A discinid shell on Ikarashi beach, Niigata, Japan

Yoshino ISHIZAKI* and Yuta SHIINO**

Abstract

A shell of discinid brachiopod was washed ashore on Ikarashi beach, Niigata, Japan. Because the detailed morphology of the extant discinids in Japan has not been previously examined, we described the external and internal structures of this specimen to provide insights into the taxonomy and biogeography of the present discinid. The specimen is a well-preserved dorsal valve characterised by the external ornamentations of concentric growth lines and fine, radiated ridges called costellae. The internal surface of the shell exhibits two distinct pairs of muscle scars (posterior adductor and anterior adductor I), two faint pairs of muscle scars (anterior adductor II and oblique lateral) and two supposed pairs of muscle scars (oblique posterior and oblique internal). Based on the external characters, the specimen evidently has diagnoses of the genus *Discradisca*, thus being identified as *Discradisca* sp. The most similar species to the present specimen is *Discradisca stella* Gould, but the dorsal valve of *Discradisca* seems to share characters that are impossible to identify using both qualitative and quantitative methods. On the Japanese coast, there are three species if the original descriptions are correct, of which *Discradisca stella* and *Discradisca sparselineata* (Dall) show similar habitats and distributions. Given that the dysoxic, interstitial habitat of *Discradisca* could alter the secretion of shell during growth, a clue to reveal the taxonomic problem would be an ecomorphological viewpoint, specifically addressing the test of relationship between morphology and microhabitat.

Key words: flotsam, Discinidae, Japan Sea, Tsushima Current, beachcombing.

---

* Graduate School of Science and Technology, Niigata University, Niigata 950-2181, Japan
** Department of Geology, Faculty of Science, Niigata University, Niigata 950-2181, Japan

Corresponding author: Y. Shiino,
y-shiino@geo.sc.niigata-u.ac.jp
(Manuscript received 30 November, 2022; accepted 1 February, 2023)

Introduction

Beachcombing is crucial to exploring drifted objects that wash up on beaches, which provides basic information on geology and biology in terms of ocean current dynamics (e.g., Donovan, 2011; Seo and Tanangonan, 2014; Davies et al., 2022). Of these drifted objects, most benthic animals are dead with no evidence of the actual habitat, while they can be regarded as proof to expect a likely ecosystem under the shallow sea. The more minor the animal, the more important will be to discuss their diversity and distribution because of little evidence in the world.

Ikarashi beach, facing the Sea of Japan, is located 900 m northwest of Niigata University, Japan (Fig. 1) and consists of fine-grained sands with bioclasts. There are abundant drifted objects such as driftwoods and marine debris of Japan, Korea and Russia based on their notation (Ishizaki et al., 2023), possibly transported by the Tsushima Warm Current. Typically, planktonic animals show mere seasonality by means of the inflow of the Tsushima Warm Current (e.g., Matsuoka et al., 2001, 2002; Itaki, 2003; Itaki et al., 2003; Kurihara et al., 2006, 2007, 2008; Kurihara and Matsuoka, 2009, 2010), while some benthic animals appear to expand their distribution northwards along the coast of the Sea of Japan (e.g., Gallagher et al., 2015; Yoshioka, 2020). To understand the dynamics of biogeographic changes in benthic animals, periodic reports of the presence or absence of benthic animals are needed.

The linguliformean brachiopod, which was recently found in Ikarashi beach, appears to be a conical shape of dorsal valve with fine radial costellae, representing a species of the genus *Discradisca* Stenzel (1965). Discinid shells on beaches have been reported from the Sea of Japan since 2011 (Oki Marine Biological Station, 2011; Ogiso et al., 2014, 2019; Yoshioka, 2016, 2017, 2020), with no detailed morphological information. As a preliminary step to identify the discinid species, we described the external and internal morphology of this specimen, followed by perspectives of the morphological variation and the distribution of *Discradisca*.

Material and methods

1. Sampling locality

A discinid brachiopod shell was collected from Ikarashi beach, Niigata, Japan (Figs. 1, 2: 37° 52'14.8"N, 138° 55'30.6"E) at a lower tide (tide level of 14 cm) on 2 November 2022. At the locality 5 m from the shoreline beside the wharf, small shells 5–10 mm in size remained on the beach by the undertow and accumulated parallel to the shoreline (Fig. 2A, B). The shell assemblage consists mainly of small bivalves (e.g., *Protothaca jedoensis* (Lischke, 1874) and *Donax semigranosus* Dunker, 1877) and echinoderms *Scaphechinus mirabilis* Agassiz (1863) (Fig. 2C).

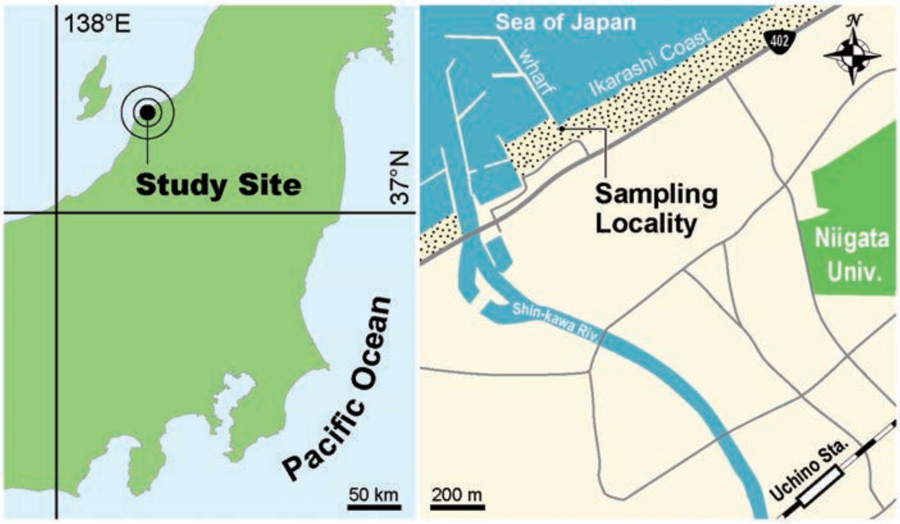

Fig. 1. Map showing the sampling locality of Ikarashi beach, Niigata, Japan.

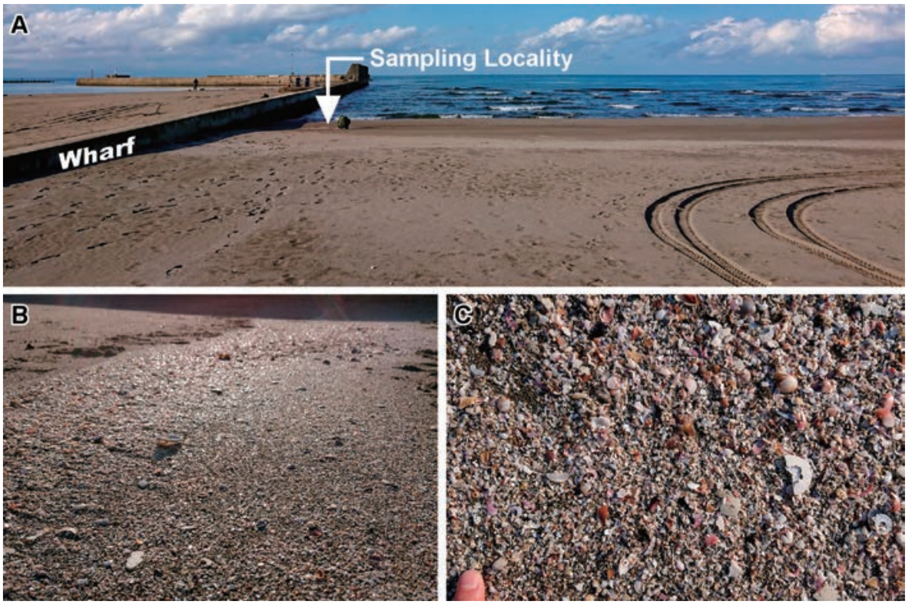

Fig. 2. Photographs of the sampling locality. **A**. Photograph showing the sampling point and wharf. **B**. Shell assemblage on the beach. **C**. Magnified photograph of shell assemblage.

2. Brachiopod specimen

The discinid brachiopod specimen is a dorsal valve of *Discradisca* sp. cf. *D. stella* (Gould, 1862), showing well-preserved external ornamentations and internal structures associated with soft parts. The specimen is 11.1 mm length, 10.8 mm width and 3.7 mm height. Schematic illustrations of the valve morphology and terminology adopted herein are shown in Fig. 3. Among the terminology, primary radiated ridges are generally so-called costae, while the secondarily branched ridges are costellae (Williams et al., 1997a). In the present specimen, we could not find any difference between costae and costellae, so we adopted costellae for all the radiated ridges.

The external and internal morphology of the specimen was observed in colour and greyscale photographs using a digital camera Sony α7R IV (Sony Corporation, Japan). Prior to greyscale photographing, a whitening treatment with ammonium chloride was performed on the specimen.

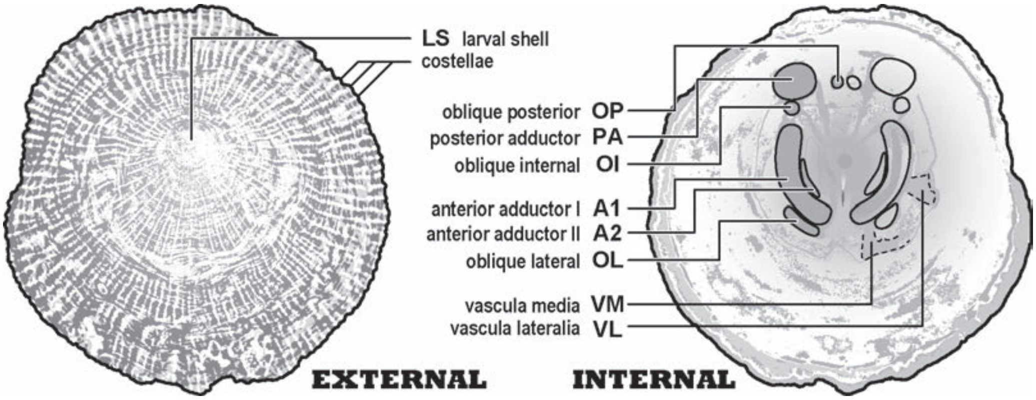

Fig. 3. Schematic illustrations of *Discradisca* sp. cf. *D. stella* (Gould, 1862), showing terminology.

3. Distribution of *Discradisca* species

To examine the distribution of extant *Discradisca* in Japan, we listed all the reports of discovery available on published articles and short reports as formal references and websites of public institutions and private blogs as informal references. Several reports lack evidence of species identification; therefore, we declined to use the original description but adopted *D.* sp.

Results and discussion

1. Morphological descriptions

Figure 4 is a colour photograph showing a colour pattern, and Figures 5 and 6 are greyscale photographs showing morphology. The specimen of the external surface shows a geometric colour pattern by means of a combination of a concentric pattern (sahara colour: code #c49c64, straw colour: code #d3b47f) and radial pattern (bark brown: code #63390e) (Fig. 4A). The radial pattern of dark colour is shown in the interval of costellae but not on the costellae themselves (Fig. 4A, D, E). The colour pattern of the internal surface is comparatively pale (cherished gold colour: code #c1975a), while the area associated with the internal structure, such as muscle scars, shows a brown colour (bright tan colour: code #835121) (Fig. 4B, F).

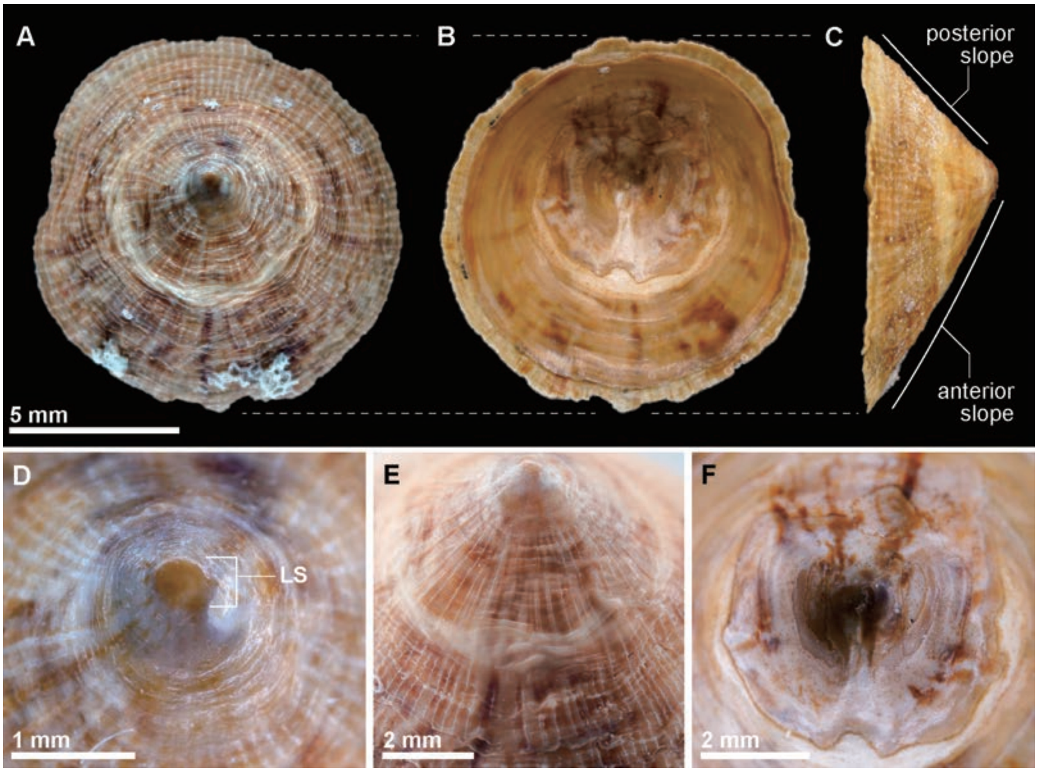

Fig. 4. Colour photographs of *Discradisca* sp. cf. *D. stella* (Gould, 1862). **A**. External view. **B**. Internal view. **C**. Latelal view. **D**. Magnified image around the apex showing a larval shell (LS). **E**. Magnified image of costellae anterior to larval shell. **F**. Magnified image of the internal surface. LS: larval shell.

The dorsal valve shows a nearly circular outline with a conical shape (Figs. 4A, C, 5A). The anterior slope of the cone gently convex, while the posterior slope is slightly concave (Fig. 4C). The lateral slopes are slightly convex to flat and smoothly continue towards the convex anterior slope and the concave posterior slope. The dorsal apex is smooth and located very slightly posterior to the centre.

The external surface exhibits fine radial costellae and numerous concentric growth lines (Fig. 5A). There are three patterns of external ornamentations: central, transitional and peripheral areas (Fig. 5B). The central area, inside of approximately 2.3 mm diameter, is characterised by faint concentric growth lines with no radial costellae (Fig. 5B: central). The most central part is a larval shell 350 μm in diameter, which has no ornamentation of either concentric growth lines or radial costellae (Figs. 4D, 5B, C: LS). The transitional area, inside of approximately 5.6 mm diameter except the central area, has concentric growth lines and comparatively faint, fine radial costellae (Fig. 5B: transitional). Both ornamentations of the posterior part are finer and more distinct than those of the anterior part. A new costella is occasionally inserted at which the interval of two radial costellae increased during growth (Fig. 5B: white arrowhead). In this case, the insertion of a new costella occurs when the distance between the two costellae reaches approximately 0.3 mm. In the case of shell up to

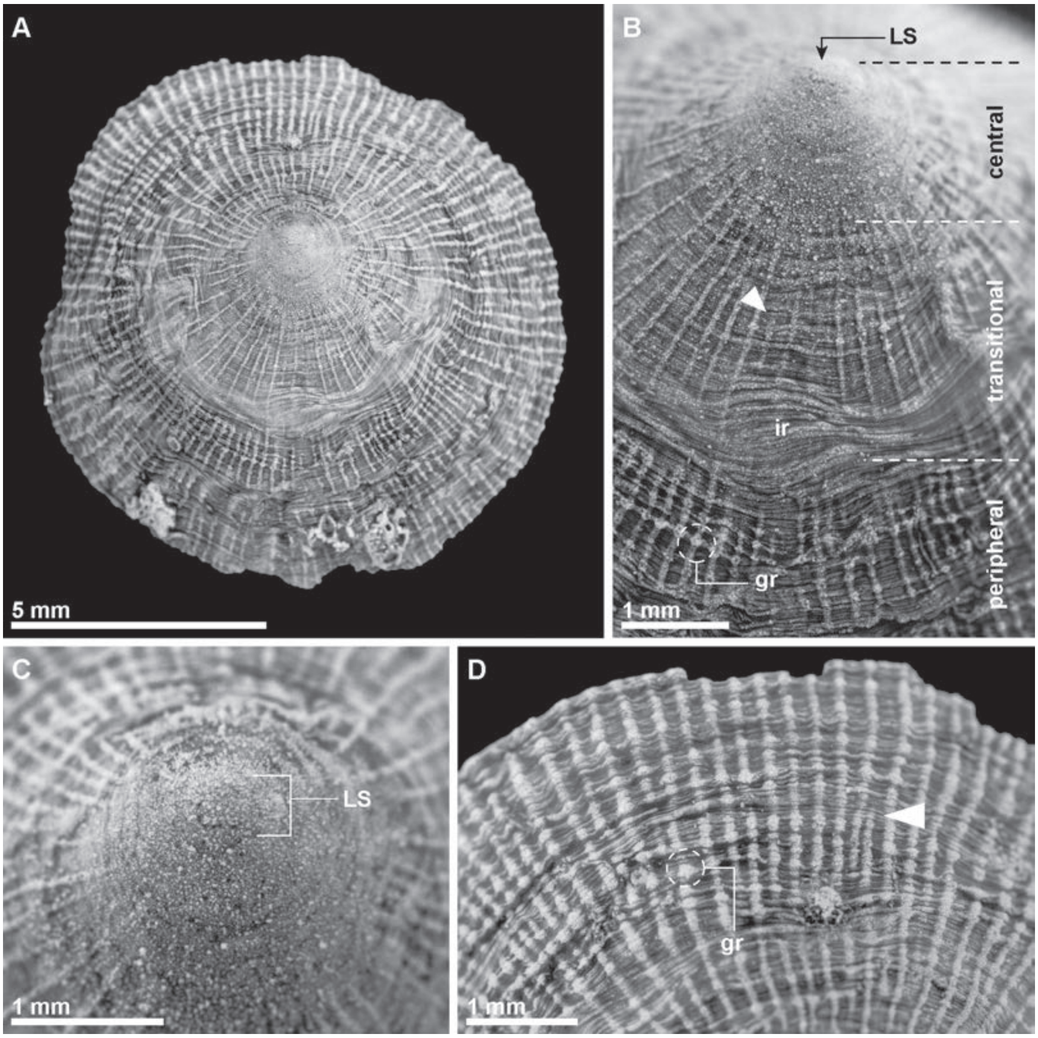

Fig. 5. External morphology of *Discradisca* sp. cf. *D. stella* (Gould, 1862). **A**. External view. **B**. Magnified image of costellae anterior to larval shell. Note that the new costella inserted at a point of white arrowhead. **C**. Magnified image around the apex showing a larval shell (LS). **D**. Magnified image of costellae posterior to larval shell. Note that a costella disappears at a point of white arrowhead. LS: larval shell, ir: irregular growth lines, gr: granule on costella.

5 mm in diameter (15.7 mm in circumference), the number of radial costellae is 57, and therefore, the average interval of the two costellae is 0.28 mm. The transitional area changes to the peripheral area with the straw-coloured boundary area of irregular growth lines with no radial costellae (Fig. 5B: ir). The peripheral area has distinct concentric growth lines and distinct, fine radial costellae (Fig. 5B: peripheral). The intersection of the concentric growth lines and radial costellae are distinctly granular (Fig. 5B, D: gr). Similar to the transitional area, the costellae are often inserted peripherally as two costellae always maintain the same interval. The costellae sometimes disappear when the two costellae become close to each

other by means of shell curvature (Fig. 5D: white arrowhead). In the case of shell up to 9.6 mm in diameter (30.2 mm in circumference), the number of radial costellae is 110, and therefore, the average interval of the two costellae is 0.28 mm.

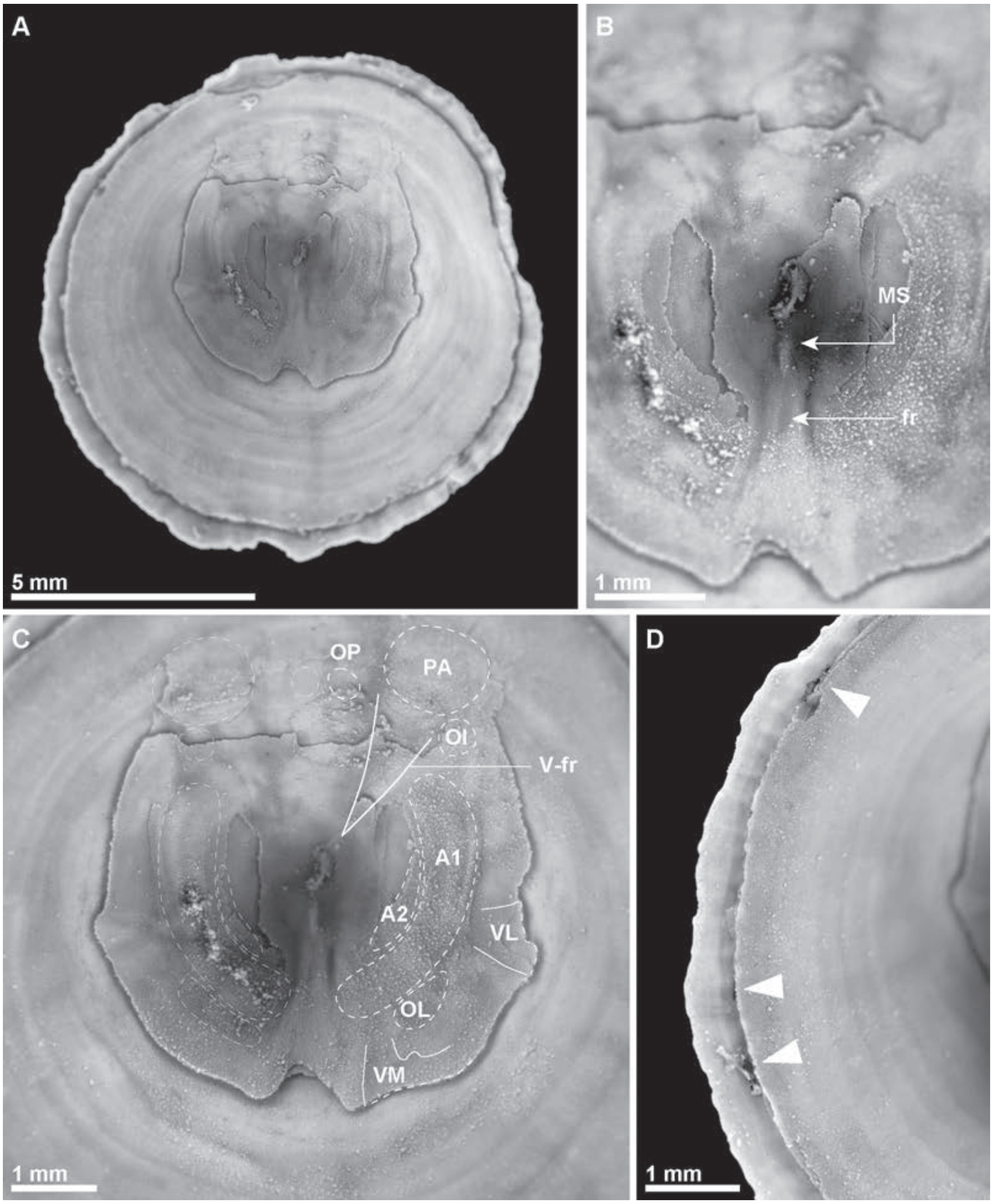

Fig. 6. Internal morphology of *Discradisca* sp. cf. *D. stella* (Gould, 1862). **A**. Internal view. **B**. Magnified image around the median septum. **C**. Magnified image series of muscle scars. **D**. Magnified image of the left peripheral margin of A. MS: median septum, fr: furrows anterior to median septum, OP: oblique posterior, PA: posterior adductor, OI: oblique internal, A1: anterior adductor I, A2: anterior adductor II, OL: oblique lateral, VM: vascula media, VL: vascula lateralia, V-fr: V-shaped furrow.

The internal surface is smooth but exhibits several impressions that are associated with the internal structures (Fig. 6). A short median septum is located anterior to the inside of the apex (Fig. 6B: MS). A furrow-like structure extends from the anterior end of the median septum (Fig. 6B: fr). Muscle scars occur around the inside of the apex, showing a concentric arrangement. There are two distinct pairs, two faint pairs and two supposed pairs of muscle scars.

Two pairs of adductor muscle scars are distinct (Fig. 6C: PA, A1), the so-called posterior adductor and anterior adductor I (Williams et al., 1997b). The scars of posterior adductor muscles are subcircular in outline. The scar is smooth, while its margin is furrowed, forming a very slightly elevated platform. The right and left sides of the scar connect V-shaped furrows that extend from the inside of the apex, as if they are "speech bubbles" in shape (Fig. 6C: V-fr). The scars of anterior adductor I are located in the area lateral to the median septum (Fig. 6C: A1). The outline of the scar is longitudinally elongated, curved, and elliptical. The scar is slightly concave with its margin of weak furrow, similar to the posterior adductor. The furrow of the margin is the deepest antero-internally.

The two faint pairs of scars are the anterior adductor II and oblique lateral muscles (Fig. 6C: A2, OL). The scars of anterior adductor II and oblique lateral muscles are located at the area inside and anterolateral to the scars of anterior adductor I, respectively. The scar of anterior adductor II is longitudinally elongated and curved, elliptical outline, which arranges along the inner side of the anterior adductor I (Fig. 6C: A2). The scar of oblique lateral muscle seems to be posterolaterally elongated, with a short elliptical outline (Fig. 6C: OL). Both scars of anterior adductor II and oblique lateral muscles are slightly emphasised with those margins of weak furrows.

Based on the presence of faint margins with furrows, scars of oblique internal and oblique posterior muscles are assumed (Fig. 6C: OI, OP). The former is located just anterior to the scar of the posterior adductor muscle, and the latter is located between the right and left of the scars of posterior adductor muscles. Both scars are small and subcircular in outline. In discinid brachiopods, there would be a pair of scars for brachial retractor muscles laterally distant from the scars of oblique lateral muscles, but we could not identify it in the present specimen.

Only the proximal parts of the vascula media and lateralia are partially preserved as faint impressions (Fig. 6C: VM, VL). The vascula media extends from the area slightly anterior to the scars of anterior adductor I and seems to bend laterally along the visceral area (Fig. 6C: VM). The vascula lateralia laterally extends from the periphery of the visceral area around the scars of anterior adductor I (Fig. 6C: VL). Because the inner layer of the shell is partially removed, the distal network of the vascular system is unknown.

The margin of the shell exhibits a single lamella, which encloses small pebbles inside (Fig. 6D: white arrowhead).

2. Insights into morphological variation

The taxonomy of fossil and living discinid brachiopods is mainly based on the ornamentations of dorsal and ventral valves, the convexity of shells and the structure associated with the pedicle (e.g., Williams et al., 2000; Mergl, 2010; Masunaga and Shiino, 2021). In the case of *Discradisca*, the characteristics of radial costellae and concentric growth lines in the dorsal valve have been frequently adopted to identify their species (e.g., Bitner, 2010, 2014).

The characteristics of the present specimen fit with those of *Discradisca stella*, which has distinct, fine costellae and concentric growth lines in the dorsal valve (e.g., Bitner, 2010). However, this conclusion remains problematic because the relief of both ornamentations seems to be enhanced during growth. If the present animal died before the fully grown stage up to 5 mm, the morphology could be similar to that of *Discradisca sparselineata* (Dall, 1920), which is characterised by faint costellae.

Discradisca indica (Dall, 1920) is similar to *Discradisca stella* but differs in distinctly granular and more widely spaced costellae (e.g., Bitner, 2010). In the case of *Discradisca indica* shown in Bitner et al. (2008: Fig. 2B), the number of costellae is approximately 69 with a circumference of 11.7 mm, resulting in a 0.17 mm average interval of two costellae. This calculated value implied finer costellae than the present *Discradisca* sp. cf. *D. stella,* the taxonomic problem that is a future direction to explore detailed morphological analyses.

Fig. 7. Distribution of *Discradisca* in Japan.

Table 1. Distribution of *Discradisca* in Japan.

Table 1. Distribution of *Discradisca* in Japan.

Locality number	Locality name	Species	latitude (if described)	Depth or depth zone	Substrate and environment	Environment	Method	Sampling Date	Reference
1	Hakodate	*Discradisca sparselineata*	-	-	-	-	-	-	Dall (1920)
2	Kattoshi (Hokkaido)	*Discradisca* sp.	-	-	Underside of boulders and bioclasts	Sandy tidal flat and rocky coast	-	-	Laboratory of Animal Ecology, School of Agriculture, Hokkaido University (2018)
3	Asamushi (Aomori)	*Discradisca* sp.	-	-	-	-	-	-	Research Center for Marine Biology, Graduate School of Life Sciences, Tohoku University
4	Ayukawa (Ishinomaki)	*Discradisca rikuzenensis*	-	37 m	-	-	-	-	Hatai (1940)
5	Tokyo bay	*Discradisca stella*	-	-	-	-	-	-	Dall (1920)
5	Tokyo bay	*Discradisca sparselineata*	-	-	-	-	-	-	Dall (1920)
6	Hayama (Sagami bay)	*Discradisca stella*	-	15 m	Bivalve *Neopycnodonte cochl*	-	Gill-net and hand trawl fishings	1963-1996	Ikeda and Kuramochi (1997)
6	Hayama (Sagami bay)	*Discradisca sparselineata*	-	15 m	-	-	Gill-net and hand trawl fishings	1963-1996	Ikeda and Kuramochi (1997)
6	Hayama (Sagami bay)	*Discradisca* sp.	-	200-300 m	-	-	Gill-net and hand trawl fishings	1963-1996	Ikeda and Kuramochi (1997)
7	Enoshima (Sagami bay)	*Discradisca stella*	-	-	-	-	-	-	Dall (1920)
8	Hazu (Mikawa bay)	*Discradisca sparselineata*	-	Intertidal zone	Boulders	Tidal flat	-	-	Ishikawa et al. (2016)
9	Toba bay	*Discradisca* sp.	-	-	-	-	-	-	Toba Aquarium (2014)
10	Shirahama (Wakayama)	*Discradisca stella*	-	Middle intertidal to subtidal zone	Underside of boulders	-	-	-	Kawamura et al. (2016)
11	Osaka bay	*Discradisca stella*	-	-	Flat, underside of boulders	Rocky coast near mouth of Osaka bay	-	2006-2010	Association for the Research of Littoral Organisms in Osaka Bay (2012); Otani (2019)
11	Osaka bay	*Discradisca* sp.	-	50 m	Molluscan shells	-	-	-	omoyasu ta (2020)
12	Tanoshiro coast (Awaji Island)	*Discradisca stella*	-	-	-	-	-	2020.07.18	Suzuki (2020)
13	Fukura (Awaji Island)	*Discradisca stella*	-	-	-	-	-	-	Dall (1920)
13	Awaji Island	*Discradisca sparselineata*	-	-	-	-	-	-	Dall (1920)
14	Ushimado (Okayama)	*Discradisca stella*	-	-	Underside of boulders slightly buried in sand	Gravelly tidal flat and rocky coast	-	-	Ushimado Marine Institute, Okayama University
14–19	Bisan-seto ocean area	*Discradisca stella*	-	-	Underside of boulders slightly buried in sand	Gravelly tidal flat and rocky coast	-	-	Tamano Marine Institute, Okayama University (1978); Wada and Yoshimatsu (2020a)
15	Okayama	*Discradisca sparselineata*	-	Middle intertidal to subtidal zone	Flat, hard substrates such as boulders and bivalves	Mouth of bay, strait and tide pool	-	-	Fukuda (2010); Wada and Yoshimatsu (2020b)
16	Tamano (Okayama)	*Discradisca sparselineata*	-	Middle intertidal to subtidal zone	Flat, hard substrates such as boulders and bivalves	Mouth of bay, strait and tide pool	-	-	Fukuda (2010); Wada and Yoshimatsu (2020b)
17	Kurashiki (Okayama)	*Discradisca sparselineata*	-	Middle intertidal to subtidal zone	Flat, hard substrates such as boulders and bivalves	Mouth of bay, strait and tide pool	-	-	Fukuda (2010); Wada and Yoshimatsu (2020b)
18	Hiro Island (Hiroshima, Shiwaku Islands)	*Discradisca* . sp. cf. *D. sparselineata*	34°24'47.4"N, 133°43'53.4"E	21 m	-	-	Dredge	2010.11.09	Hirose et al. (2012)
19	Kasaoka bay (Okayama)	*Discradisca* sp.	-	-	-	-	-	2016	@menashi_sato (2016)
20	Hashira Island (Hashirajima, Yamaguchi)	*Discradisca sparselineata*	-	-	-	-	-	-	Kato (1996)
21	Mouth of Kumanoe river (Miyazaki)	*Discradisca* sp.	-	Intertidal zone	Underside of gravel slightly buried in sand	Transitinal zone of rocky coast to sandy tidal flat	-	-	Miura et al. (2012)
22	Nobeoka bay (Miyazaki)	*Discradisca* sp.	-	Intertidal zone	Underside of gravel slightly buried in sand	Transitinal zone of rocky coast to sandy tidal flat	-	-	Miura et al. (2012)

23	Iorigawa (Kadogawa bay)	*Discradisca* sp.	32°29'N,131°41'E	Intertidal zone	Underside of gravel slightly buried in sand	Transitinal zone of rocky coast to sandy tidal flat with effect of blackish water	-	2010.5-9	Miura et al. (2012)
24	Nojima (Miyazaki)	*Discradisca* sp.	-	Intertidal zone	Underside of gravel slightly buried in sand	Transitinal zone of rocky coast to sandy tidal flat	-	-	Miura et al. (2012)
25	Kumamoto	*Discradisca sparselineata*	-	-	-	-	-	-	Kumamoto Prefectural Rare Wild Fauna and Flora Review Committee (2009)
26	Nagasaki	*Discradisca stella*	-	-	-	-	-	-	Dall (1920)
27	Hirado (Nagasaki)	*Discradisca stella*	-	-	-	-	-	-	Dall (1920)
28	Sakaisuido (Shimane)	*Discradisca* sp.	-	-	-	-	-	-	Osawa and Kurata (2016)
29	Yumigahama (Shimane)	*Discradisca* sp.	-	-	-	-	Beachcombing	2017.1.3	Yoshioka (2017)
30	Oki Islands	*Discradisca stella*	-	-	-	-	-	-	Oki Marine Biological Station (2011)
31	Karo coast (Tottori)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.12.27	Yoshioka (2017)
32	Kanzaki coast (Kyoto)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.12.27	Yoshioka (2017)
33	Tai coast (Wakasa bay)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.7.1	Yoshioka (2016)
34	Takasu coast (Fukui)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.7.1	Yoshioka (2016)
35	Komaiko coast (Ishikawa)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.7.1	Yoshioka (2016)
36	Masuhogaura (Ishikawa)	*Discradisca* sp.	-	-	-	-	Beachcombing	2012.12.19	Yoshioka (2016)
37	Tsukumo bay (Ishikawa)	*Discradisca sperselineata*	-	2.8-4.9 m	Underside of boulders slightly buried in sand of	Rocky coast	SCUBA diving	2014.10.7; 2018.7.31	Ogiso et al. (2014, 2019)
38	Tara Island (Kuki, Notojima, Ishikawa)	*Discradisca stella*	-	2 m	Underside of boulders	-	SCUBA diving	2018.6.8	Ogiso et al. (2019)
39	Yaetsu beach (Toyama)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.6.6	Yoshioka (2016)
40	Hamakurosaki coast (Toyama)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.5.1; 2016.6.6; 2018-2020	Yoshioka (2016, 2020)
41	Naoetsu coast (Niigata)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.6.3	Yoshioka (2016)
42	Ikarashi beach (Niigata)	*Discradisca* sp.	-	-	-	-	Beachcombing	2016.6.20	Yoshioka (2016)
42	Ikarashi beach (Niigata)	*Discradisca* sp.	37°52'14.8"N, 138°55'30.6"E	-	-	-	Beachcombing	2022.11.02	This study
14-19	Bisan-seto area (Seto Island Sea)	Planktonic larvae of *Disciradisca* spp.	-	30 m (water column)	-	-	Kitahara's water bottle and plankton net	2010.8-2012.11	Yoshimatsu (2014)

3. Distribution of *Discradisca* species around Japan

All the discoveries of extant *Discradisca* at 42 localities in Japan are shown in Fig. 7 and Table 1. *Discradisca* has been frequently reported from the Bisan-seto area (locality number 14–19), while its distribution is almost whole along the Japanese coast (Fig. 7).

The living *Discradisca* always attach to a hard substratum such as boulders and bioclasts, almost all of which are slightly buried in sediments (Table 1). Oxygen-poor conditions may easily occur beneath the sediment-water interface (Bromley, 1996), which results in unique faunal characteristics. For example, linguliformean brachiopods, including discinids, could adapt to dysoxic environments as opportunists regardless of extant and fossil species (Chen et al., 2005; Peng et al., 2007; Masunaga and Shiino, 2021). Such a tolerance for oxygenic differences would realise the wide distribution along the Japanese coast, avoiding the severe competitive framework.

According to the original descriptions, three species have been reported from Japan: *Discradisca stella*, *Discradisca sparselineata* and *Discradisca rikuzenensis* Hatai (1940). It has been suggested that a colony consists of a single species, and occasionally neighbouring two colonies have different species (Ogiso et al., 2019). However, planktonic larva is not superior to swimming for selective settlement but depends mainly on passive settlement (Abelson, 1997; Shiino and Tokuda, 2016). If *Discradisca* species could form a monospecific colony, it leads to the possibilities of 1) sudden settlement close to the colony after free-spawning and 2) a difference in the spawning period that enables the dispersal of planktonic larvae via sea flows unique to the period.

In the former possibility, a new colony of a single species forms beside the original colony, resulting in the limited distribution of the species. This seems to be not the present case because the distributions of *Discradisca stella* and *Discradisca sparselineata* overlap with each other (Table 1). In the latter possibility, there is no evidence to explain the difference in spawning period among *Discradisca* species. Discinid larvae are planktotrophic, which enables them to persist in plankton for prolonged periods and travel over considerable distances (Williams et al., 1997b). According to Yoshimatsu (2014), planktonic larvae of *Discradisca* spp. occur from July to November in the Bisan-seto area (Seto Island Sea), where adult individuals of *Discradisca stella* and *Discradisca sparselineata* also inhabit shallow seawater. The appearance of discinid larvae seems to be no difference in the spawning period among the genera, although the larvae may include the two species of *Discradisca*.

Discradisca may have a wide variety of shell forms regarding the outline, convexity, number of radial costellae and intensity of external ornamentations. Given that the animal inhabits narrow, interstitial spaces, such as the underside of gravel (e.g., Kato, 1996), morphological variation could occur with regard to not only the difference in species but also the difference in microhabitats.

Acknowledgements

We express our sincere thanks to a reviewer Yousuke Ibaraki (Fossa Magna Museum, Itoigawa, Japan) and a journal editor Atsushi Matsuoka for their constructive suggestions. This study was financially supported in part by the JSPS KAKENHI Grant Number JP 20K04147, 21K03736 and 22K03795.

References

Abelson, A. and Denny, M., 1997, Settlement of marine organisms in flow. *Annu. Rev. Ecol. Syst.*, **28**, 317–339.

Agassiz, A., 1863, Synopsis of the echinoids collected by Dr. W. Stimpson on the North Pacific Exploring Expedition under the command of Captains Ringgold and Rodgers. *Proc. Acad. Nat. Sci. Philadelphia*, **15**, 352–361.

Association for the Research of Littoral Organisms in Osaka Bay, 2012, Rocky shore macrobiota of southeastern Osaka Bay: Results of surveys carried out in the years 2006–2010. *SHIZENSHI-KENKYU, Occasional Papers from the Osaka Museum of Natural History*, **3**, 211–224 (in Japanese).

Bitner, M. A., Logan, A. and Gischler, E., 2008, Recent brachiopods from the Persian Gulf and their biogeographical significance. *Sci. Mar.*, **72**, 279–285.

Bitner, M. A., 2010, Biodiversity of shallow-water brachiopods from New Caledonia, SW Pacific, with description of a new species. *Sci. Mar.*, **74**, 643–657.

Bitner, M. A., 2014, Living brachiopods from French Polynesia, Central Pacific, with descriptions of two new species. *Pac. Sci.*, **68**, 245–265.

Bromley, R. G., 1996, *Trace Fossils. Biology, Taphonomy and Applications.* Geological Institute, University of Copenhagen, Denmark, 361p.

Chen, Z. Q., Kaiho, K. and George, A. D., 2005, Early Triassic recovery of the brachiopod faunas from the end-Permian mass extinction: A global review. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **224**, 270–290.

Dall, W. H., 1920, Annotated list of the recent Brachiopoda in the collection of the United States National Museum, with descriptions of thirty-three new forms. *Proc. U. S. National Mus.*, **57**, 261–377.

Davies, L., Kemp, A., O'Loughlin, C. and Korczynskyj, D., 2022, Is conscientious beachcombing the key to 'unlock' marine plastic pollution trends through citizen science? A case study from Cockburn Sound, Western Australia. *Mar. Pollut. Bull.*, **177**, 1–14.

Donovan, S. K., 2011, Beachcombing and palaeoecology. *Geol. Today*, **27**, 25–33.

Dunker, W., 1877, Mollusca nonnulla nova maris Japonici. *Malakozoologische Blätter*, **24**, 67–75.

Fukuda, H., 2010, Discinid brachiopod. *In* Nature Environment Division, Life and Environment Department, Okayama Prefecture, ed., *Red Data Book in Okayama: Animal Edition*, Nature Environment Division, Life and Environment Department, Okayama Prefectural Government, Okayama, 258 (in Japanese). *

Gallagher, S. J., Kitamura, A., Iryu, Y., Itaki, T., Koizumi, I. and Hoiles, P. W., 2015, The Pliocene to recent history of the Kuroshio and Tsushima Currents: a multi-proxy approach. *Prog. Earth Planet. Sci.*, **2**, article number 17, 1–23.

Gould, A. A., 1862, *Otia conchologica: Descriptions of shells and mollusks, from 1839 to 1862.* Gould and Lincoln, Boston, 256 p.

Hatai, K. M., 1940, The Cenozoic Brachiopoda of Japan. *Sci. Rep. Tohoku Imperial Univ. 2nd Ser. (Geology)*, **20**, 1–413.

Hirose, M., Ohtsuka, S., Kondo, Y., Hirabayashi, T., Tomikawa, K. and Shimizu, N., 2012, Two species of brachiopods collected from central part of Seto Inland Sea, western Japan. *Bull. Hiroshima Univ. Mus.*, **4**, 43–48 (in Japanese).

Ikeda, H. and Kuramochi, T., 1997, Brachiopods collected from Sagami Bay. *Nat. Hist. Rep. Kanagawa*, **18**, 39–44 (in Japanese).

Ishikawa, S., Niki, M. and Yoshikawa, T., 2016, *Field Guide to Biodiversity of Higashi-Hazu Tidal Flat in*

Mikawa Bay. School of Marine Science and Technology of Tokai University, Shizuoka, 81p. (in Japanese). *

Ishizaki, Y., Ogura, M., Takahashi, C., Kaneko, M., Imura, A. and Shiino, Y., 2023, Burrow morphology of ghost crab *Ocypode stimpsoni* on Ikarashi beach, Niigata, Japan. *Plankton Benthos Res.*, **18**, 1–12.

Itaki, T., 2003, Depth-related radiolarian assemblage in the water column and surface sediments of the Japan Sea. *Marine Micropaleontol.*, **47**, 253–270.

Itaki, T., Matsuoka, A., Yoshida, K., Machidori, S., Shinzawa, M. and Todo, T., 2003, Late spring radiolarian fauna in the surface water off Tassha, Aikawa Town, Sado, central Japan. *Sci. Rep., Niigata Univ. Ser. E (Geol.)*, no. 18, 41–51.

Kato, M., 1996, The unique intertidal subterranean habitat and filtering system of a limpet-like brachiopod, *Discinisca sparselineata*. *Can. J. Zool.*, **74**, 1983–1988.

Kawamura, M., Okanishi, M., Nakano, T., Kato, T., Harada, K., Yamauchi, H., Sentoku, A., Koizumi, T., Nakayama, R., Nakamachi, T., Yoshikawa, A. and Takahashi, Y., 2016, *A Field Guide to Coastal Marine Life in Shirahama, Wakayama, Japan*. Seto Marine Biological Laboratory, Kyoto University, Wakayama, 64p. (in Japanese). *

Kumamoto Prefectural Rare Wild Fauna and Flora Review Committee, 2009, *Kumamoto Prefecture's Important Wild Fauna and Flora, Red Data Book in Kumamoto, Revised Volume*. Kumamoto Prefectural Environment and Living Department Nature Conservation Division, Kumamoto, 597p. (in Japanese). *

Kurihara, T. and Matsuoka, A., 2009, A late-winter (March 10, 2008) living radiolarian fauna in surface–subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ. (Geol.),* no. 24, 81–90.

Kurihara, T. and Matsuoka, A., 2010, Living radiolarian fauna of late autumn (November 13, 2008) in surface–subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ. (Geol.),* no. 25, 83–92.

Kurihara, T., Shimotani, T. and Matsuoka, A., 2006, Water temperature, salinity, algal-chlorophyll profiles and radiolarian fauna in the surface and subsurface waters in early June, off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 21, 31–46.

Kurihara, T., Uchida, K., Shimotani, T. and Matsuoka, A., 2007, Radiolarian faunas and water properties in surface and subsurface waters of the Japan Sea in September 2005, off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 22, 43–56.

Kurihara, T., Uchida, K., Shimotani, T. and Matsuoka, A., 2008, Radiolarian faunal characteristics in surface–subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan in June 2007: inflowing radiolarians on the Tsushima Warm Current. *Sci. Rep., Niigata Univ. (Geol.)*, no. 23, 65–74.

Laboratory of Animal Ecology, School of Agriculture, Hokkaido University, 2018, Encyclopedia of Organisms in Kattoshi (Kattoshi Ikimono Zukan). https://sites.google.com/view/kattoshifriends (in Japanese: accessed 18th November 2022). *

Lischke, C. E., 1874, Diagnosen neuer Meeres-Conchylien von Japan. *Jahrbücher der Deutschen Malakozoologischen Gesellschaft*, **1**, 57–59.

Masunaga, M. and Shiino, Y., 2021, Death or living assemblage? The Middle Permian discinid brachiopods in the Kamiyasse area, Southern Kitakami Mountains, northeastern Japan. *Paleontol. Res.*, **25**, 258–278.

Matsuoka, A., Shinzawa, M., Yoshida, K., Machidori, S., Kurita, H. and Todo, T., 2002, Early summer radiolarian fauna in surface waters off Tassha, Aikawa Town, Sado Island, central Japan. *Sci. Rep., Niigata Univ. Ser. E (Geol.)*, no. 17, 17–25.

Matsuoka, A., Yoshida, K., Hasegawa, S., Shinzawa, M., Tamura, K., Sakumoto, T., Yabe, H., Niikawa, I. and Tateishi, M., 2001, Temperature profile and radiolarian fauna in surface waters off Tassha, Aikawa Town, Sado Island, central Japan. *Sci. Rep., Niigata Univ. Ser. E (Geol.)*, no. 16, 83–93.

Mergl, M., 2010, Discinid brachiopod life assemblages: Fossil and extant. *Bulletin of Geosciences*, **85**, 27–38.

Miura, T., Miura, K., Tomioka, H., Saeki, M. and Mihashi, R., 2012, Benthic mollusks, crustaceans and a brachiopod recorded around the Iorigawa seagrass-bed areas in Kadokawa Bay, Miyazaki, Japan. *Bull. Fac. Agric. Univ. Miyazaki*, **58**, 51–68 (in Japanese).

Ogiso, S., Hirose, M., Higashide, Y. and Kohtsuka, H., 2019, Notes on the two species of the genus *Discradisca* (Brachiopoda, Discinidae) inhabiting the coast of Noto Peninsula, Sea of Japan. *Rep. Noto Mar. Cent.*, **25**, 1–8 (in Japanese).

Ogiso, S., Matada, M., Kohtsuka, H. and Hirose, M., 2014, A first record of *Discradisca sparselineata* (Brachiopoda: Discinidae) from Ishikawa Prefecture, Sea of Japan. *Rep. Noto Mar. Cent.*, **20**, 11–16 (in Japanese).

Oki Marine Biological Station, 2011, *Fauna of the Sea around the Oki Marine Biological Station*. Marine Biological Science Section, Shimane University, Shimane, 32p. (in Japanese).

omoyasu ta, 2020, Juvenile *Discradisca* (Wakai Suzumegaidamashi). YouTube, https://www.youtube.com/watch?v=ZnmpxwldDIQ (in Japanese: accessed 18th November 2022). *

Osawa, M. and Kurata, K., 2016, First report of discinid brachiopod (Brachiopoda: Discinidae) from the Sea of Japan. *Abstracts for Joint Meeting of the 23rd Regular Meeting of ReCCLE, Shimane University and the 4th Regular Meeting of Japanese Association for Estuarine Science*, 7 (in Japanese). *

Otani, M., 2019, *Discradisca stella* (Gould, 1860) (Brachiopoda: Discinidae) recorded at the inter-tidal zone of Osaka Bay, Japan. *Wadatsumi*, **1**, 7–10 (in Japanese). *

Peng, Y. Q., Shi, G. R., Gao, Y. Q., He, W. H. and Shen, S. Z., 2007, How and why did the Lingulidae (Brachiopoda) not only survive the end-Permian mass extinction but also thrive in its aftermath? *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **252**, 118–131.

Research Center for Marine Biology, Graduate School of Life Sciences, Tohoku University, Asamushi biological archive. http://www.biology.tohoku.ac.jp/lab-www/asamushi/asamushi_archive/brachiopoda.html (in Japanese: accessed 18th November 2022).

Seo, T. and Tanangonan, J., 2014, Recent marine malacofauna in Kagawa Prefecture. *Mem. Fac. Agric. Kinki Univ.*, **47**, 87–124 (in Japanese).

Shiino, Y. and Tokuda, Y., 2016, How does flow recruit epibionts onto brachiopod shells? Insights into reciprocal interactions within the symbiotic framework. *Palaeoworld*, **25**, 675–683.

Stenzel, H. B., 1965, Stratigraphic and paleoecologic significance of a new Danian brachiopod species from Texas. *Geologische Rundschau*, **54**, 619–631.

Suzuki, M., 2020, *Discradisca stella.* https://tonysharks.com/Tree_of_life/Eukaryote/Opisthokonta/Suzumegaidamashi/Suzumegaidamashi.html (in Japanese: accessed 18th November 2022). *

Tamano Marine Institute, Okayama University, 1978, Research on biota and major experimental animals in the Bisan-Seto Sea area. *In* Directors-Council of National Marine and Inland Biological Stations in Japan, ed., *Research on Biota and Major Experimental Organisms around Marine and Inland Biological Stations, Japan (Fiscal Year Final Research Report 1975–1977 of Grants-in-Aid for Scientific Research)*, 158–170. Directors-Council of National Marine and Inland Biological Stations in Japan, Fukuoka (in Japanese). *

Toba Aquarium, 2014, Observation Diary. https://aquarium.co.jp/diary/2014/10/12656 (in Japanese: accessed 18th November 2022). *

Ushimado Marine Institute, Okayama University, List of marine invertebrates near the UML. https://www.science.okayama-u.ac.jp/~rinkai/Fauna.htm (in Japanese: accessed 18th November 2022).

Wada, T. and Yoshimatsu, S., 2020a, *Discradisca stella* (Gould, 1862). *In* Nature Environment Division, Life and Environment Department, Okayama Prefecture, ed., *Red Data Book in Okayama: Animal Edition*, Nature Environment Division, Life and Environment Department, Okayama Prefectural Government, Okayama, 785 (in Japanese). *

Wada, T. and Yoshimatsu, S., 2020b, *Discradisca sparselineata* (Dall, 1920). *In* Nature Environment Division, Life and Environment Department, Okayama Prefecture, ed., *Red Data Book in Okayama: Animal Edition*, Nature Environment Division, Life and Environment Department, Okayama Prefectural Government, Okayama, 785 (in Japanese). *

Williams, A., Brunton, C. H. C. and MacKinnon, D. I., 1997a, Morphology. *In* Kaesler, R. L., ed., *Treatise on Invertebrate Paleontology, Part H: Brachiopoda Revised Volume 1*, Geological Society of America and University of Kansas, Boulder and Lawrence, 321–422.

Williams, A., Carlson, S. J. and Brunton, C. H. C., 2000, Linguliformea. *In* Kaesler, R. L., ed., *Treatise on Invertebrate Paleontology, Part H: Brachiopoda Revised Volume 2,* Geological Society of America and University of Kansas, Boulder and Lawrence, 30–157.

Williams, A., James, M. A., Emig, C. C., Mackay, S. and Rhodes, M. C., 1997b, Anatomy. *In* Kaesler, R. L., ed., *Treatise on Invertebrate Paleontology, Part H: Brachiopoda Revised Volume 1*, Geological Society of

America and University of Kansas, Boulder and Lawrence, 7–188.

Yoshimatsu, S., 2014, 2 kinds of larval morphology which belong to the Lingulida (Brachiopoda: Lingulata) from the eastern part of the Seto Inland Sea, Japan. *Bull. Plankton Soc. Japan*, **61**, 15–22 (in Japanese).

Yoshioka, T., 2016, Beached shells of *Discradisca* (Brachiopoda) in Hokuriku along the coast of the Japan Sea. *Jour. Jap. Drif. Soc.*, **14**, 39–40 (in Japanese).

Yoshioka, T., 2017, Disciniscid dorsal shells washed up on the beaches in San' in region, Japan. *Bull. Toyama Sci. Mus.*, **41**, 85–86 (in Japanese).

Yoshioka, T., 2020, Mass stranding of discinid brachiopod shells related to artificial habitat disturbance. *Jour. Jap. Drif. Soc.*, **18**, 13–18 (in Japanese).

@menashi_sato, 2016, Wansoku! https://blog.goo.ne.jp/853972310/e/161b7f01f697af600017f65bddef6a8d (in Japanese: accessed 18th November 2022). *

* English translation from the original written in Japanese