwater immersion. Future studies with otolith microstructure and microchemistry analyses may provide us with a better understanding of its biological characters and life history (Humphreys et al., 2006).

Several morphological characters are found to be divergent between *U. cyamommatus* specimens from Christmas Island (n = 5) and Panglao Island (n = 4) with only slight overlaps (Table 1). Eels from Christmas Island have a longer tail (57.7–61.1, vs. 56.3–57.7% of TL in specimens from Panglao Island), a shorter trunk (29.7–33.3, vs. 33.3–33.8% of TL), more outer dentary teeth (29–32, vs. 22–29), and fewer pre-anus vertebrae (56–59, vs. 59–62). Unfortunately, no tissue subsample is available for further molecular analysis to test their conspecificity. The insular distribution is a common phenomenon for anchialine aquatic creatures, and some studies have revealed strong gene flow and genetic homogeneity among populations which may attribute to the dispersal of pelagic larvae (Kano & Kase, 2004; Russ et al., 2010). It is quite reasonable for moray eels since they have an extended leptocephalus larval stage [up to 98 days in *U. micropterus* (Bleeker, 1852a)] that may ensure the widespread distribution and gene flow (Reece et al., 2011; Huang et al., 2018; Li et al., 2021). In morphology, for elongate and long-tailed muraenid species such as *Strophidon* spp., intraspecific variations of tail length and trunk length can be up to more than 7% and 5% of TL, respectively, and the differentiation in pre-anal fin vertebrae (usually one or two vertebrae after the anus in species of the subfamily Muraeninae) can be up to 11 vertebrae (Huang et al., 2020). The morphological variations of all *U. cyamommatus* specimens are well within these ranges, supporting their conspecificity. Although these variations may simply be attributed to a sampling bias, considering the two sampling sites are far apart (3,000 km cross-equator straight distance), we take a more conservative decision that excludes Panglao Island specimens from the type series. Nevertheless, *U. cyamommatus* could be widely distributed in similar habitats from Australia and the East Indies. More investigations in the future are required to clarify its distribution range and population connectivity.

Fig. 7. Radiograph showing the skeletal structure of *Uropterygius cyamommatus*, new species, ZRC 46849-1, 352 mm TL (photographed by HHT). Arrow indicates the position of anus.

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