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A newly recorded brittle star, *Amphiophiura megapoma* (Ophiuroidea: Ophiurida: Ophiopyrgidae), from the mesophotic zone in the East Sea, Korea

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Contribution to Environmental Biology

- The discovery of *Amphiophiura megapoma* in the mesophotic zone of the East Sea, Korea, enhances our understanding of its distribution and ecology.
- These findings are significant as mesophotic zones have been hypothesized to serve as refuges from marine environmental changes.

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Abstract: This study introduces a newly discovered brittle star, *Amphiophiura megapoma*, from the mesophotic zone in the East Sea, Korea. It is the second species belonging to the genus *Amphiophiura* (which includes 57 species) to be recorded in Korean waters after *A. sculpta*. The specimen was discovered during a September 2022 survey, by SCUBA diving in the upper mesophotic zone of the East Sea, Korea. This study presents the morphological characteristics of *A. megapoma*, highlighting its differences from the related species within a comprehensive taxonomic description. It provides high-resolution images of *A. megapoma* and a taxonomic key for *Amphiophiura* species in Korea.

Keywords: Echinodermata, taxonomy, morphology, trimix diving

1. INTRODUCTION

The mesophotic zone is typically defined as being from 30 m to 150 m depth, intermediate in illumination between its shallower and deeper counterparts (Turak and DeVantier 2019). It is characterized by light-dependent communities surviving in light-limited environments and harbors unique biota that include both eurybathic organisms and those exclusively adapted to deep-water habitats (Schneider *et al.* 2019). The challenges and economic constraints associated with conducting in situ surveys and underwater sampling have historically hindered scientific research at these depths. In the previous centuries, marine biodiversity surveys predominantly focused on infralittoral and shallow depths. However, advancements in submersible technology during the 1970s enabled exploration of the deep sea (Grassle *et al.* 1975; Heirtzler and Grassle 1976; Barnes *et al.* 1977; Corliss *et al.* 1979; Tunnicliffe *et al.* 1986), resulting in remarkable discoveries of marine life and a significant re-evaluation of marine biodiversity patterns (e.g., Rex (1981) and Grassle (1985)). Nevertheless, the mesophotic zone has received limited attention due to its depth range, being too shallow for safe submersible operation yet too deep for conventional SCUBA diving (Pyle 1996; Hinderstein *et al.*

2010; Kahng *et al.* 2010).

Genus *Amphiophiura* Matsumoto, 1915 comprises 57 extant species (Stöhr *et al.* 2023). Among them, only one species, *A. sculpta* (Duncan, 1879), had been recorded in the Korean marine fauna prior to this study (Yi and Irimura 1988; MABIK 2023). *Amphiophiura* exhibits distinct morphological characteristics compared to other genera within the same family, Ophiopyrgidae Perrier, 1893 (Matsumoto 1915, 1917; Fell 1960): 1) disk high, and arms not very high (higher than broad), 2) disk and ventral interbrachal covered with prominent scales, and 3) arm spines arranged in a single row. Numerous species of *Amphiophiura* inhabit the lower sublittoral and upper abyssal benthic zone (ranging from 100−3,000 m), and sometimes the lower abyssal benthic zone (below 4,000 m) (Lyman 1878; Matsumoto 1917; McKnight 2003; Liu 2008). In September 2022, a trimix diving team for scientific research conducted a survey in the upper mesophotic zone (below 70 m, upper sublittoral benthic zone) of the East Sea, Korea. During this survey, an *Amphiophiura* specimen was discovered, marking an extraordinary finding in the upper mesophotic zone.

In this study, a newly recorded brittle star found during a mesophotic zone survey is presented, accompanied by a comprehensive taxonomic description and high-resolution images. Furthermore, a taxonomic key to species within the genus *Amphiophiura* in Korea is provided.

2. MATERIALS AND METHODS

A sample was collected from the water around Namae-ri in Gangwon-do, in the East Sea, Korea (Fig. 1). The sample was collected by trimix SCUBA diving (Fig. 1), and preserved in ethyl alcohol solution (＞95%) after sorting in land. The collected sample was deposited in the National Marine Biodiversity Institute of Korea (MABIK; Seocheon, Korea). The sample for observation was lightly bleached following the procedure by Stöhr *et al.* (2012) and bleached specimens were dried in an oven for six hours at 55°C. Specimen observation and photography for figures were performed using a Nikon SMZ1000 stereomicroscope (Nikon, Tokyo, Japan), a DP22 digital camera (Olympus, Tokyo, Japan), and a Helicon Focus 7.7.5 (Helicon Soft Ltd., Oakland, CA, USA) for combinations of images with varying focus. Observation of major morphological characteristics and measurement of body part for ophiuroids such as length of an arm and a disk were performed following the method of Shin (2012). The sample was identified using traditional taxonomic characters described by Clark (1911). All the abbreviations in this study are referred from Hendler (2018) and Goharimanesh *et al.* (2021).

3. SYSTEMATIC ACCOUNTS

Phylum Echinodermata Klein, 1778
Class Ophiuroidea Gray, 1840
Superorder Euryophiurida O'Hara, Hugall, Thuy, Stöhr and Martynov, 2017
Order Ophiuroida Müller and Troschel, 1840 *sensu* O'Hara *et al.*, 2017
Suborder Ophiurina Müller and Troschel, 1840 *sensu* O'Hara *et al.*, 2017
Family Ophiopyrgidae Perrier, 1893
Genus *Amphiophiura* Matsumoto, 1915

Key to the species of genus *Amphiophiura* in Korea

1. Arm slightly long (R＝over 2.9r), radial shield almost separated from each other ·····*A. megapoma*
– Arm short (R＝below 2.0r), radial shield adjoined each other two-thirds of the length ·····*A. sculpta*

***Amphiophiura megapoma* (H.L. Clark, 1911)**
큰뚜껑양편빗살거미불가사리 (신칭) (Fig. 2)

Ophiura megapoma H.L. Clark, 1911: 79, 80, fig. 23.
Amphiophiura megapoma: Matsumoto, 1917: 264; Fujita *et al.*, 2014: 210; Stöhr *et al.*, 2023: 242734.

Material examined. One specimen, off the water of Namae-ri, Hyeunnam-myeon, Yangyang-gun, Gangwon-do, Korea (37°58′42.7″N 128°48′42.9″E) (Fig. 1), 1 September 2022, depth of 53.6 m, water temperature of 2.7°C, inhabits muddy to fine sand sediments, deposited in MABIK (MABIKIV00172890).

Description. Disk rather thick, flat, rounded pentagonal outline, and covered with numerous conspicuous scales (Fig. 2A). Arms five, rather high, and slightly long. Radial shield moderate sized, bared, rather longer than broad, separated each other with small scales, but slightly connected at middle part (Fig. 2B).

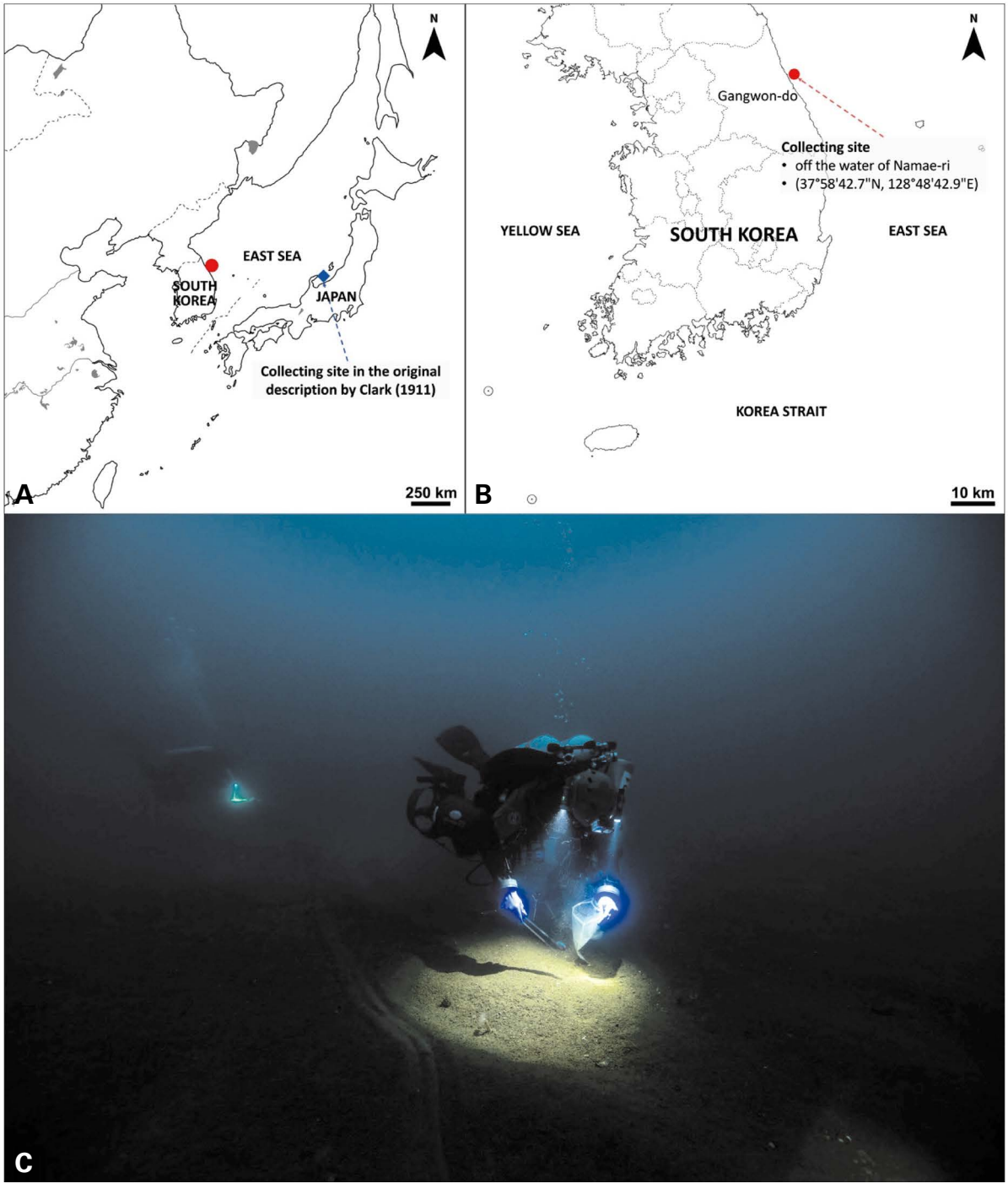

Fig. 1. Collecting sites of *Amphiophiura megapoma* (H.L. Clark, 1911), and the trimix diving survey in this study. A and B, collecting sites of *A. megapoma* in this study and the original description by Clark (1911); C, a photograph of the trimix diving survey conducted in the mesophotic zone as part of this study.

Genital slits long and conspicuous (Fig. 2E). Genital scales short, wider than long, rounded square or oval shape, and gradually larger toward aboral side (Fig. 2B, C). Tentacle pore covered with four to six large scales at outer side of pore (Fig. 2D, E), and number of scales gradually decrease toward tip. Oral shields longer than

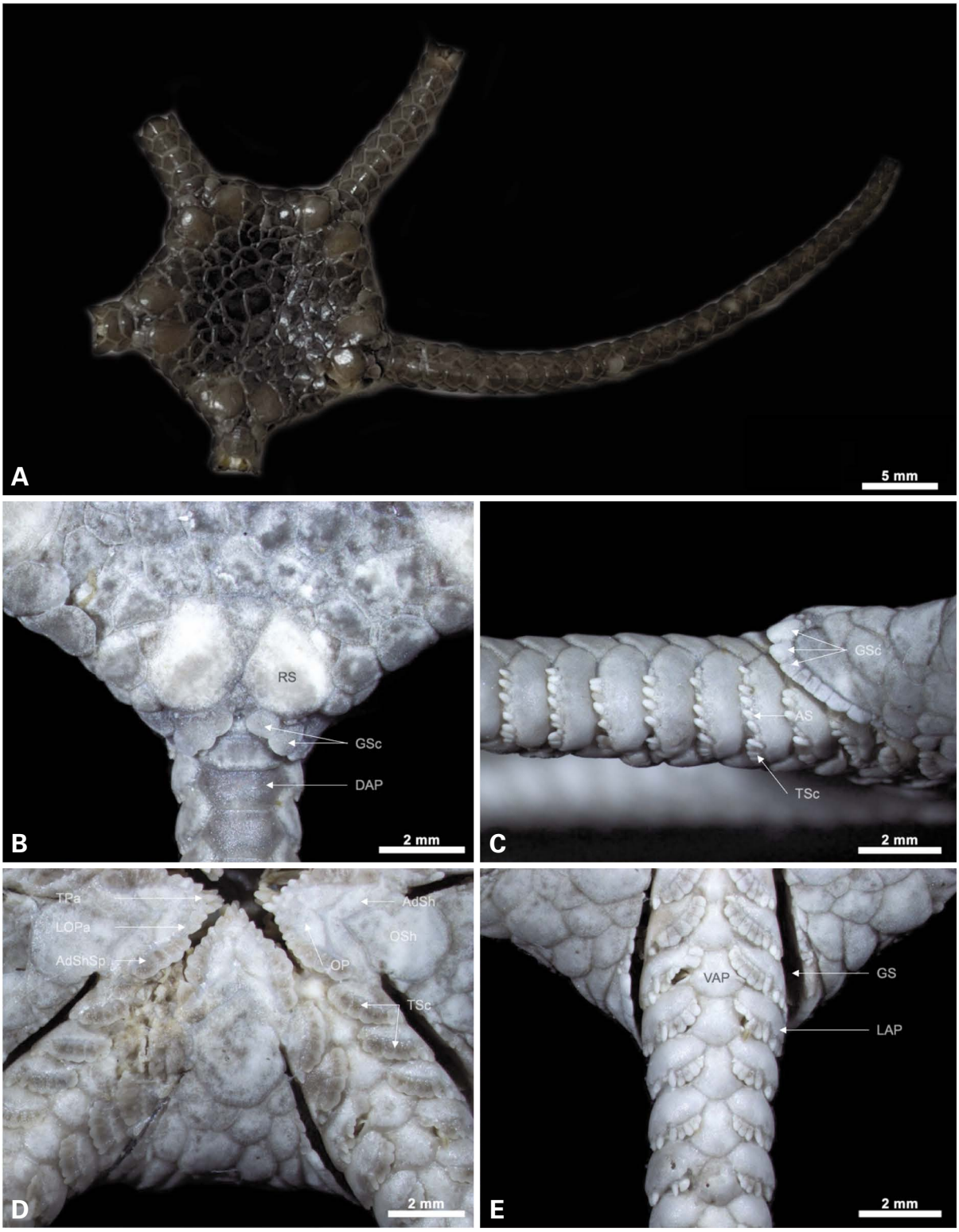

Fig. 2. *Amphiophiura megapoma* (H.L. Clark, 1911) (MABIKIV00172890). A, aboral side in life; B, radial shield, genital scales, and dorsal arm plates; C, lateral side of the arm proximally; D, oral part and around; E, ventral side of the arm. Abbreviation. AdSh, adoral shield; AdShSp, adoral shield spine; AS, arm spine; DAP, dorsal arm plate; GS, genital slit; GSc, genital scale; LAP, lateral arm plate; LOPa, lateral oral papillae; OP, oral plate; OSh, oral shield; TPa, tooth papilla; TSc, tentacle scale; RS, radial shield; VAP, ventral arm plate.

broad, rounded distally but angular proximally (Fig. 2D). Adoral shields rather longer than broad (Fig. 2D). Oral plate smaller then adoral shield, longer than broad, much wider distal part than proximal part, and one to two rounded granules on inner side of plate or not (Fig. 2D). Dorsal arm plate hexagonal, wider than long at basal, and passing basal part rapidly longer than broad (Fig. 2B). Lateral arm plate moderate size with six arm spines at basal, and number of arm spine gradually decrease toward tip. Tooth papilla one, lateral oral papillae five to seven, and adoral shield spines one to two (Fig. 2D).

Size. Diameter of disk (r) = 16.4 mm, length from the middle of disk to the tip of arm (R) = 50.1 mm, width of arm at proximal = 3.3 mm, and R = 3.1r.

Color. The specimen color in life is dark olive on the aboral side and pale gray on the oral part and ventral side of arm.

Distribution. Korea (East Sea), Japan (Toyama Bay, Hokkaido), Kuril Islands, Sea of Okhotsk.

Remarks. *Amphiophiura megapoma* was initially reported as *Ophiura megapoma* by Hebert L. Clark (1911). Matsumoto (1915) subsequently established a new genus, *Amphiophiura*, which included *O. megapoma* and 29 other species. The specimen in this study exhibits the same morphological characteristics, although there are a few minor differences from the original description by Clark (1911): 1) the number of proximal arm spines (holotype: four or five; this study: five), and 2) the number of proximal tentacle scales (holotype: four to seven; this study: five to seven). Around the waters of Korea, five *Amphiophiura* species were recorded (Table 1): *A. megapoma*, *A. oediplax* (Clark, 1911), *A. penichra* (Clark, 1911), *A. pomphophora* (Clark, 1911), and *A. sculpta* (Duncan, 1879). Among them, *A. sculpta* has been previously recorded from a depth of 50 m in the Yellow Sea, Korea (Yi and Irimura 1988). However, this species distinctly differs from *A. megapoma* in two major morphological characteristics: 1) the ratio of R/r (*A. megapoma* = 2.9–3.1; *A. sculpta* = 1.5), and 2) the radial shields are joined or separated (*A. megapoma* = separated; *A. sculpta* = joined) (Table 1). Furthermore, *A. megapoma* has more arm spines compared to *A. oediplax*, *A. penichra*, and *A. pomphophora*, and the radial shields of these three species are joined (Table 1). Consequently, the collected *Amphiura* specimen was identified as *A. megapoma*, representing the first record in the Korean marine fauna, and the first collection rec-

Table 1. Taxonomic comparison between five *Amphiophiura* species from adjacent waters of Korea

	Content \ Species	*A. megapoma* (Clark, 1911)	*A. oediplax* (Clark, 1911)	*A. penichra* (Clark, 1911)	*A. pomphophora* (Clark, 1911)	*A. sculpta* (Duncan, 1879)
1)	Formation of radial shield	almost separated with small scales, slightly adjoined each other in the middle	adjoined each other along the almost length	adjoined each other two-thirds of the length	adjoined each other two-thirds of the length	adjoined each other two-thirds of the length
2)	Presence of rounded granules in oral plate	present	absent	absent	absent	absent
3)	Number of arm spine proximally	5	1	1	3	8
4)	R/r	2.9–3.1	2.4	2.9	3.0	1.5
5)	Distribution	East Sea to the Sea of Okhotsk	East Sea to the Sea of Okhotsk	Northern Japan (Hokkaido)	Western Japan (middle East Sea)	Yellow Sea, and Korea Strait
6)	Habitat depth range (m)	53.6–298	72–1845	338–1732	122–331	50–254

*Abbreviations: R, the length from the center of disk to the tip of the arm; r, the length of the diameter of the disk.

ord at depths below 100 m.

CRediT authorship contribution statement

T Lee: Investigation, Formal analysis, Resources, Supervision, Writing-Original draft, Writing-Review & editing.

Declaration of Competing Interest

The author declares no conflicts of interest.

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