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Short Article

Modern benthic foraminiferal fauna (Rhizaria) in Miyazu Bay, central Japan

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Abstract: We investigated modern benthic foraminifera in Miyazu Bay, central Japan, based on 20 surface sediment samples in April 2019, in order to consider ecological characteristics of modern benthic foraminifera. Horizontal distributions of the major species of living (stained) benthic foraminifera in Miyazu Bay are divided into the several groups that seem to be generally affected by (1) the water depths and the substrates (grain size) and probably by (2) the influence of the pelagic water on the bay. These spatial occurrences of modern benthic foraminifera in Miyazu Bay seem to support a hypothesis that enhanced winter monsoons may explain changes in the abundance of opportunistic benthic foraminifera in the coastal areas along Wakasa Bay.

Key words: Wakasa Bay; distribution of benthic foraminifera; Aso-kai lagoon; dispersal of benthic foraminifera

Introduction

Seasonal contrast of climates in the Japanese Islands is strongly affected by East Asian summer/winter monsoon (e.g., Nakagawa et al., 2009). In particular, the north and west coasts of the Japanese Islands are characterized by high precipitation in winter due to heavy snow fall. The abundant snow falls are a result of the intense seasonal northwesterly winds driven by the East Asian winter monsoon which carry large amounts of moisture from the surface ocean under the influence of the Tsushima Warm Current. Thus, variations in climate, regional hydrology and behavior of marine organism along the north and west coasts of the Japanese Islands are closely related to the East Asian winter monsoon (e.g., Suzuki et al., 2020), in addition to precipitation in the summer monsoon.

A number of small inlets and lagoons are present along the shoreline of Wakasa Bay which is located along the north coast of central Japan (Fig. 1). Several paleoclimatic studies have been carried out based on past sediment records. For example, studies of sediment cores from Lake Suigetsu have provided high quality proxy data on paleoclimatic conditions during the Holocene (e.g., Fukusawa, 1997; Suzuki et al., 2016). Takata et al. (2014) investigated fossil benthic foraminifera from

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a sediment core in Aso-kai lagoon along Wakasa Bay (Fig. 1). They recognized high abundances of benthic foraminifera in AD ~1070, ~1400 and ~1600, and suggested that these events resulted from an enhanced East Asian winter monsoon through passive dispersal of benthic foraminifera into the lagoon. In addition, Takata et al. (2019) investigated modern benthic foraminifera in Maizuru Bay (~20 km ESE-direction from Aso-kai lagoon). They found individuals of several species of benthic foraminifera in the water column, based on plankton tow sampling. According to these observations, they confirmed the passive dispersal potential of some benthic foraminifera in the coasts of Wakasa Bay.

This insight about the dispersal potential of benthic foraminifera would aid the interpretation of core-based study of Aso-kai lagoon, and improve understanding of past variation of the East Asian winter monsoon. In contrast, there have been no studies of modern benthic foraminifera in Miyazu Bay (Fig. 1) which sits between Aso-kai lagoon and the open ocean. Information about modern benthic foraminifera in this bay would provide an opportunity for a more precise paleoenvironmental study of Aso-kai lagoon. In this study, we investigate the horizontal distribution of living (stained) benthic foraminifera from Miyazu Bay, based on 20 surface sediments, in order to describe some of the ecological characteristics of modern benthic foraminifera in this setting.

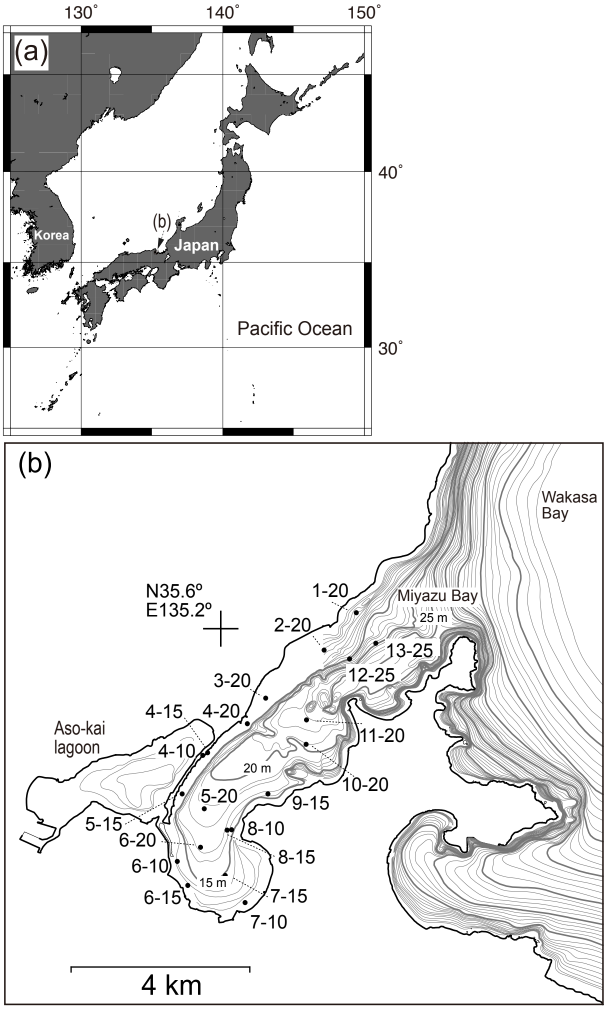

Fig. 1 Locality map of the study area (bathymetric data referred from the Japan Hydrographic Association)

Materials and methods

Miyazu Bay is an elongate inlet along the coast of Wakasa Bay (central Japan) (Fig. 1) with a long axis in a northeast to southwest direction. The deepest part of the bay is approximately 30 m deep. Small rivers discharge into the Miyazu Bay, such as the Ohte River (in the southern bay). In addition, Aso-kai lagoon, a brackish lagoon, is located in the southwest part of the bay (Fig. 1). It is largely separated from Miyazu Bay by sand bars ("Amano-hashidate" and "Sho-tenkyo"), and only connected by a narrow channel (~4 m deep), which branches into two in the southern area of the lagoon (Fig. 1).

Seasonal variations of water temperature and dissolved oxygen content at a depth of 10 m in Miyazu Bay are shown in Fig. 2 (Kyoto Prefecture; http://www.pref.kyoto.jp/suishitu/jyoujikanshi/wakasawan.html). Water temperatures at that depth range from ~11 ºC to ~28 ºC. Dissolved oxygen content at a depth of 10 m is higher than 5 mg l^{-1} throughout the year (Fig. 2). The salinity of the waters on April 23, 2019 in the bay ranged between 31.05 and 34.35 (mean 33.90 throughout the water column among the 6 stations) (Sawada and Suzuki, unpublished data). In particular, there is also no marked lateral salinity gradient in the hypolimnetic water (>34) from the inner (station 6-20) to outer parts (station 1-20) of the bay (Sawada and Suzuki, unpublished data). The substrate in the bay generally consists of sandy sediment, whereas substrates at greater depths (>20 m water depth) sometimes consist of muddy sediments (Table 1). In addition, surface sediments at some stations along the east coast of the bay consist of various grain size sediments ranging from gravel to mud. This seems to be

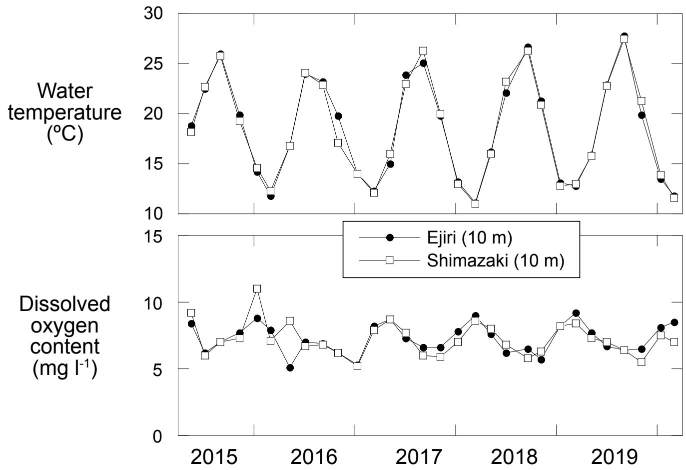

Fig. 2 Seasonal variation of water temperature and dissolved oxygen content at 10 m water depth at Stations Ejiri and Shimazaki (near our stations 11-20 and 6-20, respectively) in Miyazu Bay during 2015-2019 (data from Kyoto Prefecture; http://www.pref.kyoto.jp/suishitu/jyoujikanshi/wakasawan.html).

due to the complicated and steep geomorphology along the east coast of the bay, compared to the west coast of the bay (Fig. 1).

We used a Smith-Macintyre type sampler to collect surface-sediment samples from 43 stations along 13 transects of Miyazu Bay (Fig. 1; Table 1) on April 23, 2019, using a R/V Ryokuyo-maru (Kyoto University). Sediment samples with a thickness of two centimeters were collected from a sub-core that had a diameter of 5 cm for foraminiferal analysis (39.3 cm^3).

The foraminiferal subsamples were washed through a 250-mesh sieve (63-µm openings). The residues were stained with rose Bengal solution (0.5 g l^{-1}) for 24 hours, after which they were washed with warm water to remove excess dye (Oda, 1978). The residues were dried at 40ºC and split into 1/2 to 1/32 aliquots. Living (stained) foraminiferal specimens were collected from the 20 samples and were identified under a stereo-binocular microscope. Taxonomic assignments followed Matoba (1970), Nomura and Seto (1992), Oki (1989) and Akimoto et al. (2002). Generic classification was based on Loeblich and Tappan (1987). The number of specimens per unit volume (# cm^{-3}) was calculated in each sample.

Table 1 Locations, water depths and substrates of our study stations in Miyazu Bay.

Station	Latitude		Longitude		Depth (m)	Substrate
13-25*	35	35.688	135	14.362	25.0	mud
13-20	35	35.202	135	14.205	21.9	mud
12-25*	35	35.498	135	13.969	24.3	mud
12-20	35	35.224	135	13.935	24.1	mud
11-20*	35	34.771	135	13.322	21.2	mud
11-15	35	34.785	135	13.607	20.4	mud
10-20*	35	34.477	135	13.321	19.7	mud
10-15	35	34.246	135	13.546	15.8	sandy mud
10-10	35	34.172	135	13.522	13.8	gravelly-sandy mud
9-15*	35	33.883	135	12.746	15.3	mud
9-10	35	33.969	135	12.878	10.2	gravelly medium sand
9-5	35	33.945	135	12.890	4.2	gravelly medium sand
8-15*	35	33.449	135	12.136	14.8	mud
8-10*	35	33.455	135	12.199	12.8	sandy mud
8-5	35	33.451	135	12.219	8.9	fine-medium sand
7-15*	35	32.907	135	12.106	14.6	mud
7-10*	35	32.584	135	12.401	9.2	mud
7-5	35	32.516	135	12.423	4.6	mud
6-20*	35	33.271	135	11.738	16.8	(no description)
6-15*	35	32.790	135	11.543	14.9	(no description)
6-10	35	33.076	135	11.384	14.8	(no description)
6-5	35	33.006	135	11.346	10.4	(no description)
5-20*	35	33.728	135	11.794	18.6	mud
5-15*	35	33.884	135	11.461	13.0	fine sand
5-10	35	33.971	135	11.487	13.2	mud
5-5	35	34.026	135	11.472	6.0	fine sand
4-center	35	34.651	135	12.454	20.8	(no description)
4-20*	35	34.722	135	12.435	20.4	(no description)
4-15*	35	34.375	135	11.842	15.4	(no description)
4-10*	35	34.345	135	11.768	10.9	(no description)
4-5	35	34.325	135	11.710	4.1	(no description)
3-center	35	35.015	135	12.808	21.6	mud
3-20*	35	35.027	135	12.713	20.6	mud
3-15	35	34.916	135	12.477	15.9	mud
3-10	35	34.977	135	12.466	7.8	fine sand
3-5	35	34.958	135	12.408	5.5	fine sand
2-20*	35	35.605	135	13.590	20.3	(no description)
2-15	35	35.773	135	13.672	14.5	(no description)
2-10	35	35.844	135	13.347	8.9	(no description)
2-5	35	35.971	135	13.235	5.5	(no description)
1-20*	35	36.050	135	14.070	17.1	sandy mud
1-15	35	36.192	135	13.955	13.6	sand
1-10	35	36.062	135	13.673	10.1	fine sand

* shows samples that we studied benthic foraminiferal fauna

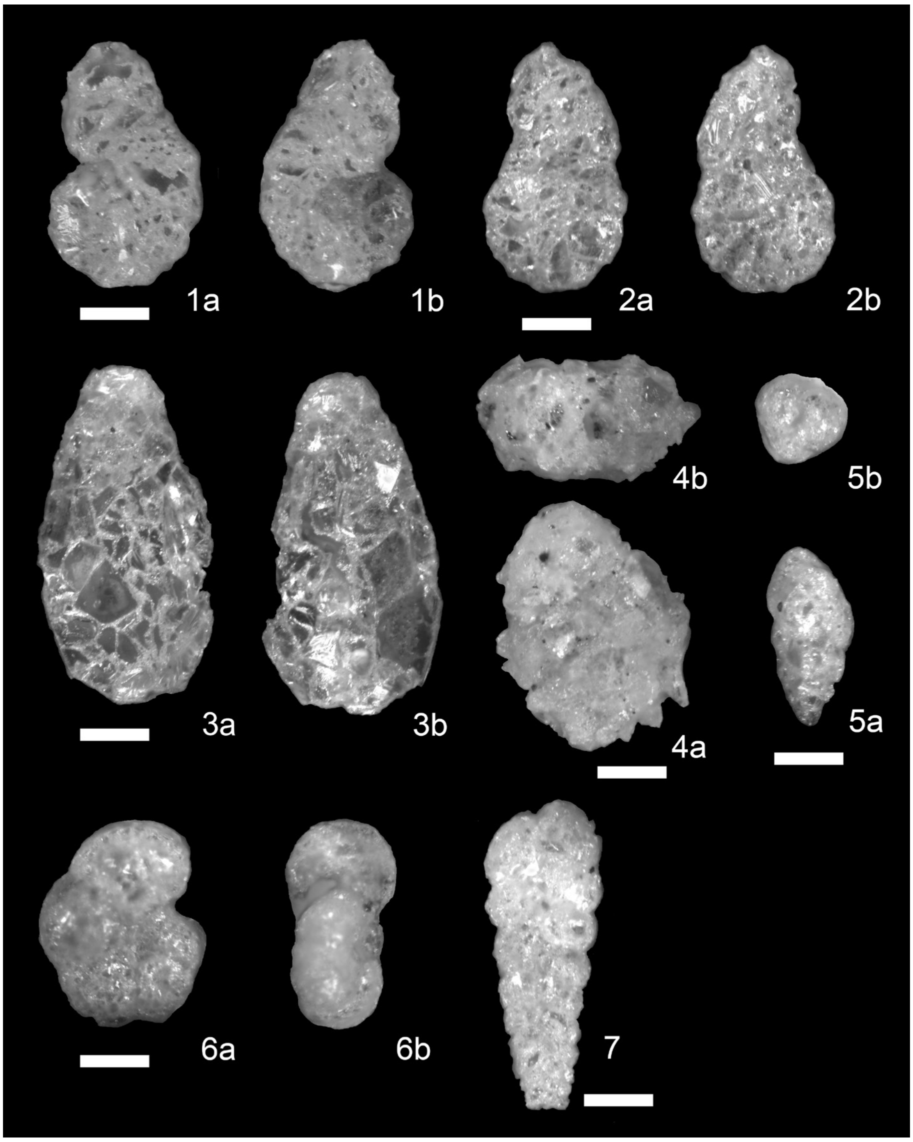

Fig. 3 Light micrographs of benthic foraminifera in Miyazu Bay.
1a, b, 2a, b. *Ammomarginulina* sp. A; 3a, b. *Nouria* sp.; 4a, b. *Textularia foliacea*; 5a, b. *Eggerelloides advenus*; 6a, b. *Haplophragmoides sphaeriloculum*; 7. *Textularia earlandi*. Scale bar=100μm.

Results and discussion

Living (stained) specimens of benthic foraminifera were present at all 20 stations in Miyazu Bay. Fifty-three genera and 73 species were recognized in this study (Appendix 1). *Ammomarginulina* sp. A, *Eggerelloides advenus*, *Haplophragmoides spaeriloculum*, *Noninella stella*, *Nonionellina* sp. A and *Pseudononion japonicum* were common constituents (Fig. 3). This faunal association is similar to that of Maizuru Bay (Takata et al., 2019), for example the common *Noninella stella* and *Nonionellina* sp. A. Agglutinated species, such as *Ammomarginulina* sp. A and *Haplophragmoides spaeriloculum*, are also similar, although they are sometimes more common in Miyazu Bay, especially in the outer portion. Preservation of benthic foraminifera was generally good with no sign of strong destruction or abrasion, suggesting no marked transportation of foraminiferal tests (Fig. 3). Although we cannot totally dismiss possible post-mortem transport of foraminiferal tests, these features imply that this benthic foraminiferal assemblage was unlikely to be biased by significant

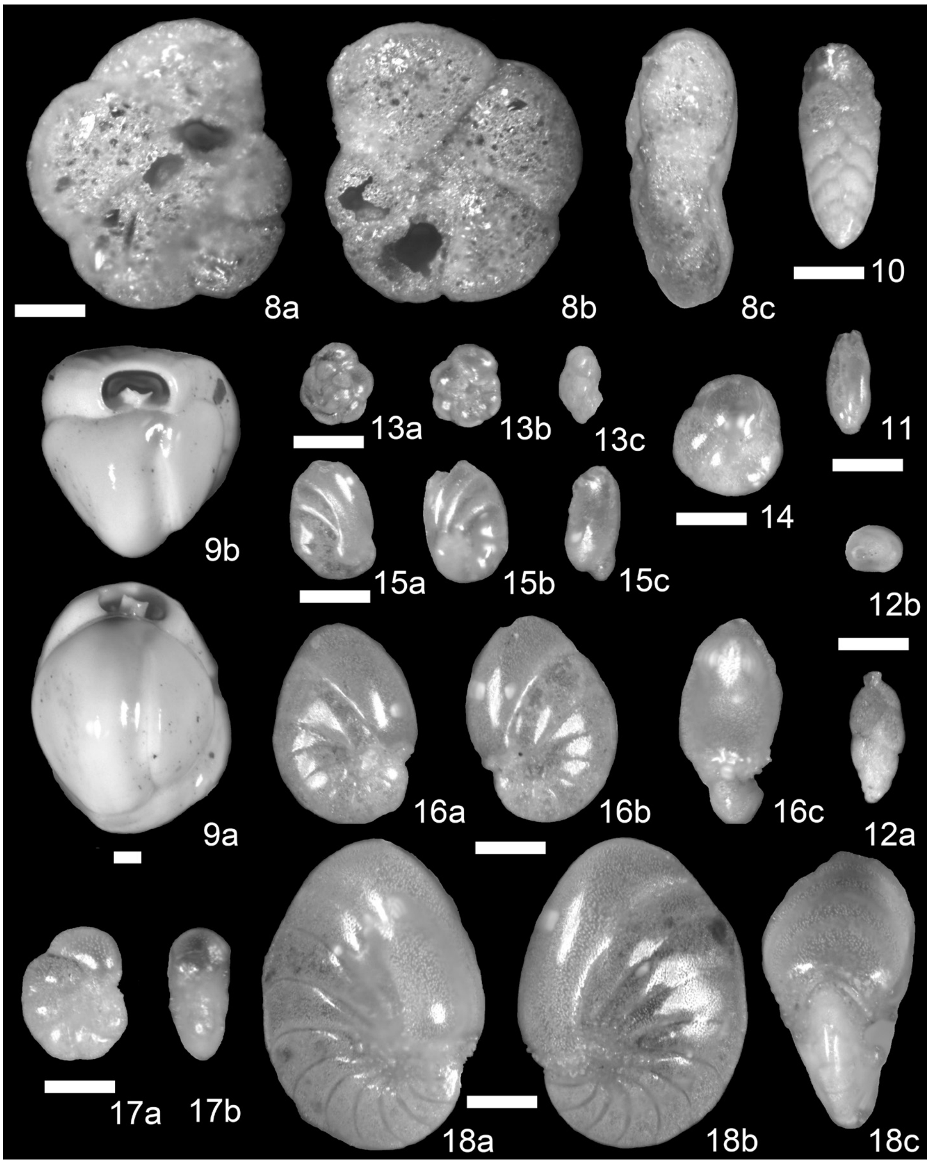

Fig. 3 Continued.
8a-c. *Trochammina pacifica*; 9a, b. *Triloculina rotunda*; 10. *Brizalina striatula*; 11. *Buliminella elegantissima*; 12a, b. *Uvigerinella glabra*; 13a-c. *Ammonia* sp. A; 14. *Pseudoparrella tamana*; 15a-c. *Nonionella stella*; 16a-c. *Nonionellina* sp. A.; 17a, b. *Elphidium excavatum* forma excavata; 18a-c. *Pseudononion japonicum*. Scale bar=100 μm.

transportation from another area, such as the outside area of Miyazu Bay.

Horizontal distributions of the major species of modern benthic foraminifera within Miyazu Bay show different patterns (Fig. 4). (a) *Nonionella stella* is generally abundant in the inner part of the bay. (b) *Nonionellina* sp. A and *Pseudononion japonicum* are common along the west coast of the bay. *Nonionellina* sp. A tends to be more common in the inner part of the bay, whereas *P. japonicum* is present in the outer part of the bay. (c) *Eggerelloides advenus* is specifically common at the two stations along the east coast of the bay. (d) *Ammomarginulina* sp. A is common in the outer part of the bay. (e) Finally, *Haplophragmoides spaeriloculum* is generally common at the several stations along the coasts of the bay. Thus, these horizontal distributions imply that these major species occupy specific habitats.

Some species of benthic foraminifera show specific

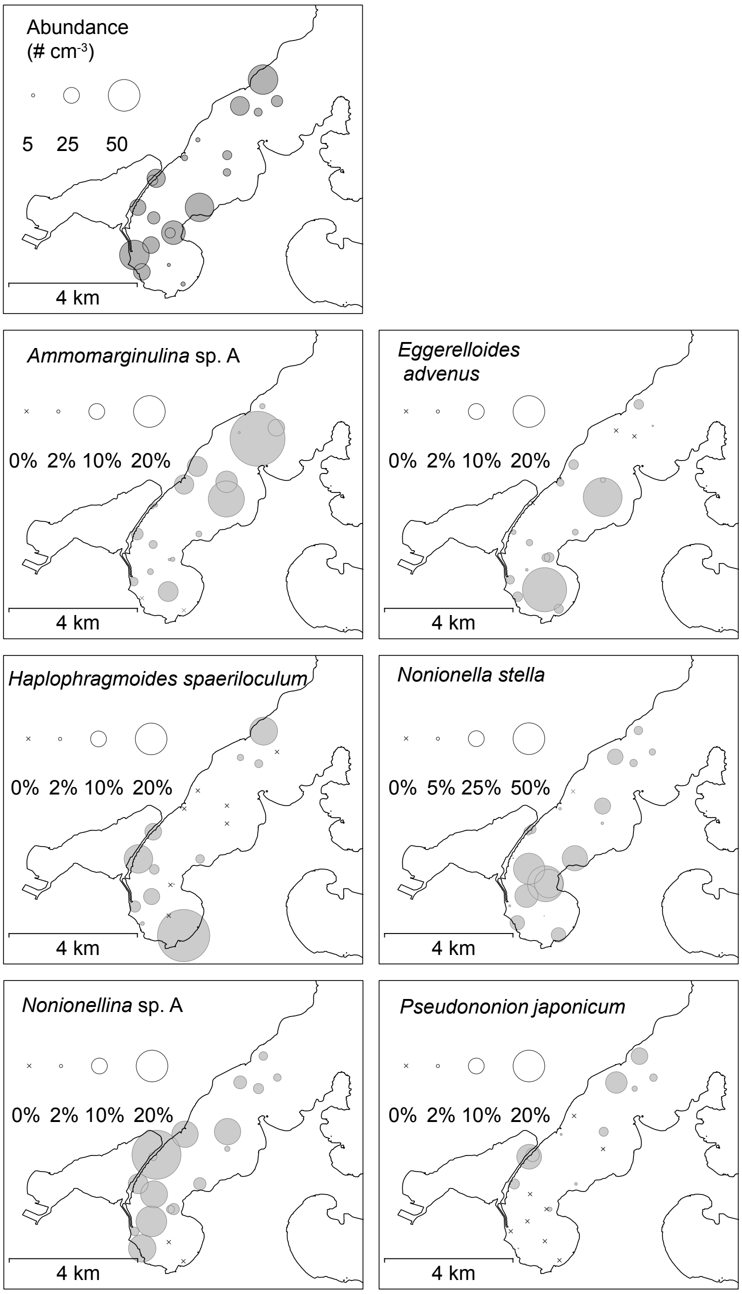

Fig. 4 Distribution of the abundance of living (stained) benthic foraminifera per unit volume (# cm^{-3}) and the relative abundances of six selected species of living (stained) benthic foraminifera in Miyazu Bay.

trends with variations of water depth and/or median grain size (Sawada and Suzuki, unpublished data) (Fig. 5). *Ammomarginulina* sp. A tends to be common in deeper (20–25 m water depth) and fine-grained substrates in the stations off the east coasts. In contrast, *H. sphaeriloculum* tends to be common in the shallower depths (<20 m water depth). In addition, *N. stella* is basically abundant in the fine-grained substrates, despite no marked tendency with water depth. This species is known as a low oxygen tolerant species (e.g., Bernhard and Bowser, 1999) and is common in the seasonally oxygen-poor hypolimnetic water of Maizuru Bay (Takata et al., 2019).

Neritic benthic foraminifera commonly show specific distributions in relation to horizontal salinity gradients established by coastal water/pelagic water mixing

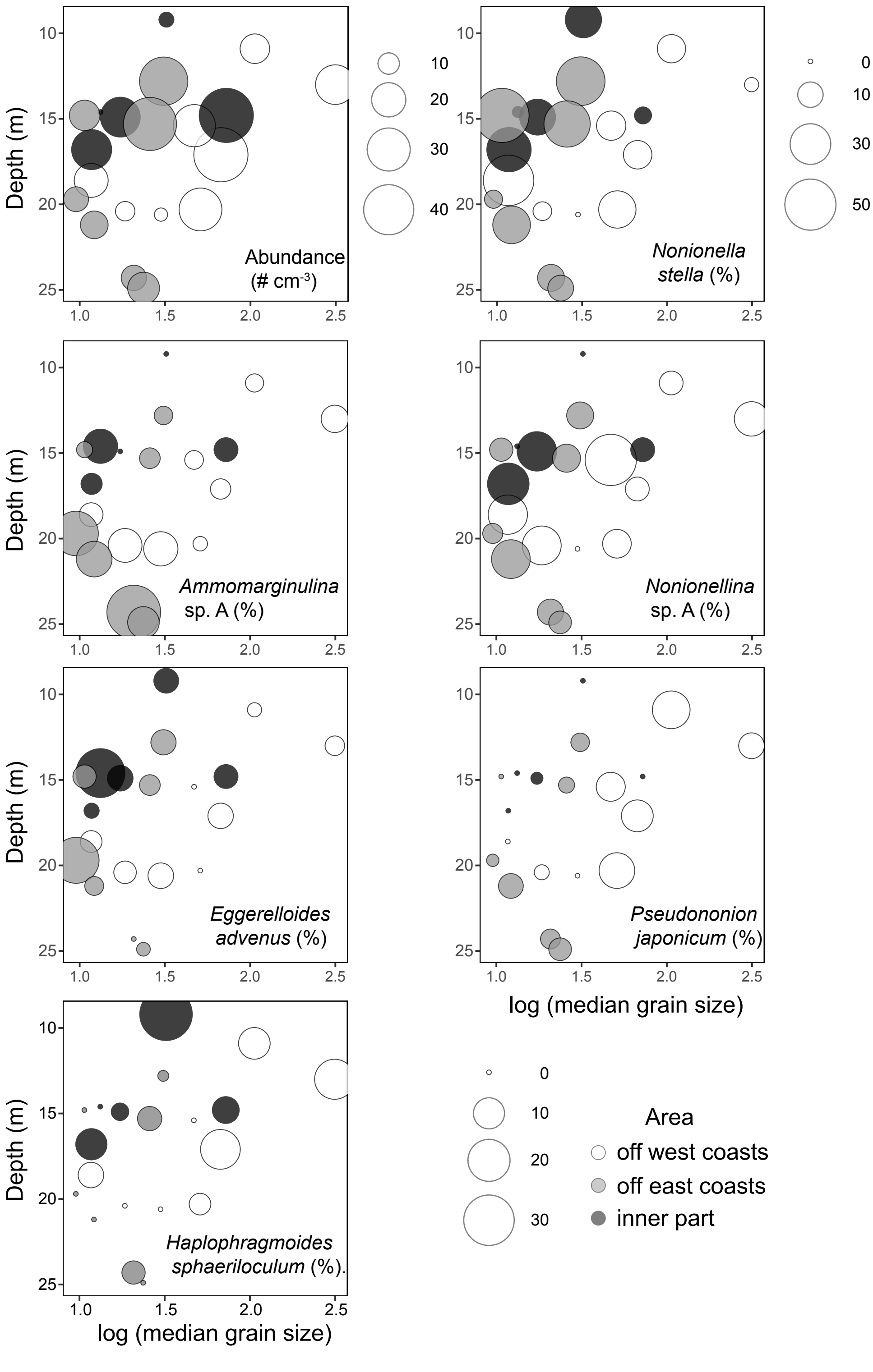

Fig. 5 Crossplots between the median grain size and water depth in the Miyazu Bay. The circle symbols represent the abundances of benthic foraminifera per unit volume and the relative abundance of major six species. The stations in the three areas are as follows: off the west shore: transects 1 to 5; off the east shore: transects 8 to 13; inner bay: transects 6 and 7.

(Matoba, 1970; Kosugi et al., 1991; Nomura and Seto, 1992). In Miyazu Bay, Habe and Yamazi (1955) studied modern benthos and noted a general tendency in the distribution of benthos that is related to the inflow of the pelagic water from the outer sea (Wakasa Bay) into Miyazu Bay, seen generally along the west coast. The common occurrences of *Noninellina* sp. A and *P. japonicum* along the western shoreline of the bay seem to be consistent with the influence of the anti-clockwise inflow of pelagic water to the bay. In contrast, the common *E. advenus* has been reported from neritic eutrophic environments (Tsujimoto et al., 2006). Common *E. advenus* at the two stations off the east coast of Miyazu Bay is also consistent with this kind of hydrology in Miyazu Bay (i.e., weaker influence of the pelagic water). Thus, despite no marked salinity gradient in Miyazu Bay usually (Sawada and Suzuki, unpublished data), the inflow of the pelagic water into the bay seems to affect the spatial occurrences of several species.

In summary, the distribution of modern benthic foraminifera in Miyazu Bay seem to be generally affected by (1) the water depths and the substrates (grain size) (*Ammomarginulina* sp. A, *H. sphaeriloculum* and *N. stella*) and probably by (2) the influence of the pelagic water on the bay (*Nonionellina* sp. A, *P. japonicum* and *E. advenus*).

Takata et al. (2014) reported high abundances of benthic foraminifera in Aso-kai lagoon (core ASC2) at the following times: *ca*. AD 1070, 1400 and 1600. The increased abundance of benthic foraminifera at these dates were largely due to the abundance of *E. advenus*. Alve and Goldstein (2010) suggested that *Eggerelloides scaber* (which has a similar test morphology to *E. advenus*) might spread through propagule dispersal. Enhanced wind mixing may have driven past dispersal events of *E. advenus* in Aso-kai lagoon, as proposed by Takata et al. (2014). In addition, Takata et al. (2014) hypothesized that *E. advenus* may have dispersed into Aso-kai lagoon from the outer sea (Wakasa Bay), whereas this study indicates that the species is more likely to have dispersed from the inner-middle portion of Miyazu Bay to the lagoon (Fig. 4). These observations support the hypothesis that enhanced winter monsoons may explain changes in the abundance of opportunistic benthic foraminifera in the Aso-kai lagoon. In contrast, Takata et al. (2019) demonstrated that occurrences of major benthic foraminifera, including opportunistic species, are quite variable at one location at different times. Further study is highly recommended focusing on seasonal monitoring of benthic foraminifera, in order to evaluate the possibility that passive dispersal of benthic foraminifera is due to intense wind mixing of the water column driven by the East Asian winter monsoon. Such studies will require additional seasonal surveys, with plankton net towing and sediment trap mooring (e.g., Nomura and Seto, 2004; Nomura et al., 2010).

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Faunal reference list

Ammobaculites exiguus Cushman and Brönnimann, 1948, Contribution from the Cushman Laboratory for Foraminiferal Research, 24, p. 38, pl. 7, figs. 7, 8.

Ammonia "beccarii" (Linné) forma 1 Matoba, 1970, Science Reports of Tohoku University, 2nd ser. (Geology), 42 (1), pl. 5, figs. 8, 9.

Ammonia japonica (Hada) = *Rotalia japonica* Hada, 1931, Science Reports of the Tohoku Imperial University, ser. 4, Biology, 6 (3), p. 137, text-figs. 93.

Bolivina humilis Cushman and McCulloch = *Bolivina seminuda* Cushman var. *humilis* Cushman and McCulloch, 1942, Allan Hancock Pacific Expeditions, 6, p. 211, pl. 26, figs. 1–6.

Bolivina robusta (Brady) = *Bulimina (Bolivina) robusta* Brady, 1881; Brady, 1884, Report on the Scientific Results of the Voyage of the H. M. S. Challenger during the years 1873–1876, Zoology, 9, p. 421, pl. 53, figs. 7–9.

Bolivina tokiokai Uchio, 1962, Publications of the Seto

Marine Biological Laboratory, 10, p. 245, pl. XVIII, figs. 5a, b.

Brizalina striatula (Cushman) = *Bolivina striatula* Cushman, 1922, Department of Marine Biology, 311, p. 27, pl. 3, fig. 10.

Buccella frigida (Cushman) = *Pulvinulina frigida* Cushman, 1922a, Contributions to Canadian Biology, p. 12.

Buccella makiyamai Chiji, 1961, Prof. Jiro Makiyama Mem. Volume, p. 234, text-figs. 2a-c, pl. 1, figs. 13a–14b.

Bulimina marginata d'Orbigny, 1826, Annales des Sciences Naturelles, 7, p. 269, pl.12, figs. 10-12.

Bulimina nojimaensis Asano, 1950, Illustrated Catalogue of Japanese Tertiary Smaller Foraminifera, pt. 2, p. 4, text-figs. 15, 16.

Buliminella elegantissima (d'Orbigny) = *Bulimina elegantissima* d'Orbigny, 1839, Voyage dans l'Amérique méridionale–Foraminifères, t. 5, pt. 5, p. 51, pl. 7, figs. 13, 14.

Cancris auriculus (Fichtel and Moll) = *Nautilus auriculus* var. α Fichtel and Moll, 1798, Testacea microscopica, aliaque minuta ex generibus Argonauta et Nautilus, ad naturam picta et descripta (Microscopische und andere klein Schalthiere aus den geschlechtern Argonaute und Schiffer, p. 108, pl. 20, figs. a-c.

Cibicides lobatulus (Walker and Jacob) = *Nautilus lobatulus* Walker and Jacob in Kanmacher, 1798, Adam's Essays on the Microscope. In, Kanmmacher, E. ed., the Second Edition, with Considerable Additions and Improvements. Chapter 11, p. 642, pl. 14, fig. 36.

Eggerelloides advenus (Cushman) = *Verneuilina advena* Cushman, 1922, Contributions to Canadian Biology, 9, p. 9.

Elphidium advenum (Cushman) = *Polystomella advena* Cushman, 1922, Department of Marine Biology, 311, p. 56, pl. 9, figs. 11, 12.

Elphidium excavatum (Terquem) forma clavata = *Elphidium clavatum* Cushman, emend, Loeblich and Tappan, 1953, Smithsonian Miscellaneous Collections, 121 (7), p. 98, 101, 102, pl. 19, figs. 8a, b, 9, 10.

Elphidium excavatum (Terquem) forma excavata = *Polystomella excavata* Terquem, 1875, Essai sur le classement des animaux qui vivent sur la plage et dans les environs de Dunqerque, Fasc. 2, p. 20, pl. 2, figs. 2a, b.

Elphidium kaneharai Ishiwada, 1958, Reports, Geological Survey of Japan, 180, p. 18, text-figs. 2a, b; pl. 1, 17–20.

Elphidium reticulosum Cushman, 1933, Bulletin United States National Museum, p.51, pl.12, figs. 5a, b.

Elphidium somaense Takayanagi, 1955, Contributions from the Institute of Geology and Paleontology, Tohoku University, 45, p. 43, 52, text-figs. 28a, b.

Fursenkoina compactiformis (McCulloch) = *Neobuliminoides compactiformis* McCulloch, 1977, University of Southern California, p. 248, pl. 104, fig. 25.

Geminospira simaensis Makiyama and Nakagawa, 1941, Journal of the Geological Society of Japan, 48, p. 241, figs. 3–5.

Goessella iizukae Takayanagi, 1955, Contributions from the Institute of Geology and Paleontology, Tohoku University, 45, p. 41, text-fig. 25.

Hanzawaia nipponica Asano 1944, Journal of the Geological Society of Japan, 41, p. 99, pl. 4, figs. 1a, b, 2a, b.

Haplophragmoides canariensis (d'Orbigny) = *Nonionina canariensis* d'Orbigny, 1839, Foraminiferes des Iles Canaries, in Barker-Webb and Berthelot, Hist. Nat. des Iles Canaries 2, p. 128, pl. 2, figs. 33, 34.

Haplophragmoides sphaeriloculum Cushman, 1917, Proceedings of the United States National Museum, 51, p. 652.

Haynesina sp. A = *Haynesina* sp., Kosugi et al., 1991, Fossil (51), p.53, figs. 5, 10-11.

Islandiella algida (Cushman) = *Cassidulina algida* Cushman, 1944, Special Publications Cushman Laboratory for Foraminiferal Research, (12), p. 35, pl. 4, figs. 24a–c.

Murrayinella minuta (Takayanagi) = *Rotalia*? *minuta* Takayanagi, 1955, Contributions from the Institute of Geology and Paleontology, Tohoku University, 45, p. 52, text-figs. 29a–c.

Nonion manpukuziensis Otuka, 1932, Journal of the Geological Society Tokyo, 39, p. 654, fig. 1.

Nonionella stella Cushman and Moyer = *Nonionella miocenica* Cushman var. *stella* Cushman and Moyer, 1930, Contribution from the Cushman Laboratory for Foraminiferal Research, 6, p. 56, pl. 7, fig. 17.

Oolina hexagona (Williamson) = *Entosolenia squamosa* (Montagu) var. *hexagona* Williamson, 1848, Annals and Magazine of Natural History, ser. 2, p. 20, pl. 2, fig. 23.

Pseudononion japonicum Asano, 1936, Journal of the Geological Society of Japan, 43 (512), p. 347, text-figs. a-c.

Pseudoparrella naraensis Kuwano, 1950, Journal of the Geological Society of Japan, 56 (657), p. 317, text-fig. 6.

Pseudoparrella tamana Kuwano, 1950, Journal of the Geological Society of Japan, 56, p. 317, text-figs. 5a-c.

Pseudorotalia gaimardii compressiuscula (Brady) = *Rotalia papillosa* Brady *compressiuscula* Brady, 1884, Report on the Scientific Results of the Voyage of the H. M. S. Challenger during the years 1873–1876, Zoology, 9, p. 708, pl. 107, fig. 1; p. 108, fig. 1.

Quinqueloculina akneriana d'Orbigny, 1846, Foraminifères fossiles du Bassin Tertiaire de Vienne (Autriche), p. 290, pl. 18, figs. 16-21.

Quinqueloculina elongata Natland, 1938, Bulletin of the Scripps Institution of Oceanography of the University of California, Technical Series, Tech. Ser. 4, (5), p. 141, pl. 4, fig. 5.

Quinqueloculina lamarckiana d'Orbigny, 1839, in de la Sagra R., Histoire physique, politique et naturelle de l'ile de Cuba, p. 189, pl. 11, figs. 14–15.

Quinqueloculina seminulum (Linné) = *Serpula seminulum* Linné, 1758, Systema Naturae, p. 786.

*Rectobolivina raphan*a (Parker and Jones) = *Uvigerina (Sagrina) raphanus* Parker and Jones, 1865, Philosophical Transactions of the Royal Society, 155, p. 364, pl. 18, figs. 16a-b, 17.

*Reussella aculeat*a Cushman, 1954, Contribution from the Cushman Laboratory for Foraminiferal Research, 21, p. 41, pl. 7, figs 10–11.

Sagrinella convallaria (Millett) = *Bolivina convallaria* Millett, 1900, Journal of the Royal Microscopical Society, p. 544, pl. 4, fig. 7a, b.

Stainforthia fusiformis (Williamson) = *Bulimina pupoides* d'Orbigny var. *fusiformis* Williamson, 1858, On the Recent foraminifera of Great Britain, p. 63, pl. 5, figs. 129, 130.

Textularia earlandi Parker, 1952, Bulletin of the Museum of Comparative Zoology, 106 (10), p. 458.

Textularia foliacea Heron-Allen and Earland, 1915, Transactions of the Zoological Society of London, 20, p. 628, pl. 47, figs. 17–20.

Triloculina rotunda d'Orbigny, 1826, Annales des Sciences Naturelles, p. 298.

Trochammina cf. *japonica* Ishiwada = Cf. *Trochammina japonica* Ishiwada, 1950, Bulletin of the Geological Survey of Japan, 1 (4), p. 190, pl., figs. 2a-c.

Trochammina pacifica Cushman, 1925, Contribution from the Cushman Laboratory for Foraminiferal Research, 1, p. 39, pl. 6, fig. 3.

Uvigerina proboscidea Schwager, 1866, Reise der Österreichischen Fregatte Novara um die Erde in den Jahren, p. 250, pl. 7, fig. 96.

Uvigerinella glabra (Millett) = *Uvigerina auberiana* d'Orbigny var. *glabra* Millett, 1903, Journal of the Royal Microscopical Society, p. 268, pl. 5, figs. 8a, b.

Virgulinella fragilis Grindell and Collin, 1976, Rev. Espanola Micropaleont., 8 (2), p. 274, 277, 278, pl. 1, figs. 1-8, text-fig. 2.

References

Akimoto, K., Matsui, C., Shimokawa, A. and Furukawa, K., (2002) Atlas of Holocene benthic foraminifers of Shimabara Bay, Kyushu, Southwest Japan. The Kagoshima University Museum Monographs, 2:1–112.

Alve, E. and Goldstein, S.T. (2010) Dispersal, survival and delayed growth of benthic foraminiferal propagules. Journal of Sea Research, 63:36–51.

Bernhard, J.M. and Bowser, S.S. (1999) Benthic foraminifera of dysoxic sediments: chloroplast sequestration and functional morphology. Earth-Science Reviews 46:149–165.

Fukusawa, H. (1997) High-resolution reconstruction of paleoenvironmental informations detected by using lake sediment. Journal of Environmental Information Science, 26:42–53. (in Japanese)

Habe, T. and Yamazi, I. (1955) Bio-oceanographical characteristics of the Miyazu-wan. Bulletin of the Biogeographical Society of Japan. vols. 16–19:399–406. (in Japanese)

Kosugi, M., Kataoka, H. and Hasegawa, S. (1991) Classification of foraminifer communities as indicators of environments in an inner bay and its application to reconstruction paleoenvironment. Fossils, 50:37–55. (in Japanese with English abstract)

Loeblich, A.R. Jr. and Tappan, H. (1987) Foraminiferal genera and their classification. Van Nostrand Reinhold, New York, 970p. and its plates (1–847).

Matoba, Y. (1970) Distribution of recent shallow water foraminifera of Matsushima Bay, Miyagi Prefecture, Northeast Japan. Science Reports of Tohoku University, ser. 2 (Geology) 42:4–85.

Nakagawa, T., Okuda, M., Yonenobu, H., Miyoshi, N., Fujiki, T., Gotanda, K., Tarasov, P.E., Morita, Y., Takemura, K. and Horie, S. (2009) Regulation of the monsoon climate by two different orbital rhythms and forcing mechanisms. Geology, 36:491–494.

Nomura, R. and Seto, K. (1992) Benthic foraminifera from brackish Lake Nakaumi, San-in district, southwestern Honshu, Japan. In: Centenary of Japanese Micropaleontology, (eds.) Ishizaki, K., Saito, T., pp. 227–240, Terra Scientific Publishing Company, Tokyo.

Nomura, R. and Seto, K. (2004) Water conditions during the time of red tide occurrence in spring, 2003, and the associated benthic foraminifera in Lake Nakaumi. LAGUNA, 11:125–130. (in Japanese with English abstract)

Nomura, R., Seto, K. and Tsujimoto, A. (2010) High tide dispersion of marine benthic foraminifera into brackish waters: implications for dispersion processes during sea-level rise. LAGUNA, 17:15–21.

Oda, M. (1978) I Foraminifera and Ostracoda, In: Manual of Microfossil studies, (ed.) Takayanagi, Y., pp. 33–46, Asakura Books, Tokyo. (in Japanese)

Oki, K. (1989) Ecological analysis of benthonic foraminifera in Kagoshima Bay, south Kyushu, Kapan. South Pacific Study, 10:1–191.

Suzuki K.W., Fuji, T., Kasai, A., Itoh, S., Kimura, S. and Yamashita, Y. (2020) Winter monsoon promotes the transport of Japanese temperate bass *Lateolabrax japonicus* eggs and larvae toward the innermost part of Tango Bay, the Sea of Japan. Fisheries Oceanography, 29:66–83.

Suzuki, Y., Tada, R., Yamada, K., Irino, T., Nagashima, K., Nakagawa, T. and Omori, T. (2016) Mass accumulation rate of detrital materials in Lake Suigetsu as a potential proxy for heavy precipitation: a comparison of the observational precipitation and sedimentary record. Progress in Earth and Planetary Science, 3：5 https://doi.org/10.1186/s40645-016-0081-x.

Takata, H., Tanaka, S., Seto, K., Sakai, S., Takayasu, K. and Khim, B.-K. (2014) Biotic response of benthic foraminifera in Aso-kai lagoon, central Japan, to changes in terrestrial climate and ocean conditions (~AD 700–1600). Journal of Paleolimnology, 51:421–435.

Takata, H., Nomura, R., Sampei, Y., Tanaka, S. and Khim, B.-K. (2019) Dispersal potential of neritic benthic foraminifera in the coastal areas of the Japanese Islands and its application to paleoenvironmental studies. Estuarine, Costal and Shelf Science, 227:Article 106288.

Tsujimoto, A., Nomura, R., Yasuhara, M. and Yoshikawa, S. (2006) Benthic foraminiferal assemblages in Osaka Bay, southwestern Japan: faunal changes over the last 50 years. Paleontological Research, 10:141–161.

Appendix 1 Faunal list of living (stained) benthic foraminifera in Miyazu Bay.

Station	1-20	2-20	3-20	4-10	4-15	4-20	5-15	5-20	6-10	6-15
Ammobaculites exiguus					1					
Ammobaculites sp. A			4							
Ammomarginulina sp. A	6	1	6	2	2	8	7	10	3	
Eggerelloides advenus	7		3	1		3	3	8	3	8
Gaudryina sp.	1		1							
Goessella iizukae				2	2					
Haplophragmoides canariensis			2			2		5		
Haplophragmoides sphaeriloculum	21	3		8	1		17	7	4	3
Haplophragmoides sp. indet.										
Lagenammina sp.	17	14	5	1	3		5	2	10	5
Leptohalysis sp.	2				2		1			11
Nouria ? sp.	2	2	1	3	1		5	3	2	5
Reophax sp.	1			1	1	4				
Textularia earlandi	2						1	2	2	
Textularia foliacea		1	3	2	3	7	1	1	6	4
Textularia sp. indet.		1								
Trochammina cf. *japonica*					2					
Trochammina pacifica			1	3		3	1	1	6	6
Agglutinated Foram. gen. et sp. indet.	1			3	1	1				
Massilina ? sp.								1		
Miliolinella sp.										
Quinqueloculina akneriana							3		5	
Quinqueloculina elongata	2			9			6	1		
Quinqueloculina lamarckiana	1						4			
Quinqueloculina seminulum				2			2			3
Sigmoillina sp.										
Siphonaperta sp.		1	3			6		1	3	5
Spiroloculina sp.									1	
Triloculina rotunda				3			2			
Calc. Porc. Foram. gen. et sp. indet.	1									
Ammonia "*beccarii*" forma 1								3		
Ammonia japonica		1		3	1		2			2
Ammonia sp. A	1		1		1	1				2
Amphicoryna sp.	1									
Bolivina cf. *decussata*										
Bolivina humilis	1						2			
Bolivina robusta	1		1							
Bolivina tokiokai	1									
Bolivina sp. indet.										
Brizalina striatula	2		2		1	1	1	3		3
Buccella frigida							1			1
Buccella makiyamai	1									
Bulimina marginata	1	2				1			1	1
Bulimina nojimaensis								4	1	
Buliminella elegantissima			2		1	1	1	1		

Appendix 1 Continued.

Station	1-20	2-20	3-20	4-10	4-15	4-20	5-15	5-20	6-10	6-15
Cancris auriculus										
Cibicides lobatulus										
Elphidium advenum		1	2		1		1			
Elphidium excavatum forma clavata					2					
Elphidium excavatum forma excavata		1	1	3		3	3		3	1
Elphidium kaneharai				1						
Elphidium reticulosum		1								
Elphidium somaense						1		1	1	1
Fissurina sp.			1							
Fursenkoina compactiformis	1	2			1	1	1	2		1
Fursenkoina sp. A				1						
Geminospira simaensis										
Globocassidulina sp.						1				
Guttulina sp.										
Hanzawaia nipponica			1							
Haynesina sp. A			2							1
Islandiella algida	1		1							
Murraynella minuta										
Nonion manpukuziensis								1		
Nonionella stella	15	18		10	10	3	2	94	2	29
Nonionellina sp. A	6	6		4	22	11	12	33	3	22
Oolina hexagona		1								
Pseudononion japonicum	12	10		12	6	1	6			1
Pseudoparrella naraensis	1							1		1
Pseudoparrella tamana			3		6	4		3		1
Pseudorotalia gaimardii compressiuscula	1	2	2						1	
Rectobolivina raphana	1									
Reussella aculeata	2	2					2	1		3
Rosalina sp.							1			
Sagrinella convallaria		1					1			
Stainforthia fusiformis										3
Uvigerina proboscidea										
Uvigerinella glabra		1			1	2		3		2
Virgulinella fragilis								1		3
Calc. Hyaline Foram. gen. et sp. indet.	1	1		3		1	1			
Total	114	73	48	77	72	66	95	193	57	128
Split	16	16	5.3	8	16	5.3	10.7	4	32	8

Appendix 1 Continued.

Station	6-20	7-10	7-15	8-10	8-15	9-15	10-20	11-20	12-25	13-25
Ammobaculites exiguus			1							
Ammobaculites sp. A										
Ammomarginulina sp. A	5		13	5	3	8	27	19	21	9
Eggerelloides advenus	2	3	29	11	8	8	29	4		1
Gaudryina sp.										
Goessella iizukae				1		1				
Haplophragmoides canariensis		3			1	2			1	
Haplophragmoides sphaeriloculum	13	17		1		12			2	
Haplophragmoides sp. indet.				1						
Lagenammina sp.				2	6	5	8		2	4
Leptohalysis sp.	2	4		8		7				
Nouria ? sp.	5			3	1	4		20	1	14
Reophax sp.	2							5	2	
Textularia earlandi	1		11	4	2	2		1		1
Textularia foliacea				4		1	3		3	2
Textularia sp. indet.			1		3					
Trochammina cf. *japonica*										
Trochammina pacifica	2		5		1		1	3	3	
Agglutinated Foram. gen. et sp. indet.	1									
Massilina ? sp.										
Miliolinella sp.				2						
Quinqueloculina akneriana	2			2					1	
Quinqueloculina elongata				3						
Quinqueloculina lamarckiana										
Quinqueloculina seminulum				1						
Sigmoillina sp.							1			
Siphonaperta sp.	4				2	6	2	2	1	3
Spiroloculina sp.		1								
Triloculina rotunda										
Calc. Porc. Foram. gen. et sp. indet.										
Ammonia "*beccarii*" forma 1								2		
Ammonia japonica						2	2	1		1
Ammonia sp. A	2		11	3	8	1	8			
Amphicoryna sp.										
Bolivina cf. *decussata*						1				
Bolivina humilis										
Bolivina robusta								1	2	1
Bolivina tokiokai										
Bolivina sp. indet.				1						
Brizalina striatula			6	8	3	2	2	4	2	3
Buccella frigida	1						1			
Buccella makiyamai										
Bulimina marginata						2				2
Bulimina nojimaensis			3		1			1	3	
Buliminella elegantissima		2	2	4	2	1	4			

Appendix 1 Continued.

Station	6-20	7-10	7-15	8-10	8-15	9-15	10-20	11-20	12-25	13-25
Cancris auriculus										3
Cibicides lobatulus	1									
Elphidium advenum	4							1		5
Elphidium excavatum forma clavata			1				4			
Elphidium excavatum forma excavata	2				1	1	3		1	
Elphidium kaneharai										
Elphidium reticulosum										
Elphidium somaense		2	2	9	9	28		1		
Fissurina sp.										
Fursenkoina compactiformis		2	1	1		6		1		11
Fursenkoina sp. A										
Geminospira simaensis				1						
Globocassidulina sp.										
Guttulina sp.			1							
Hanzawaia nipponica										
Haynesina sp. A			1				1			1
Islandiella algida			1							
Murraynella minuta			1	1						
Nonion manpukuziensis										
Nonionella stella	47	12	1	82	92	88	5	35	7	9
Nonionellina sp. A	25			13	8	17	4	23	4	4
Oolina hexagona										
Pseudononion japonicum				5		4	1	8	2	4
Pseudoparrella naraensis	2					2	3	1		
Pseudoparrella tamana	2	4	1	1	5	1	4	1	1	6
Pseudorotalia gaimardii compressiuscula							1			
Rectobolivina raphana									1	
Reussella aculeata			6	1			1	1		1
Rosalina sp.										1
Sagrinella convallaria			1							
Stainforthia fusiformis										
Uvigerina proboscidea								1		1
Uvigerinella glabra	3	2	3	4	6	7	3	3	1	
Virgulinella fragilis			2							
Calc. Hyaline Foram. gen. et sp. indet.				1			1			
Total	128	52	104	183	162	219	119	139	61	87
Split	8	5.3	2	8	4	8	4	4	8	8