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Careproctus io (Teleostei: Liparidae), a New Snailfish from the Western North Pacific, with Comments on Generic Limits

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The new snailfish *Careproctus io* is described on the basis of three specimens collected from the western North Pacific, off northeastern Honshu Island, Japan. The new species can be distinguished from congeners by the following characters: vertebrae 40–42; dorsal-fin rays 36 or 37; anal-fin rays 30; pectoral fin deeply notched with 28 or 29 rays, lower lobe reaching to anal-fin origin; large pelvic disk 34.2%–34.5% HL (10.3%–10.9% SL); teeth strongly trilobed on both jaws, inner teeth weakly trilobed or shouldered; cephalic pore pattern 2-6-7-2, chin pores paired; gill slit above pectoral-fin base; body bright red, non-variegated in life. Species of *Careproctus* Krøyer, 1862 typically have fewer pectoral-fin rays than anal-fin rays, although some recently-described species, including the present new species, have similar ray counts in both fins. The relationships between such counts, as well as pelvic disk size, are investigated for various snailfish, genera, and the generic limits of *Careproctus* discussed.

Key Words: Actinopterygii, Scorpaeniformes, *Careproctus*, COI, pelvic disk size.

Introduction

Snailfishes (Teleostei: Scorpaeniformes: Liparidae) are included in a morphologically diverse family, comprising over 30 genera and 440 species, residing in temperate and cold waters worldwide (Fricke et al. 2023; Gardner et al. 2023). Members of the family are generally characterized by a tadpole-shaped body with soft scaleless skin, and a ventral sucking disk formed by the highly modified pelvic fins (Chernova et al. 2004; Orr et al. 2019; Gerringer et al. 2021). Some genera (i.e., *Elassodiscus* Gilbert and Burke, 1912; *Paraliparis* Collett, 1879; *Rhinoliparis* Gilbert, 1896; *Acantholiparis* Gilbert and Burke, 1912; *Nectoliparis* Gilbert and Burke, 1912; *Lipariscus* Gilbert, 1915), however, either lack or have a highly reduced pelvic disk. They typically inhabit the deep pelagic zone, and have been considered as derived from shallow-water, large disked species of *Liparis* Scopoli, 1777 (Burke 1930). The most species-rich genus is *Careproctus* Krøyer, 1862, represented by ca. 150 species worldwide [ca. 60 species found in the North Pacific (Fricke et al. 2023)]. *Careproctus* is diagnosed by a distinct pelvic disk, single nostril, no pseudobranchs, pectoral-fin rays typically fewer than anal-fin rays, and body color that is generally not variegated (but see Orr and Maslenikov 2007). However, some recently described species have similar numbers of pectoral- and anal-fin rays, in addition to variegated reddish coloration (Gardner et al. 2023). Furthermore, the pelvic disk size in *Careproctus* varies greatly between species, from 2.5% of head length (HL) in *C. parvidiscus* Imamura and Nobetsu, 2002 to 56.2% HL in *C. macrodiscus* Schmidt in Taranetz, 1937 (Kido 1988; Imamura and Nobetsu 2002), raising questions regarding the monophyly of the genus. In fact, the molecular phylogenetic study by Orr et al. (2019) recovered *Careproctus* nested within other genera.

Along the Pacific coast of Tohoku District, northern Honshu Island, Japan, continuous surveys for assessments of ground fish resources by the Demersal Fish Resources Division, Fisheries Stock Assessment Center, Fisheries Resources Institute, Japan Fisheries Research and Education Agency, have resulted in the discovery of several new species (Shinohara et al. 2009) and new distributional records (Misawa et al. 2020). During recent surveys, three specimens of a previously unknown snailfish belonging to the genus *Careproctus* were collected. Their small body size (ca. 40 mm in standard length), similar pectoral- and anal-fin ray numbers, and large pelvic disk most closely resembled *C. bromius* Gardner, Orr, and Tornabene, 2023 and *C. staufferi* Orr, 2016, but the former were clearly distinguishable from both species in having non-variegated body coloration. They are herein described as a new species of *Careproctus*. In addition, the generic limits of *Careproctus* are discussed from the viewpoint of meristics and pelvic disk size.

Materials and Methods

Methods for counts and measurements followed Orr and Busby (2006), with descriptive terminology following Stein et al. (2001). Standard and total lengths are abbreviated as SL and TL, respectively. Osteological characters and counts of median-fin rays and vertebrae were taken from radiographs and a computed tomography scanning system (phoenix nanotom|M, Baker Hughes), with data reconstructed by phoenix datos|x (Baker Hughes) and visualized by VGStudio Max 3.1 (Volume Garaphics GmbH). Cephalic pores were observed by staining with Aniline Blue (Wako Chemicals). One non-type specimen (damaged during capture) was cleared and double stained (C&S) for bone and cartilage examination, including the pectoral girdle, following the protocol of Kawamura and Hosoya (1991). Institutional codes follow Sabaj (2022).

Generic limits of *Careproctus* were considered from pelvic disk size and length, and numbers of dorsal- anal-, and pectoral-fin rays, taken from one or two specimens each of 88 species, representing 13 genera of Liparidae (Supplementary Table 1).

For DNA barcoding, the sequences of partial cytochrome *c* oxidase subunit I (COI) gene were determined for the type specimens. Total DNA was extracted from muscle tissue preserved in 99.5% ethanol, using the Wizard Genomic DNA Purification Kit (Promega). The fragment of COI was amplified with the primers designed by Folmer et al. (1994) (LCO1490: 5′-GGT CAA CAA ATC ATA AAG ATA TTG G-3′; HCO2198: 5′-TAA ACT TCA GGG TGA CCA AAA AAT CA-3′), using the KAPA2G Robust PCR Kit (KAPA Biosystems). The PCR conditions consisted of an initial 5 min at 94°C, followed by 30 cycles of 15 sec at 94°C, 15 sec at 45°C, and 30 sec at 72°C, with a final extension at 72°C for 7 min, with. The PCR products were purified with ExoSAP-It Express (Thermo Fisher Scientific), and sequenced using the forward primer at Eurofins Genomics. The sequences determined here are available from INSDC (International Nucleotide Sequence Database Collaboration) under accession numbers LC789194 and LC789195. Sequence similarity searches were performed using the BLAST function (Zhang et al. 2000) from the National Center for Biotechnology Information (http://blast.ncbi.nlm.nih.gov/Blast.cgi), and the sequences aligned, using MAFFT version 7.511 (Katoh and Standley 2013), with previously determined snailfish sequences (Orr et al. 2019) and a sequence of *C. surugaensis* Murasaki, Takami, and Fukui, 2017 determined here (using the same method as above; INSDC accession number, LC797962). Neighbor-joining (NJ) and maximum likelihood (ML) tree reconstructions were attempted using MEGA 11 (Tamura et al. 2021) and IQ-TREE 1.6.12 (Nguyen et al. 2015), respectively. A pairwise matrix of genetic distances was prepared for NJ using Tamura and Nei's (1993) model, and the best evolutionary model for ML found by ModelFinder (Kalyaanamoorthy et al. 2017) under Bayesian information criterion, TIM2 + F + I + G4 being selected. Branch supports were measured using nonparametric bootstrapping with 1000 replications, based on the same algorithm (Felsenstein 1985) for the NJ tree, and using ultrafast bootstrap with 1000 replications (Hoang et al. 2018) for the ML tree.

Table 1. Measurements of *Careproctus io* sp. nov.

	Holotype	Paratype
	FAKU 148130	FAKU 150259
Standard length (mm)	37.3	42.8
As % of standard length		
Head length	31.7	29.8
Snout length	11.9	8.4
Orbit length	8.9	8.9
Interorbital width	10.3	9.9
Maxilla length	15.9	12.5
Gill slit length	6.1	4.5
Body depth at pelvic disk	24.4	23.2
Pectoral-fin length (upper lobe)	19.0	18.1
Pectoral-fin length (lower lobe)	27.1	24.2
Predorsal length	31.1	31.3
Preanal length	44.3	41.0
Pelvic disk length	10.9	10.3
Pelvic disk width	10.3	8.9
Caudal-fin length	18.6	19.8
As % of caudal fin length		
Dorsal-fin connection to caudal fin	23.1	27.8
Anal-fin connection to caudal fin	25.6	31.3

Careproctus io sp. nov.
[New standard Japanese name: Mini-kon'nyakuuo]
(Figs 1, 2; Table 1)

Holotype. FAKU 148130, 37.3 mm SL (44.2 mm TL), female, off Iwaki, Fukushima, Japan, 36.9359°N, 141.5477°E, 419 m depth, 13 November 2020, otter trawl, R/V *Wakataka-maru*, coll. R. Misawa and E. Morikawa.

Paratypes. Two specimens: FAKU 150259, 42.8 mm SL (51.3 mm TL), male, off Ofunato, Iwate, Japan, 39.0360°N, 142.1736°E, 465 m depth, 19 June 2023, beam trawl, R/V *Kaiyo-maru No. 6*, coll. E. Morikawa; FAKU 150605 (stained and dissected, used only for osteological description), 33.3 mm SL (TL unknown), female, same data as FAKU 150259.

Diagnosis. A species of *Careproctus* with the following combination of characters: vertebrae 40–42; dorsal-fin rays 36 or 37; anal-fin rays 30; pectoral fin with 28 or 29 rays, deeply notched, lower lobe reaching to anal-fin origin; large pelvic disk 34.2%–34.5% HL (10.3%–10.9% SL); teeth strongly trilobed on both jaws, inner teeth weakly trilobed or shouldered; cephalic pore pattern 2-6-7-2, chin pores paired; gill slit above pectoral-fin base; body bright red, non-variegated in life.

Description. Counts and measurements shown in Table 1. Data for holotype given first, followed by paratype data in parentheses, if different.

Body short, robust, subcylindrical anteriorly, slightly compressed posteriorly; dorsal profile humpbacked, gradu-

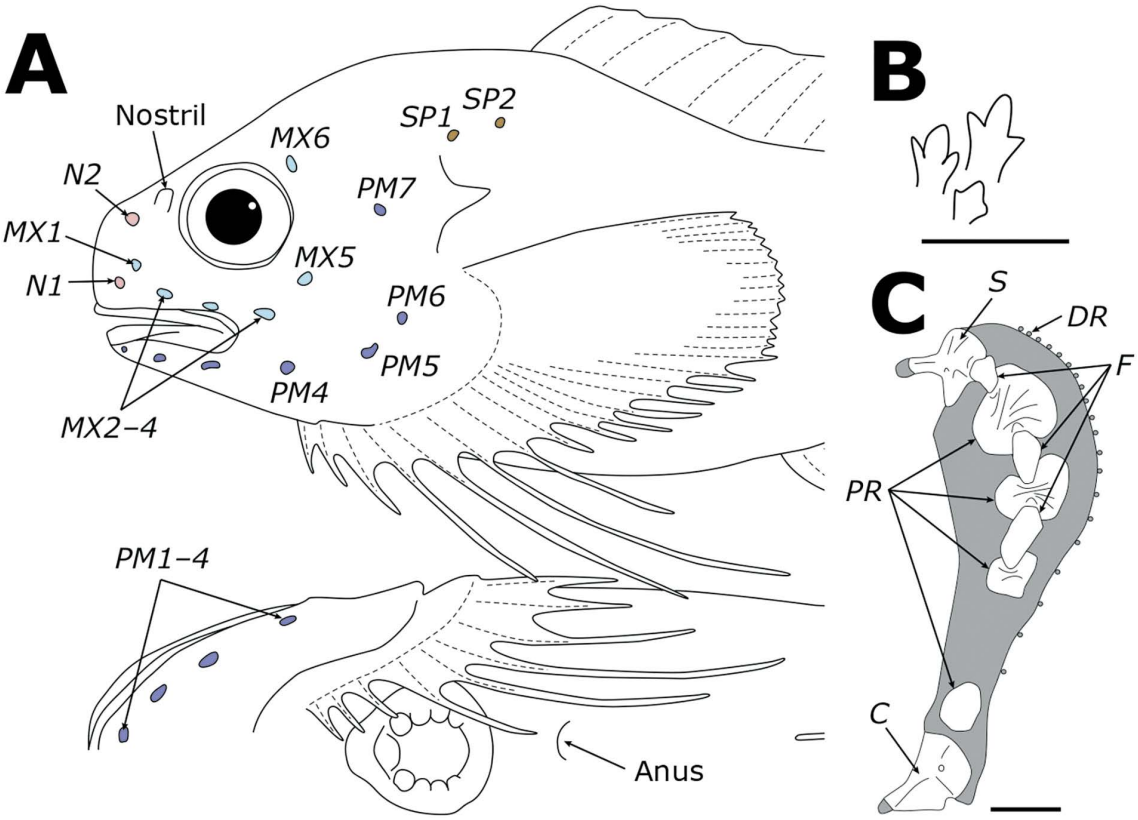

Fig. 1. Schematic drawing of *Careproctus io*, holotype, FAKU 148130, 37.3 mm SL. A, Lateral and ventral views of head; B, teeth; C, pectoral girdle. Abbreviations: *C*, coracoid; *DR*, distal radials; *F*, interradial fenestra; *MX*, maxillary pores; *N*, nasal pores; *PM*, preoperculo-mandibular pores; *PR*, proximal radials; *S*, scapula; *SP*, suprabranchial pores. Scale bars: B, 0.25 mm; C, 1.0 mm.

ally sloping posteriorly, deepest at nape (Fig. 1A). Head robust, rounded. Eye large, upper margin slightly below dorsal contour. Interorbital space almost flat. Skin relatively thin, without subcutaneous gelatinous layer; prickles absent. Head robust, large, dorsal profile strongly sloping from nape to snout. Interorbital region flat, smooth. Snout blunt, protruding slightly beyond tip of upper jaw. Mouth subterminal; maxilla extending to mid orbit; oral cleft extending to anterior margin of orbit. Premaxillary teeth strongly trilobed, in 8 oblique rows forming broad bands; inner teeth becoming larger, weakly trilobed or shouldered (Fig. 1B). Mandibular teeth trilobed in 8 oblique rows; inner teeth becoming larger. Diastema absent at symphysis of upper and lower jaws. Orbit round, moderately large; pupil large, rounded. Nostril single, with short tube at level of mid orbit. Pore size of cephalic lateralis moderate: nasal pores 2, maxillary pores 6, preoperculo-mandibular pores 7, suprabranchial pores 2; cephalic pore pattern 2-6-7-2 (damaged in paratypes) (Fig. 1A). Chin pores paired in separate pits. Coronal pore absent. Gill slit small, upper margin level with dorsal rim of orbit, extending ventrally to just above pectoral-fin base. Opercular flap angular, pointed posterodorsally.

Vertebrae 42 (40), precaudal 10 and caudal 32 (30). Dorsal fin without lobes, rays 36 (37), tip of rays slightly exserted. Anteriormost dorsal-fin pterygiophore inserted between neural spines 3 and 4 (or 2 and 3), bearing single short ray (Fig. 2A). Membrane of posterior dorsal-fin rays continuous with caudal fin. Anal-fin rays 30. Anal-fin origin below vertebrae

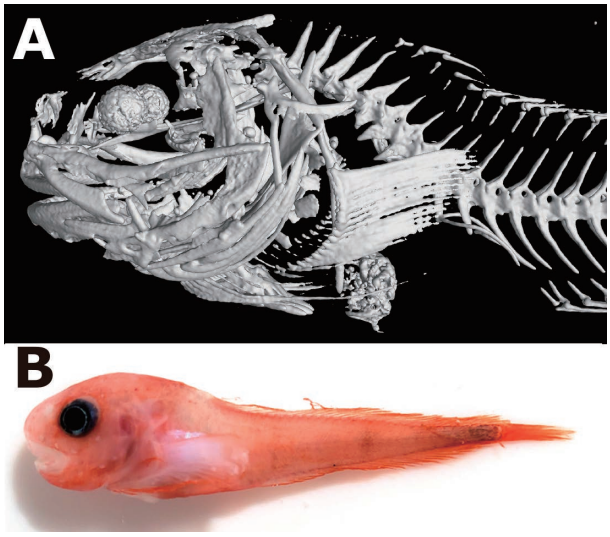

Fig. 2. Holotype of *Careproctus io*, FAKU 148130, 37.3 mm SL. A, Micro-CT scan image of head; B, fresh condition.

12. Membrane of posterior anal-fin rays continuous with caudal fin. Caudal fin slightly rounded. Principal caudal-fin rays 10 (11); dorsal procurrent rays 2 (3), ventral procurrent rays 2 (1). Hypurals and parhypural fused into single plate; its upper and lower portions separated by narrow slit. Pleural ribs in 2 pairs, on abdominal vertebrae 9 and 10 (8 and 9).

Pectoral fin deeply notched, with 28 (29) rays, just reach-

ing to level of anal fin origin; upper lobe with 20 rays; lower lobe moderately elongate, with 8 (9) rays, 6th ray from ventralmost longest, just reaching to anal-fin origin. Tip of pectoral-fin rays free of membrane, lower rays more strongly exserted; rays in notch slightly more widely spaced than rays of lobes. Uppermost pectoral-fin base level with ventral rim of orbit. Lowermost pectoral-fin base below posterior rim of orbit. Proximal pectoral radials 4 (3 + 1), curved triangular (based on FAKU 150605; Fig. 1C). Upper and lower part of radials 1 and 2 notched; upper part of radial 3 deeply notched; radial 4 without notch. Interradial fenestrae 3, extending between scapula and proximal radials 1–3; fenestra 1 blunt triangular, fenestrae 2 and 3 elliptic. Scapula broadly Y-shaped, with strong helve, extending closely to uppermost proximal radial. Coracoid pear-shaped, with thin lamella. Pelvic disk large, round; length slightly greater than width. Anus posterior to gill slit, slightly closer to pelvic disk than to anal-fin origin. Pyloric caeca 9 (8).

Coloration (Fig. 2B). In life, head, body, and fins bright red; snout, lips, and posterior part of pectoral-fin base pale pink; caudal peduncle somewhat darker; pelvic disk pale pink; eye black. After preservation, head, body, and fins white; caudal peduncle somewhat darker; eye black; stomach and peritoneum white.

Reproduction. Ovary of holotype pouch-like, translucent whitish, with yolked eggs (0.50 mm maximum diameter). Testes of paratype (FAKU 150605) enlarged, color creamy-white.

Distribution. Known only from the Pacific coast of northern Honshu Is., Japan (off Fukushima and Iwate) at depths of 419–465 m.

Etymology. The specific name is a noun in apposition after *Io*, a Greek mythological character who wandered the world without rest, due to the unsettled phylogenetic position of the new species (see under Remarks). The standard Japanese name "Mini" reflects its small body size.

Remarks. The new species is characterized by similar numbers of pectoral- and anal-fin rays, reminiscent of *Liparis*, *Allocareproctus* Pitruk and Fedorov, 1993, *Prognatholiparis* Orr and Busby, 2001, and *Lopholiparis* Orr, 2004 (Fig. 3A). In addition, the pelvic disk size of the new species is relatively large for species of *Careproctus*, instead being similar to that of *Liparis*, *Allocareproctus*, and *Prognatholiparis*. Although species with a larger pelvic disk generally have a smaller number of dorsal-fin rays (Fig. 3B), plots of these two characters for the new species were not typical for *Careproctus*. However, *C. io* has a single nostril (vs. two nostrils in *Liparis*), no pseudobranchs (vs. pseudobranchs present in *Liparis*), a subterminal mouth (vs. lower jaw projecting in *Prognatholiparis*), no papillae on rims of the cephalic lateralis pores (vs. papillae present in *Allocareproctus*), and no enlarged cephalic bones (vs. enlarged cephalic bones present in *Lopholiparis*), thereby clearly distinguishing the former from the latter genera (Figs 1A, 2A) (Orr and Busby 2001, 2006; Orr 2004; this study).

In contrast, a BLAST search of the COI sequences (652 bp) of the new species showed them to be most similar to those of *Pseudoliparis swirei* Gerringer and Linley, 2017 (92.6%; INSDC accession numbers, KY659181–KY659184) and *Notoliparis kermadecensis* (Nielsen, 1964) (92.6%; KY659176, KY659179, KY659180). However, both *Pseudoliparis* Andriashev, 1955 and *Notoliparis* Andriashev, 1975 are characterized by a coronal pore (Andriashev 1975; Andriashev and Pitruk 1993), clearly differing from the new species which lacks coronal pores. Neighbor-joining (NJ) and maximum likelihood (ML) trees reconstructed herein using the COI sequence of the new species and those determined by Orr et al. (2019), did not clearly resolve the phylogenetic position of the new species (Supplementary Figs 1, 2), recovering a monophyletic relationship of the latter with a clade of "Elassodisca" and *Prognatholiparis* (bootstrap value: < 50%) and "Melanura" (< 50%) of Orr et al. (2019) in the ML and NJ trees, respectively. Therefore, the new species is here conservatively treated as a member of *Careproctus*, although future studies may not support this decision.

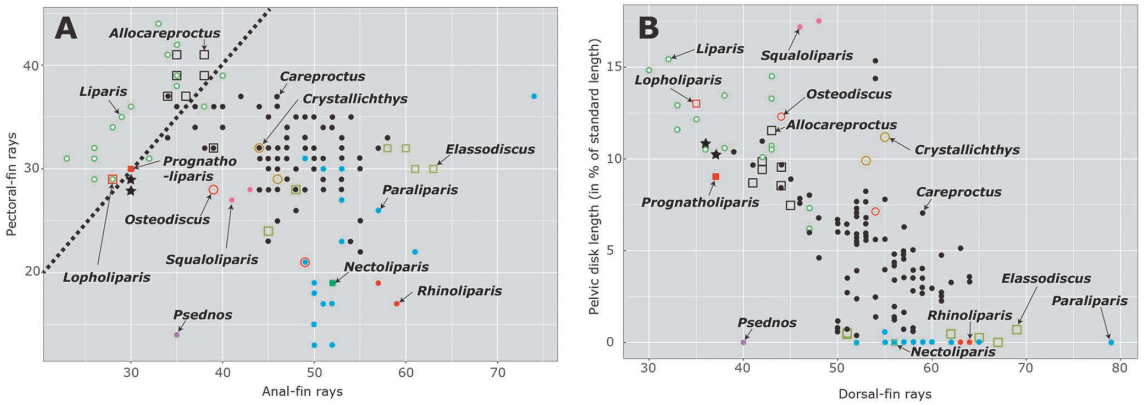

Fig. 3. Relationship of pectoral-fin ray to anal-fin ray numbers (A), and relationship of pelvic disk length (in % of SL) to dorsal-fin ray number (B). Solid stars indicate *Careproctus io*. Dashed line indicates previously recognized limit of *Careproctus*, with similar numbers of pectoral-fin and anal-fin rays.

Discussion

Among the species of *Careproctus*, *C. io* is characterized by having lower numbers of dorsal- and anal-fin rays (36–37 and 30, respectively), similar to *C. bromius* (38–42 and 32–37, respectively), *C. candidus* Gilbert and Burke, 1912 (37–49 and 35–41, respectively), *C. nelsoni* Orr, 2016 (39–41 and 33–35, respectively), and *C. staufferi* (40–42 and 33–37, respectively) (Orr 2016; Gardner et al. 2023; this study). All of these species share other characters, including trilobed teeth, cephalic pore pattern 2-6-7-2, and a relatively large pelvic disk (10.3%–10.9% SL in *C. io*; 8.8%–11.1% SL in *C. bromius*; 9.9%–13.0% SL in *C. nelsoni*; 9.2%–13.2% SL in *C. staufferi*) (Orr 2016; Gardner et al. 2023; this study). However, *C. io* can be distinguished from all the others by its uniformly reddish coloration in life (vs. variegated or mottled white and red coloration), and from *C. bromius*, *C. candidus*, and *C. staufferi* by its long pectoral-fin lower lobe, reaching to the anal-fin origin (vs. relatively short, not reaching the anal-fin origin) (Orr 2016; Gardner et al. 2023; this study). In addition, the new species differs from *C. nelsoni* in having fewer pyloric caeca (8–9 vs. 15) (Orr 2016; this study).

Careproctus patagonicus Matallanas and Pequeño, 2000 (Southern Ocean) is also characterized by lower numbers of dorsal- and anal-fin rays (37 and 34, respectively, known only from the holotype), but differs from *C. io* in the cephalic pore pattern (2-6-7-1 vs. 2-6-7-2) and proximal pectoral radial number (1 vs. 4) (Matallanas and Pequeño 2000).

Although Kido (1988) and Orr and Maslenikov (2007) recognized pectoral-fin ray numbers being typically lower than those of the anal fin as a diagnostic character of *Careproctus* (established for most species of *Careproctus*; Fig. 3A), some species have very similar numbers of anal- and pectoral-fin rays, viz., *C. candidus*, *C. bromius*, *C. kamikawai* Orr, 2012, *C. klisi* Gardner, Orr, and Tornabene, 2023, *C. lycopersicus* Orr, 2012, *C. ovigerus* (Gilbert, 1896), *C. staufferi*, and *C. nelsoni* (see Orr 2012; Gardner et al. 2023; this study). Most of the latter species have been newly described since the studies by Kido (1988) and Orr and Maslenikov (2007), and this character is clearly no longer diagnostic of *Careproctus*. The present new species also has similar anal- and pectoral-fin ray numbers, but can be distinguished from *C. candidus*, *C. bromius*, *C. staufferi*, and *C. nelsoni* as described above, and from *C. klisi* by its uniformly reddish body coloration (vs. variegated coloration in *C. klisi*) (Gardner et al. 2023). Dorsal- and anal-fin ray numbers in *C. kamikawai* (43–45 and 34–38, respectively), *C. lycopersicus* (42–45 and 34–38, respectively), and *C. ovigerus* (40–45 and 35–36, respectively) are greater than those of *C. io* (36–37 and 30, respectively) (Orr 2012; this study), the latter three species being further distinguishable from *C. io* by their large gill slit extending at least to pectoral-fin ray 4 (vs. a small gill slit entirely above the pectoral fin).

Within *Careproctus*, *C. io* has a relatively large pelvic disk and lower numbers of dorsal- and anal-fin rays, plots of dorsal-fin ray numbers against relative pelvic disk size of the latter being somewhat similar to those of *Liparis*, *Allocareproctus*, and *Prognatholiparis* (Fig. 3B). Such is also the case of the relationship between pectoral- and anal-fin ray numbers (Fig. 3A). It should be noted that the dorsal-fin ray numbers and pelvic disk size seemed to be negatively correlated (Fig. 3B; $P < 0.01$, Spearman's $\rho = -0.718$). Because the number of body segments (i.e., vertebrae and myotomes) seem likely to affect body flexibility in fishes, they may be important for swimming kinematics (Andriashev 2003; McDowall 2003). Due to the first dorsal pterygiophore position usually being stable in cottid fishes and related taxa, including snailfishes (Yabe 1985), and the dorsal fin usually being attached to the caudal fin in snailfishes, dorsal fin and vertebral counts are likely to be correlated. Many snailfishes have a pelvic disk with which they attach themselves to rocks, algae, and other objects (Mecklenburg et al. 2002), suggesting that pelvic disk size is also relevant to swimming mode. A large well-developed pelvic disk has been considered as a plesiomorphic condition, which has been reduced and/or lost independently in at least three lineages across the evolution of snailfishes (Orr et al. 2019; Gerringer et al. 2021). Gerringer et al. (2021) found depth-related declines in pelvic disk size and loss of the disk in some deeper-dwelling snailfish species, suggesting that the decrease in wave action and flow rate with increasing depth likely reduces the need for strong pelvic disks. Because energetically efficient anguilliform swimming and axial elongation in fishes is favored in deep sea habitats (Neat and Campbell 2013), deeper-dwelling and semi-pelagic species of *Paraliparis* and related genera may have lost the pelvic disk with increasing body segmentation, as suggested by Andriashev (2003).

Comparative materials examined. *Careproctus kamikawai*: UW 150325, paratype, 35.0563°N, 121.3901°W, 468 m depth. *Careproctus lycopersicus*: UW 119816, paratype, 113.5 mm SL, 52.6500°N, 172.2400°W, 397 m depth; UW 119817, paratype, 142.6 mm SL, 60.2640°N, 179.1680°W, 877 m depth. *Careproctus nelsoni*: UW 155798, holotype, 57.9 mm SL, 52.3675°N, 171.2406°W, 329 m depth; *Careproctus stafferi*: UW 155801, holotype, 83.0 mm SL, 53.1043°N, 169.8535°W, 290 m depth. *Lopholiparis flerxi* Orr, 2004: UW 47868, holotype, 31.5 mm SL, 51.4600°N, 178.4600°W, 285 m depth. *Prognatholiparis ptychomandibularis* Orr and Busby, 2001: UW 42341, holotype, 85.2 mm SL, 52.3184°N, 172.7453°W, 455 m depth.

Supplementary Information

Supplementary Figure 1. Maximum likelihood tree for mitochondrial COI marker. Numbers on nodes represent ultrafast bootstrap values.

Supplementary Figure 2. Neighbor-joining tree for mitochondrial COI marker. Numbers on nodes represent bootstrap values.

Supplementary Table 1. A dataset prepared for Fig. 3. Numbers of dorsal-, anal- and pectoral-fin rays, and pelvic disk length in 13 genera (88 species) of snailfishes.

All supplementary materials are available at https://doi.org/10.5281/zenodo.10348390.

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Authors Contributions

Yoshiaki Kai: Conceptualization; Investigation; Visualization; Writing – original draft. Eisuke Morikawa: Resources; Writing – reviewing & editing. Ryo Misawa: Resources; Writing – reviewing & editing.

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Declarations

Competing interests. The authors declare no conflicts of interest.

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