Living radiolarian fauna of late autumn (November 13, 2008) in surface-subsurface waters of the Japan Sea off Tassha, Sado Island, central Japan

Toshiyuki KURIHARA* and Atsushi MATSUOKA**

Abstract

The radiolarian fauna on November 13, 2008 is documented from surface-subsurface waters (< 100 m depth) in the Japan Sea off Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan. The sea-water temperature of the water mass from the surface to 100 m depth ranged from 19.4 to 17.1℃. The temperature at 100 m depth (17.1℃) was the highest value in the year-round record from March 2008 to February 2009. Seventeen spumellarian and 20 nassellarian species were identified from 1711 shells. The fauna is characterized by abundant warm-water species, including *Tetrapyle octacantha*, *Spongosphaera streptacantha*, *Pseudocubus obeliscus*, and *Didymocyrtis tetrathalamus*, along with *Acanthodesmia vinculata*, *Acanthosphaera circopora*, and *Dictyocoryne profunda* group. Given the abundance of *T. octacantha* and *S. streptacantha*, the species composition of the November fauna in 2008 is similar to that of September faunas recorded in our previous studies off Sado Island. This finding indicates that the radiolarian fauna inflowing within the Tsushima Warm Current around Sado Island in 2008 was under the influence of the same water current system from September to November, probably the Taiwan-Tsushima Warm Current System. In addition, the common occurrence of warm-water species dwelling in tropical to subtropical surface waters (e.g., *D. tetrathalamus*) demonstrates the influence of warm waters of the Kuroshio.

Key words: Japan Sea, Kuroshio, Radiolaria, Sado Island, Tsushima Warm Current.

---

* Graduate School of Science and Technology, Niigata University, Niigata 950-2181, Japan
** Department of Geology, Faculty of Science, Niigata University, Niigata 950-2181, Japan
(Manuscript received 21 December, 2009; accepted 14 January, 2010)

Introduction

The Japan Sea, surrounded by the Japanese Islands, the Korean Peninsula, and the Eurasian Continent, is a semi-enclosed marginal sea with an average depth of 1,667 m and a maximum depth of 3,796 m (National Astronomical Observatory, 2007). The four main straits (the Tsushima, Tsugaru, and Soya and Tatar straits) connect the Japan Sea with the East China Sea, the Pacific Ocean, and the Okhotsk Sea, respectively. The Tsushima Strait plays an important role in terms of warm-water inflow; the warm current that flows through the Tsushima Strait is termed the Tsushima Warm Current (TWC). The TWC has long been considered a branch of the Kuroshio (e.g., Nitani, 1972). According to Isobe (1999a, b), however, the formation of the TWC is strongly related to the Taiwan-Tsushima Warm Current System (TTWCS), at least from April to August, and in turn it is strongly affected by the Kuroshio surface layer from October to December (Fig. 1).

Based on the results of nearly a decade of study by our research group from a base at the Sado Marine Biological Station (administered by the Faculty of Science, Niigata University, Japan), it is clear that the composition of the living radiolarian fauna in surface-subsurface waters of the Japan Sea around Sado Island is influenced by the inflow of the TWC (Matsuoka et al., 2001; Kurihara et al., 2006, 2007, 2008). In addition, warm-water species within the TWC are considered to be closely related to radiolarians of the Kuroshio, because the bulk of the warm waters of the TWC is believed to be derived from the Kuroshio region through the East China Sea (Lie and Cho, 1994; Hsueh et al., 1996); however, as mentioned above, the TWC is affected by the TTWCS and the inflow of warm water from the Kuroshio through the Tsushima Strait shows significant seasonality (Isobe, 1999a, b). Consequently, it is possible that warm-water radiolarian species of the Japan Sea originate from several current systems during different seasons.

Since March 2008, we have been conducting year-round plankton sampling off Tassha, Sado Island, Niigata Prefecture, central Japan (Fig. 1). The aim of this project is to provide information regarding the process of the transition of the seasonal radiolarian fauna in the Japan Sea. We collected a plankton sample on November 13, 2008. Based on the theory of Isobe (1999a, b), the TWC in November is expected to have been strongly affected by the Kuroshio surface layer. Herein, we describe the radiolarian fauna of this sample and briefly discuss its characteristics in terms of faunal composition.

Materials and methods

Plankton sampling was conducted on November 13, 2008 at 38°05'N, 138°10'E, approximately 6 km west of Tassha, Sado City, Sado Island, Niigata Prefecture, central Japan (Fig. 1). The operation was carried out by the vessel *Iwayuri* owned by Y. Kobayashi (Minshuku Iwayuri). A plankton sample (1113-9SD-1) was collected from 100 m depth to the

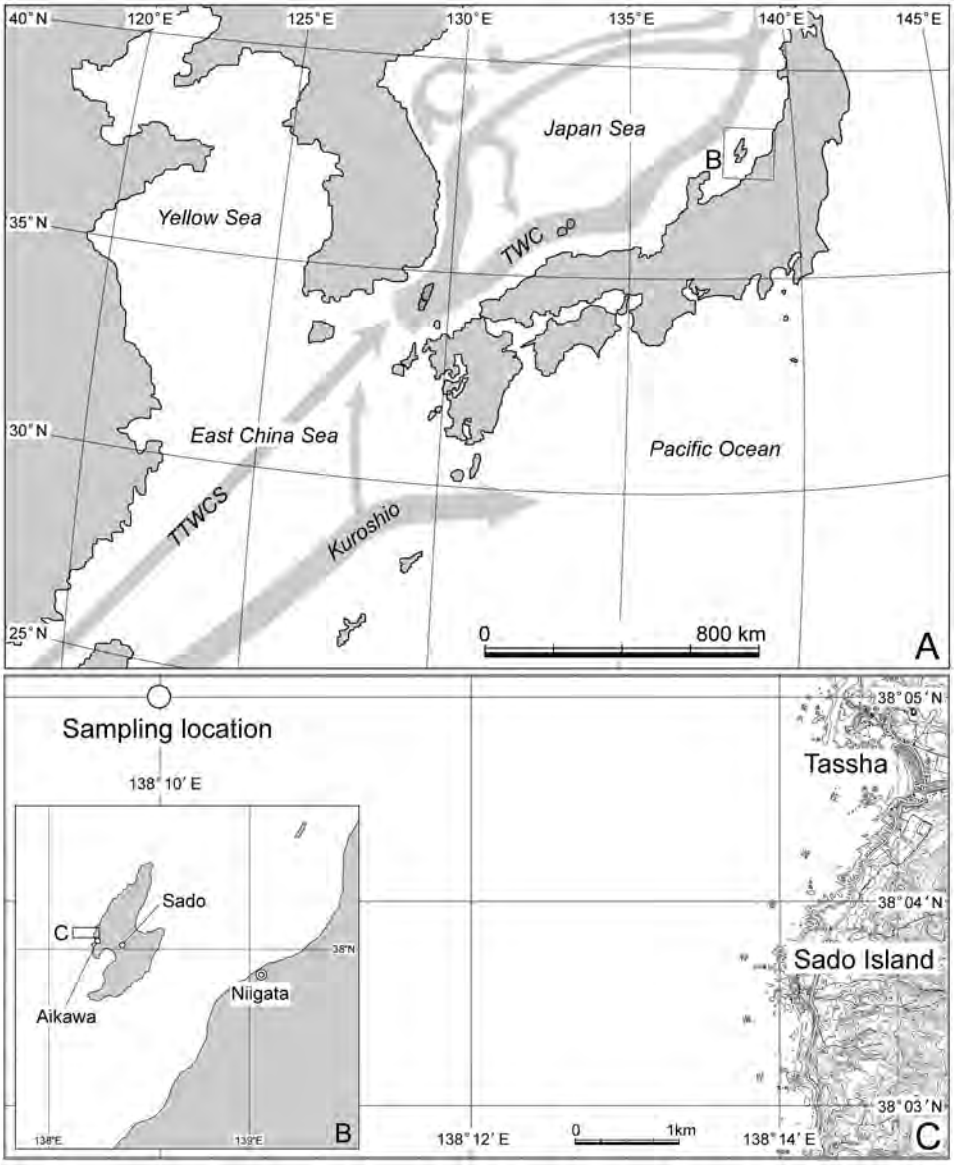

Fig. 1. (A): Main surface currents within the Japan Sea and the East China Sea. The base maps were compiled from Senjyu (1999) and Isobe (1999a, b). TWC: Tsushima Warm Current, TTWCS: Taiwan-Tsushima Warm Current System. (B), (C): Index maps showing the location of the sampling site. Topographic data are sourced from the 1:25,000 "Aikawa" map sheet published by the Geographical Survey Institute of Japan.

surface using a Marukawa-type 100 µm opening net with a mouth diameter of 0.3 m. In addition to plankton sampling, sea-water temperature was measured at 0-100 m depth using a conventional digital thermometer. Table 1 lists the sea-water temperatures at 0-100 m depth

Table 1. Sea-water temperature of the water mass measured from 100 m depth to the surface from March 2008 to February 2009 at the sampling location off Tassha, Sado Island.

Depth (m)	Sea-water temperature (°C)										
	2008/3/10	2008/4/16	2008/5/28	2008/6/16	2008/7/15	2008/9/9	2008/10/14	2008/11/13	2008/12/4	2009/1/7	2009/2/24
0	9.7	12.4	14.7	15.3	23.4	25.3	21.4	19.4	17.3	12.9	9.3
10	9.7	11.3	13.6	15.0	22.8	25.3	21.3	19.4	17.3	12.9	9.3
20	9.7	11.0	12.0	15.1	19.6	24.6	21.2	19.4	17.2	12.9	9.5
30	9.7	10.9	10.6	14.0	17.4	22.4	21.1	19.4	17.2	12.9	9.6
40	9.7	10.5	10.6	13.4	15.9	20.5	21.1	19.4	17.2	12.8	9.6
50	9.7	10.4	10.5	12.6	15.6	19.2	19.9	19.3	17.2	12.8	9.6
60	9.6	10.4	9.8	10.9	14.8	18.1	17.3	19.1	17.1	12.8	9.6
70	9.6	10.4	9.0	9.7	14.1	16.7	16.5	18.9	17.0	12.7	9.6
80	9.6	10.2	8.6	8.6	13.5	15.4	16.0	18.6	17.0	12.6	9.4
90	9.6	9.9	8.4	8.5	13.0	14.8	15.1	18.3	17.0	12.6	8.6
100	9.6	9.5	8.4	8.4	12.4	14.1	14.3	17.1	17.0	12.6	7.9

from March 2008 to February 2009.

The siliceous residue of sample 1113-9SD-1 was obtained by acid dissolution (ca. 50% sulfuric acid) of organic matter and washing in a sieve (46 μm mesh). The residue was then mounted on a glass slide using Canada balsam for observation under a transmitted light microscope (Nikon Coolscope and Olympus BX51).

Results and discussion

The sea-water temperature from the surface to 100 m depth, as measured on November 13, 2008, ranged from 19.4 to 17.1 ℃ (Table 1). The temperature of the shallow water mass (< 40 m depth) was constant at 19.4 ℃, whereas the temperature of the water mass deeper than 40 m showed a decrease from 19.3 to 17.1 ℃ with increasing depth. The temperature at 100 m depth was the highest value (17.1 ℃) in the year-round record from March 2008 to February 2009 (Table 1), probably indicating that a seasonal northwesterly wind had started to blow off the Asian Continent, leading to thermal diffusion and water mixing. Alternatively, a thicker layer of warm water than that in summer may have flowed into the area around Sado Island in November 2008.

The identified radiolarian species and numbers of skeletons are listed in Table 2. Photomicrographs of selected species are shown in Figs. 2 and 3. From 1711 radiolarian shells within the siliceous residue, we identified 17 spumellarian and 20 nassellarian species, including *Acanthosphaera circopora* Popofsky, *Arachnosphaera myriacantha* Haeckel, *Cyrtidosphaera reticulata* Haeckel, *Dictyocoryne profunda* Ehrenberg group, *Dictyocoryne* aff. *truncatum* (Ehrenberg), *Didymocyrtis tetrathalamus* (Haeckel), *Diplosphaera hexagonalis* Haeckel, *Euchitonia elegans* (Ehrenberg), *Larcopyle buetschlii* Dreyer, *Myelastrum trinibrachium* Takahashi, *Plegmosphaera pachypila* Haeckel, *Spongaster tetras* Ehrenberg, *Spongodiscus biconcavus* Haeckel, *Spongotrochus glacialis* Popofsky, *Spongosphaera streptacantha* Haeckel, *Styptosphaera spongiacea* Haeckel, *Tetrapyle*

Table 2. List of radiolarian species and numbers of recovered skeletons from sample 1113-9SD-1.

Spumellarian species	#shells	Nassellarian species	#shells
Acanthosphaera circopora Popofsky	70	*Acanthodesmia vinculata* Müller	71
Arachnosphaera myriacantha Haeckel	8	*Arachnocorys circumtexta* Haeckel	26
Cyrtidosphaera reticulata Haeckel	1	*Ceratocyrtis* sp.	8
Dictyocoryne profunda Ehrenberg group	52	*Clathrocircus* sp.	6
Dictyocoryne aff. *truncatum* (Ehrenberg)	6	*Eucecryphalus cervus* (Ehrenberg)	22
Didymocyrtis tetrathalamus (Haeckel)	141	*Eucyrtidium hexastichum* (Haeckel)	8
Diplosphaera hexagonalis Haeckel	1	*Lipmanella dictyoceras* (Haeckel)	30
Euchitonia elegans (Ehrenberg)	12	*Lithomelissa setosa* Jørgensen	4
Larcopyle buetschlii Dreyer	3	*Lophophaena hispida* (Ehrenberg)	20
Myelastrum trinibrachium Takahashi	40	*Lophophaena laticeps* (Jørgensen)	13
Plegmosphaera pachypila Haeckel	19	*Lophophaena variabilis* (Popofsky)	5
Spongaster tetras Ehrenberg	3	*Lophospyris pentagona* (Ehrenberg)	24
Spongodiscus biconcavus Haeckel	5	*Neosemantis distephanus* Popofsky	6
Spongotrochus glacialis Popofsky	12	*Peridium spinipes* Haeckel	19
Spongosphaera streptacantha Haeckel	225	*Phormacantha hystrix* (Jørgensen)	9
Styptosphaera spongiacea Haeckel	23	*Plectacantha trichoides* Jørgensen	1
Tetrapyle octacantha Müller	273	*Pseudocubus obeliscus* Haeckel	194
other spumellarians	138	*Pseudodictyophimus gracilipes* (Bailey)	11
Total numbers of spumellarian shells	1032	*Spirocyrtis scalaris* Haeckel	6
		Zygocircus productus (Hertwig)	17
		other nassellarians	179
		Total numbers of nassellarian shells	679
Total numbers of radiolarian shells	1711		

octacantha Müller, *Acanthodesmia vinculata* Müller, *Arachnocorys circumtexta* Haeckel, *Ceratocyrtis* sp., *Clathrocircus* sp., *Eucecryphalus cervus* (Ehrenberg), *Eucyrtidium hexastichum* (Haeckel), *Lipmanella dictyoceras* (Haeckel), *Lithomelissa setosa* Jørgensen, *Lophophaena hispida* (Ehrenberg), *Lophophaena laticeps* (Jørgensen), *Lophophaena variabilis* (Popofsky), *Lophospyris pentagona* (Ehrenberg), *Neosemantis distephanus* Popofsky, *Peridium spinipes* Haeckel, *Phormacantha hystrix* (Jørgensen), *Plectacantha trichoides* Jørgensen, *Pseudocubus obeliscus* Haeckel, *Pseudodictyophimus gracilipes* (Bailey), *Spirocyrtis scalaris* Haeckel, and *Zygocircus productus* (Hertwig). In addition to these species, 138 unidentified spumellarian individuals and 179 unidentified nassellarian individuals were obtained from the sample. The standing stock of radiolarian shells per 1 m^3 of sea water in the sample was calculated to be 242.2 shells/m^3.

Among the spumellarian species listed above, *T. octacantha, S. streptacantha*, and *D. tetrathalamus* were abundant in the sample, together making up 37.3% of the total fauna. *Acanthosphaera circopora*, *D. profunda* group, and *M. trinibrachium* form the next-most dominant group, making up 9.5% of the fauna. Among the nassellarians, *P. obeliscus* is the

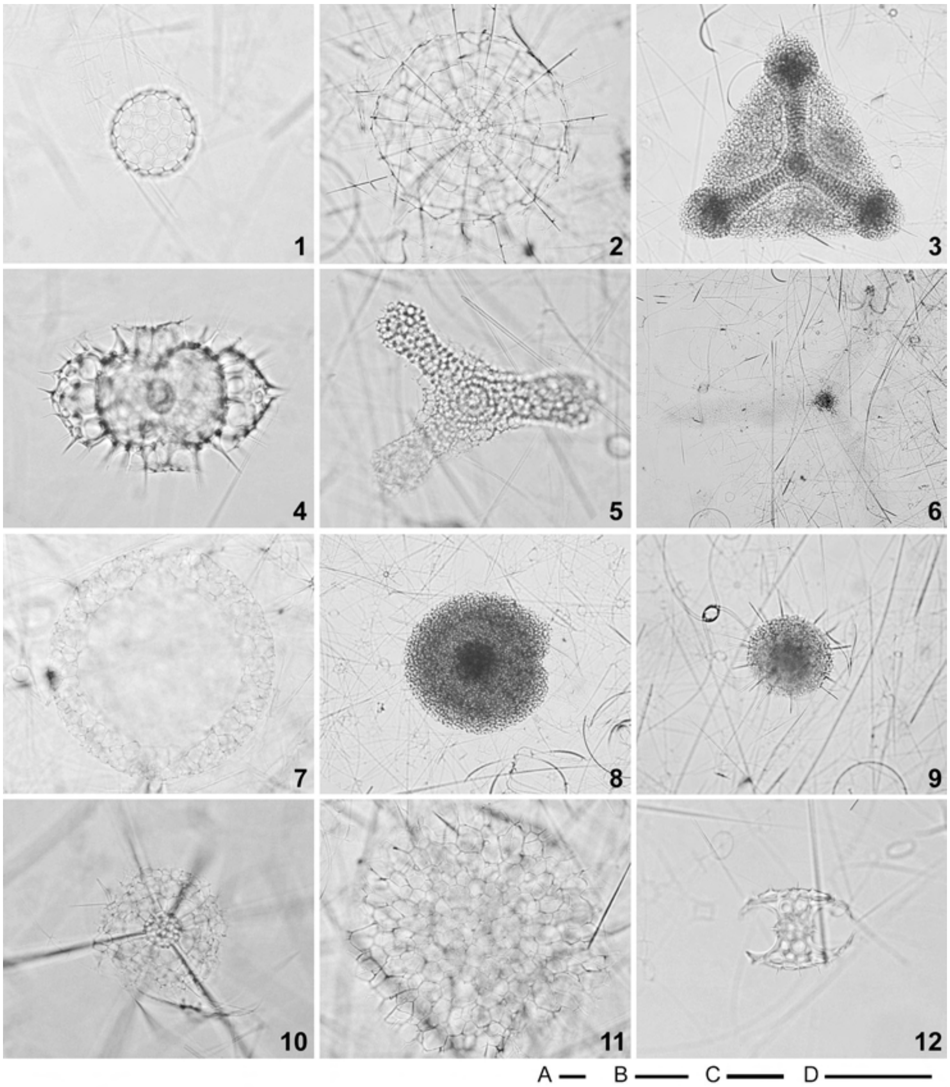

Fig. 2. Photomicrographs (transmitted light) of radiolarian skeletons from sample 1113-9SD-1. 1: *Acanthosphaera circopora* Popofsky, 2: *Arachnosphaera myriacantha* Haeckel, 3: *Dictyocoryne profunda* Ehrenberg group, 4: *Didymocyrtis tetrathalamus* (Haeckel), 5: *Euchitonia elegans* (Ehrenberg), 6: *Myelastrum trinibrachium* Takahashi, 7: *Plegmosphaera pachypila* Haeckel, 8: *Spongodiscus biconcavus* Haeckel, 9: *Spongotrochus glacialis* Popofsky, 10: *Spongosphaera streptacantha* Haeckel, 11: *Styptosphaera spongiacea* Haeckel, 12: *Tetrapyle octacantha* Müller. Scale bars A to D are 100 µm long. Scale bar A applies to 6; B applies to 3, 8, C applies to 2, 9, and D applies to 1, 4, 5, 7, 10-12.

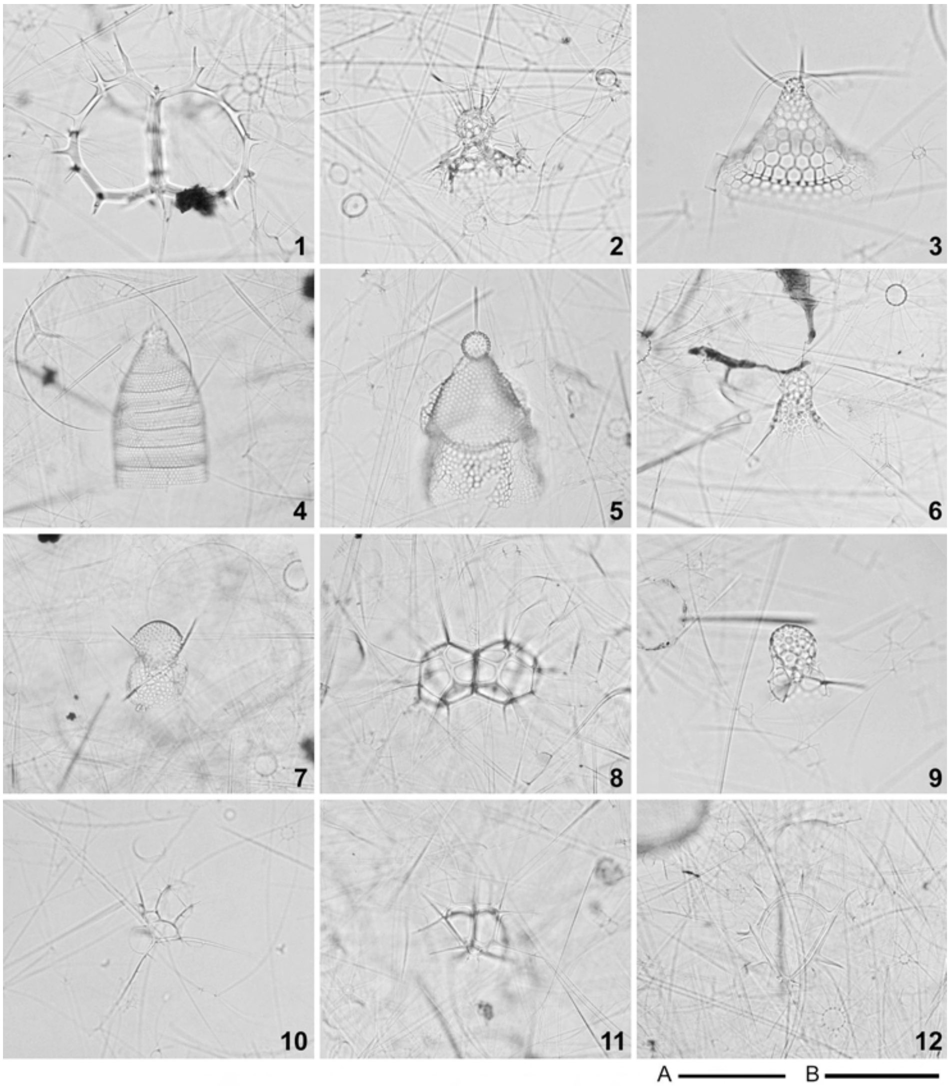

Fig. 3. Photomicrographs (transmitted light) of radiolarian skeletons from sample 1113-9SD-1. 1: *Acanthodesmia vinculata* Müller, 2: *Arachnocorys circumtexta* Haeckel, 3: *Eucecryphalus cervus* (Ehrenberg), 4: *Eucyrtidium hexastichum* (Haeckel), 5: *Lipmanella dictyoceras* (Haeckel), 6: *Lophophaena hispida* (Ehrenberg), 7: *Lophophaena laticeps* (Jørgensen), 8: *Lophospyris pentagona* (Ehrenberg), 9: *Peridium spinipes* Haeckel, 10: *Phormacantha hystrix* (Jørgensen), 11: *Pseudocubus obeliscus* Haeckel, 12: *Zygocircus productus* (Hertwig). Scale bars A and B are 100 µm long. Scale bar A applies to 1, 3–12 and B applies to 2.

most dominant species, making up 11.3% of the total fauna. *Acanthodesmia vinculata* is also abundant, making up 4.1% of the fauna (Table 2).

Tetrapyle octacantha, commonly found in samples collected off Sado Island throughout the year (Matsuoka et al., 2001, 2002; Itaki et al., 2003; Kurihara et al., 2006, 2007, 2008; Kurihara and Matsuoka, 2005, 2009), is considered a warm surface-water species, preferring coastal seawater (e.g., Kling, 1979; Kling and Boltovskoy, 1995; Chen and Tan, 1997; Yamashita et al., 2002). According to Kurihara et al. (2007, 2008), *S. streptacantha* is present from June to October around Sado Island and absent from March to May (the authors collected no data from November to February); the abundance of this species largely corresponds to the seasonal increase in the flow force of the TWC. *Didymocyrtis tetrathalamus*, which shows a similar occurrence pattern to that of *T. octacantha*, is commonly seen in low-latitude regions of the Pacific (Nigrini, 1970; Lombari and Boden, 1985). *Dictyocoryne profunda* is generally considered to occur in warm surface water (e.g., Renz, 1976; Kling, 1979; Dworetzky and Morley, 1987; Boltovskoy et al., 1996; Yamashita et al., 2002), and is abundant in subtropical warm surface-waters of the Kuroshio region in the East China Sea off Sesoko Island, Okinawa (Matsuoka, 1993, 2009).

Among the nassellarians, *P. obeliscus* is a common constituent of the fauna off Sado Island, and its blooming is frequently observed during the summer (Kurihara and Matsuoka, 2005; Kurihara et al., 2007). Among the other species, *A. myriacantha*, *D. hexagonalis*, *E. elegans*, *S. tetras*, *S. biconcavus*, *A. vinculata*, *L. hispida*, *S. scalaris*, *M. trinibrachium*, and *E. hexastichum* are commonly observed in the surface water around Okinawa; the former eight species are listed as abundant and commonly occurring species in the late-autumn radiolarian fauna off Sesoko Island, Okinawa (Matsuoka, 2009).

The radiolarian fauna within sample 1113-9SD-1 is characterized by abundant warm-water species that are commonly seen in tropical to subtropical warm surface-waters. Around Sado Island, the winter radiolarian fauna (March 10, 2008) has been reported by Kurihara and Matsuoka (2009), characterized by abundant cold-water dwellers in the Japan Sea (e.g., *C. reticulata* and *L. buetschlii*). The composition of the November fauna of the present study is completely different from that of the winter fauna, as it contains a small amount of cold-water species.

As mentioned above, in a study of the origin of the volume transport of the TWC and its seasonality, Isobe (1999a, b) reported continuous volume transport between the Taiwan and Tsushima straits from January to September, representing the TTWCS. This current system breaks down in autumn, when about two-thirds of the volume transport of the TWC originates directly from the Kuroshio region. Given the abundance of *T. octacantha* and *S. streptacantha* in the present study, the fauna is considered to be similar to the September fauna described in our previous studies (Matsuoka et al., 2001; Kurihara et al., 2007); i.e., radiolarians inflowed by the TWC around Sado Island in 2008 were basically under the influence of the same water current system from September to November, probably the TTWCS. No marked change in the fauna was observed during autumn; however, the high standing stock of *D. tetrathalamus* and *D. profunda* group and the occurrence of *A. myriacantha*, *E. elegans*, and other warm-water species indicate the influence of warm waters of the Kuroshio. Future research, based on continuous sampling over a period of several years, is needed to explore the potential of radiolarians in determining the origin of water currents that flow into the Japan Sea.

Acknowledgments

We thank Prof. M. Nozaki of the Sado Marine Biological Station (Faculty of Science, Niigata University) for the use of facilities at the station throughout our study. We also thank Mr. Y. Kobayashi of Minshuku Iwayuri for carrying out plankton sampling and Mr. T. Shimotani for his assistance during this study. We gratefully acknowledge Dr. H. Kurita for reviewing the manuscript.

References

Boltovskoy, D., Oberhänsli, H. and Wefer, G., 1996, Radiolarian assemblages in the eastern tropical Atlantic: patterns in the plankton and in sediment trap samples. *Jour. Marine Systems*, **8**, 31-51.

Chen, M. and Tan, Z., 1997, Radiolarian distribution in surface sediments of the northern and central South China Sea. *Marine Micropaleontol.*, **32**, 173-194.

Dworetzky, B. A. and Morley, J. J., 1987, Vertical distribution of radiolaria in the eastern equatorial Atlantic: Analysis of a multiple series of closely-spaced plankton tows. *Marine Micropaleontol.*, **12**, 1-19.

Hsueh, Y., Lie, H. and Ichikawa, H., 1996, On the branching of the Kuroshio west of Kyushu. *Jour. Geophys. Res.*, **101**, 3851-3857.

Isobe, A., 1999a, On the origin of the Tsushima Warm Current and its seasonality. *Cont. Shelf Res.*, **19**, 117-133.

Isobe, A., 1999b, The Taiwan-Tsushima Warm Current System: Its path and the transformation of the water mass in the East China Sea. *Jour. Oceanogr.*, **55**, 185-195.

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.

Kling, S. A., 1979, Vertical distribution of polycystine radiolarians in the central north Pacific. *Marine Micropaleontol.*, **4**, 295-318.

Kling, S. A. and Boltovskoy, D., 1995, Radiolarian vertical distribution patterns across the southern California Current. *Deep-Sea Res. I*, **42**, 191-231.

Kurihara, T. and Matsuoka, A., 2005, Shell variability of *Pseudocubus obeliscus* Haeckel in the early autumn radiolarian fauna off Tassha, Sado Island, central Japan. *Sci. Rep., Niigata Univ., Ser. E (Geol.)*, no. 20, 29-45.

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., Ser. E (Geol.)*, no. 24, 81-90.

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., Ser. E (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., Ser. E (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., Ser. E (Geol.)*, no. 23, 65-74.

Lie, H. and Cho, C., 1994, On the origin of the Tsushima Warm Current. *Jour. Geophys. Res.*, **99**, 25081-25091.

Lombari, G. and Boden, G., 1985, Modern radiolarian global distributions. *Cushman Found. Foraminiferal Res., Spec. Pub.*, vol. 16A, 3-125.

Matsuoka, A., 1993, Living radiolarians around the Sesoko Island, Okinawa Prefecture. *Fossils (Kaseki)*, no. 54, 1-9. (in Japanese with English abstract)

Matsuoka, A., 2009, Late autumn living radiolarian fauna from sub-tropical surface waters in the East China Sea off Sesoko Island, Okinawa, southwest Japan. *News of Osaka Micropaleontologist (NOM), Special Volume*, no. 14, 11-29.

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.

National Astronomical Observatory, 2007, Rika nenpyo (Chronological Scientific Tables). Maruzen Co., Ltd., Tokyo, 1034 p. (in Japanese)

Nigrini, C., 1970, Radiolarian assemblages in the North Pacific and their application to a study of Quaternary sediments in core V20-130. *In* Hays, J. D., ed., *Geological Investigations of the North Pacific*. Geol. Soc. America, Memoir, vol. 126, 139-183.

Nitani, H., 1972, Beginning of the Kuroshio. *In* Stommel, H. and Yoshida, K., eds., *Kuroshio -its physical aspects*. University of Tokyo Press, 353-369.

Renz, G. W., 1976, The distribution and ecology of Radiolaria in the Central Pacific: plankton and surface sediments. *Bull. Scripps Inst. Oceanogra.*, no. 22, 1-267.

Senjyu, T., 1999, The Japan Sea Intermediate Water; its characteristics and circulation. *Jour. Oceanogra.*, **55**, 111-122.

Yamashita, H., Takahashi, K. and Fujitani, N., 2002, Zonal and vertical distribution of radiolarians in the western and central Equatorial Pacific in January 1999, *Deep-Sea Res. II*, **49**, 2823-2862.