

# Ophiuroid fauna of cobalt-rich crust seamounts in the Northwest Pacific Ocean

Wanying Chen<sup>1</sup>, Jieying Na<sup>1, 2</sup>, Chengcheng Shen<sup>1</sup>, Ruiyan Zhang<sup>1, 2</sup>, Bo Lu<sup>1</sup>, Hong Cheng<sup>1</sup>, Chunsheng Wang<sup>1, 2, 3, 4</sup>, Dongsheng Zhang<sup>1, 2, 3\*</sup>

<sup>1</sup>Key Laboratory of Marine Ecosystem Dynamics, Second Institute of Oceanography, Ministry of Natural Resources, Hangzhou 310012, China

<sup>2</sup>School of Oceanography, Shanghai Jiao Tong University, Shanghai 200240, China

<sup>3</sup>Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), Zhuhai 519082, China

<sup>4</sup>State Key Laboratory of Satellite Ocean Environment Dynamics, Second Institute of Oceanography, Ministry of Natural Resources, Hangzhou 310012, China

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## Abstract

Seamounts are vulnerable ecosystems in the deep sea and can be heavily impacted by human activities, such as bottom fishing and deep-sea mining. The species composition and distribution patterns of benthic fauna is key information for the designation of marine protected areas and environmental management plans. Three contracts for cobalt-rich crust exploration have been granted to China, Japan and Korea in the Northwest Pacific Ocean by the International Seabed Authority. However, our knowledge of benthic biodiversity in this area is extremely insufficient. During 2013–2020, eight Chinese Ocean Mineral Resources R&D Association (COMRA) cruises were conducted to investigate the benthic assemblages of nine seamounts in this region. In this study, 191 ophiuroids collected from seamounts in the Northwest Pacific were identified into 29 species in 11 families. Ophiacanthidae and Euryalidae were the two most dominant families with 12 and 6 species, respectively. Ophiotomidae and Ophiopyrgidae were represented by two species each, while seven families were represented by only one species. Four species were widely distributed among 4–5 seamounts, and 17 species were found only at a single site. An integrated regional taxonomic dataset of Ophiuroidea was generated and analyzed. A total of 23 and 14 species were obtained from the Magellan Seamount Chain (MSC) and the Marcus-Wake seamounts (MWS), respectively, with 8 species shared between the two seamount groups. The individual-based rarefaction curves did not reach an asymptote, suggesting that the sampling effort was inadequate for either the entire region or each single seamount. Most species distributed in a narrow depth range, and the species composition was different between water depths above and below 2 000 m. Our results greatly improve the understanding of megafaunal biodiversity from seamounts in the Northwest Pacific Ocean, and highlight the necessity of further surveys to provide more robust information for environmental protection and management in this region.

**Key words:** Ophiuroidea, taxonomy, community, seamount, Northwest Pacific

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## 1 Introduction

Seamounts are typical vulnerable deep-sea marine ecosystems (Watling and Auster, 2017). Owing to their raised topography, seamounts alter the flow of ocean currents, providing suitable habitats, with enhanced food particles and hard-rock substrates, for sessile suspension-feeding invertebrates such as corals, sponges, and crinoids (Clark et al., 2012; McClain et al., 2010; Samedi et al., 2007; Schlacher et al., 2014). These sessile organisms are highly vulnerable to deep-sea fishing and mining activities (Clark et al., 2016), and have limited recovery capacity because of their exceptional longevity, slow growth rates, and low fecundity (Andrews et al., 2009; Carreiro-Silva et al., 2013; Roark

et al., 2009; Samedi et al., 2007). Bottom trawling not only removes these biogenic species, but also has been implicated in changing community structures (Althaus et al., 2009; Koslow et al., 2001), especially for associated species such as fishes, echinoderms, and crustaceans (Atkinson et al., 2011; Clark et al., 2016; Mangano et al., 2013).

Ophiuroidea, with more than 2 000 known species, is the largest class of Echinodermata (Stöhr et al., 2012) and its biodiversity in deep-sea environments has been considerably underestimated (Christodoulou et al., 2019). As common associates of key biogenic species, such as corals and sponges (Cho and Shank, 2010), which show high density and diversity within

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\*Corresponding author, E-mail: [dszhang@sio.org.cn](mailto:dszhang@sio.org.cn)

seamount fauna (Clark and Bowden, 2015; Koslow et al., 2001; O'Hara and Tittensor, 2010; Ordines et al., 2019), ophiuroids have emerged as a key taxonomic group in understanding the patterns of seamount biodiversity and ecology (O'Hara, 2007). Although the relationships between ophiuroids and their hosts is more likely physical than biological (Fujita and Ohta, 1988; O'Hara et al., 2008), these associations may be beneficial to the recovery of corals from catastrophic events such as landslides or oil spills (Girard et al., 2016; Grange, 1991). However, ophiuroids can also be damaged by fishing trawling, and they are recognized as indicators of "vulnerable marine ecosystems" (Thompson et al., 2017).

The northwest Pacific holds the largest number of seamounts worldwide (Yesson et al., 2011), and many of these are covered by cobalt-rich crusts (CRC), a valuable mineral. Recently, the International Seabed Authority (ISA) granted four contracts for CRC exploration (Fig. 1), and the marine benthos from CRC seamounts are likely to be disturbed by potential mining activities. To protect marine biodiversity and seamount ecosystems, an international workshop was jointly convened by the ISA and the Chinese Ocean Mineral Resources R&D Association (COMRA) in 2018, to develop a Regional Environmental Management Plan for the CRC in the "Triangle Area" in the Northwest Pacific Ocean (ISA Technology Study No. 23). To date, however, only a few studies have focused on megafauna from CRC seamounts (Morgan et al., 2015; Schlacher et al., 2014). Our knowledge gap regarding the benthic biodiversity in this area impedes the scientifically driven designation of areas of particular environmental interest. Seamounts in the "Triangle Area" are mostly composed of two seamount groups, the Marcus-Wake seamounts (MWS) and the Magellan Seamount Chain (MSC) located in the north-

ern and southern parts of this area, respectively. During the 1970's and 1980's, benthic fauna was reported from the MWS (Paternak et al., 1981). Recently, several cruises have been conducted by COMRA, surveying seamounts from both the MWS and MSC. A few benthic species have also been reported from other seamounts in the "Triangle Area" (Dong et al., 2017; Na et al., 2021; Shen et al., 2020; Wang et al., 2016; Xu et al., 2016, 2017; Zhang et al., 2018, 2019, 2020). However, these studies are so sporadic that a comprehensive dataset is needed to provide useful biodiversity information for the development of the regional environmental management plan.

In this study, we present an integrated regional taxonomic dataset for Ophiuroidea from CRC seamounts in the "Triangle Area". By analyzing this dataset, we aimed to (1) provide a checklist of ophiuroid fauna from seamounts in this area, and (2) reveal the spatial distribution and community structure of ophiuroid fauna. These data should be able to be input into the designation of areas of particular environmental interest in the Northwest Pacific in the future.

## 2 Materials and methods

### 2.1 Study area and sampling sites

The study area locates in the northwest Pacific, in the east of the Mariana Trench. During 2013 to 2020, several cruises were conducted to investigate biodiversity, connectivity and megafauna of seamounts in this area. The Human Occupied Vehicles (HOV, *Jiaolong*) and two Remotely Operated Vehicles (ROV, *Haima* and *Hailong-III*) were used to collect benthic animals using manipulator and suction pump. In the earlier cruises in 2013 and 2014, our main object was to understand the species di-

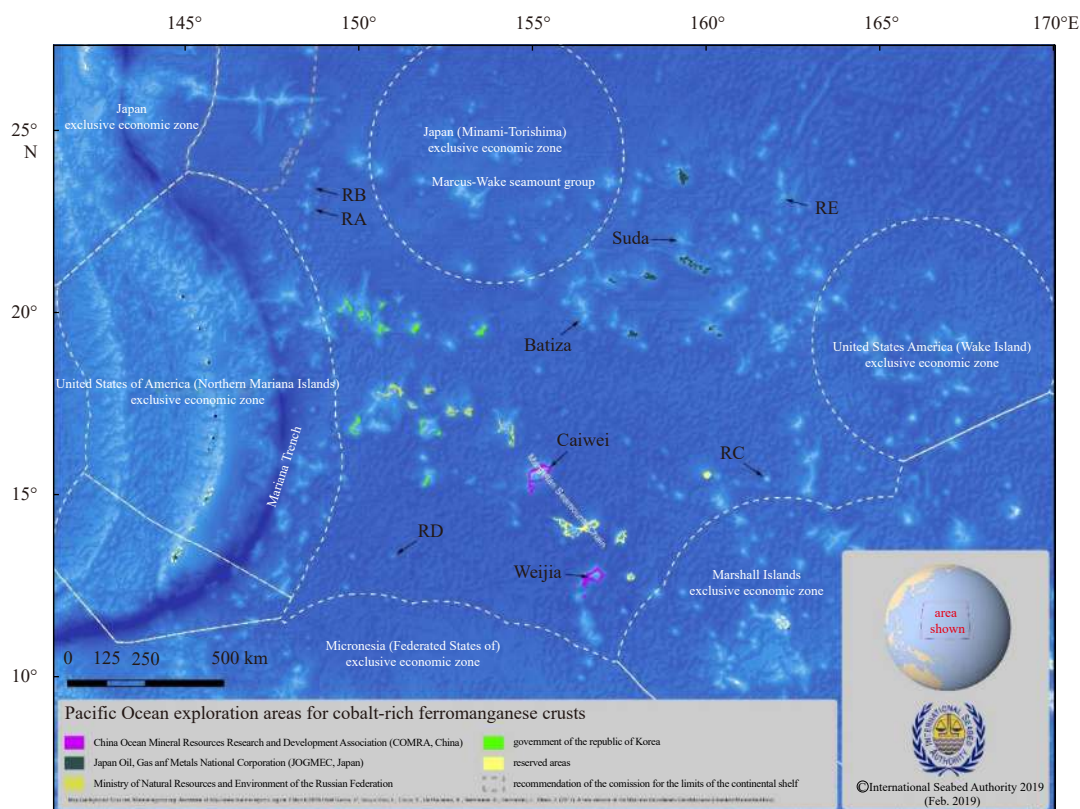


Fig. 1. Study area and sampling seamounts in the Northwest Pacific Ocean (modified from the picture on the ISA website). The codes of RA–RE were temporally used to represent these seamounts which are un-named.

versity, thus, operators were trying to collect different animals which never been collected. Since 2017, to evaluate the connectivity between seamounts in this area, small echinoderms such as ophiuroids and crinoids became the prioritized targets, collected individuals per dive increased distinctly (Table 1). Detailed sampling information is presented in Table 1 and Fig. 1 (the codes of RA–RE were temporally used to represent these seamounts which are un-named). Among the nine seamounts, five were located in the northern part of the study area (north of 19°N). The Batiza, Suda, and RE seamounts belong to the MWS, and the RA and RB seamounts, together with another seamount, form a small vertical seamount chain located in the northwest of the study area, which plays a role in connecting the MWS and MSC. Four seamounts were located in the southern part of the study area (south of 19°N). The Caiwei and Weijia seamounts belong to the MSC and are the two seamounts within China's contract area. The RC Seamount in the southeastern part of the study area belongs to the Marshall Seamount area, and the RD Seamount in the southwest part is isolated from the other seamounts by a deep-sea basin.

## 2.2 Taxonomy identification

Specimens were generally identified based on morphological characteristics. Specimens used for morphological identification were examined and photographed using a dissection microscope (AXIO Zoom V16, Zeiss Microscopy GmbH, Jena, Germany) equipped with a camera (Axiocam 506 color, Zeiss). The taxonomy identification was conducted follow the latest taxonomic system (O'Hara et al., 2018), the main references for mor-

phological identification were Paterson (1985), O'Hara and Stöhr (2006), Stöhr et al. (2012) and O'Hara et al. (2018), and the major references for endoskeleton characteristics were Martynov (2010) and Thuy and Stöhr (2011, 2016).

## 2.3 Community structure and vertical distribution analysis

To evaluate the adequacy of the sampling effort, the “rare-curve” function of the Vegan package in R version 4.0.2 was used to compute individual-based rarefaction curves, based on three datasets: the ALL dataset including all nine seamounts, the MWS dataset including five northern seamounts (the RA, RB, RE, Suda, and Batiza seamounts), and the MSC dataset including four southern seamounts (the Caiwei, Weijia, RC, and RD seamounts). The MWS and MSC datasets represented the northern and southern seamounts in the study area. Individual-based rarefaction curves were also computed using the same method mentioned above to assess the sampling effort for the Caiwei and Weijia seamounts, which were the two most adequately sampled seamounts, with seven and 10 ROV dives, respectively. Additionally, the 6 epibenthic species (Table 2) were removed from the dataset, the rarefaction analysis was repeated using the exclusive epizoic species dataset. A vertical distribution plot of ophiuroid species was prepared using GraphPad Prism v7.0.

## 3 Results

### 3.1 Taxonomic check list

A total of 191 ophiuroid specimens were identified into 29 species belonging to 11 families and 14 genera.

**Table 1.** Cruise information, sampling sites, and individual numbers of ophiuroids collected in this study

Cruise	Date	Depth/m	Seamount	HOV/ROV	Sites	Latitude	Longitude	Individuals
DY35	2014.7.17	2 372–2 742	Caiwei	HOV	JL-CW-DV76	15°30'46"N	155°20'08"E	3
DY35	2014.7.23	2 348–3 293	Caiwei	HOV	JL-CW-DV80	15°58'37"N	155°16'59"E	6
DY35	2014.7.24	1 521–2 070	Caiwei	HOV	JL-CW-DV81	15°40'50"N	154°55'04"E	7
DY35	2014.7.29	1 557–2 459	Caiwei	HOV	JL-CW-DV83	21°37'10"N	159°14'06"E	4
DY31	2013.10.24	1 900–2 707	Caiwei	HOV	JL-CW-DV70	15°56'28"N	155°33'57"E	2
DY31	2013.11.1	1 407–2 010	Caiwei	HOV	JL-CW-DV71	15°53'34"N	155°28'14"E	1
DY31	2013.9.7	2 150–2 746	Caiwei	HOV	JL-CW-DV72	15°40'36"N	154°53'45"E	1
DY37	2016.4.30	1 581–2 091	Weijia	HOV	JL-WJ-Dive105	13°00'20"N	156°55'53"E	2
DY41	2017.9.28	~1 670	Weijia	ROV	HM-WJ-ROV01	12°41'41"N	156°32'17"E	13
DY41	2017.9.22	~1 995	Weijia	ROV	HM-WJ-ROV02	12°22'37"N	156°17'13"E	2
DY41	2017.9.18	~1 571	Weijia	ROV	HM-WJ-ROV04	13°01'27"N	156°53'04"E	14
DY41	2017.9.19	~1 643	Weijia	ROV	HM-WJ-ROV05	12°53'04"N	157°01'45"E	4
DY41	2017.9.21	~1 935	Weijia	ROV	HM-WJ-ROV06	12°47'22"N	156°41'25"E	17
DY48	2018.8.25	~2 294	Suda	ROV	HL-SD-ROV11	22°10'23"N	159°14'57"E	6
DY51	2018.8.28	1 739–1 753	Weijia	ROV	HM-WJ-ROV09	12°54'33"N	156°44'29"E	1
DY51	2018.9.20	1 684–1 699	Weijia	ROV	HM-WJ-ROV12	12°43'51"N	156°32'22"E	2
DY56	2019.9.4	1 067–1 088	RA	ROV	HL-RA-ROV01	23°00'13"N	148°31'05"E	5
DY56	2019.9.12	1 616–1 690	Batiza	ROV	HL-BG-ROV04	20°00'56"N	156°32'25"E	6
DY56	2019.9.17	9 95–1 097	RC	ROV	HL-RC-ROV05	15°32'24"N	161°46'48"E	3
DY56	2019.9.17	1 160–1 511	RC	ROV	HL-RC-ROV06	15°31'44"N	161°45'12"E	4
DY56	2019.9.19	961–1 650	RC	ROV	HL-RC-ROV07	15°30'20"N	161°47'50"E	2
DY56	2019.9.20	780–1 163	RC	ROV	HL-RC-ROV08	15°31'48"N	161°48'36"E	4
DY56	2019.9.21	2 007–2 655	RC	ROV	HL-RC-ROV09	15°27'37"N	161°46'08"E	13
DY56	2019.10.5	2 200–2 700	RD	ROV	HL-RD-ROV10	13°23'28"N	149°52'50"E	9
DY56	2019.10.9	2 440–2 900	RD	ROV	HL-RD-ROV12	12°21'18"N	149°51'50"E	12
DY61	2020.9.16	2 400–2 790	RB	ROV	HL-RB-ROV01	23°30'59"N	148°34'44"E	9
DY61	2020.9.22	1 200–2 300	RE	ROV	HL-RE-ROV03	23°13'48"N	161°12'12"E	4
DY61	2020.9.23	1 350–2 000	RE	ROV	HL-RE-ROV04	23°13'50"N	162°21'14"E	20
DY61	2020.10.13	2 300–2 500	Weijia	ROV	HL-WJ-ROV12	12°40'52"N	156°31'12"E	15

**Table 2.** List of Ophiuroidea from nine seamounts in the Northwest Pacific Ocean

Order	Family	Species	Habitat	Seamount										
				CW	WJ	RC	RD	RA	RB	RE	BA	SD		
Amphilepidida	Amphiuridae	<i>Amphiura</i> cf. <i>grandisquama</i>	sponge		1									
	Hemieuryalidae	<i>Ophiozonella</i> sp.	sponge					1						
Ophiacanthida	Ophiothamidae	<i>Ophioleila elegans</i>	sponge	4	11	2			1			1	2	
	Ophiacanthidae	<i>Ophiacantha richeri</i>	sponge/coral		1								2	
	Ophiacanthidae	<i>Ophiacantha</i> sp. 1	sponge/coral		3	1	6			3		1		
	Ophiacanthidae	<i>Ophiacantha</i> sp. 2	sponge/coral		3				1					
	Ophiacanthidae	<i>Ophiacantha</i> sp. 3	coral/crinoid	1	2									
	Ophiacanthidae	<i>Ophiacanthidae</i> sp.	sponge		2									
	Ophiacanthidae	<i>Ophioplinthaca athena</i>	sponge/coral/rock	11			9	3		6				
	Ophiacanthidae	<i>Ophioplinthaca</i> cf. <i>clothilde</i>	sponge/coral				3	11						
	Ophiacanthidae	<i>Ophioplinthaca defensor</i>	sponge	1	37	4					14	1		
	Ophiacanthidae	<i>Ophioplinthaca semele</i>	sponge				1							
	Ophiacanthidae	<i>Ophioplinthaca grandisquama</i>	coral				3							
	Ophiacanthidae	<i>Ophioplinthaca</i> sp.1	coral				1							
	Ophiacanthidae	<i>Ophioplinthaca</i> sp.2	sponge		1									
	Ophiocamacida	Ophiocamacidae	<i>Ophiocamax</i> cf. <i>drygalskii</i>	Rock		4						6	1	
		Ophiotomidae	<i>Ophiopristis</i> sp.1	Rock		1								
Ophiotomidae		<i>Ophiopristis</i> sp.2	Rock								1			
Ophioscolecida		Ophiohelidae	<i>Ophiohelidae</i> sp.	sponge					1					
		Ophiurida	Ophiopyrgidae	<i>Amphiophiura</i> sp.				1						
		Ophiopyrgidae	<i>Ophiuroglypha</i> cf. <i>irrorata</i>	sediment	1									
Euryalida	Ophiomusidae	<i>Ophiomusa</i> sp.	sediment						1				1	
	Asteronychidae	<i>Astrodia</i> sp.	sponge	5										
	Euryalidae	<i>Asteroschema ajax</i>	coral	1	1									
	Euryalidae	<i>Asteroschema</i> cf. <i>intectum</i>	coral										1	
	Euryalidae	<i>Asteroschema horridum</i>	coral				1		2		3			
	Euryalidae	<i>Asteroschema sublaeve</i>	coral										1	
	Euryalidae	<i>Asteroschema</i> sp.	coral										1	
	Euryalidae	<i>Ophiocreas oedipus</i>	coral		3									

Note: CW, Caiwei Seamount; WJ, Weijia Seamount; BA, Batiza Seamount; SD, Suda Seamount.

### Class Ophiuroidea Gray, 1840

#### Order Ophiacanthida O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017

#### Suborder Ophiacanthina O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017

#### Family Ophiacanthidae Ljungman, 1867

#### Genus *Ophioplinthaca* Verrill, 1899

#### *Ophioplinthaca defensor* Koehler, 1930

*Ophioplinthaca defensor* Koehler, 1930: 84–86, pl. 9, Figs 1 and 2

Non *Ophioplinthaca vicina*—Litvinova, 1981: 126–127, Figs 3, 5, and 6 = *Ophioplinthaca defensor* Koehler, 1930.

Material examined: Weijia guyot, St. WJ-ROV01, 8 specimens (RSIO41002–RSIO41009); Weijia guyot, St. WJ-ROV04, 4 specimens (RSIO41017, RSIO41021, RSIO41022, RSIO41025); Weijia guyot, St. WJ-ROV05, 1 specimen (RSIO41031); Weijia guyot, St. WJ-ROV06, 16 specimens (RSIO41033–RSIO41048); Weijia guyot, St. WJ-ROV12, 8 specimens (RSIO61072–RSIO61074, RSIO61079, RSIO61080, RSIO61082–RSIO61084); Batiza seamount, St. BG-ROV04, 1 specimen (RSIO56008); RC seamount, St. RC-ROV06, 3 specimens (RSIO56015, RSIO56016, RSIO56056); RC seamount, St. RC-ROV07, 1 specimen (RSIO56020); Caiwei guyot, St. CW-DV81, 1 specimen (RSIO35010); RE seamount, St. RE-ROV04, 14 specimens (RSIO61019, RSIO61021–RSIO61033). The vouch numbers have been changed recently, and the corresponding vouch number between this study and those used in Na et al.

(2021) were listed in Table A1.

This species was described by Na et al. (2021). In this study, more specimens from other seamounts are included, suggesting a wide distribution in the Northwest Pacific.

Habitat: Associated with various deep-sea sponge species.

Diagnosis: Disc incised interradially to almost 1/2 d.d.; disc spines spherical or conical, smooth or with a few tiny thorns at the apex; radial shields large, triangular, covering a large proportion of the disc, mostly contiguous; jaw as long as wide, with 1 apical and 4 oral papillae, cylindrical to capitate, 1–2 times as long as wide; 1 oval tentacle scale, shorter than ventral arm plate.

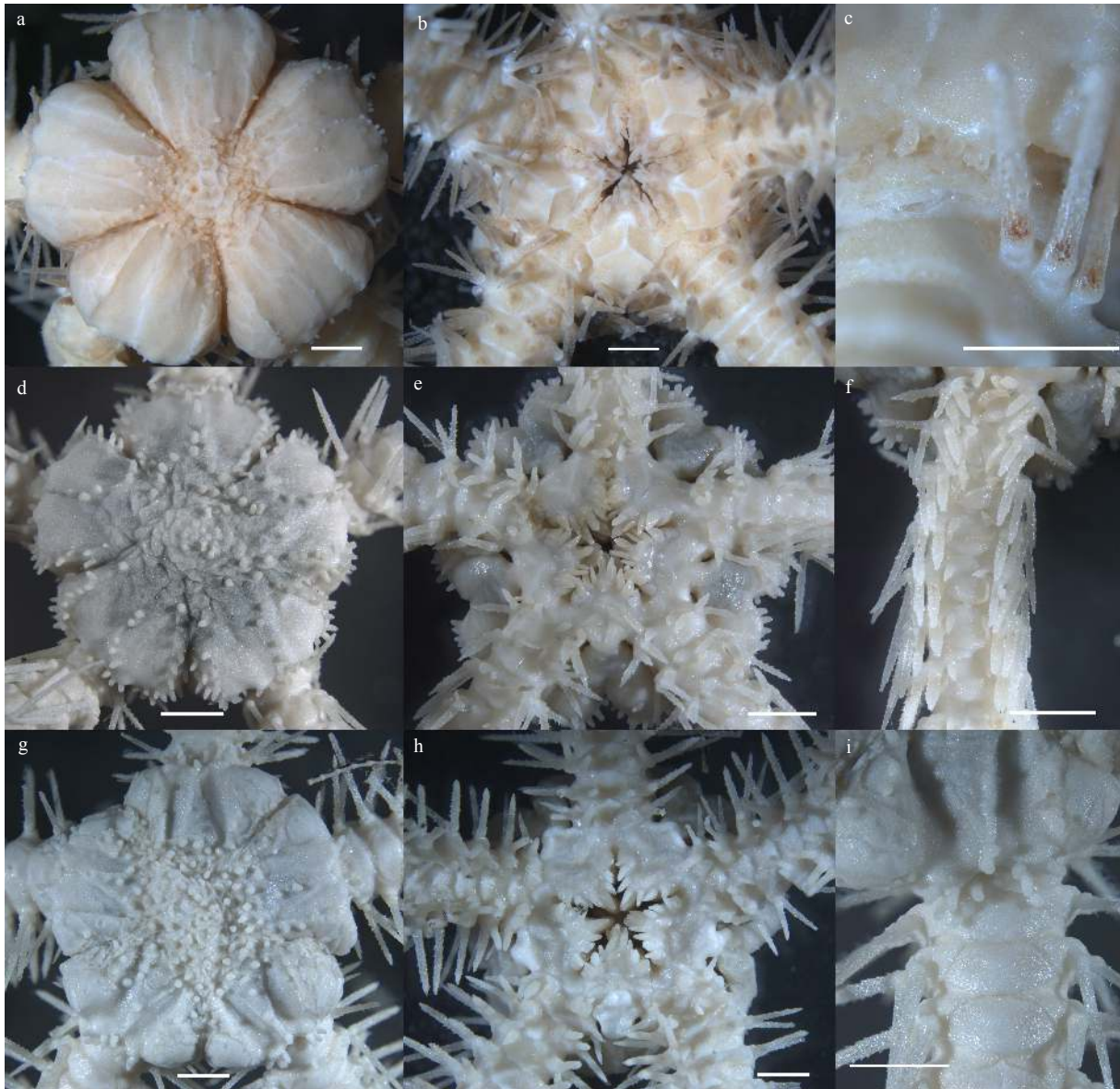
Remark: The specimens reported by Litvinova (1981) as *O. vicina* from the Marcus-Necker Seamounts in the NW Pacific also have large disc spines and contiguous radial shields, which are more similar to *O. defensor* and may belong to this species (O'Hara and Stöhr, 2006).

Distribution: Indonesia (385 m), Australia (1 024–1 816 m), New Zealand (1 876–1 853 m), Marcus-Necker seamounts (1 700–2 300 m), Weijia guyot (1 571–1 935 m), Caiwei guyot (1 660 m), Batiza seamount (1 678 m), RC seamount (1 245–1 257 m), RE seamount (2 345 m).

#### *Ophioplinthaca grandisquama* Chen, Na & Zhang, 2021

Material examined: RC seamount, St. RC-ROV05, 3 specimens (RSIO56013, RSIO56014, RSIO56060).

Habitat: All three specimens were attached to an octocoral (*Calyptraphora* sp.).



**Fig. 2.** Morphological characters of Ophiuroidea. a–c. *Ophioplinthaca athena* RSIO61064: dorsal aspect (a), ventral aspect (b), and disc granules (c) on the distal margin of disc; d–f. *Ophioplinthaca cf. clothilde* RSIO56054: dorsal aspect (d), ventral aspect (e), ventral view of arm, proximal part (f); g–i. *Ophioplinthaca* sp.2 RSIO41049: dorsal aspect (g), ventral aspect (h), disc stumps on the base of arms (i). Scale bars: 2 mm.

Disc incised interradially  $>1/5$  d.d.; disc spines stout, capitate with typically elongate to flaring head bearing numerous distinct thorns; radial shields roughly triangular,  $>1/5$  d.d. in length, contiguous distally; jaw wider than long with 3–4 lateral oral papillae and 1–2 apical papilla, conical; 1 oral tentacle scale situated between slit of jaws, slightly larger than oral papillae; 1 tentacle scale, elongated and stout.

Distribution: RC seamount (1 049 m).

***Ophioplinthaca semele* (A. H. Clark, 1949)**

*Ophiomitra semele* A. H. Clark, 1949: 20–23, Figs 8a and b

Material examined: RC seamount, St. RC-ROV08, 1 specimen (RSIO56057).

Habitat: Fine gray sand, mud and rocks (Clark, 1949); attached to a blade-like glass sponge with a sea lily.

Diagnosis: Disc slightly incised interradially to  $1/3$  d.d.; disc stumps cylindrical and swollen, up to 0.5 mm high, upper half

covered in obvious thorns; radial shields triangular,  $\sim 1/3$  d.d. in length, contiguous for  $1/3$ – $1/2$  of length; jaw as long as wide with 2–3 thin apical papillae and 4–5 lateral oral papillae, pointed,  $\leq 3$  times longer than wide, distal 2 oral papillae slightly broadened and leaf-shaped, standing vertically; 1 tentacle scale, leaf-like.

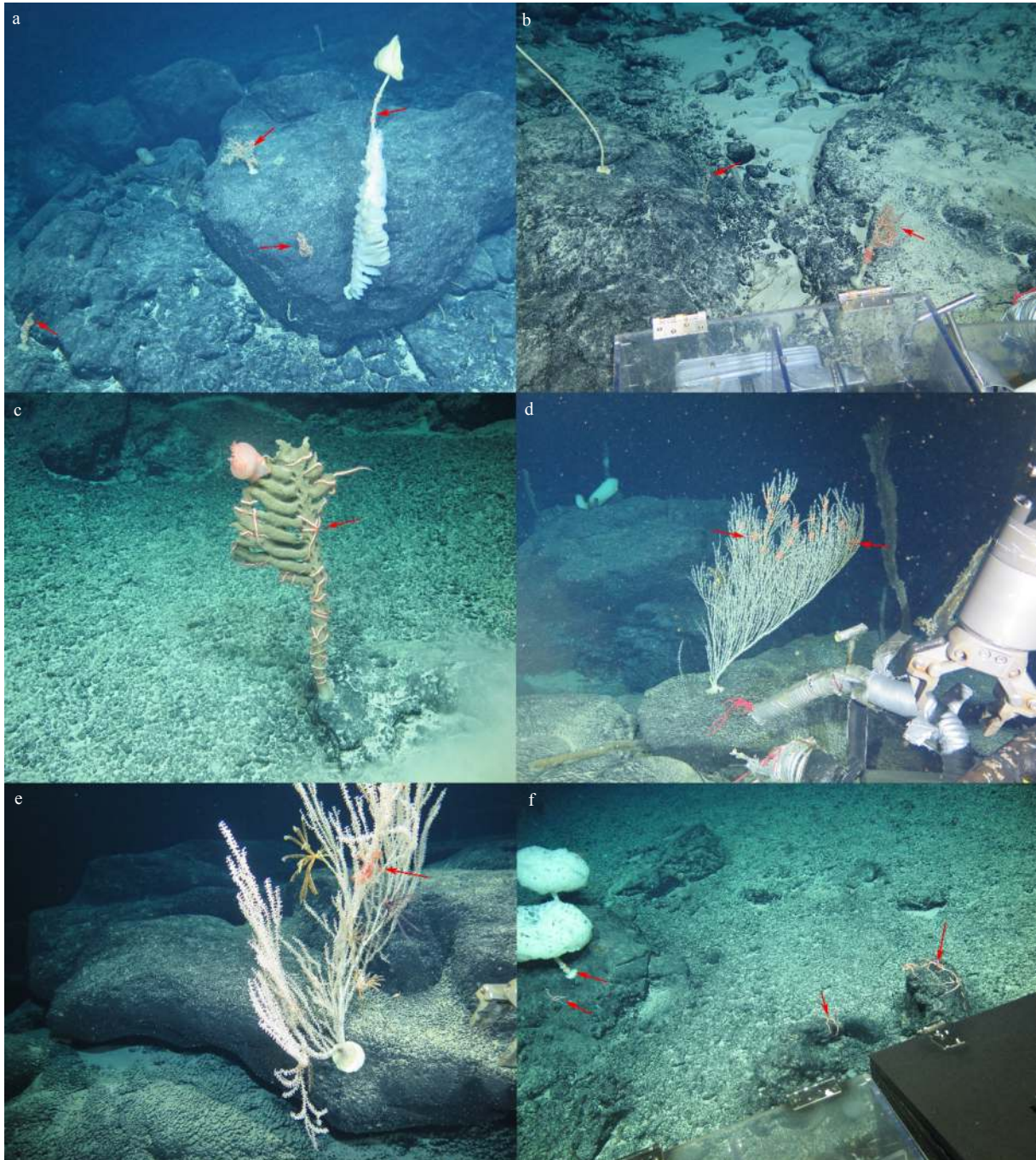
Distribution: Hawaii (101–1 251 m), RC seamount (1 042 m).

***Ophioplinthaca* sp.1**

Material examined: RC seamount, St. RC-ROV08, 1 specimen (RSIO56058).

Habitat: Attached to an octocoral (*Narella* sp.).

Diagnosis: Disc incised interradially  $1/3$  d.d.; disc spines cylindrical to capitate with a terminal crown of thorns; radial shields twice as long as wide,  $1/4$  d.d. in length, contiguous for most of length; jaw wider than long with 1 blunt apical papilla and 3 small lateral oral papillae on each side, gradually decreasing from inside to outside; 1 tentacle scale, leaf-like, thorny.



**Fig. 3.** Different sponge and coral species and crusts with Ophioplithacid species attached. a. *Bolosominae* sp. 1 and remains of *Farrea occa*, b. sponge stalk, c. the remains of *Farrea occa*, d. *Narella* sp. 1, e. *Narella* sp. 2, and f. *Bolosominae* sp. 2. Red arrows indicate *Ophioplithaca* species.

***Ophioplithaca athena* A. H. Clark, 1949 (Figs 2a–c and 3)**

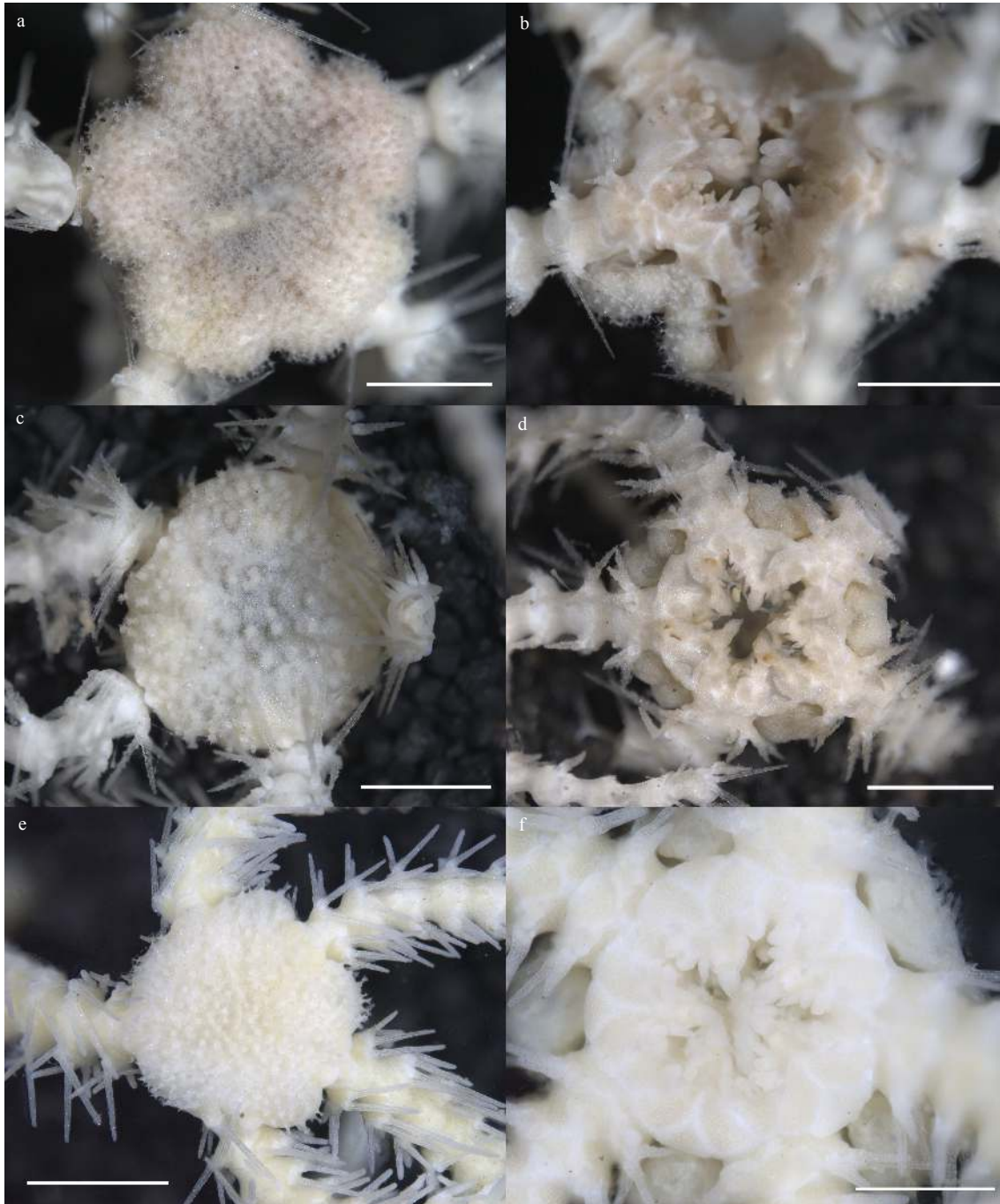
*Ophioplithaca athena* Clark, 1949: 23–24, Fig. 9.

Material examined: RC seamount, St. RC-ROV09, 9 specimens (RSIO56022–RSIO56026, RSIO56028, RSIO56029, RSIO56031, RSIO56032); RD seamount, St. RC-ROV10, 3 specimens (RSIO56035–RSIO56037); Caiwei guyot, St. CW-DV76, 3 specimens (RSIO35003–RSIO35005); Caiwei guyot, St. CW-DV80, 6 specimens (RSIO35001, RSIO35006–RSIO35009, RSIO35020); Caiwei guyot, St. CW-DV70, 2 specimens (RSIO31002, RSIO31003); RB seamount, St. RB-ROV01, 6 specimens

(RSIO61001–RSIO61004, RSIO61008, RSIO61009).

Habitat: Gray sand, mud and rocks (Clark, 1949); attached to various deep-sea sponges and coral species, or rocks (present study, Fig. 3).

Diagnosis: Disc incised interradially  $>1/3$  d.d.; disc center bears numerous granules, conical to cylindrical with a few minute flaring thorns, 0.2–0.3 mm high; granules present at margin of radial shields and extending down to base of arms with higher density than disc center; radial shields triangular, 3–3.5 times as long as wide, contiguous distally; 1 oval to leaf-shaped



**Fig. 4.** Morphological characters of Ophiuroidea. a and b. *Ophiacantha richeri* RSIO41026: dorsal aspect (a) and ventral aspect (b); c and d. *Ophiacantha* sp. 1 RSIO41015: dorsal aspect (c) and ventral aspect (d); e and f. *Ophiacantha* sp. 2 RSIO41027: dorsal aspect (e), and ventral aspect (f). Scale bars: 2 mm (a-e), 1 mm (f).

tentacle scale, almost as long as ventral arm plate.

Distribution: Hawaii (1 866–2 157 m), Caiwei guyot (2 273–2 785 m), RB seamount (2 771 m), RC seamount (2 624–2 629 m), RD seamount (2 692 m).

***Ophioplinthaca* cf. *clothilde* (Figs 2d–f and 3)**

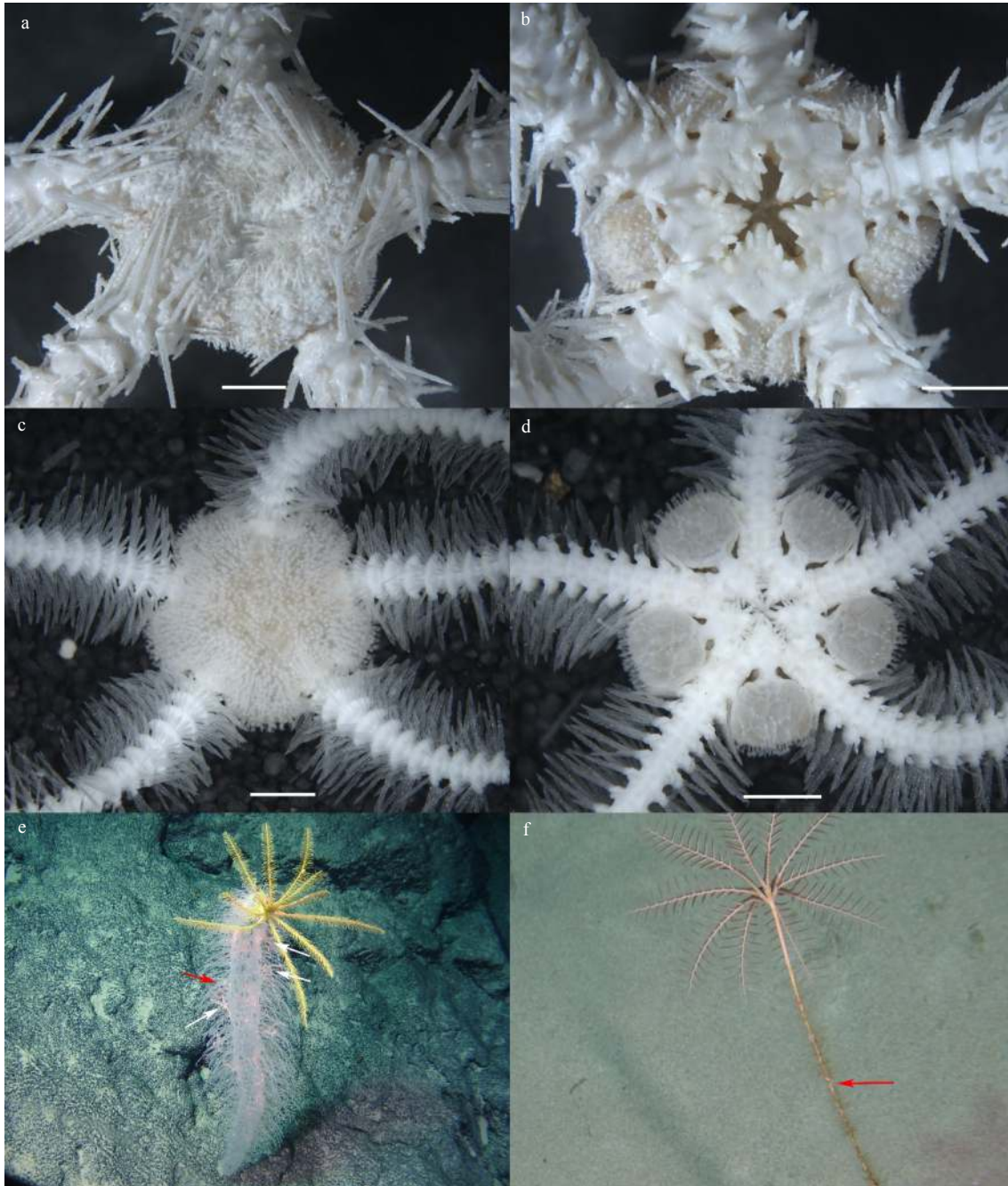
Material examined: RC seamount, St. RC-ROV09, 3 specimens (RSIO56030, RSIO56033, RSIO56059); RD seamount, St. RC-ROV12; 11 specimens (RSIO56044, RSIO56046–RSIO56055).

Habitat: Attached to various deep-sea sponges or coral species (present study).

Diagnosis: Disc slightly incised interradially to  $\sim 1/5$  d.d.; disc stumps smooth conical to cylindrical; radial shields  $\sim 1/4$  d.d. in length, scarcely depressed, contiguous distally; dorsal and ventral arm plates separated; jaw triangular, wider than long with 4–5 lateral oral papillae and 1–2 apical oral papilla, conical and pointed;  $\geq 2$  tentacle scales on the first pore, then decreased to 1 leaf-like and slightly pointed scale until near end of arm.

Distribution: Hawaiian Islands (757–1 342 m), RC seamount (2 624–2 629 m), RD seamount (2 058 m).

***Ophioplinthaca* sp. 2 (Figs 2g–i)**



**Fig. 5.** Morphological characters of Ophiuroidea. a and b. *Ophiacantha* sp. 3 RSIO35018: dorsal aspect (a) and ventral aspect (b); c and d. *Ophiacanthidae* sp. RSIO41032: dorsal aspect (c) and ventral aspect (d); e and f. photographs of *Ophiacantha* species *in situ*: *Walteria* sp. with the genus *Ophiacantha* and *Ophioleila* species attached (e) and *Bathyrinus* sp. with *Ophiacantha* species attached (f). Scale bars: 2 mm.

Material examined: Weijia guyot, St. WJ-ROV06, 1 specimen (RSIO41049).

Habitat: Attached to a sponge (*Farrea occa*).

Diagnosis: Disc incised interradially 1/5 d.d.; disc spines conical and smooth,  $\leq 0.4$  mm high; piriform radial shields slightly sunken, contiguous distally; dorsal arm plates separated except first 3 which are contiguous and armed with a few granules; jaw as long as wide with 1 apical papilla and 3–4 lateral oral papillae; 1 tentacle scale, thick and elongate with pointed end.

Distribution: Weijia guyot (1 935 m).

Remark: *Ophioplinthaca* sp. 2 is similar to the Atlantic species *O. abyssalis* [Cherbonnier and Sibuet, 1972](#) by having the continuous first three dorsal arm plates with conical disc spine, and the thick and long tentacle scales. However, due to *Ophioplinthaca* with high variable characteristic ([O'Hara and Stöhr, 2006](#)), as well as the difference in the geographical distribution, to formally name this specimen would require a major taxonomic review which is beyond the scope of the present work. Three species, *Ophioplinthaca* sp. nov., *Ophioplinthaca semele*, and *Ophioplinthaca* sp. 1, were the specifically studied in another pa-

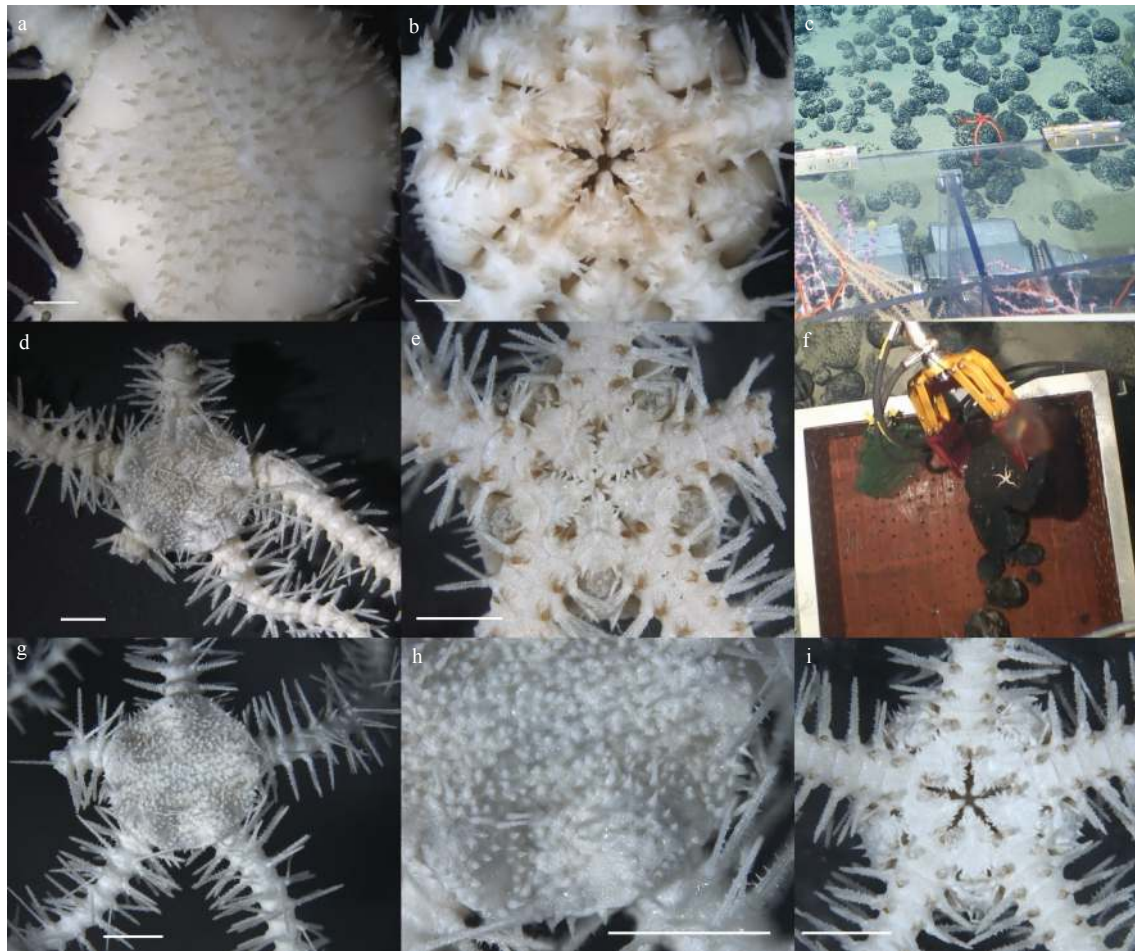


Fig. 6. Morphological characters of Ophiuroidea. a–c. *Ophiocamax* cf. *drygalskii* RSIO41013: dorsal aspect (a), ventral aspect (b), and photograph of *Ophiocamax drygalskii* in situ (c); d–f. *Ophiopristsis* sp.1 RSIO41030: dorsal aspect (d), ventral aspect (e), and photograph of *Ophiopristsis* sp.1 in situ (f); g–i. *Ophiopristsis* sp.2 RSIO61011: dorsal aspect (g), disc spines (h), and ventral aspect (i). Scale bars: 2 mm.

per (Chen et al., 2021), with detailed descriptions of their morphological characteristics. In this study, only basic information (sampling site, number of specimens, and diagnostic characteristics) are provided for further analysis of ophiuroid fauna.

#### Genus *Ophiacantha* Müller & Troschel, 1842

*Ophiacantha richeri* O'Hara & Stöhr, 2006 (Figs 4a, b and 5e)  
*Ophiacantha richeri* O'Hara & Stöhr, 2006: 48–49, Fig. 3F–H.

Material examined: Weijia guyot, St. WJ-ROV04, 1 specimen (RSIO41026); Suda seamount, St. HLIII-Dive011, 2 specimens (RSIO48002, RSIO48004).

Habitat: Attached to deep-sea sponge or coral species, usually together with *Ophioleila elegans* (present study).

Diagnosis: Disc petaloid, incised interradially, covered by dense spines; disc spines small with slender pedicel that branches at  $>1/2$  spine height into 3 terminal thorns, thorns bifurcated near tip; oral shields rhomboid, twice as wide as long, larger than adoral shields; adoral shields with distal extensions that extend around lateral angle of oral shields; 3 lateral oral papillae, outer distal oral papillae leaf-shaped; arms moniliform, arm spines thorny,  $\leq 6$ ; 1 oval tentacle scale with thorny end.

Distribution: New Caledonia (750–1 740 m), Weijia guyot (1 571 m), Suda seamount (2 294 m).

#### *Ophiacantha* sp. 1 (Figs 4c and d)

Material examined: Weijia guyot, St. WJ-ROV02, 1 specimen

(RSIO41015); Weijia guyot, St. WJ-Dive105, 2 specimens (RSIO37001, RSIO37002); Batiza seamount, St. BG-ROV04, 1 specimen (RSIO56011); RC seamount, St. RC-ROV09, 1 specimen (RSIO56027); RD seamount, St. RC-ROV10, 6 specimens (RSIO56034, RSIO56038–RSIO56042); RB seamount, St. RB-ROV01, 3 specimens (RSIO61005–RSIO61007).

Habitat: Attached to deep-sea sponge or coral species.

Diagnosis: Disc round, covered in thin overlapping plates bearing a single spine; spine a small stump (0.2 mm high) with angular stem and expanded convex apex bearing 8–12 divergent short thorns; oral shields rhombic to triangular, wider than long; adoral shields long, separating oral shield from arm plate; 3 lateral oral papillae; arm moniliform, dorsal and ventral arm plates widely separate,  $\leq 6$  arm spines, thorny, the uppermost longest, 1 long leaf-like tentacle scale with thorny tip.

#### *Ophiacantha* sp. 2 (Figs 4e and f)

Material examined: Weijia guyot, St. WJ-ROV04, 2 specimens (RSIO41016 and RSIO41027); Weijia guyot, St. WJ-ROV12, 1 specimen (RSIO61075); RA seamount, St. RA-ROV01, 1 specimen (RSIO56005).

Habitat: Attached to deep-sea sponge or coral species.

Diagnosis: Disc round, covered by dense spines; Spines elongate stumps (0.2 mm high) with angular stem and 2–6, usually 3, long fine terminal thorns; distal tips of radial shields ex-



**Fig. 7.** Morphological characters of Ophiuroidea. a-c. *Asteroschema horridum* RSIO56002: dorsal aspect (a), ventral aspect (b), and dorsal view of arm, proximal part (c); d-f. *Asteroschema sublaeve* RSIO56007: dorsal aspect (d), ventral aspect (e), and ventral view of arm, proximal part (f); g-i. *Asteroschema ajax* RSIO51001: dorsal aspect (g), ventral aspect (h), and ventral view of arm, proximal part (i); j-l. *Asteroschema cf. intactum* RSIO48001: dorsal aspect (j), ventral aspect (k), and ventral view of arm, proximal part (l). Scale bars: 2 mm.

posed, widely separate; oral shields triangular, wider than long; adoral shields short, not separating oral shield from arm plate; 3 lateral oral papillae, distal one enlarged and rectangular; arm slightly moniliform, dorsal and ventral arm plates separate,  $\leq 7$  arm spines, nearly smooth, the uppermost longest; 1 small oval tentacle scale.

***Ophiacantha* sp. 3 (Figs 5a, b and f)**

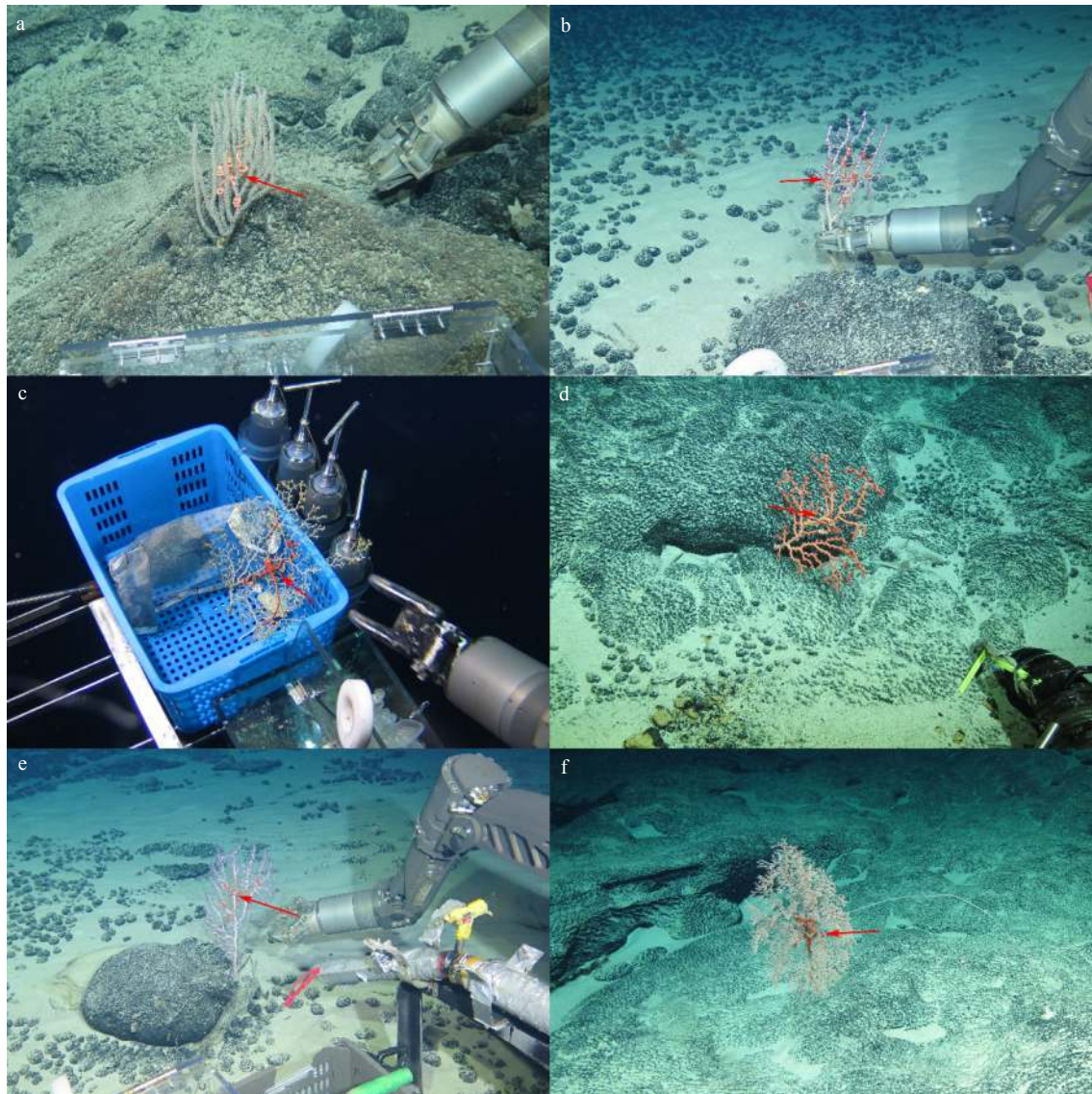
Material examined: Weijia guyot, St. WJ-ROV01, 1 specimen (RSIO41011); Weijia guyot, St. WJ-ROV12, 1 specimen (RSIO61081); Caiwei guyot, St. CW-DV81, 1 specimen (RSIO35018).

Habitat: Attached to corals or crinoids.

Diagnosis: Disc covered by dense spines; 2 types of spines; first typically delicate with long slender pedicel and 2-6 long fine

curved terminal thorns, 0.2-0.4 mm long, diminishing in size on margin and ventral surface of disc; second long and slender, 0.5-0.7 mm long,  $>7$  times as long as wide, sometimes in combination with thorny spines; oral shields wider than long, adoral shields short, not separating oral shield from arm plate; 3 lateral oral papillae, distal one irregular and not enlarged; arm slightly moniliform, arm spines relatively smooth, almost meeting on dorsal midline,  $\leq 6$  arm spines, 1 leaf-shaped thorny tentacle scale.

Remark: *Ophiacantha* is one of the largest genera and ill-defined, containing several groups of species that probably deserve their own genus and many other species that are difficult to place taxonomically (O'Hara and Stöhr, 2006). Though there are a number of characters which appear to be unique and undes-



**Fig. 8.** Different coral species with Euryalid species attached. a. *Calyptophora* sp., b. *Victrogorgia* sp., c. *Plexauridae* sp., d. *Paragorgia* sp., e. *Victrogorgia* sp., and f. *Ophiocreas oedipus* associated with *Metallogorgia melanotrichos*. Red arrows indicate Euryalid species.

cribed in these specimens, we prefer not to attach name to those specimens.

***Ophiacanthidae* sp. (Figs 5c and d)**

Material examined: Weijia guyot, St. WJ-ROV05, 2 specimens (RSIO41032, RSIO41050).

Habitat: Attached to deep-sea sponges.

Diagnosis: Disc round, covered by dense elongate spines (0.2 mm high) with slender stem and expanded convex apex bearing 8–12 long divergent thorns; distal tips of radial shields exposed, widely separated; oral shields rhombic with a truncate distal lobe, longer than wide; adoral shields long, separating oral shield from arm plate; 1 dental papillae and 5 lateral oral papillae, distal ones not enlarged and leaf-shaped;  $\leq 12$  arm spines, thorny, meeting above arm, the lowest hook-like; 1 tentacle scale, small and oval.

**Family Ophiocamacidae O'Hara, Stöhr, Hugall, Thuy, Martynov, 2018**

**Genus *Ophiocamax* Lyman, 1878**

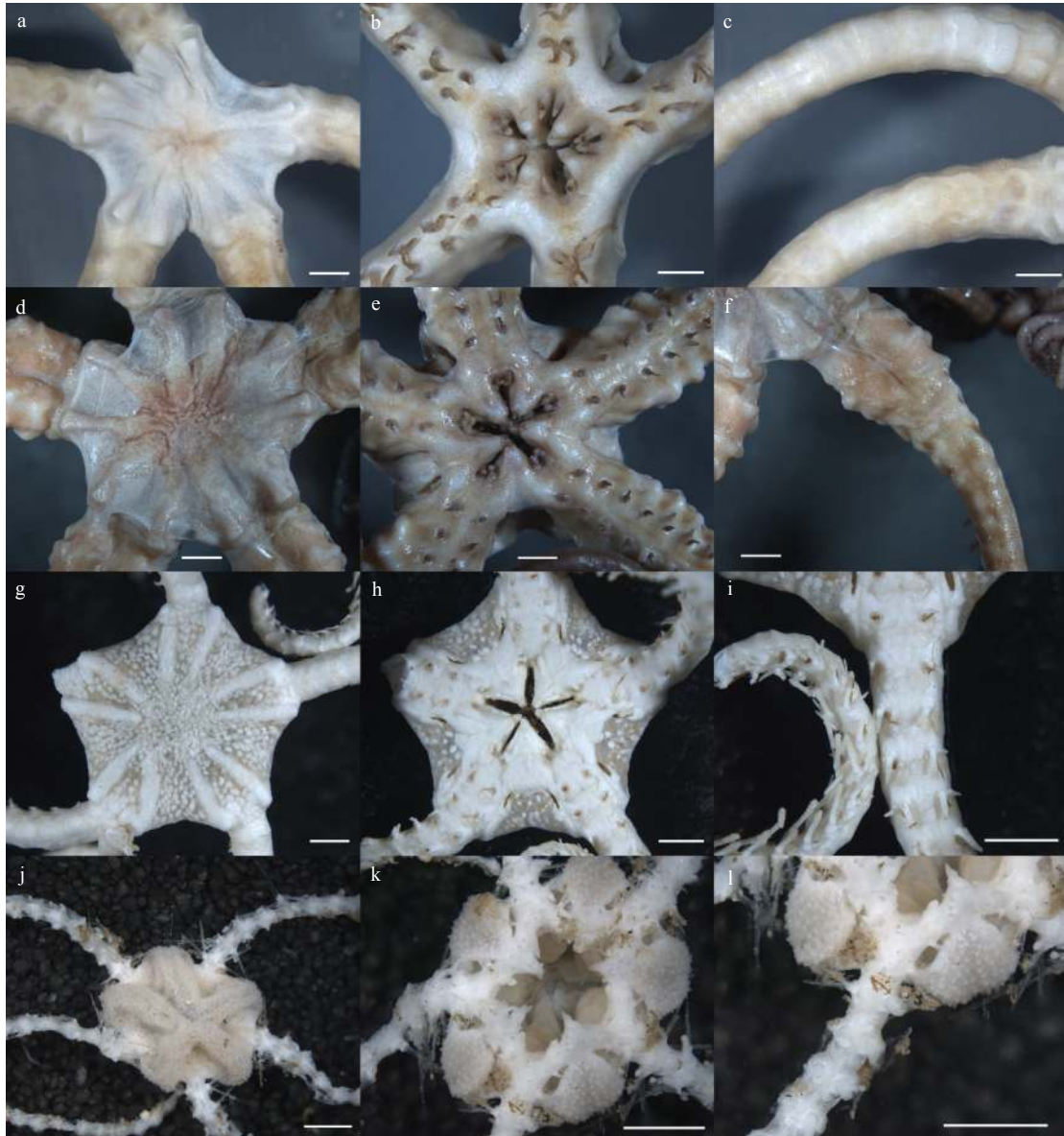
***Ophiocamax* cf. *drygalskii* Hertz, 1927 (Figs 6a–c)**

*Ophiocamax drygalskii* Hertz, 1927: 41–42, pl. 9, Figs 3–5.

Material examined: Weijia guyot, St. WJ-ROV01, 1 specimen (RSIO41013); Batiza seamount, St. BG-ROV04, 1 specimen (RSIO56009); Weijia guyot, St. WJ-ROV12, 2 specimens (RSIO61071, RSIO61078); RE seamount, St. RE-ROV04, 6 specimens (RSIO61014–RSIO61018, RSIO61020).

Habitat: All specimens were found attached to pieces of ore, sometimes together with *Ophiopristis* sp. 1 (present study, Fig. 6c).

Diagnosis: Disc round, bearing short thorny spines; spines generally more pointed in disc center; radial shields exposed, 1/4–1/5 d.d. in length, broadly contiguous; oral shield hour-glass-shaped, varied from longer than wide with very elongated proximal part to wider than long with round proximal angle, bearing short tubercle-like papillae; jaw as long as wide bearing 1–2 apical papillae and numerous smooth spiniform lateral papillae, generally clustered around oral tentacle pore;  $\leq 6$  arm spines, thorny; cluster of 3–4 elongate smooth tentacle scales projecting upward around basal pores, 1 scale distally, basal papillae perfectly resemble oral papillae, the latter rapidly adapt



**Fig. 9.** Morphological characters of Ophiuroidea. a-c. *Asteroschema* sp. RSIO56006: dorsal and aspect (a), ventral aspect (b), and dorsal view of arm, proximal part (c); d-f. *Ophiocreas oedipus* RSIO51004: dorsal aspect (d), ventral aspect (e), and dorsal view of arm, proximal part (f); g-i. *Astrodia* sp. RSIO31004: dorsal aspect (g), ventral aspect (h), and ventral view of arm, proximal part (i); j-l. *Ophioscolecida* sp. RSIO56045: dorsal aspect (j), ventral aspect (k), and ventral view of arm, proximal part (l). Scale bars: 2 mm.

their size and become pointed.

Distribution: Antarctica (2 450 m), Weijia guyot (1 670-1 839 m), RE seamount (2 345 m), Batiza seamount (1 653 m).

Remark: From the geographically closest species *O. vitrea* Lyman, 1878 (the common Indo-West Pacific species which was recently shown as being very polymorphic) (O'Hara and Stöhr, 2006), our materials differ in the following characters: radial shields are relatively small (about 1/4 of the disk diameter in our materials and usually 1/3 in *O. vitrea*); the number of arm spines are relatively small ( $\leq 6$  arm spines in our materials and usually up to 10 in *O. vitrea*). The water depth distribution of *O. vitrea* is usually above 1 000 m, while our materials were collected at depths of 1 670-2 345 m. The other Indo-West Pacific species *O. nominata* can be distinguished from our materials by the short wide radial shields, the stout disc spines with two tiers of thorns,

the thorny oral papillae and spines in the oral shield. *Ophiocamax applicatus* Koehler, 1922 described off Tasmania, Australia differs in having small radial shield covered by pointed spines, relatively small and triangular oral shield, thorny oral papilla, proximally contiguous triangular dorsal and ventral arm plates. Our materials are consistent with *Ophiocamax drygalskii* Hertz, 1927 (first described off Southern Ocean), having numerous short disc spines with few denticles at the top or along their sides, exposed radial shields about 1/4-1/5 d.d. in length, smooth oral papillae, oral shield hour-glass-shaped and  $\leq 7$  arm spines. Due to the differences in geographic distribution, we tentatively designate this species as *O. cf. drygalskii* to avoid biases caused by cryptic species or intraspecific variation.

**Family Ophiotomidae Paterson, 1985**

**Genus *Ophiopristis* Verrill, 1899**

***Ophiopristis* sp. 1 (Figs 6d–f)**

Material examined: Weijia guyot, St. WJ-ROV05, 1 specimen (RSIO41030).

Habitat: This specimen was found attached to a piece of ore together with *Ophiocamax* cf. *drygalskii*.

Diagnosis: Disc spines rugose with pointed spine; radial shields exposed, triangular, 1/6 d.d. in length; jaws longer than broad with 2 apical papillae and 3–4 pointed oral papillae; second oral tentacle pore emerges superficially onto oral surface; 2 leaf-like tentacle scales associated with pores; arm spines flattened, carry a row of sharp points along each edge; proximal tentacle pores armed with 2–3 sub-equal tentacle scales, scales reduce to 1 large leaf-like scale further along arm.

Distribution: Weijia guyot (1 841–1 955 m).

***Ophiopristis* sp. 2 (Figs 6g–i)**

Material examined: RE seamount, St. RE-ROV03, 1 specimen (RSIO61011).

Habitat: Attached to a piece of ore.

Diagnosis: Disc round, covered with thin plates bearing long spines and conical granules, rugose with pointed spire; radial shields exposed, triangular, 1/7 d.d. in length; adoral shield long and narrow, separating oral shield from first lateral arm plate; jaws longer than broad with 2 apical papillae and 3 pointed oral papillae; second oral tentacle pore emerges superficially onto oral surface, 2–3 rounded tentacle scales associated with pores; arm spines flattened, carry a row of sharp points along each edge; ventral arm plates pentagonal, distal edge concave in the middle, separated from each other; proximal tentacle pores armed with 2–3 sub-equal tentacle scales, scales reduce to 1 large leaf-like scale further along arm.

Distribution: RE seamount (1 188 m)

Remark: The two species share with the genus *Ophiopristis* the flattened and rugose arm spines, separated oral and second tentacle papillae. However, the emergent radial shields, thorny disc spines, the arrangement of the oral papillae and second oral tentacle scales are unusual. Since only one specimen was collected for each of them, we have not formally classified them.

**Order Euryalida Lamarck, 1816****Family Euryalidae Gray, 1840****Genus *Asteroschema* Örstedt in Lütken, 1856*****Asteroschema horridum* Lyman, 1879 (Figs 7a–c and 8a)**

*Asteroschema horridum* Lyman 1879: 66, pl. 17, Figs 458–461.

Material examined: RA seamount, St. RA-ROV01, 2 specimens (RSIO56001, RSIO56002); RC seamount, St. RC-ROV07, 1 specimen (RSIO56019); RE seamount, St. RE-ROV03, 3 specimens (RSIO61010, RSIO61012, RSIO61013).

Habitat: Associated with octocoral (*Calyptrophora* sp.) (present study, Fig. 8a).

Diagnosis: Disc and arms covered by skin with small, dense, distinctly conical epidermal ossicles on aboral side and minute hemispherical granular ossicles on oral side; conical ossicles bearing terminal thorns at tips; radial shields narrow elongated paired structures at base of arm, appearing to converge but not meeting centrally; first tentacle pore without arm spines, single spine present in second arm segments, 2 arm spines from sixth arm segment; inner spine large, twice the length of arm segment in middle of arm and bearing distinct thorny projections in the last 1/5 of distal end.

Distribution: New Zealand (643–1 165 m), New Caledonia (1 140 m), RA seamount (1 084–1 086 m), RC seamount (1 257 m), RE seamount (2 345 m).

***Asteroschema sublaeve* Lütken & Mortensen, 1899 (Figs 7d–f and 8b)**

*Asteroschema sublaeve* Lütken & Mortensen, 1899: 187–188, pl. 22, Figs 13 and 14.

Material examined: Batiza seamount, St. BG-ROV04, 1 specimen (RSIO56007).

Habitat: Associated with octocoral (*Victorgorgia* sp.) (present study, Fig. 8b).

Diagnosis: Disc and arms covered by skin with small, dense, granule-shaped epidermal ossicles on aboral side and plate-shaped ossicles on oral side; granule ossicles slightly rounded and convex at center; plate-shaped dermal ossicles flat and thick; radial shields narrow elongated paired structures at base of arm, converge and almost meet centrally; first tentacle pore without arm spines, single spine present in second arm segments, 2 arm spines from the 13th or 17th arm segment; inner spine large, twice the length of arm segment in middle of arm and bearing distinct thorny projections on the top 1/2–2/3.

Distribution: East Pacific (605–1 271 m), Batiza seamount (1 660 m).

***Asteroschema ajax* A. H. Clark, 1949 (Figs 7g–i and 8c)**

*Asteroschema ajax* A. H. Clark, 1949: 11–13, Fig. 3b.

Material examined: Caiwei guyot, St. CW-DV81, 1 specimen (RSIO35016); Weijia guyot, St. WJ-ROV09, 1 specimen (RSIO51001).

Habitat: Associated with octocoral (*Plexauridae* sp.) (present study, Fig. 8c).

Diagnosis: Disc and arms covered by skin with small, dense, granule-shaped epidermal ossicles on aboral side and plate-shaped ossicles on oral side; granule ossicles slightly rounded and convex at center, bearing divergent thorns; plate-shaped dermal ossicles flat and thick; radial shields narrow elongate paired structures at base of arm, converge and almost meet centrally; the first 10 or 12 arm segments expanded; first tentacle pore without arm spines, single spine present in second arm segments, 2 arm spines from third arm segment; inner spine large, twice length of arm segment in middle of arm, bears short thorny projections in the top 1/2–2/3.

Distribution: New Zealand (1 664–1 920 m), Australia (763 m), Hawaii (49–966 m), Caiwei guyot (1 660 m), Weijia guyot (1 740 m).

***Asteroschema* cf. *intectum* Lyman, 1878 (Figs 7j–l and 8d)**

*Asteroschema intectum* Lyman 1878: 235, pl. 3, figs 59–61.

Material examined: Suda seamount, St. HLIH-Dive011, 1 specimen (RSIO48001).

Habitat: Associated with octocoral (*Paragorgia* sp.) (present study, Fig. 8d).

Diagnosis: Disc and arms covered by skin with small, dense, granule-shaped epidermal ossicles on aboral side and plate-shaped ossicles on oral side; granule ossicles slightly rounded and convex at center; plate-shaped dermal ossicles flat and thick; radial shields narrow elongated paired structures at base of arm, converge and meet centrally; first and second tentacle pores without arm spines, single spine present in third arm segments, 2 arm spines from the 18th arm segment; inner spine large, one and a half times length of arm segment in middle of arm, bears long divergent thorny projections in the top 1/2.

Distribution: Gulf of Mexico (55–2 195 m), Japan (728 m), Suda seamount (2 294 m).

Remark: *Asteroschema intectum* Lyman, 1878 firstly described off Moscow Bay is defined by the long and slender arm, granulated above, but naked on the sides and under surface. Later this species was also reported in Japan, but no specific morphological description (Okanishi and Fujita, 2013). We examined the specimen in this study and found that the shape of the radial shield and the distribution of granule ossicles were in line with the *A.*

*intectum*. However, due to the differences in geographic distribution and insufficient description in early literature, we tentatively designate this species as *A. cf. intectum* for supplementary research in the future.

***Asteroschema* sp. (Figs 8e and 9a–c)**

Material examined: BG seamount, St. BG-ROV04, 1 specimen (RSIO56006).

Habitat: Associated with octocoral (*Victrogorgia* sp.) (present study, Fig. 8e).

Diagnosis: Disc and arms covered by skin with small, dense, granule-shaped epidermal ossicles on aboral side and plate-shaped ossicles on oral side; granule ossicles slightly rounded and convex at center; plate-shaped dermal ossicles flat and thick; radial shields narrow elongated paired structures at base of arm, converge but not meet centrally; first tentacle pore without arm spines, single spine present in second arm segments, 2 arm spines from 13th or 17th arm segment; inner spine thick, as long as arm segment in middle of arm, bears distinct thorny projections in the top 1/2.

Remark: This specimen is consistent with most characteristics of *Asteroschema intectum*, but still can be distinguished by the shape of radial shields and the number of arm spines. In the original literature, the author only described the external morphological characteristic but not the internal skeleton and arm spines.

**Genus *Ophiocreas* Lyman, 1879**

***Ophiocreas oedipus* Lyman, 1879 (Figs 8f and 9d–f)**

*Ophiocreas oedipus* Lyman, 1879: 65–66, pl. 16, Figs 443–446.

Material examined: Weijia guyot, St. WJ-ROV01, 1 specimen (RSIO41001); Weijia guyot, St. WJ-ROV12, 1 specimen (RSIO61070); Weijia guyot, St. WJ-ROV12, 1 specimen (RSIO51004).

Habitat: Obligately associated with an octocoral (*Metallogorgia melanotrichos*) (Cho, 2008; Mosher and Watling, 2009; present study, Fig. 8f).

Diagnosis: Disc and arms covered with thick skin without external ossicles; arms not branched, about 20 times dd, slender except at base, base heavily swollen for first 6–7 arm segments.

Distribution: New Zealand (551–1 644 m), North Atlantic (1 968–2 228 m), southeast Atlantic (1 200 m), Australia (805–1 169 m), New Caledonia (350–1 600 m), New Zealand (617–1 771 m), Weijia guyot (1 670–1 703 m).

**Family Asteronychidae Ljungman, 1867**

**Genus *Astrodia* Verrill, 1899**

***Astrodia* sp. (Figs 9g–i)**

Material examined: Caiwei guyot, St. CW-DV83, 4 specimens (RSIO35002, RSIO35012–RSIO35014); Caiwei guyot, St. CW-DV72, 1 specimen (RSIO31004).

Habitat: Attached to sponges.

Diagnosis: Disc pentagonal with slightly notched interradial edges; external ossicles plate-shaped, in contact with aboral disc and separated on periphery; lateral interradial disc surface covered by naked skin, several granules scattered on periphery, short genital slits on lateral disc, approximately 1/3–1/4 height of disc; lateral arm plates oblong, do not project from arm surface on middle to distal portion of arms.

Remark: *Astrodia* is currently composed of four species, *A. abyssicola* (Lyman, 1879), *A. excavata* (Lütken & Mortensen, 1899), *A. plana* (Lütken & Mortensen, 1899) and *A. tenuispina* (Verrill, 1884). This specimen can be distinguished from the four species by external ossicles plate-shaped and short genital slits.

**Order Ophiroscolecida O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017**

***Ophiroscolecida* sp. (Figs 9j–i)**

Material examined: RD seamount, St. RC-ROV12, 1 specimen (RSIO56045).

Habitat: Attached to a sponge.

Diagnosis: Dorsal disc and arms with thickened skin, thin glassy disc scales, scattered dense conical granules; radial shields narrow, concealed by disc scales; oral plates tumid proximally, with 1 apical papilla and 4 lateral oral papillae, lie flattened in distal direction; arms moniliform; arm spines glassy and long.

Remark: This specimen is possibly a juvenile, which is difficult to identify. Through the inspection of the families Ophiophelidae and Ophiroscolecidae, our specimen is different from the existing species, so it was classified into order level, more studies are needed to identify it to lower taxonomic level.

**Order Amphilepidida O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017**

**Suborder Gnathophiurina Matsumoto, 1915**

**Superfamily Ophiactoidea Ljungman, 1867**

**Family Ophiothamnidae O'Hara, Stöhr, Hugall, Thuy, Martynov, 2018**

**Genus *Ophioleila* A. H. Clark, 1949**

***Ophioleila elegans* A. H. Clark, 1949**

*Ophioleila elegans* A. H. Clark, 1949: Figs 2a–f and 3a–j.

Material examined: Weijia guyot, St. WJ-ROV01, 1 specimen (RSIO41012); Weijia guyot, St. WJ-ROV04, 7 specimens (RSIO41018–RSIO41020, RSIO41023, RSIO41024, RSIO41028, RSIO41029); Batiza seamount, St. BG-ROV04, 1 specimen (RSIO56010); RC seamount, St. RC-ROV08, 2 specimens (RSIO56021, RSIO56043); Caiwei guyot, St. CW-DV81, 4 specimens (RSIO35011, RSIO35015, RSIO35017, RSIO35019); Weijia guyot, St. WJ-ROV12, 1 specimen (RSIO51002); Suda seamount, St. HLIII-Dive011, 2 specimens (RSIO48006–RSIO48007); Weijia guyot, St. WJ-ROV12, 2 specimens (RSIO61076, RSIO61077).

Habitat: Associated with glass sponges and might be epizoic at depths of 1 300–1 800 m (Zhang et al., 2018).

Diagnosis: Ten enlarged swollen lobes, sack-shaped, longer than wide, curve around disc edge, covering most of the disc; lobes covered by imbricated scales bearing cylindrical or conical granules with terminal crown of thorns; adoral shields enlarged, separate oral shields from first lateral arm plates, bear 2 cylindrical or subconical oral papillae along proximal side, distal one protects external oral tentacle pore; jaw as long as wide with cluster of 3–5 oral or tooth papilla;  $\leq 7$  arm spines, short and thorny.

Distribution: Hawaii (748–1 342 m), Weijia guyot (1 571–1 703 m), Caiwei guyot (1 660 m), Batiza seamount (1 660 m), RC seamount (1 146 m), Suda seamount (2 294 m).

**Superfamily Amphiuroidae Ljungman, 1867**

**Family Amphiuroidae Ljungman, 1867**

**Genus *Amphiura* Forbes, 1843**

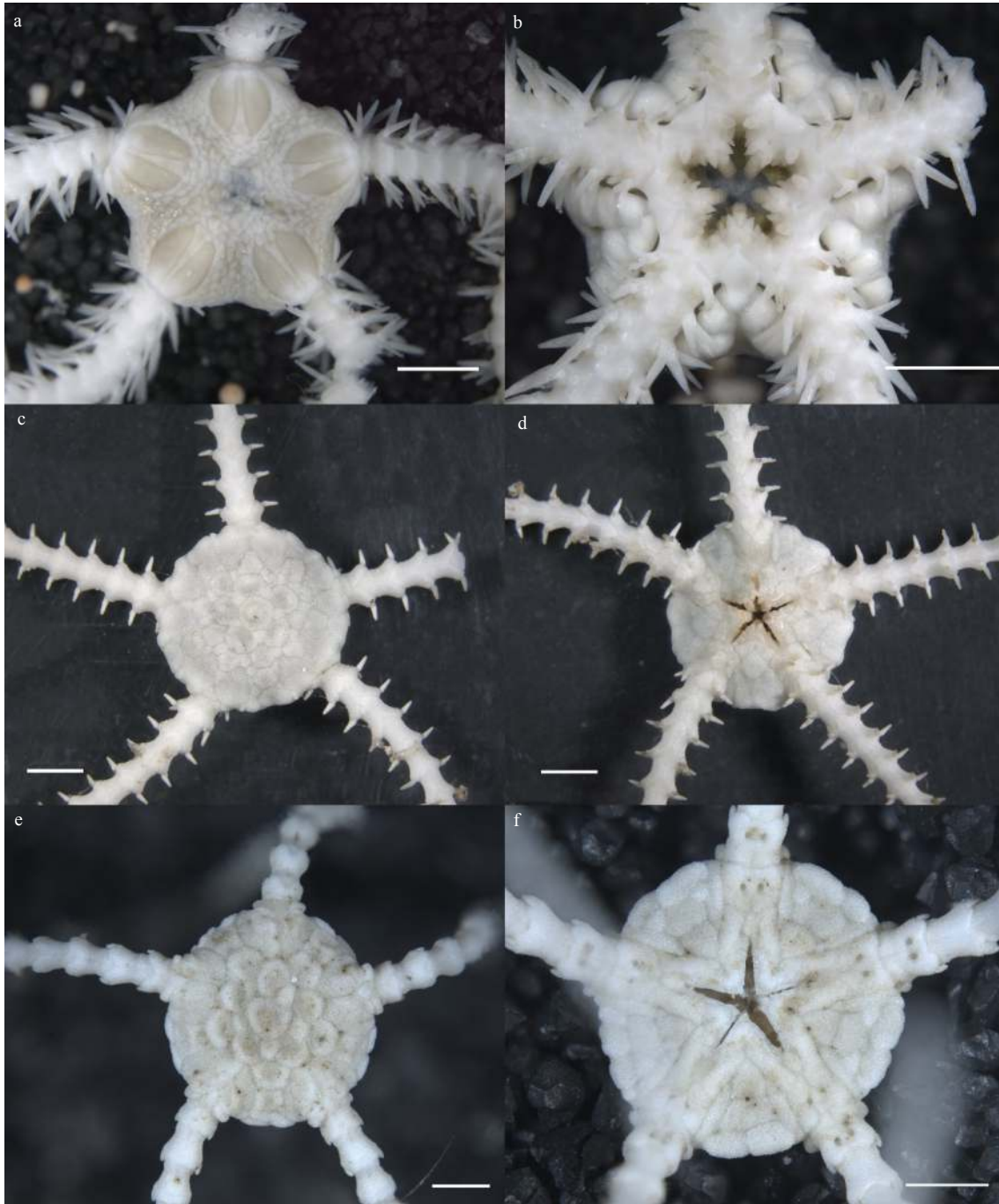
***Amphiura cf. grandisquama* Lyman, 1869 (Figs 10a and b)**

*Amphiura grandisquama* Lyman, 1869: 334–336.

Material examined: Weijia guyot, St. WJ-ROV02, 1 specimen (RSIO41014).

Habitat: dwelling in a dead sponge.

Diagnosis: Disc pentagonal with slightly notched interradial edges,  $\sim 11$  scales from center to interradial margin; radial shields 2.5 times as long as wide, proximally divergent, separated by a row of plates; adoral shields narrow and long, separating oral shields from first lateral arm plates; 2 infradental papillae on the top and two lateral oral papillae on each sides, inner papilla conical and small, outer ones large, rounded or triangular, flattened on adoral plate; dorsal and ventral arm plates just contiguous;  $\leq 5$  arm spines basally, cylindrical with blunt rounded tip, the



**Fig. 10.** Morphological characters of Ophiuroidea. a and b. *Amphiura* cf. *grandisquama* RSIO41014: dorsal aspect (a) and ventral aspect (b); c and d. *Ophiozonella* sp. RSIO56003: dorsal aspect (c) and ventral aspect (d); e–f. *Ophiomusa* sp. RSIO56004: dorsal aspect (e) and ventral aspect (f). Scale bars: 2 mm.

lowest longest and thickest; 1 round and large tentacle scale.

Distribution: West Atlantic (450–1 174 m), Philippines (452–686 m), Australia (494 m), Gulf of Mexico (20–1 635 m), East Atlantic (494–690 m), Gulf of Guinea (410–478 m), Weijia guyot (1 995 m).

**Suborder Ophionereidina O’Hara, Hugall, Thuy, Stöhr & Martynov, 2017**

**Superfamily Ophiolepidioidea Ljungman, 1867**

**Family Hemieuryalidae Verrill, 1899**

**Genus *Ophiozonella* Matsumoto, 1915**

***Ophiozonella* sp. (Figs 10c and d)**

Material examined: RA seamount, St. RA-ROV01, 1 specimen (RSIO56003).

Habitat: Attached to a sponge.

Diagnosis: Disc flat, covered by plates, neither granules nor spines, primaries slightly larger than other plates, approximately 5 scales from center to interradial margin; radial shields triangular, slightly longer than wide, distally contiguous; ventral interradial covered by 4 large plates and 1 enlarged oral shield; genital slits short, approximately 1/3 height of disc; jaws small with 4

quadrilateral oral papillae on each side; arm moniliform, with dorsal and ventral plates widely separated; 2 short arm spines on the ventral side of LAPs, 1 oval tentacle scale.

Remark: This specimen is consistent with most characteristics of *Ophiozonella media* Koehler, 1904, but still can be distinguished by the position of radial shields and the number of oral papillae.

**Order Ophiurida Müller & Troschel, 1840 sensu O'Hara et al., 2017**

**Suborder Ophiomusina O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017**

**Family Ophiomusaidae O'Hara, Stöhr, Hugall, Thuy & Martynov, 2018**

**Genus *Ophiomusa* Hertz, 1927**

***Ophiomusa* sp. (Figs 10e and f)**

Material examined: RA seamount, St. RA-ROV01, 1 specimen (RSIO56004); Suda seamount, St. HLIII-Dive011, 1 specimen (RSIO48005).

Habitat: Fine-grained muddy sediments.

Diagnosis: Disc flat, covered by plates, neither granules nor spines, primaries a little larger than other plates, ~5 scales from center to interradial margin; radial shields small, broadly contiguous, but at the distal end separated by a small triangular plate; oral shields with straight distal side, up to 7 plates between them and disc margin; arm moniliform, dorsal arm plate minute, triangular very widely separated; only two ventral arm plates; 3 arm spines; 2 visible proximal pairs of tentacle pores.

Remark: This specimen has the appearance of a juvenile *Ophiomusa*, with two visible proximal pairs of tentacle pores. It has 7 plates between the oral shield and disc margin, which is different from most species of *Ophiomusa*.

**Suborder Ophiurina Müller & Troschel, 1840 sensu O'Hara et al., 2017**

**Family Ophiopyrgidae Perrier, 1893**

**Genus *Ophiuroglypha* Hertz, 1927**

***Ophiuroglypha irrorata* (Lyman, 1878) (Figs 11a and b)**

*Ophiuroglypha irrorate* Lyman, 1878: 73–74, pl. 9, Figs 106–108.

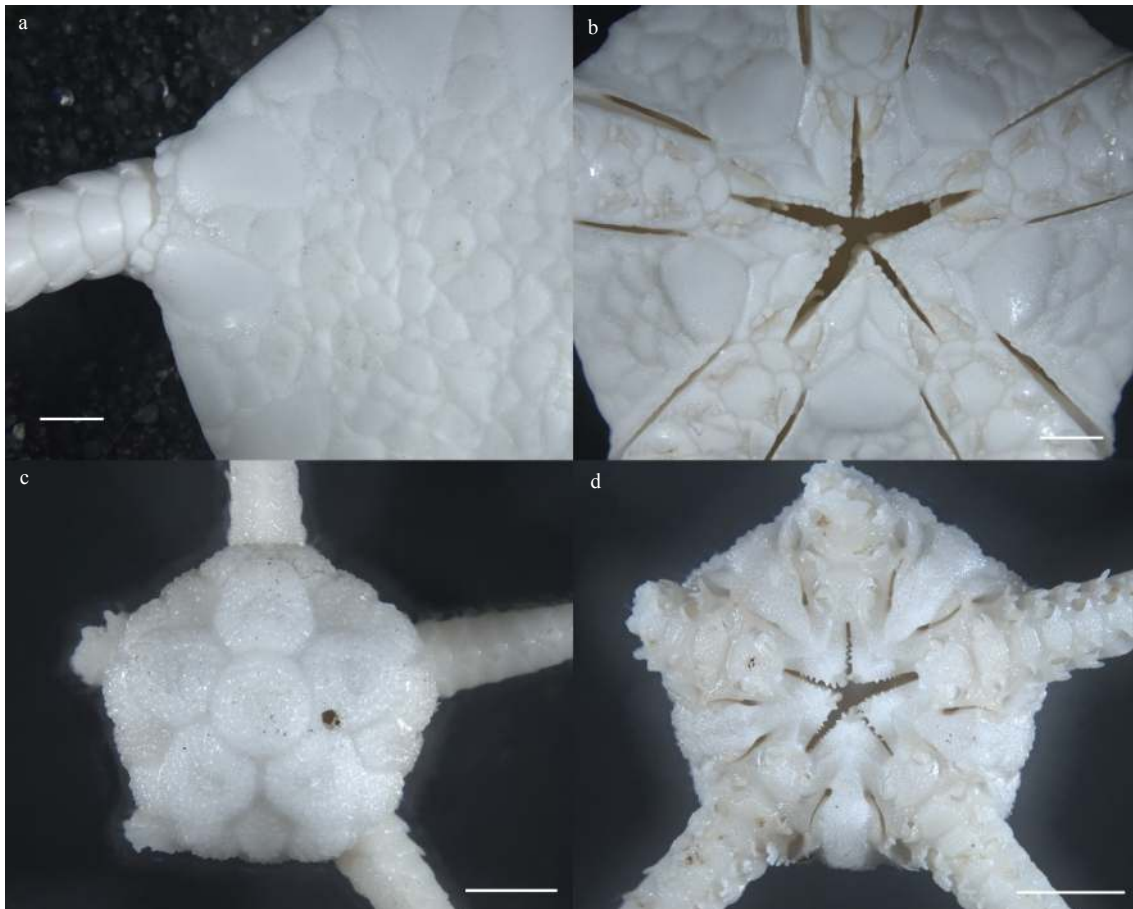
Material examined: Caiwei guyot, St. CW-DV71, 1 specimen (RSIO31001).

Habitat: Fine-grained muddy sediments.

Diagnosis: Disc flat and pentagonal, primaries a little larger than other plates, ~8 scales from center to interradial margin; radial shields triangular, longer than wide, separated; papillae of arm-comb close-set, flat, with rounded ends; genital slits long, without distinct genital papillae; jaw longer than wide with 1 apical papilla and 5–6 quadrilateral oral papillae on each side; second tentacle pore opening outside of mouth slit, bears several scales; the adradial tentacle scale on basal arm segments slightly expanded, look like small supplementary ventral arm plates on either side of the main plate; 3 very short, small, sharp arm spines, situated low on the edge of the side arm-plate; distal arm spines slightly hooked.

**Genus *Amphiophiura* Matsumoto, 1915**

***Amphiophiura* sp. (Figs 11c and d)**



**Fig. 11.** Morphological characters of Ophiuroidea. a and b. *Ophiuroglypha irrorata* RSIO31001: dorsal aspect (a) and ventral aspect (b); c and d. *Amphiophiura* sp. RSIO56017: dorsal aspect (c) and ventral aspect (d). Scale bars: 2 mm.

Material examined: RC seamount, St. RC-ROV06, 1 specimen (RSIO56017).

Habitat: Fine-grained muddy sediments.

Diagnosis: Disc round and raised, covered by large pentagonal centro-dorsal plate and 5 equal-sized heptagonal radial plates in the center, all plates bearing some resemblance of small grains; radial shield pentagonal, about 1/6 d,d. continuous distally; ventral interradii occupied by a thick plate and enlarged radial shields; radial shields much longer than wide, and two plates from oral shield to primary interradii; genital slits long, with a series of small genital papillae arranged continuously in distal-wards forming the arm comb; dorsal and ventral arm plates decreasing in size along arm;  $\leq 5$  arm spines, tube-foot-shaded; tentacle pores enlarged, partly covered by 1–2 scales.

Remark: The shape of this animal is reminiscent of *Amphiophiura bakeri* McKnight, 2003 and *Amphiophiura fisheri* A. H. Clark, 1949. Our material differs from the two species by having a single large plate between oral shield and dorsal margin, 2 plates from oral shield to primary interradii.

### 3.2 Species composition and community structure

A total of 191 ophiuroid specimens were identified in 29 species belonging to 11 families (Table 2). Ophiacanthidae was the dominant family, represented by two genera, *Ophiacantha* and *Ophioplinthaca*, with 4 and 7 species, respectively. Euryalidae is the second most diverse family, with 6 species identified. Additionally, two species belonging to Ophiopyrgidae and two species belonging to Ophiotomidae were identified. Six families (Amphiuridae, Hemieuryalidae, Ophiocamacidae, Ophiomusaidae, Ophiothamnidae, and Asteronychidae) and one order (*Ophioscocida*) were represented by only one species. Four species, including *Ophiacantha* sp. 1, *Ophioplinthaca defensor*, *Ophioplinthaca athena*, and *Ophioleila elegans*, were widely distributed and identified from four or five seamounts. *Asteroschema horridum* and *Ophiocamax* cf. *drygalskii* were identified from three seamounts, while *Ophiacantha richeri*, *Ophiacantha* sp. 2, *Ophiacantha* sp. 4, *Ophioplinthaca* cf. *clothilde*, *Ophiomusa* sp., and *Asteroschema ajax* were each identified from two seamounts. The remaining 17 species were identified from only one seamount. Several species are potentially new to science. Three species, *Ophioplinthaca grandisquama* n. sp., *Ophioplinthaca semele*, and *Ophioplinthaca* sp.1, were specifically studied with detailed morphological descriptions in another paper (Chen et

al., 2021).

Twenty-three species were identified from the four southern seamounts (Caiwei, Weijia, RC, and RD), 14 species were identified from the five northern seamounts (RA, RB, RE, Batiza, and Suda). Among the 4 southern seamounts, thirteen species belong to 6 families were identified from the Weijia Seamount, with 6 species only identified from the Weijia Seamount. *Ophioplinthaca defensor* and *Ophioleila elegans* were the dominant species. Five species, including *Amphiura* cf. *grandisquama*, *Ophiacantha* sp. 3, *Ophioplinthaca* sp. 2, *Ophiopristis* sp. 1, and *Ophiocreas oedipus*, were only identified from the Weijia Seamount. Seven species were identified from the Caiwei Seamount, which was dominated by *Ophioplinthaca athena*, *Astrodia* sp. and *Ophiuroglypha irrorata* were only identified from the Caiwei Seamount. Ten species were identified from the RC Seamount, dominated by six species from the genus *Ophioplinthaca*, three of which were only discovered at this seamount. Four species were identified from the RD seamount, three of which were also discovered at other southern seamounts, *Amphiophiura* sp. was only discovered in this seamount. Among the 5 northern seamounts, the RA and RB seamounts are close together (Fig. 1); four and two species were identified from them, respectively, however, without common species discovered between them, which is probably due to inadequate sampling efforts. Regarding the other three northern seamounts, four species were identified from the RE seamount, six from the Batiza seamount, and four from the Suda Seamount. Overall, eight common species, most of which belong to the Ophiacanthidae, were discovered between the northern and southern seamounts.

To evaluate the sampling effort, individual-based species rarefaction analyses were conducted based on the geographical locations of the seamounts. The individual-based rarefaction curves of the whole study area and two separate divisions all failed to reach an asymptote, suggesting that the sampling effort was inadequate (Fig. 12a). This signifies the potential to accumulate additional species with increased sampling effort. Comparison of the MSC and MWS curves suggests that the estimated numbers of species from the north and south seamounts was similar. The individual-based curves of the two most intensively sampled seamounts (the Weijia and Caiwei seamounts) showed similar trends (Fig. 12b) to the curves of the whole study area and the two separate divisions (Fig. 13a).

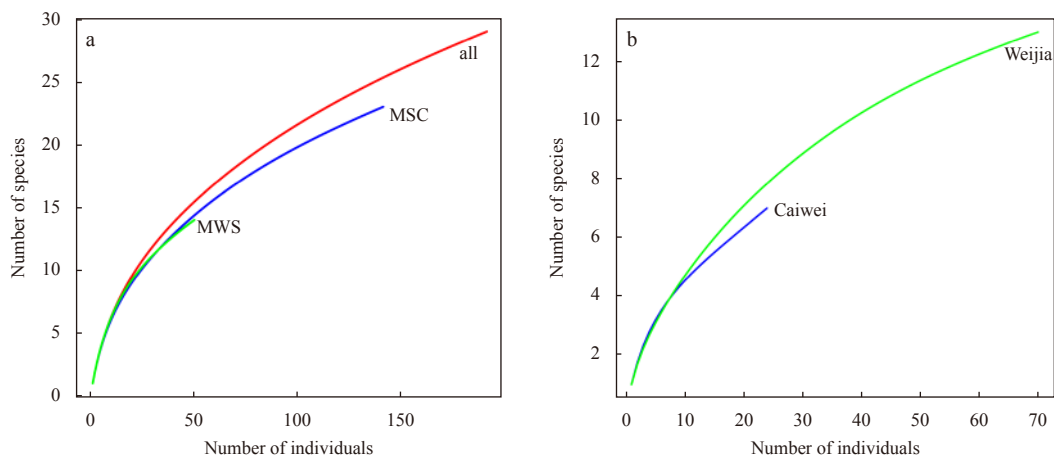
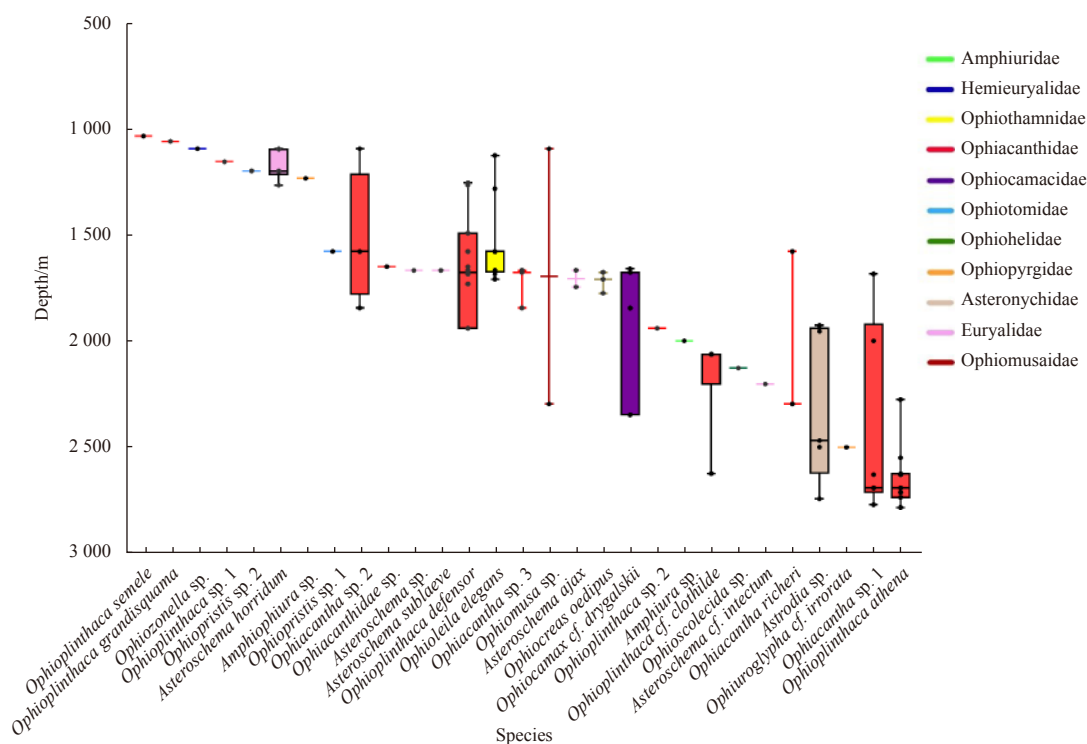


Fig. 12. Rarefaction curves based on individuals of Ophiuroids. a. Calculated using the All, MWS, and MCS datasets; and b. calculated using data from the Caiwei and Weijia seamounts.



**Fig. 13.** Depth distribution of 29 ophiuroid species, arranged by increasing median occurrence depth. The vertical bars and boxes are colored according to family.

### 3.3 Vertical distribution

The 29 species of ophiuroid were distributed across depths of 1 024–2 785 m. To evaluate the vertical distribution of ophiuroid fauna, the water depth was divided into two zones: the upper depths (1 000–2 000 m) and the lower depths (2 000–3 000 m). The two zones were further divided into two sub-zones as follows: the upper depths 1 (1 000–1 500 m) and the upper depths 2 (1 500–2 000 m), and the lower depths 1 (2 000–2 500 m) and the lower depths 2 (2 500–3 000 m). Twenty-six species were collected from the upper depths, 10 species were collected from the lower depths, and only four species were collected from both the upper and lower depths (Fig. 13). Among the 24 species from the upper depths, 11 species were collected from the upper depths 1, while 16 species were collected from the upper depths 2, with only three species in common. All 10 species from the lower depths were collected from the lower depths 1, four of which were also collected from the lower depths 2. Among the 29 species, 15 species were collected from only one sampling site, whereas the other 14 species were collected from multiple sampling sites, most of them were distributed in a narrow depth range (average depth range: 584.4 m). *Ophiacantha* sp. 1 and *Ophiomusa* sp. were the only two species with a wide depth range of more than 1 000 m. Ophiacanthidae was the family with the largest vertical distribution range and included species collected from both the shallowest and deepest water depths. Five of the six species belonging to the family Euryalidae were distributed in the upper depths, suggesting that euryalids or their hosts may prefer to live in shallower waters.

## 4 Discussion

This study aims to provide a taxonomic list of ophiuroid fauna from seamounts in the northwest Pacific Ocean, and make a preliminary analysis of species composition and community struc-

ture. Seamount is a special ecosystem with rough seafloor, making sampling very difficult. Different types of dredges and trawls were widely used for physical samples collecting from seamount (Koslow et al., 2001; de Forges et al., 2000). On the other hand, HOV and ROV were useful sophisticated platforms, which are capable of collecting both physical specimens and video/image-derived data. Generally, collections of HOV/ROV are majorly composed of corals and sponges which are easily targeted, while ophiuroids are normally byproducts. In this study, the main object was to understand the species diversity in the earlier cruises in 2013 and 2014, thus, operators were trying to collect different animals which never been collected. However, since 2017, to evaluate the connectivity between seamounts in this area, small echinoderms such as ophiuroids and crinoids became the prioritized targets, collected individuals per dive increased distinctly (Table 1). Nonetheless, the accessibility of HOV/ROV to benthos is limited by the complex topography, which may also result in biases of our collections. Therefore, the species composition and distribution were interpreted with caution.

### 4.1 Species richness and composition

It has been suggested that seamounts are hotspots of biodiversity in the deep sea (Shank, 2010). De Forges et al. (2000) reported that 29%–34% of the macro- and megafaunal species on seamounts in the Southwest Pacific Ocean are potential seamount endemics. However, this hypothesis of high seamount fauna endemism was challenged by many later studies. All 62 galatheid shrimps reported from northern Norfolk seamounts have subsequently been found elsewhere (Samadi et al., 2006). O' Hara (2007) found that only 15 of 318 species were endemic to a single seamount, which was probably due to under sampling rather than endemism. Additionally, several studies, including the northwest Pacific Ocean, have provided evidence that ophi-

uroids are highly able to disperse between seamounts, even hundred kilometers apart (Cho and Shank, 2010; Na et al., 2021; O'Hara et al., 2014).

In this study, 17 of the 29 species were found at a single seamount, and many species may be new to science. This may be caused by the inadequate sampling effort in this area. Only 191 specimens were collected through 29 HOV/ROV dives, the dataset is too small to make a conclusion on the endemism in the study area. Nonetheless, 14 species were identified into species level, among which five species (*Ophioplinthaca semele*, *O. athena*, *O. clothilde*, *Asteroschema ajax* and *Ophioleila elegans*) were originally reported from the Hawaiian Islands (Clark, 1949), of the five Hawaiian species, *Ophioleila elegans* and *Asteroschema ajax* had been reported in western Pacific (Okanishi et al., 2011; Zhang et al., 2018). *Ophioplinthaca defensor*, *Ophiacantha richeri* and *Asteroschema horridum* were as well distributed in the western Pacific (Baker, 1980; Na et al., 2021; O'Hara and Stöhr, 2006). These Pacific species suggested that the Northwest Pacific may share similar ophiuroid fauna with the Southwest Pacific and the middle Pacific. Three cosmopolitan species were also discovered in the study area, as well as the other two species from Antarctic and Atlantic. Probably, these widely distributed species may contain cryptic species within them (Sponer and Roy, 2002; Stöhr et al., 2020), and require DNA analysis and detailed morphological description. With fifteen species seemed to be undescribed, our results emphasized the potentially high species richness in the deep-sea. Recently, a greatly increased number of ophiuroid species in the abyssal basin was recovered in the eastern Pacific, and the majority of species (44.2%) was present only in one sampling area (Christodoulou et al., 2020). Therefore, further sampling effort is necessary for the evaluation of deep-sea biodiversity and endemism.

#### 4.2 Spatial distribution of ophiuroids

The latitudinal distribution pattern of marine fauna is widely accepted for various biological groups, such as plankton, benthos, and fish (O'Hara et al., 2019; Salinas et al., 2015; Siqueira et al., 2016), and geographical scales (Morgan et al., 2015; O'Hara et al., 2011), which are mainly affected by environmental factors, including oxygen and energy availability, etc (Levin et al., 2003; Woolley et al., 2016). In the Northwest Pacific, both particulate organic carbon (POC) flux and zooplankton have latitudinal gradients (Buesseler et al., 2020; Sun and Wang, 2017). Therefore, we originally expected a latitudinal distribution pattern of ophiuroid fauna from seamounts in the study area. Comparison of ophiuroid fauna between MWS and MSC showed that only eight species were shared by the two seamount groups, 15 species were only discovered in the MSC while 6 species were only discovered in the MWS. It is possible that the difference of ophiuroid fauna between the two seamount groups was attributed to the environmental gradient. However, due to the inadequate sampling effort and biases of ROV collections, we refrain to make any conclusion on this point. Recent studies have suggested that ophiuroids lacked genetic structure among seamounts, highlighting their ability for long-distance dispersal (Hunter and Halanych, 2008; O'Hara et al., 2014). The strong dispersal ability of ophiuroids may facilitate the dispersal of ophiuroids around the study area. Therefore, further extensively study on diversity and connectivity are necessary to analyze the biogeography pattern of seamount fauna in the Northwest Pacific.

Depth plays an important role in structuring faunal composition (Clark et al., 2010; Victorero et al., 2018). O'Hara et al. (2014)

suggested a bathymetric break of approximately 1 700 m for *Ophiactis abyssicola* complex in the Southwest Pacific. Cho and Shank (2010) found significant differences among 100–250 m depth intervals for different species of ophiuroids. This study suggests that the species compositions between depths (1 000–1 500 m vs. 1 500–2 000 m and 1 000–2 000 m vs. 2 000–3 000 m) were distinct. However, these depth differences may be as well the result of inadequate sampling. For example, two species were collected from two depths more than 1 000 m apart, *Ophiomusa* sp. from 1 084 m to 2 294 m and *Ophiacantha richeri* from 1 571 m to 2 200 m. The lack of these two species between these depths may be an artifactual sampling bias. In the North Atlantic, several species from the genera *Ophioplinthaca*, *Asteroschema*, and *Ophiocreas* were consecutively distributed between 1 300 m and 2 300 m (Cho and Shank, 2010), and no narrow-ranged species were found on the seamounts in the Southwest Pacific Ocean (O'Hara, 2007). Therefore, further sampling effort is needed to assess the depth zonation of ophiuroid fauna.

#### 5 Conclusions

Although the importance of megafauna from seamounts in the NW Pacific has been recognized because of the high possibility of human activities (ISA Study Tech No. 23), knowledge of their biodiversity and distribution in this area is extremely lacking, with insufficient sampling effort (Menegotto and Rangel, 2018). This study provides the first comprehensive description of ophiuroid fauna from nine seamounts in this area, with 29 species from 11 families dominated by Ophiacanthidae. To date, this is the largest available data and distinctly improve our understanding of megafaunal biodiversity from seamounts in the Northwest Pacific. Further surveys are necessary to provide more robust information for environmental protection and management of cobalt-rich crust seamounts in the Northwest Pacific.

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## Appendix:

Table A1. The vouch number listed in Na et al. (2021) and present study

Species	Specimen number	Vouch numbers in Na et al. (2021)	Vouch numbers in present study
<i>Ophioplinthaca defensor</i>	81-1	RSIO358101	RSIO35010
<i>Ophioplinthaca defensor</i>	1-02	RSIO410102	RSIO41002
<i>Ophioplinthaca defensor</i>	1-03	RSIO410103	RSIO41003
<i>Ophioplinthaca defensor</i>	1-04	RSIO410104	RSIO41004
<i>Ophioplinthaca defensor</i>	1-05	RSIO410105	RSIO41005
<i>Ophioplinthaca defensor</i>	1-06	RSIO410106	RSIO41006
<i>Ophioplinthaca defensor</i>	1-07	RSIO410107	RSIO41007
<i>Ophioplinthaca defensor</i>	1-08	RSIO410108	RSIO41008
<i>Ophioplinthaca defensor</i>	1-09	RSIO410109	RSIO41009
<i>Ophioplinthaca defensor</i>	4-12	RSIO410412	RSIO41017
<i>Ophioplinthaca defensor</i>	4-07-2	RSIO410407	RSIO41021
<i>Ophioplinthaca defensor</i>	4-08	RSIO410408	RSIO41022
<i>Ophioplinthaca defensor</i>	4-11	RSIO410411	RSIO41025
<i>Ophioplinthaca defensor</i>	5-02	RSIO410502	RSIO41031
<i>Ophioplinthaca defensor</i>	6-02	RSIO410602	RSIO41033
<i>Ophioplinthaca defensor</i>	6-04	RSIO410604	RSIO41034
<i>Ophioplinthaca defensor</i>	6-05	RSIO410605	RSIO41035
<i>Ophioplinthaca defensor</i>	6-06	RSIO410606	RSIO41036
<i>Ophioplinthaca defensor</i>	6-07	RSIO410607	RSIO41037
<i>Ophioplinthaca defensor</i>	6-08	RSIO410608	RSIO41038
<i>Ophioplinthaca defensor</i>	6-10	RSIO410610	RSIO41039
<i>Ophioplinthaca defensor</i>	6-11	RSIO410611	RSIO41040
<i>Ophioplinthaca defensor</i>	6-12	RSIO410612	RSIO41041
<i>Ophioplinthaca defensor</i>	6-13	RSIO410613	RSIO41042
<i>Ophioplinthaca defensor</i>	6-14	RSIO410614	RSIO41043
<i>Ophioplinthaca defensor</i>	6-15	RSIO410615	RSIO41044
<i>Ophioplinthaca defensor</i>	6-16	RSIO410616	RSIO41045
<i>Ophioplinthaca defensor</i>	6-17	RSIO410617	RSIO41046
<i>Ophioplinthaca defensor</i>	6-18	RSIO410618	RSIO41047
<i>Ophioplinthaca defensor</i>	6-19	RSIO410619	RSIO41048
<i>Ophioplinthaca defensor</i>	ROV04-B06-1	RSIO560406	RSIO56008
<i>Ophioplinthaca defensor</i>	ROV06-B05-1	RSIO560605	RSIO56056
<i>Ophioplinthaca defensor</i>	ROV06-B06-1	RSIO560601	RSIO56015
<i>Ophioplinthaca defensor</i>	ROV06-B07-1	RSIO560607	RSIO56016
<i>Ophioplinthaca defensor</i>	ROV07-B05-1	RSIO560705	RSIO56020
<i>Ophioplinthaca defensor</i>	ROV04-B04-6		RSIO61019
<i>Ophioplinthaca defensor</i>	ROV04-B09-2		RSIO61021
<i>Ophioplinthaca defensor</i>	ROV04-B09-3-1		RSIO61022
<i>Ophioplinthaca defensor</i>	ROV04-B09-3-2		RSIO61023
<i>Ophioplinthaca defensor</i>	ROV04-B09-3-3		RSIO61024
<i>Ophioplinthaca defensor</i>	ROV04-B09-3-4		RSIO61025
<i>Ophioplinthaca defensor</i>	ROV04-B10-1		RSIO61026
<i>Ophioplinthaca defensor</i>	ROV04-B10-2		RSIO61027
<i>Ophioplinthaca defensor</i>	ROV04-B10-3		RSIO61028
<i>Ophioplinthaca defensor</i>	ROV04-B10-4		RSIO61029
<i>Ophioplinthaca defensor</i>	ROV04-B10-5		RSIO61030
<i>Ophioplinthaca defensor</i>	ROV04-B10-6		RSIO61031
<i>Ophioplinthaca defensor</i>	ROV04-B10-7		RSIO61032
<i>Ophioplinthaca defensor</i>	ROV04-B10-8		RSIO61033
<i>Ophioplinthaca defensor</i>	ROV12-B05-3		RSIO61072
<i>Ophioplinthaca defensor</i>	ROV12-B05-4		RSIO61073
<i>Ophioplinthaca defensor</i>	ROV12-B05-5		RSIO61074
<i>Ophioplinthaca defensor</i>	ROV12-B08-1-1		RSIO61079
<i>Ophioplinthaca defensor</i>	ROV12-B08-1-2		RSIO61080

to be continued

Continued from Table A1

Species	Specimen number	Vouch numbers in Na et al. (2021)	Vouch numbers in present study
<i>Ophioplinthaca defensor</i>	ROV12-B09-1		RSIO61082
<i>Ophioplinthaca defensor</i>	ROV12-B09-2		RSIO61083
<i>Ophioplinthaca defensor</i>	ROV12-B09-3		RSIO61084