Living radiolarians sampled on 7 June 2010 in surface–subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan

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Abstract

Radiolarians living in surface–subsurface waters (0–200 m depth) were documented from the Japan Sea off Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan on 7 June 2010, along with water properties (temperature, salinity, and fluorescence intensity). Plankton samples were collected from two depth intervals (0–100 m and 100–200 m), and Rose Bengal staining was used to discriminate “living” from “dead” specimens. The temperature ranged from 8.9 ℃ to 10.5 ℃ at 100–200 m depth, and from 10.5 ℃ to 17.4 ℃ at 0–100 m depth. Salinity shows little variation at depths of 0–200 m, ranging from 34.1 to 33.7 psu. Fluorescence intensity shows a peak at around 54 m depth. The radiolarian fauna of the deeper sample (607-11SD-8; 100–200 m depth), from which 23 “living” and 15 “dead” specimens were obtained, consists mainly of cold-water species such as *Larcopyle buetschlii* and *Cyrtidosphaera reticulata*, along with *Cladococcus bifurcus*, *Acanthosphaera circopora*, and *Phormacantha hystrix*. The shallower sample (607-11SD-5; 0–100 m depth) contains 16 “living” and 2 “dead” specimens, including *C. reticulata*, *L. buetschlii*, and *A. circopora*, although the standing stock is very low. The existence of “living” specimens of *L. buetschlii* and *C. reticulata* at 100–200 m depth shows that these cold-water species are able to survive in deeper waters (>100 m depth) during the warm season in the central Japan Sea. The depth distributions of other species (e.g., *A. circopora*) in the subsurface water were also determined, providing ecological information on living radiolarians in the Japan Sea.

Key words: depth distribution, Japan Sea, Radiolaria, Sado Island, subsurface water.

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Introduction

Radiolaria are one of the most prosperous marine planktonic protists throughout Phanerozoic time, being widely distributed in the world's oceans and seas at various depths (e.g., Renz, 1976; Kling, 1979). Recent studies around the Japanese Islands have provided information on the depth distributions of several living radiolarian species in the Japan Sea (Itaki, 2003; Ishitani and Takahashi, 2007).

Since 2000, our research group has been studying living radiolarians of the Japan Sea off Sado Island, based from the Sado Marine Biological Station (administered by the Faculty of Science, Niigata University, Japan). The results reveal that radiolarians living in surface–subsurface waters (<100 m depth) show a distinctive seasonality in terms of faunal composition, and that warm-water species of the early summer to late autumn faunas are influenced by the inflow of the Tsushima Warm Current (TWC) (Matsuoka et al., 2001, 2002; Itaki et al., 2003; Kurihara et al., 2006, 2007, 2008; Kurihara and Matsuoka, 2009, 2010). From winter to early summer, the occurrence of cold-water species such as *Larcopyle buetschlii* Dreyer in surface–subsurface waters is dependent on the vertical faunal distribution, which in turn is controlled by the vertical water-mass structure of the Japan Sea Proper Water and by water mixing related to the winter monsoon; however, no previous study has examined the faunal composition below 100 m depth off Sado Island.

In June 2010, we collected plankton samples from 0–200 m depth off Tassha, Sado Island, Niigata Prefecture, central Japan (Fig. 1). In the present paper, we describe radiolarians from two different depth intervals (100–200 m and 0–100 m), distinguishing between "living" and "dead" specimens, and briefly discuss the mode of life of several of the faunal constituents.

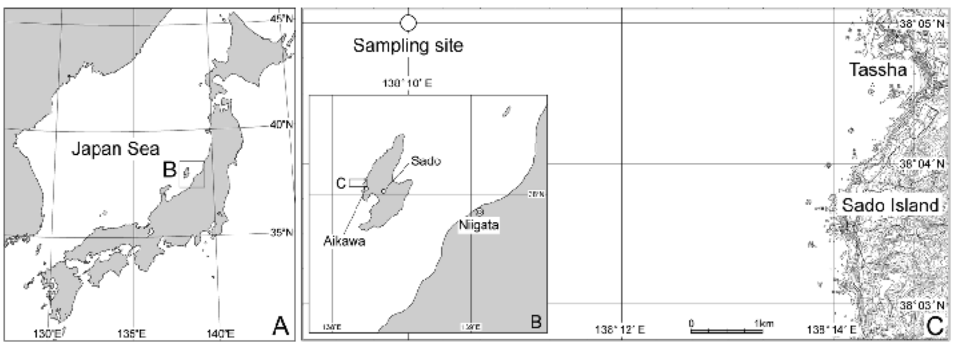

Fig. 1. Index map showing the location of the sampling site. The base maps are modified from Kurihara and Matsuoka (2009). Topographic data are sourced from the 1:25,000 "Aikawa" map sheet published by the Geospatial Information Authority of Japan.

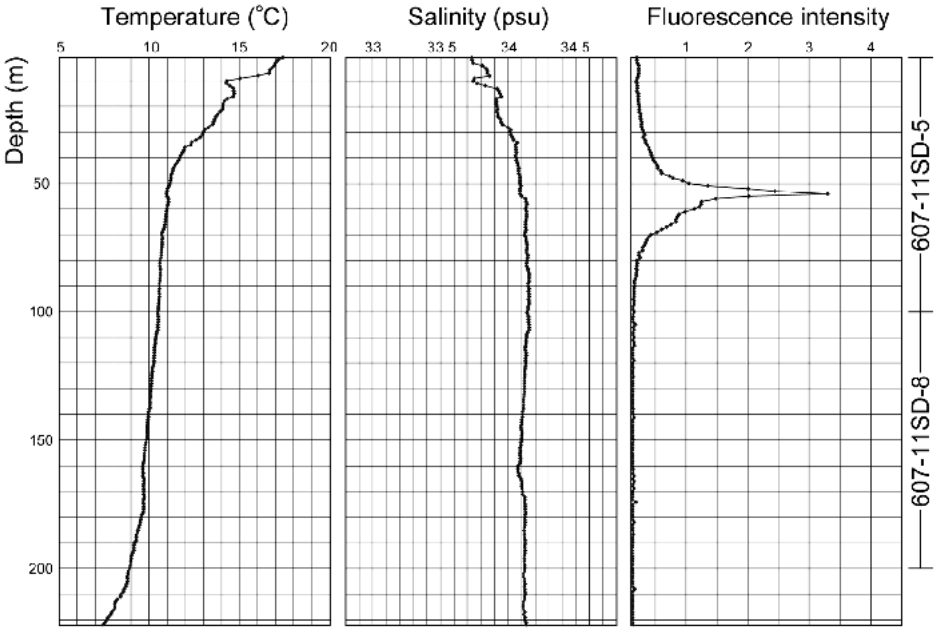

Fig. 2. Sampling intervals (607-11SD-8 and -5) and vertical profiles of temperature, salinity, and fluorescence intensity at the sampling site off Tassha, Sado Island.

Materials and methods

Plankton sampling was conducted on 7 June 2010 at 38°05'N, 138°10'E, approximately 6 km west of Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan (Fig. 1), from aboard the research vessel *IBIS2000* of the Sado Marine Biological Station. We measured water properties (temperature, salinity, and fluorescence intensity) using a conductivity– temperature–depth (CTD) sensor (COMPACT-CTD; Alec Electronics Co. Ltd., Japan). Eight plankton samples (607-11SD-1 to -8) were collected using a Marukawa-type 100 µm opening net with a mouth diameter of 0.3 m. The depths of sample-collection intervals were monitored by a depth sensor (MDS-MkV/D; JFE Alec Co. Ltd., Japan). Sea-water temperature at 0–100 m depth was measured using a conventional digital thermometer.

Among the eight samples, sample 607-11SD-8 was collected from 100–200 m depth by closing the net using a messenger. We obtained sample 607-11SD-5 from 0–100 m depth without a messenger. These plankton samples were washed in a sieve (46 µm mesh), preserved in an aqueous ethanol solution (ca. 90%), and stained by Rose Bengal to distinguish between "living" specimens (i.e., the protoplasm of radiolaria was completely stained) and "dead" (unstained) specimens. The stained residue was mounted on a glass slide using Canada balsam for observation under a transmitted light microscope (Olympus BX51).

Table 1. List of radiolarian species and numbers of recovered specimens from samples 607-11SD-8 and -5. L: "living" (stained) specimen, D: "dead" specimen.

Sample number	607-11SD-8		607-11SD-5	
Sampling depth	200-100 m		100-0 m	
	#shells			
SPUMELLARIA	L	D	L	D
Acanthosphaera circopora Popofsky	5	0	1	0
Cladococcus bifurcus Haeckel	3	4	0	0
Cyrtidosphaera reticulata Haeckel	6	2	11	2
Larcopyle buetschlii Dreyer	3	4	3	0
Spongosphaera streptacantha Haeckel	0	1	0	0
Spongotrochus glacialis Popofsky	1	0	0	0
other spumellarians	1	0	1	0
NASSELLARIA				
Lipmanella dictyoceras (Haeckel)	2	0	0	0
Phormacantha hystrix (Jørgensen)	2	3	0	0
Plectacantha trichoides Jørgensen	0	1	0	0

Results and discussion

Vertical profiles of temperature, salinity, and fluorescence intensity at the sampling point, from 222 m depth to the surface, were constructed from CTD data at 1-m intervals (Fig. 2). The temperature at 100–200 m depth (the interval from which sample 607-11SD-8 was collected) shows a gentle increase with decreasing depth, from 8.9 ℃ to 10.5 ℃. The salinity of this interval is almost constant at approximately 34.1 psu. The fluorescence intensity was below background values within this interval, indicating very low contents of algal chlorophyll.

Sample 607-11SD-5 was collected at 0–100 m depth. The temperature within this interval shows an increase from 10.5 ℃ to 17.4 ℃ with decreasing depth. Whereas the temperature gradient is low at 100–47 m depth, similar to that at 100–200 m depth, the water mass shallower than 47 m depth shows a high temperature gradient, probably influenced by solar insolation heating from the surface and the inflow of the TWC. The salinity at 56–100 m depth is almost constant at around 34.1 psu. In water shallower than 56 m, salinity varies from approximately 34.1 to 33.7 psu with decreasing depth. Within the 0–100 m depth interval, fluorescence intensity shows a single peak at around 54 m depth.

We obtained 56 shells from samples 607-11SD-8 and -5, including nine identified and one unidentified spumellarian species (Table 1). In sample 607-11SD-8 (200–100 m depth), 23 "living" specimens, whose protoplasms were stained, and 15 "dead" specimens (empty skeletons)

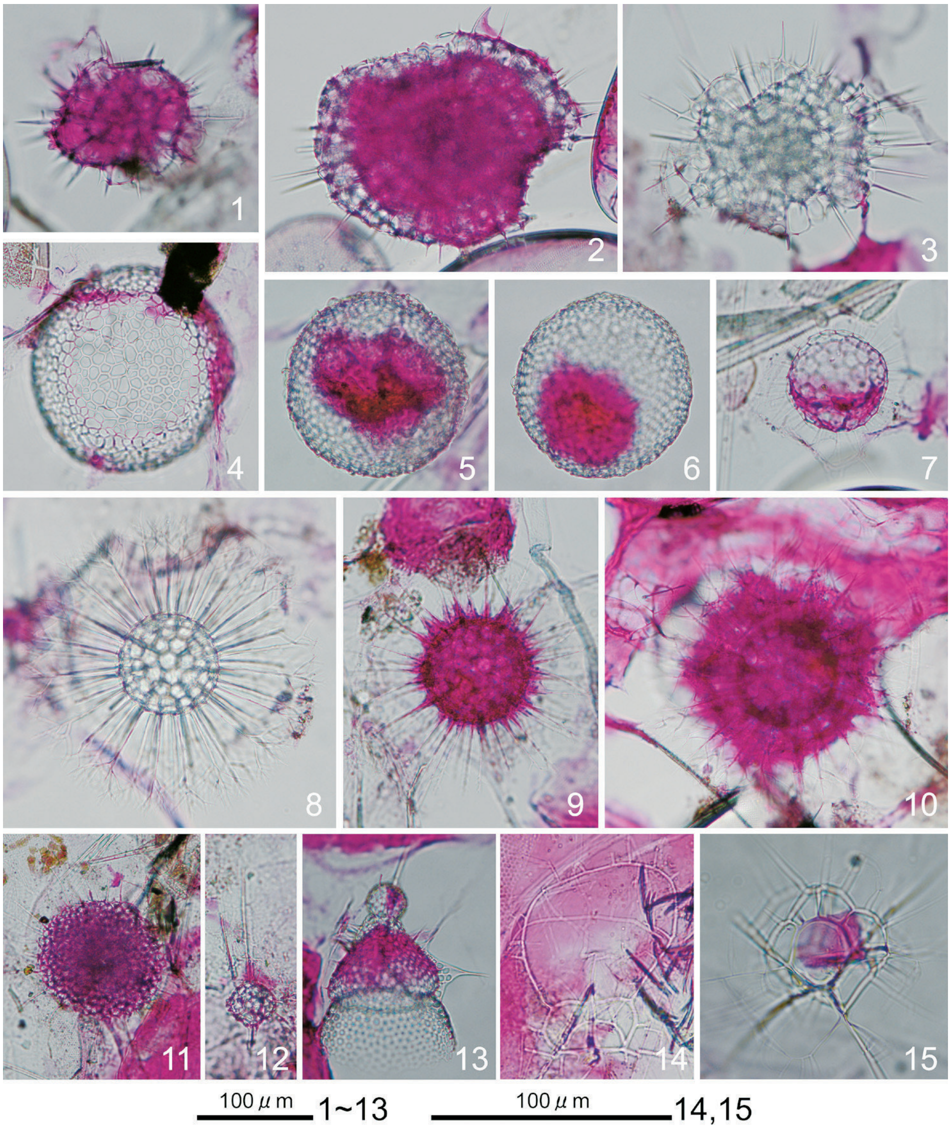

Fig. 3. Photomicrographs (transmitted light) of radiolarians stained by Rose Bengal from sample 607-11SD-8 (100–200 m depth). 1–3: *Larcopyle buetschlii* Dreyer, 1, 2: "living" (stained) specimens; 3: "dead" specimen. 4–6: *Cyrtidosphaera reticulata* Haeckel, 4: "dead" specimen; 5, 6: "living" (stained) specimens. 7: *Acanthosphaera circopora* Popofsky, "living" (stained) specimen. 8–10: *Cladococcus bifurcus* Haeckel, 8: "dead" specimen; 9, 10: "living" (stained) specimens. 11: *Spongotrochus glacialis* Popofsky, "living" (stained) specimen. 12: *Spongosphaera streptacantha* Haeckel (juvenile form), "dead" specimen. 13: *Lipmanella dictyoceras* (Haeckel), "living" (stained) specimen. 14: *Plectacantha trichoides* Jørgensen, "dead" specimen. 15: *Phormacantha hystrix* (Jørgensen), "living" (stained) specimen.

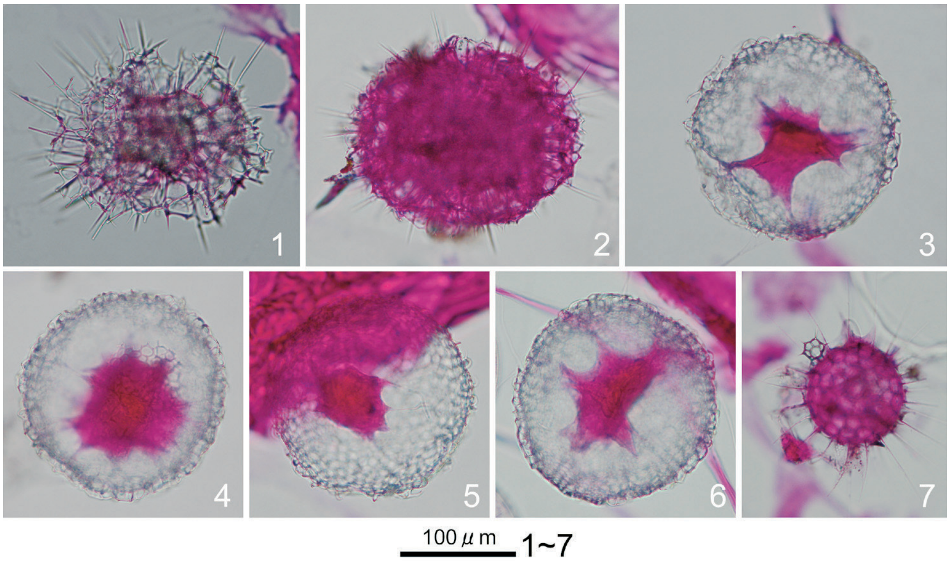

Fig. 4. Photomicrographs (transmitted light) of radiolarians stained by Rose Bengal from sample 607-11SD-5 (0–100 m depth). 1, 2: *Larcopyle buetschlii* Dreyer, "living" (stained) specimens. 3–6: *Cyrtidosphaera reticulata* Haeckel, "living" (stained) specimens. 7: *Acanthosphaera circopora* Popofsky, "living" (stained) specimen.

were counted. In contrast, sample 607-11SD-5 (100–0 m depth) yielded 16 "living" specimens from 18 specimens collected in total. The following species were identified from sample 607-11SD-8: *Acanthosphaera circopora* Popofsky, *Cladococcus bifurcus* Haeckel, *Cyrtidosphaera reticulata* Haeckel, *L. buetschlii*, *Spongosphaera streptacantha* Haeckel (juvenile form), *Spongotrochus glacialis* Popofsky, *Lipmanella dictyoceras* (Haeckel), *Phormacantha hystrix* (Jørgensen), and *Plectacantha trichoides* Jørgensen (Fig. 3). Among these, *A. circopora*, *C. bifurcus*, *C. reticulata*, *L. buetschlii*, and *P. hystrix* are relatively abundant, whereas the others are minor (two shells or fewer). From 607-11SD-5, we obtained *A. circopora*, *C. reticulata*, and *L. buetschlii* (Fig. 4), with *C. reticulata* being dominant.

In comparing the present results with previously reported data (0–100 m depth), the early June fauna in 2005 contains abundant *C. reticulata*, and plagiacanthid and lophophaenid nassellarians together with *L. buetschlii* (Kurihara et al., 2006). Therefore, the common occurrence of *C. reticulata* and *L. buetschlii* in samples 607-11SD-8 and -5 of the present study is similar to the early June fauna of 2005 in terms of faunal composition. In late winter (March 2008), the abundant occurrence of *C. reticulata* and *L. buetschlii* has been reported from 0–100 m depth at the same sampling site of the present study (Kurihara and Matsuoka, 2009); in contrast, these species were absent or rare in September 2005 and November 2008

(Kurihara et al., 2007; Kurihara and Matsuoka, 2010). According to Itaki (2003), the adult and juvenile forms of *L. buetschlii* are abundant at depths of 200–1000 m and 0–200 m, respectively, in the northeastern Japan Sea (off western Hokkaido). Based on these data, Kurihara and Matsuoka (2009) suggested that adults of *L. buetschlii* and probably *C. reticulata* in the central Japan Sea survive in deeper waters below 100 m depth during the warm season. This proposal has been confirmed by the present results, which provide the first evidence of *C. reticulata* and *L. buetschlii* in subsurface water deeper than 100 m. It is also clear that the mode of life of these species is completely different from that of inflowing species transported seasonally by the TWC, such as *S. streptacantha*, *Tetrapyle octacantha* Müller, and *Didymocyrtis tetrathalamus* (Haeckel) (Kurihara et al., 2008; Kurihara and Matsuoka, 2010).

Acanthosphaera circopora and *C. bifurcus* were commonly present in the deeper sample (607-11SD-8; 100–200 m depth), in which all specimens of *A. circopora* were stained by Rose Bengal, indicating that this species lives mainly in subsurface water (100–200 m depth) rather than in surface water (0–100 m depth). *Acanthosphaera circopora* is commonly seen in the Japan Sea, being abundant in the September 2005 fauna at 54–77 m depth (17–18 ℃) [= *Acanthosphaera actinota* (Haeckel) of Kurihara et al. (2007)], the March 2008 fauna at 0–100 m depth (9.6–9.7 ℃) (Kurihara and Matsuoka, 2009), and the November 2008 fauna at 0–100 m depth (17.1–19.4 ℃) (Kurihara and Matsuoka, 2010). Although these occurrences indicate a wide range of temperature tolerance for the species, its ecological behavior remains poorly understood because no living specimen has been observed to date; however, the present results raise the possibility that future sampling and observations of living specimens in deeper waters (>100 m) will provide substantive information on ecologically unknown species such as *A. circopora*.

Ishitani and Takahashi (2007) reported the depth distributions of several species in subsurface waters of the Japan Sea. For example, the authors described the occurrence of "living" specimens of *Stichocorys seriata* Jørgensen from waters of 120–200 m depth (June 2002) at two sites in the central and northern Japan Sea [Station 6 off Noto Peninsula and Station 7 off Akita, of Ishitani and Takahashi (2007)]. Although we collected samples during the same season (June), we did not obtain *S. seriata*, possibly reflecting various factors and annual variations, including regional differences in radiolarian distribution and water-column properties. We currently have an understanding of the depth distribution and niche segregation of only a small percentage of the species living in surface–subsurface waters, and it is necessary to add to this knowledge by ongoing studies in order to enable paleoenvironmental analyses of the Japan Sea.

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