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The intertidal macrobenthic fauna of the Hatakejima Experimental Field, Wakayama Prefecture, Japan, in 2019

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Abstract. Hatakejima Experimental Field is located in Tanabe Bay, Wakayama Prefecture, Japan, which is composed of Hatakejima Island and Komarujima Islet, connected to the former in low tide. Hatakejima Island was purchased by Kyoto University and was designated as the “Hatakejima Experimental Field” in 1968. The year 2019 marks the 50th year of the long-term surveys that have been formally conducted on the experimental field since 1969 (i.e., the Century of Research Project). We conducted a field survey to record the macrobenthic fauna of the experimental field in 2019. A total of 168 species of 11 phyla were recorded in this survey. In each phylum, the number of species is listed as follows in descending order: Mollusca (78 spp.), Arthropoda (27 spp.), Echinodermata (23 spp.), Annelida (21 spp.), Cnidaria (7 spp.), Porifera (3 spp.), Nemertea (3 spp.), Platyhelminthes (2 spp.), Chordata (2 spp.), Bryozoa (1 sp.), and Hemichordata (1 sp.). We also recorded and discussed the influence of recent environmental changes around the Hatakejima Experimental Field. Tropical sea urchin species disappeared in the winter of 2017–2018 following the large meander of the Kuroshio Current, which led to decreasing water temperatures. The population of the seagrass *Zostera japonica* drastically decreased on the western sandy shore of the island in 2019, most likely because of two big typhoons in September 2018. We must conduct continuous observations to aid the recovery of seagrass-associated communities and protect the experimental field to keep high biodiversity of macrobenthic fauna in the future.

Keywords: long-term monitoring, invertebrates, diversity, non-indigenous species, large meander of the Kuroshio, winter mortality

1. Introduction

The Hatakejima Experimental Field of the Seto Marine Biological Laboratory (SMBL), Kyoto University, is located in Tanabe Bay, which opens up to the Pacific Ocean on the southwestern coast of the Kii Peninsula, southern Japan (33.69°N, 135.37°E). (Fig. 1). This experimental field comprises Hatakejima Island (ca. 2.6 ha) and Komarujima Islet (ca. 550 m^2). At low tide, the vast intertidal zone appears and becomes a land bridge between the two. The intertidal zone has a great variety of marine fauna because it harbors various substrata such as rocky shores, gravel (boulders, cobbles, and pebbles) shores, sandy beaches, and muddy sand flats. Additionally, there is an environmental gradient from the western wave-exposed coast to the sheltered eastern coast. In the 35 undergraduate courses that were conducted from 1949 to 1983 around in the islands, 468 invertebrates, 39 fishes, and 114 seaweeds/seagrasses were identified by sight (Ohgaki and Tanase, 1984a, 1984b).

Hatakejima Island was purchased by Kyoto University and has been protected since 1968 and designated as the “Hatakejima Experimental Field”. Hence, the intertidal zone has been preserved and protected from the overexploitation of marine organisms. Since 2015, the landscape of the Hatakejima Experimental Field has been administratively protected as a part of the Tanabe-Shirahama Marine Park Area of Yoshino-Kumano National Park.

In 1960s, SMBL researchers launched a project called the Century of Research Project (i.e., long-term surveys) to monitor marine organism diversity and abundance on the coast of the Hatakejima Experimental Field (e.g., Tokioka, 1982; Ohgaki, 1984; Ohgaki et al., 2019). The monitoring comprises three surveys: (1) a sea urchin survey, (2) an entire coast survey, and (3) a south coast survey.

The sea urchin survey started in 1963 to monitor the density of major sea urchin species populations in a permanent quadrat on the westernmost coast of the experimental field (Fig. 1). After conducting annual surveys for 52 years, Ohgaki et al. (2019) concluded that water temperature and eutrophication were significant factors influencing sea urchin abundance and species richness on the experimental field.

The first monitoring survey of the large area of Hatakejima Island began in 1969 immediately after the establishment of the experimental field (Tokioka, 1982; Ohgaki, 1984). This monitoring survey has been continued as the entire coast survey and the south coast survey as follows. In the entire coast survey, the whole area of the experimental field was subdivided into 43 plots, and the presence or absence and relative abundance of 91 selected species of intertidal invertebrates were recorded (Ohgaki, 1984; Ohgaki et al., 1985). In the south coast survey, researchers recorded all intertidal marine organisms including seaweeds identified by sight in the 16 rocks along the southern and western coasts of Hatakejima Island. These surveys were conducted every 5 years. Presently, the results of these surveys 1969–2008 are available in the following papers: Tokioka (1969), Ohgaki et al. (1985), and Ohgaki (1984, 2001, 2002, 2003, 2012). The results of the 2013 and 2018 surveys are in preparation (Nakano et al., unpublished).

Our target is to continue these surveys for a century and hand over the survey protocols to the next generation of researchers, following Dr. Takashi Tokioka, the leading member of the first south coast survey, who helped establish the Hatakejima Experimental Field and initiated the Century of Research Project (Ohgaki, 2001). The year 2019 marked exactly half a century since entire coast survey began in 1969. The flora of the island in 2019 has been published (Maesako et al., 2019).

The aim of this survey is to record characteristics concerning intertidal fauna in 2019. We also recorded the landscape and environment of the island before the anticipated Nankai earthquake, which is expected to come in the next 30 years (Headquarters for Earthquake Research Promotion, 2013). Earthquakes and tsunamis can drastically change environments and affect the abundance and composition of macrobenthic fauna (Abe et al., 2015; Jaramillo et al., 2012; Kanaya et al., 2015; Miura et al., 2012; Seike et al., 2013); thus, it is important to record the fauna and landscape of Hatakejima Experimental Field before such events. Additionally, we mentioned the current taxonomy of the intertidal animals to relate the current scientific names to the past ones used in previous surveys conducted at the experimental field.

2. Material and Methods

We conducted a field survey on May 9 and 10, 2019, at the Hatakejima Experimental Field, following the protocols of the entire coast survey conducted from the end of April to early May (Ohgaki et al., 1997). In this season, finding a variety of organisms is easy because the tidal level of the diurnal spring low tide is the lowest tide in the year around the experimental field (The Japan Meteorological Agency, 2020).

In this survey, we set up five sections, which represent a variety of coastal habitats in the experimental field (Fig. 1). Section A (Plots 4, 5, and 6 of the entire coast survey) is the most sheltered area, which mainly comprises rocky shore and muddy sand facing to the inner section of Tanabe Bay. Section B (Plots 1, 26, and 27) is relatively exposed, which comprises rocky and boulder shores facing to the inner section of Tanabe Bay. Section C (Plot 18 and the adjacent boundaries) is fairly sheltered, which comprises sandy flats and surrounding rocky shores between Hatakejima Island and Komarujima Islet. Section D (Plots 36 and 37) is relatively exposed, with a cobble–boulder shore. Section E (Plots 39, 40, and 41) is the most exposed which comprises rocky shore facing to the mouth of Tanabe Bay. This section includes a fixed quadrat for the sea urchin survey (Ohgaki et al., 2019).

To conduct the field survey effectively, four teams (two to three persons per team) were formed for the following main taxonomic groups: mollusks, crustaceans, annelids, cnidarians, echinoderms, and the other animals. In each section, we recorded the maximum density of each species; individuals were identified on the surface of the coast via hour-long observations. The maximum density (individuals/m^2) is classified as follows: Class (1) = only one individual, Class 1 = two to nine individuals, Class 2 = 10–99 individuals, Class 3 = 100–999 individuals, and Class 4 = more than 1,000 individuals. During the survey, we took photographs of the five sections and other remarkable landscapes of the experimental field.

Species identifications were made according to the identification guides of Nishimura (1992), Nishimura (1995), Uchida and Soyama (2001), Imahara (2016), the Sessile Organisms Society of Japan (2017), Okutani (2020), and Tanaka et al. (2019). Scientific names follow WoRMS (2020).

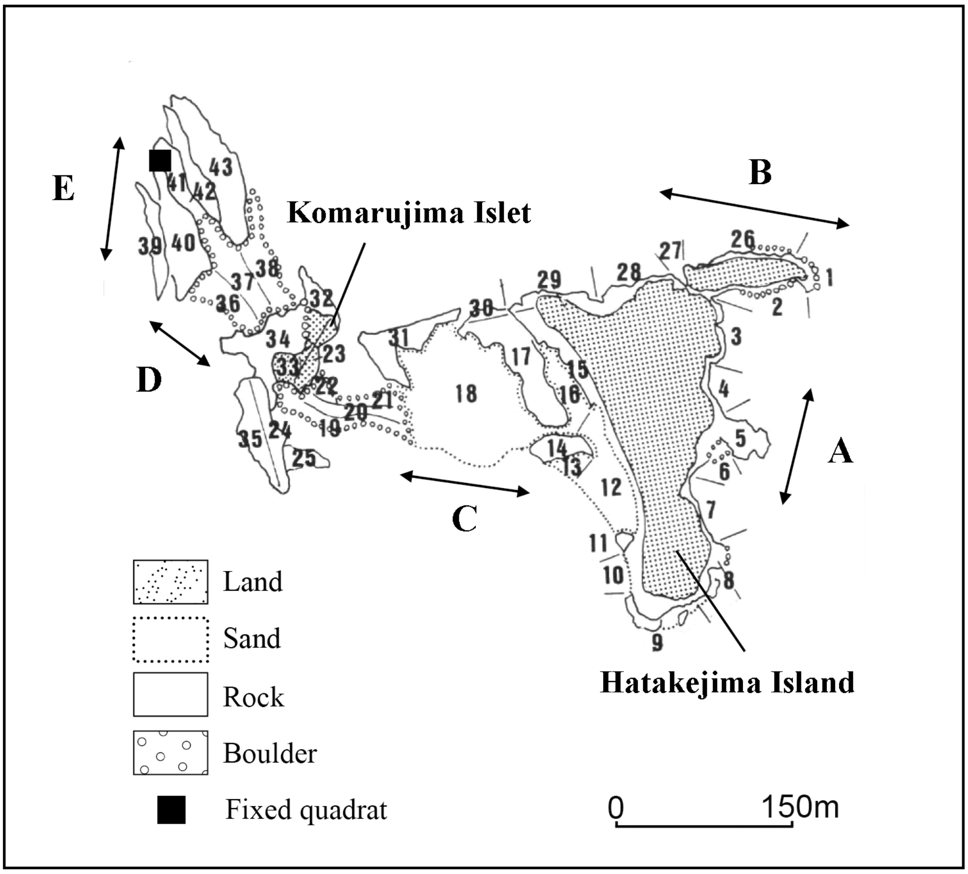

Figure 1. A map of the Hatakejima Experimental Field. The sections (A–E) are the survey areas of this study. The numbers (1–43) indicate the subdivided plots for the entire coast survey.

3. Results

3.1. Intertidal macrobenthic fauna and landscapes of the Hatakejima Experimental Field

All species observed in this survey are listed in Appendix Table 1 and summarized in Table 1. The landscapes and representatives of macrobenthic fauna are shown in Fig. 2, 3 and Plates 1–7. The characteristic intertidal macrobenthic fauna and the surrounding landscape of each section are described as follows.

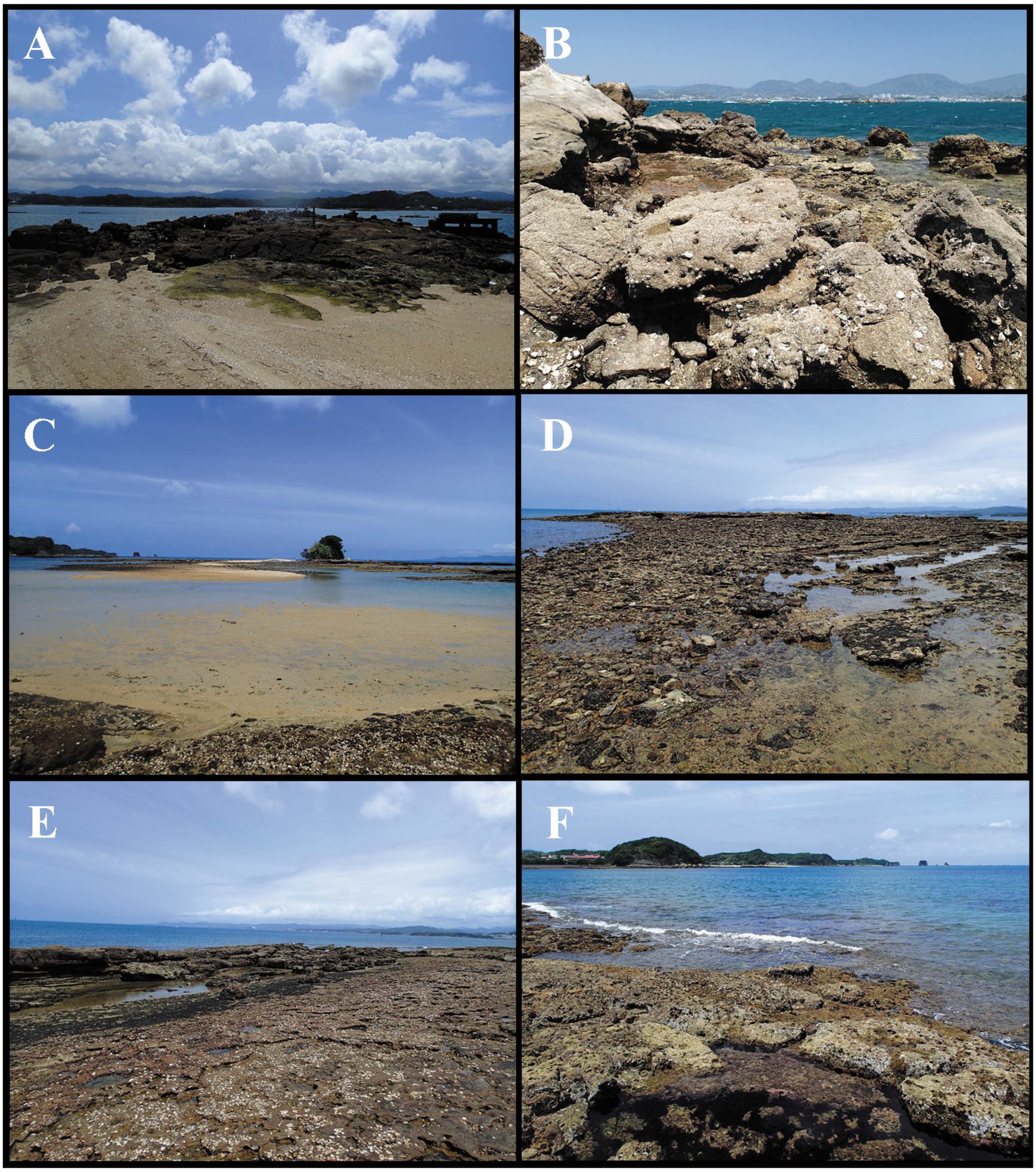

Figure 2. The landscape of the Hatakejima Experimental Field. **A**, Section A. **B**, Section B. **C**, Section C. **D**, Section D. **E–F**, Section E. Photographs A, C–F were taken on May 10, 2019 and a photograph B was taken on April 28, 2013.

Table 1. Number of the species of each phylum of intertidal macrobenthic animals at Stations A–E of Hatakejima Experimental Field.

Phylum	No. of species (spp.)					
	A	B	C	D	E	Total
Porifera	3	3	2	0	3	3
Cnidaria	2	5	3	1	3	7
Platyhelminthes	1	0	1	1	1	2
Nemertea	0	1	1	2	0	3
Bryozoa	1	0	0	1	1	1
Mollusca	42	42	22	24	33	78
Annelida	3	9	3	8	10	21
Arthropoda	11	8	16	10	8	27
Echinodermata	2	4	14	12	12	23
Hemichordata	0	0	1	0	0	1
Chordata	0	0	1	1	1	2
Total	64	72	64	60	72	168

Section A mainly comprised a rocky shore surrounded by muddy sand flats (Fig. 2A). A stalked barnacle *Capitulum mitella*, and two acorn barnacles *Chthamalus challengeri* and *Fistulobalanus albicostatus* were attached to the surface of rocks in the high intertidal zone. In the middle to high intertidal zone, a small mussel *Xenostrobus atratus* and two oysters *Saccostrea scyphophilla* and *Saccostrea kegaki* covered the surface of the rocks, and clusters of the gastropod *Clypeomorus bifasciata* were identified. The mussel *Brachidontes mutabilis* also covered the surface of rocks in the low to middle intertidal zone. In the low intertidal zone, a sponge *Hymeniacidon sinapium* and a bryozoan *Watersipora subatra* covered the wet surface of rocks, and a hermit crab *Pagurus filholi* and a shrimp *Palaemon pacificus* were lurking in places shaded by rocks in the tide pools.

Section B comprised a rocky shore with several tide pools and a boulder shore with large boulders 1–3 m in diameter (Fig. 2B). A supralittoral gastropod *Echinolittorina radiata* and a stalked barnacle *Ca*. *mitella* and an acorn barnacle *Ch*. *challengeri* were attached to the surface of rocks in the high intertidal zone. An oyster *Sa. scyphophilla* covered the surface of the rocks in the middle to high intertidal zone. In the low to middle intertidal zone, a sea anemone *Diadumene lineata*, a mussel *Br. mutabilis*, and a large acorn barnacle *Tetraclita japonica* covered the surface of the rocks, and a sea urchin *Heliocidaris crassispina* inhabited hollow areas in the tide pools. In the low intertidal zone, a sponge *Hy. sinapium*, a hydroid *Dynamena crisioides*, and a mussel *Septifer bilocularis* covered the wet surface of the rocks, and a large acorn barnacle *Megabalanus volcano* was attached to the surface of relatively exposed rocks.

Section C mainly comprised a sandy flat with cobbles and shell sand, including the surrounding rocky shores, which sheltered a large tide pool from strong waves (Fig. 2C). The sandy flat was underwater except during spring low tide. Two oysters *Sa. scyphophilla* and *Sa. kegaki* covered the surface of the surrounding rocks in the middle to high intertidal zone. A mussel *Br. mutabilis* also covered the surface of the rocks in the low to middle intertidal zone. In the low intertidal zone, a sponge *Hy. sinapium* covered the wet surface of rocks; a reef coral *Oulastrea crispata* and two hermit crabs *Pa. filholi* and *Clibanarius virescens* were observed at the bottom of the tide pools (Fig. 3). Several swirls of processed sand by an acorn worm *Balanoglossus carnosus*, large species of Hemichordata, were observed on the sandy flats, although the maximum density was only one individual/m^2.

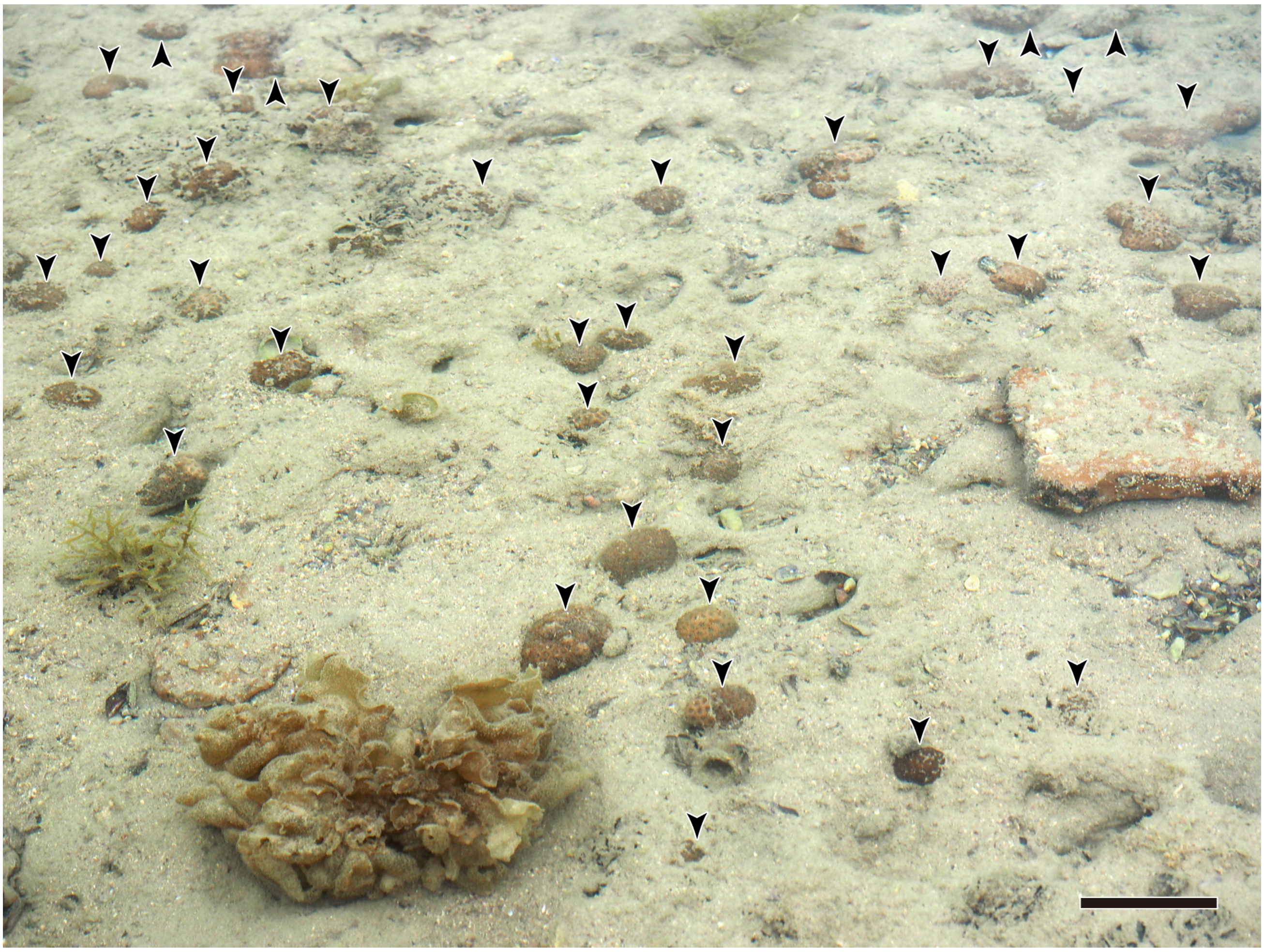

Figure 3. A representative of cnidarian species observed in this study. Dense colonies of *Oulastrea crispata* (Lamarck, 1816) in the shallow tide pool at Section C. Each arrow indicates a coral colony. Scale bar = 10 cm. A photograph was taken on May 10, 2019.

Section D was covered by cobbles, boulders, and a few scattered rocks under which contained layers of coarse sands, shell sands, and rocky flats (Fig. 2D). The cobble–boulder shore was underwater except during spring low tide. An acorn barnacle *Ch. challengeri* was attached to the surface of the rocks in the high intertidal zone. A gastropod *Monodonta confusa* was observed under the cobbles in the middle to high intertidal zone. A sea urchin *He. crassispina* and two sea cucumbers *Afrocucumis africana* and *Polycheira rufescens* were observed under boulders in the low to middle intertidal zone. Many animals were found under boulders in the low intertidal zone: two bivalves *Arca boucardi* and *Barbatia foliata*, a hermit crab *Cl. virescens*, a porcelain crab *Petrolisthes japonicus*, and a sea urchin *Hemicentrotus pulcherrimus*. An uncommon starfish Asterinidae gen. et sp. was also found in the community under the boulders.

Section E mainly comprised rocky flats washed by waves, including tide pools and a sheltered boulder shore by the surrounding rocks (Fig. 2E, F). A staked barnacle *Ca. mitella* and an acorn barnacle *Ch. challengeri* were attached to the surface of the rocks in the high intertidal zone. Two oysters *Sa. scyphophilla* and *Sa. kegaki* covered the surface of the rocks in the middle to high intertidal zone. Two tube worms Serpulidae gen. et sp. and *Spirobranchus kraussii Spirobranchus* sp. 1 (sensu Simon et al., 2019), previously identified as *Spirobranchus kraussii,* were attached to boulders in the middle intertidal zone. In the middle to low intertidal zone, a mussel *Br. mutabilis* and two large acorn barnacles *Te. japonica* and *Tetraclita squamosa* covered the surface of the rocks, and a sea urchin *He. crassispina* inhabited in hollow areas in the tide pools. In the low intertidal zone, two sponges *Halichondria okadai* and *Hy. sinapium* and two large acorn barnacles *Me. volcano* and *Megabalanus coccopoma* covered the surface of rocks; a hydroid *Amphisbetia furcata* covered the wet surface of the boulders, and a sea urchin *Echinostrephus aciculatus* inhabited in hollow areas in the tide pools.

3.2. Number of species in each phylum of intertidal macrobenthic animals

A total of 168 species of 11 phyla were recorded in this survey (Appendix Table 1). In each phylum, the number of species is listed as follows (in descending order): the phylum Mollusca (78 spp.), Arthropoda (27 spp.), Echinodermata (23 spp.), Annelida (21 spp.), Cnidaria (7 spp.), Porifera (3 spp.), Nemertea (3 spp.), Platyhelminthes (2 spp.), Chordata (2 spp.), Bryozoa (1 sp.), and Hemichordata (1 sp.) (Table 1).

Based on the comparison of the number of species observed in each section, the species numbers were relatively similar in each section (60–72 spp.) (Table 1). The numbers of mollusk species were more abundant in the eastern area of the experimental field (Sections A and B) than the middle and western areas; however, mollusk abundance was slightly less in the middle and western areas (Sections C, D, and E). Conversely, the numbers of echinoderm species were smaller in Sections A and B. However, their abundance was greater in Sections C, D, and E. The numbers of arthropod species tended to be larger in sections that included several cobbles and boulders such as in Sections A, C, and D. Many species of decapod crustaceans were observed under boulders in Section C. The numbers of annelid species were similar in Sections B, D, and E. By contrast, the numbers were slightly low in the other sections (Table 1).

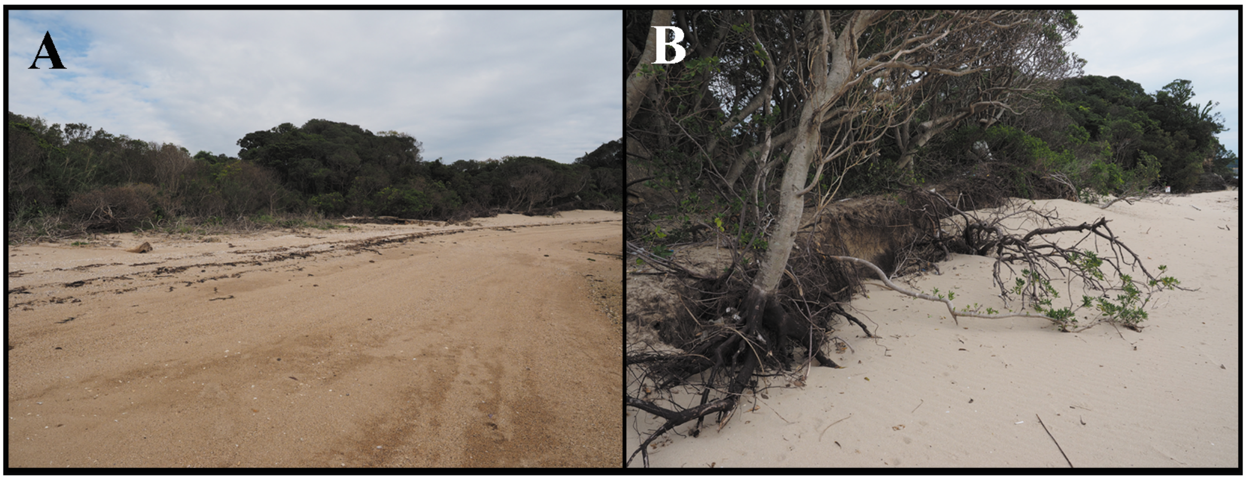

Figure 4. The landscape of the southern coast of the Hatakejima Island after two typhoons, Jebi and Trami, 2018. **A**, Extended sandy shores. **B**, Washed-up roots of vegetation. Photographs were taken on May 9, 2019.

3.3. The remarkable change in the landscapes of the Hatakejima Experimental Field in 2019

On the western coast of Hatakejima Island (Plot 12 of the entire coast survey, see Fig. 1), we found changes in the landscape around the sandy beach areas. The roots of trees and shrubs were exposed outside the soil as the land was scraped off (Fig. 4). Additionally, a green bed of the seagrass *Zostera japonica* was extremely reduced (Fig. 5A, B). This reduced abundance was unusual because this seagrass is typically observed in the low intertidal zone in this season (Fig. 5C, D).

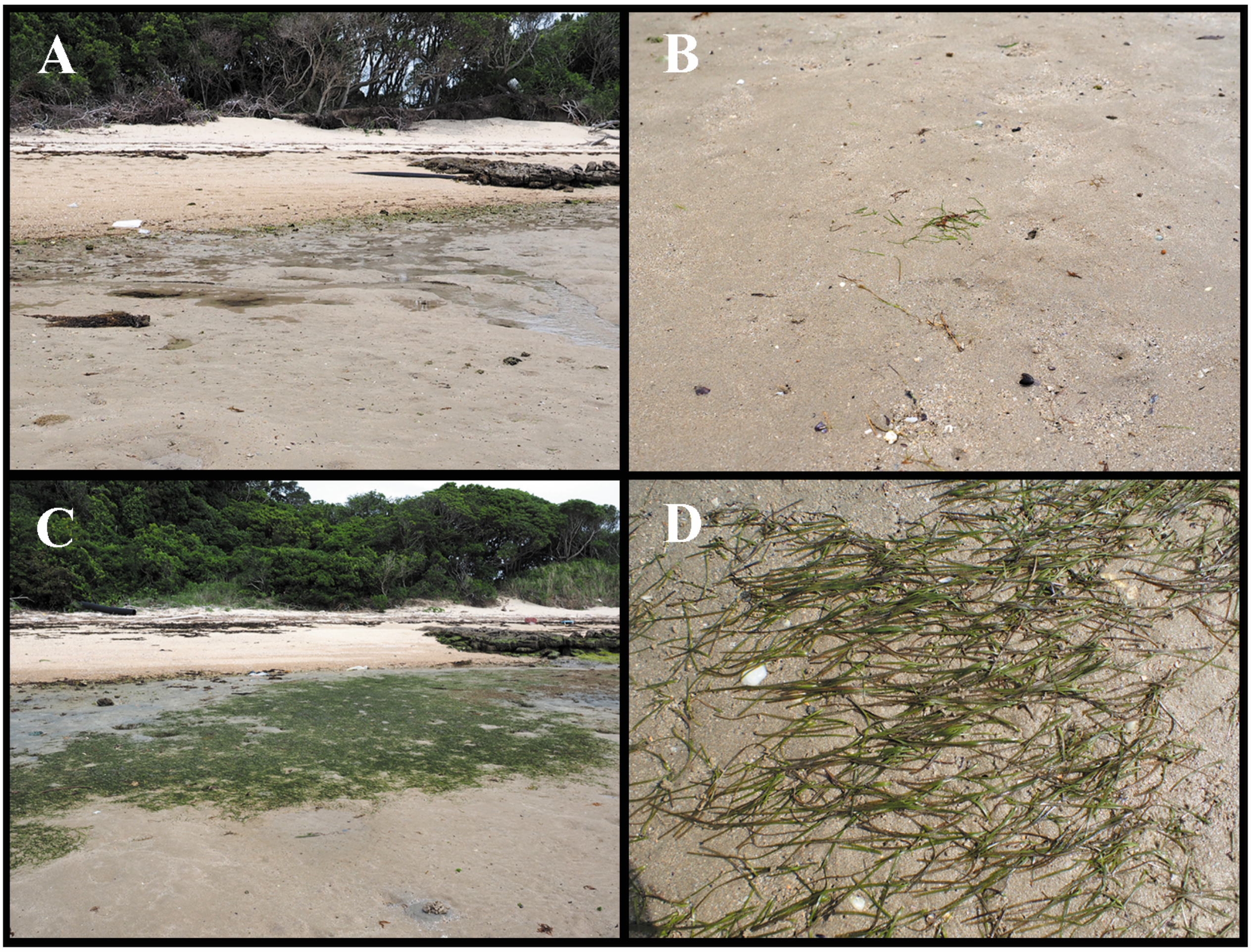

Figure 5. The population of *Zostera japonica* on the southwestern coast of Hatakejima Island. **A**, The view of the southwestern coast on June 4, 2019. **B**, The closed view of the *Zostera japonica* population on June 4, 2019. **C**, The view of the southwestern coast on May 18, 2015. **D**, The closed view of the *Zostera japonica* population on May 18, 2018, photographed by Y. Nabeshima.

4. Discussion

4.1. Comparison of macrobenthos fauna in 1969 and 2019

The published data on the intertidal macrobenthic fauna of the Hatakejima Experimental Field in 1969 is limited to the results of the south coast survey (Ohgaki, 1984). Although we cannot compare the data from the entire coast in this study with the previous data from the south coast survey from 1969, we would like to mention several characteristic species that inhabited the Hatakejima Experimental Field in 1969. The marine fauna and environment of Hatakejima Island were summarized in 1969 (Seto Marine Biological Laboratory, 1969). According to this study, four species (i.e., a tube-dwelling sea anemone *Cerianthus filiformis*, a sea cactus *Cavernularia obesa*, an acorn worm *Ba. carnosus*, and a sea cucumber *Holothuria leucospilota*) were characteristic and common at the Hatakejima Experimental Field. *Holothuria leucospilota* is still common, but the former two cnidarian species were not observed in this study because we did not conduct the field survey at the subtidal zone. Although a decrease in *Ba. carnosus* abundance was observed from 1981–1988 (Wada and Yamamoto, 1989), the species is now a common species in 2019. The gastropod species *Nerita japonica* was abundant in 1969 but was not recorded in 2019. The population of the species has been disappeared in the Hatakejima Experimental Field since 1979 (Abe, 1980; Ohgaki, 1989) and never back until now.

Although two starfish *Astropecten polyacanthus* and *Luidia maculata*, a sand dollar *Peronella japonica*, two crabs *Scopimera globosa* and *Ocypode stimpsoni*, and a sea anemone *Actinia equina* were locally common at the Hatakejima Experimental Field in 1969, only *As. polyacanthus* is still common in 2019. We did not observe *Lu. maculata* and *Pe. japonica* since they are subtidal species. Although we did not find a ghost crab *Oc. stimpsoni* in this survey, we came across a single individual of the species at the sandy beach in August 2019 during an undergraduate summer course (Fig. 6). Once, *Oc. stimpsoni* was the only species among the genus *Ocypode* distributed in the Hatakejima Experimental Field and Tanabe Bay (Ohgaki and Tanase, 1984a, 1984b). However, the southern species *Ocypode ceratophthalma*, *Ocypode sinensis*, and *Ocypode cordimanus* increased in abundance, whereas *Oc. stimpsoni* decreased in abundance in Tanabe Bay and the coast of Wakayama Prefecture from 2002 to 2010 (Watanabe et al., 2012; Wada and Watanabe, 2019). In 2010, only a specimen of *Oc. stimpsoni* was recorded at the Hatakejima Experimental Field, while 47 individuals of *Oc. ceratophthalma* was observed (Wada and Watanabe, 2019). Therefore, *Oc. stimpsoni* is presently a very rare species at the Hatakejima Experimental Field. Nomoto et al. (2020) suggested that the predation of *Oc. stimpsoni* by the southern *Oc. ceratophthalma* became more frequent due to increasing of larval supply of *Oc. ceratophthalma* with approaches of the Kuroshio Current.

Figure 6. *Ocypode stimpsoni* Ortmann, 1897 found on the sandy beach on August 5, 2019, during the undergraduate summer course. Scale bar = 1 cm.

In the past, the seagrass *Zostera marina* with two bivalves *Circe scripta* and *Pillucina pisidium*, and two gastropods *Nassarius livescens* and *Rhinoclavis kochi* have been distributed on the southern coast of the island. However, the *Zostera* communities have been disappeared at uncertain period before 1969 because of human overexploitation of a peanut worm *Siphonosoma cumanense* and a snapping shrimp *Alpheus brevicristatus* in

Zostera beds (Seto Marine Biological Laboratory, 1969). Although it was considered challenging to recover the *Zostera* communities, they have managed to recover at least once since 1969.

4.2. Overview of the transition of macrobenthic fauna over 50 years

The long-term changes of macrobenthic fauna in the Hatakejima Experimental Field have been discussed several times up until 2011 (e.g., Ohgaki et al., 1985; Ohgaki, 2001, 2002, 2003, 2012). From 1969 to 1993, the number of species was decreased in some marine organisms. In Mollusca, *Ne. albicilla*, *Ne. japonica*, *Drupella margariticola*, *Tenguella musiva*, *Clypeomorus bifasciata*, *Planaxis sulcatus*, *Septifer bilocularis*, *Sa. kegaki*, *Modiolus nipponicus*, and *Br. mutabilis* were abundant or common in 1969, however, none occurred in 1984 or 1993 (Ohgaki, 1984, Ohgaki et al., 1997). Severe red tide blooms occurred from the end of the 1970s to the beginning of the 1990s because of the increase in the production of aquaculture in Tanabe Bay (Ohgaki et al., 1999; Ohgaki, 2011). Additionally, the air and water temperatures were significantly low between 1969 and 1984 (Ohgaki et al., 1997). The disappearance of the above 10 species in the Hatakejima Experimental Field may have been caused by water pollution and/or low water temperatures (Ohgaki, 2011; Ohgaki et al., 2019). Three of these species, *Sa. kegaki*, *Pl. sulcatus* and *Ne. albicilla* were recovered until 1998, 2003, and 2008, respectively (Ohgaki, 2011). Other species were also recovered until now, and they were common at the Hatakejima Experimental Field in 2019, except for *Ne. japonica* and *El. contractus*. Since the middle of 1990s, the proportion and number of southern species increased with the recent rise in winter water temperatures (Ohgaki, 2011). *Planaxis sulcatus* and *Ne. albicilla* possess southern geographic distributions and later increased in the number of individuals in their populations (Ohgaki, 1997, 2011).

The temporal changes of bivalve species have been identified during the last 50 years. According to Yoshida (1983), *Sa. kegaki* is an oligotrophic indicator, whereas another oyster *Magallana gigas* is a eutrophic indicator. *Saccostrea kegaki* was abundant in 1969 but was not found in 1983 and increased in number until 2018. The species is now an abundant species at the Hatakejima Experimental Field. Conversely, *Ma. gigas* was not found in the experimental field from 1969 to 1983 but became abundant in 1993 and gradually decreased in number until 2018. The species is now an uncommon species at the Hatakejima Experimental Field. Another eutrophic indicator species, a mussel *Mytilus galloprovincialis* was not found in 1970 (Senawong, 1972) but became abundant from 1983 to 1998 (Ohgaki et al., 1985; Ohgaki, 2002). The species was rarely found in 2013, 2018, and the present study. Their abundance likely reflects the water pollution that occurred from the 1970s to the 1990s. During this period, the eutrophic indicators *Ma. gigas* and *My. galloprovincialis* were abundant, but the oligotrophic indicator *Sa. kegaki* was not. Conversely, the southern species *Sa. scyphophilla* was initially reported in 2008 (Ohgaki, 2002) and increased in the number of individuals until now. The species is now a common species at the Hatakejima Experimental Field. The recent rise in winter water temperatures may have caused the increase of this southern species. Thus, oligotrophic species and southern species are now commonly found in the Hatakejima Experimental Field. Most recently, the extremely low water temperatures in the winter of 2017–2018, following the large meander of the Kuroshio Current, caused the winter mortality of several southern species around the Kii Peninsula (Nakano et al., 2019). Most southern species experienced extremely reduced population sizes at the Hatakejima Experimental Field in 2018–2019.

We briefly overviewed changes in the macrobenthic fauna in this study. Long-term changes of macrobenthic fauna at the Hatakejima Experimental Field over the last 50 years should be addressed in order to conduct accurate statistical analyses in the future.

4.3. Large meander of the Kuroshio Current

The Kuroshio Current strongly influences the marine fauna of the Kii Peninsula. The approach of the Kuroshio with rising water temperature leads to an increased larval supply and the settlement of southern species and reduces their mortality in winter. During 1972–1974, 1980–1994, and 2007–2009, various tropical species including gastropods, crabs, sea stars and fishes were reported in the Kii Peninsula (e.g., Araga, 1972; Tanase, 1986; Yamamoto and Kimura, 1987; Koyama, 1992; Takeda and Marumura, 1994; Hashimoto et al., 2009). However, these tropical species were mostly disappeared with decreasing water temperature. Such marine organisms that appeared once or during a short period are known as pseudo-populations.

Most recently, tropical sea urchin species *Echinometra* sp. C (Japanese name: Ryukyu-Nagauni) was reported on the Cape Bansho near SMBL (Nakano et al., 2019). These individuals were collected in 2016 and 2017. According to Nakano et al. (2019), the flow of the Kuroshio was closer to the Kii Peninsula, and the seawater temperature was high in winter of the beginning of 2016 and 2017. Therefore, *Echinometra* sp. C could survive these winters. However, the species was locally disappeared there in the winter of the beginning of 2018, following the decreasing water temperature with large meander of the Kuroshio. The extremely low water temperature (minimum 11.5°C) in 2018 caused the mass mortality of tropical species around the Kii Peninsula. In Tanabe Bay, the mass mortality of tropical and subtropical species has often been observed in conjunction with low water temperatures below 11°C (Ohgaki, 1989). Other species of *Echinometra* was also locally disappeared around Shirahama in this winter period and several dead specimens of *Echinometra* spp. were found in tide pools in the Hatakejima Experimental Field (Fig. 7). In the sea urchin survey of the experimental field, more than 100 individuals of *Echinometra* spp. were observed before 2018; however, no individuals were found in 2018 (Kato et al., 2018). Winter mortality of sea urchins were also reported in 1963 and 1976 and appeared to be caused by the large meander of the Kuroshio or the cold winter (Tokioka, 1963, Ohgaki et al., 2019). The large meander of the Kuroshio has endured until now (The Japan Meteorological Agency, 2020). In this study, only a few individuals of the *Echinometra* sp. A were newly observed in Section C. These specimens may be new recruitments via larval dispersal from other areas.

Figure 7. Mass mortality of sea urchins of *Echinometra* spp. observed in a tide pool at the Hatakejima Experimental Field on May 5, 2018.

4.4. Non-indigenous species at the Hatakejima Experimental Field

The number of non-indigenous marine species from foreign countries has increased in the last 50 years, and up to 59 non-indigenous species occur in Japan (Iwasaki, 2018). Most of the introductions were unnoticeable because they were unintentional transported via hull fouling and ballast water or contamination in imported fishery products (Otani, 2006; Iwasaki, 2018). However, the problems caused by these species, such as marine biofouling and the threat to native species, have escalated (Mooney and Cleland, 2001; Iwasaki, 2007; Odendaal et al., 2008). In a long-term survey at the Hatakejima Experimental Field, we observed the increase and decrease of the non-indigenous species as follows.

The mussel *Mytilus galloprovincialis*, a widespread non-indigenous species from the Mediterranean Sea, was not found in this study. The present species was initially reported in Tanabe Bay in the 1930s when introductions occurred simultaneously at some ports in Japan (Ishida et al., 2005; Ohgaki, 2011). After its discovery at the Hatakejima Experimental Field in 1951, the species became common on the western and northern coast of Hatakejima Island in 1983 (Ohgaki and Tanase, 1984a, 1984b; Ohgaki, 1984). In Tanabe Bay, the population of the species experienced drastic decreases two or more times after the late 1980s (Wakayama Prefecture, 2019). These decreases were the result of frequent high-water temperatures exceeding 29°C in the summer (Kubota, 1997, 2007). As only a few individuals were found in 2008 and 2013 in the entire coast survey (Ohgaki, 2012; Nakano et al., unpublished), we believe that the population currently remains small. By contrast, another non-indigenous mussel *Perna viridis* from tropical waters in the western Pacific Ocean is increasing in Tanabe Bay (Kubota, 2011, 2018). One individual of *Pe. viridis* was collected during an undergraduate course at the Hatakejima Experimental Field in March 2016. However, this species has not been reported in the entire coast survey so far. The shift between the two non-indigenous mussels is obvious in marine fauna and could be an effect of global warming.

One individual of barnacle *Amphibalanus amphitrite*, a widespread non-indigenous species from the tropical Pacific Ocean (Wakayama Prefecture, 2019), was found at Section A and not found at Section B where the present species were abundant until 2003 (e.g., Ohgaki et al., 1985; Ohgaki, 2001, 2002, 2003). After its discovery in Tanabe Bay in the 1930s, the species became common in the 1960s and sustained its population until the 2000s (Ohgaki, 2011). The present species was recorded at the Hatakejima Experimental Field at least in 1957 (Ohgaki and Tanase, 1984a, 1984b), and it became common, especially in Section B (Ohgaki, 2001, 2002, 2003). However, the population in Section B was observed to disappear in the entire coast survey in 2008, as we observed in this study (Ohgaki, 2012); the reason remains unclear.

Another non-indigenous barnacle *Megabalanus coccopoma*, originally described in Panama by Darwin (1854), was initially recorded at the Hatakejima Experimental Field in this study. However, we believe that the species occurred in 2014 as we took photographs of an unidentified barnacle, which turned out to be *Me. coccopoma*. The species was already abundant in Section E and was attached to the shell of the closely related barnacle *Megabalanus volcano* in many cases. *Megabalanus coccopoma* is considered to have expanded its distribution along the Pacific coast of Japan since the 1980s, being initially reported from the Toushima at the mouth of Tanabe Bay in 2005 (Yamaguchi et al., 2009; Yamaguchi, 2014). As *Me. coccopoma* seems to prefer the exposed rocky shore in Tanabe Bay, where tropical species are frequently observed (Nakano et al., 2019), we speculate that the species may be different concerning its low-temperature tolerance compared with the non-indigenous barnacle *Am. amphitrite*.

4.5. Taxonomic situation and currently assigned scientific name in each phylum

Approaches to animal taxonomy have significantly advanced, especially with the integration of molecular phylogenetics during the last 50 years. During the long-term surveys, we experienced changes in the classification and scientific names that were assigned to species of marine invertebrates belonging to several phyla. Here, we discuss the taxonomic situation and the currently assigned scientific name of each taxon to maintain consistency of species identification for future surveys at the Hatakejima Experimental Field.

4.5.1. Phylum Cnidaria

A sea anemone *Anthopleura inorata* (Japanese name: Beriru-Isoginchaku) was found in the experimental field, which was identified based on the description by Uchida and Soyama (2001). The present species has been listed as *Anthopleura.* aff. *xanthoglammica* or *Anthopleura uchidai* in the previous study in the experimental field (Ohgaki, 2001, 2012). *Anthopleura* aff. *xanthoglammica* in Uchida (1992) is a synonym of *An. inornata* (Dr. Hiro'omi Uchida, personal communication, June 11, 2020). Conversely, it is unknown why the name of *An. uchidai* has been used. Presently, a redescription for the Japanese *An. inornata* may be required because it was pointed out that the present species still had the possibility to be different from the original *An. inornata* from Hong Kong (Yanagi, 2006).

Another sea anemone (Yoroi-Isoginchaku) morphologically coincided with *An. uchidai*. This species has been listed as *A. japonica* in previous studies in the experimental field (Ohgaki, 2001, 2002, 2003). *Anthopleura uchidai* was given as a new name for *An. japonica* sensu Uchida, 1938 from Mutsu Bay, Japan, and the original *A. japonica* from Shimoda, Japan, was renamed *Gyrates japonica* because the holotype did not have acrorhagi of the diagnosis of *Anthopleura* (England, 1922). As a scientific name is revised depending on the taxonomic status of species, we suggest that the Japanese common name should be written with a scientific name in order to avoid confusion between researchers of different generations during the course of the long-term survey.

4.5.2. Phylum Mollusca

Two subspecies were recognized under the name of *Monodonta labio*; *Monodonta labio confusa* (Japanese name: Ishidatami), distributed in temperate Japan, and *Monodonta labio labio* (Okinawa-Ishidatami), distributed in the Ryukyu archipelago (Sasaki, 2000). Recent molecular analysis revealed that they are genetically different from each other and can be treated as distinct species (Yamazaki et al., 2017). Furthermore, they suggested that these two species are sympatrically distributed in the mainland of Japan. *Monodonta labio* has been selected in the survey as a potential species that could extend its distribution northward from the Ryukyu archipelago following the increase in seawater temperatures. However, *Mo. confusa* and *Mo. labio* could also co-occur on the experimental field. Further molecular investigation using the specimens collected from the Hatakejima Experimental Field is required to confirm whether both species are distributed on the island or not. The shell of *Mo. labio* is normally greenish in color (Sasaki, 2000). Reddish specimens of the species were sometimes found in the island (Plate. 2I). This color pattern is thought to be intraspecific variation commonly found in Osaka Bay (Yamazaki, personal communication).

The turbinid gastropod *Lunella correensis* (Sugai) was treated as *Lunella coronata correensis* (Sasaki, 2000). The species was elevated to species rank based on molecular analyses using COI gene (Nakano et al., 2007). The genus *Lunella* is currently composed of four species, *Lunella correensis*, *Lunella coronata* (Kangiku), *Lunella cinerea* (Oobeso-Sugai), and *Lunella ogasawarana* (Ogasawara-Sugai) (Nakano et al., 2007; Williams et al., 2011). *Lunella correensis* is distributed only on the island; however, the specimens collected from boulder shores on the island tend to possess a much stronger nodule on the shell resembling *Lu. coronata* (Plate. 2K). Molecular confirmation of the species collected on boulder shores of the island is required.

A gastropod *Reishia clavigera* was originally described as two distinct species, namely, *Purpura clavigera* and *Purpura problematica*, but later, these two species were treated as a single species (Pilsbry, 1895). Abe (1985) redescribed the former species as *Re. clavigera* form P, which has rounded nodules, and the latter species as *Re. clavigera* form C, which has sharply pointed nodules (Plate. 2F, G). Allozyme analysis revealed that these two forms are different in each other, and their food availability are also different (Abe, 1994). However, they are currently treated as ecomorphs in a single species (Tsuchiya, 2017). These two forms were also considered identical based on the COI gene (Nakano et al., unpublished).

4.5.3. Phylum Annelida

Many annelid species do not show clear morphological differences over a wide range of geographical distributions, and therefore, they are recognized as cosmopolitan species. However, cryptic species are considered to be common among annelids (Nygren, 2014). Several specimens collected during the present survey include species that may need taxonomic revision. For example, the Bobbit worm *Eunice aphroditois* (Japanese name: Oni-Isome) has been reported in various oceans, but taxonomic confusion has been proposed as an explanation for its alleged wide-ranging presence (Salazar-Vallejo et al., 2011; Schulze, 2011). Such confusion is probably common for Japanese annelid species; therefore, a review of the classification of Japanese annelids would be required based on both morphological and molecular analyses.

4.5.4. Phylum Arthropoda

A common intertidal hermit crab *Pagurus minutus* (Japanese name: Yubinaga-Honyadokari), is one of the most dominant intertidal hermit crab species in East Asia and is distributed from the Primorye of East Russia, Japan, Korea, and northeast coast of China to Taiwan (Komai and Mishima, 2003). A recent molecular analysis of the East Asian *Pa. minutus* population divided this species into three distinct genetic groups: the major group, the minor group, and the Taiwan–Okinawa group (Jung et al., 2018). The major group inhabits the entire coast of South Korea (except for the northeast coast), the east coast of Honshu (Japan), and the west coast of Kyushu (Japan). The minor group predominantly inhabits the northeast coast of South Korea, whereas a small proportion inhabits the west coast of South Korea and the west coast of Kyushu (Japan). The Taiwan–Okinawa group is restricted to Taiwan and the Okinawa Islands of Japan (Jung et al., 2018). The three groups show slight differences in morphological characteristics and have distinguishing color patterns (Jung et al., 2018). The minor group has the shortest lengths of its ocular peduncle and the dactyl of its ambulatory legs, whereas the Taiwan–Okinawa group has the longest lengths in these features. The three groups have different background colors and stripe patterns of the ambulatory legs between them. Jung et al. (2018) suggested that *Pa. minutus* is separated into three groups at the species level. *Pa. minutus* specimens collected from Hatakejima Island were assigned to the major group because of its morphological and color characters. Molecular confirmation is necessary in the future.

4.5.5. Phylum Echinodermata

Presently, at least four species of sea urchins of the genus *Echinometra* are distributed in Japan: *Echinometra mathaei* (Japanese name: Hon-Nagauni), *Echinometra oblonga* (Himekuro-Nagauni), *Echinometra* sp. A (Tsumajiro-Nagauni), and *Echinometra* sp. C (Ryukyu-Nagauni) (Uehara, 1990; Arakaki et al., 1998). *Echinometra mathaei* (Nagauni) was formerly assigned to the *Echinometra* species complex in Japan. These four species were reported to be both morphologically and phylogenetically distinguished from each other (Rahman and Uehara, 2004; Landry et al., 2003; Lee and Shin, 2012). The *Echinometra* species have each been counted as distinct species from the entire coast survey in 1998 (Ohgaki, 2002). *Echinometra* sp. A, which was most common among *Echinometra* species in the field, was found in the relatively exposed area of Section C. *Echinometra mathaei* was also known to appear at the exposed rocky shore of the experimental field (Ohgaki, 2002, 2003, 2012). Conversely, *Echinometra oblonga* and *Echinometra* sp. C appear at the mouth of Tanabe Bay rather than in the experimental field inside the bay (Nakano et al., 2019). Recently, Nakano et al. (2019) reported that *Echinometra* sp. C expanded its distribution into Honshu, Japan; its previous northern limit had been the Ryukyu archipelago. The distinction of *Echinometra* spp. is necessary because the appearance of tropical sea urchins can indicate environmental change at the experimental field.

The starfish Asterinidae gen. et sp. had some characteristics of the genus *Indianastra*: small and thin body and deeply notched abactinal plates (O'Loughlin and Waters, 2004); however, the information is insufficient for accurate identification. A representative specimen does not exist; thus, only photographs can be used to identify it. The Asterinidae gen. et sp. found in Section D possessed six rays, but the number of rays is usually five in the genus *Indianastra.* We presume that the six rays are not standard for an individual of Asterinidae gen. et sp. because two of the rays were branching at the point near the mouth. As the *Indianastra* species is uncommon in the experimental field, an exact, accurate identification is necessary in the future.

4.5.6. Phylum Hemichordata

An acorn worm observed in the field producing swirls of processed sand (fecal mounds) had been identified as *Balanoglossus misakiensis* (Japanese name: Misaki-Giboshimushi) until 1969 (Komai et al., 1927; Tokioka, 1969). Following clarification from Nishimura et al. (1971), who pointed out that *Ba. misakiensis* does not produce fecal mounds, the species from the field was correctly identified as *Balanoglossus carnosus* (Wadatsumi-Giboshimushi) (Nishikawa, 2018). However, the presence of *Ba. misakiensis* may still be possible since an old specimen collected from Tanabe Bay in 1911 turned out to be *Ba. misakiensis*. However, at this time, there are no records of *Ba. misakiensis* being observed in the experimental field (Nishikawa, 2018).

4.6. Typhoon disturbance on flora in 2018

Big typhoons Jebi and Trami hit Shirahama in early and late September 2018, respectively. Both typhoons caused strong southern winds, and damaged the equipment of SMBL and the Shirahama Aquarium, and wrought havoc on the environment around Hatakejima Island, as shown in Figs. 4 and 5. These pictures were taken at the western sandy shore of the island.

A field observation of the Hatakejima Experimental Field was conducted on October 6, 2018, as a part of a field symposium held by the Kansai Organization for Nature Conservation. T.N., the first author, took participants on a tour around the island. The leaves of several plants had fallen due to heavy rains and saltwater, and many plants along the coastline were either withered and dead or washed up with their roots due to the strong waves. Many floating artificial and natural objects were observed around the building, which was protected with windbreak trees at the island's center. The high waves most likely reached the center of the island. The sandy shore was extended approximately 5–10 m landward from the western to southern coast of the island due to the washed-up sand. In a survey conducted on October 30, 2018, and August 9, 2019, Maesako et al. (2019) observed that the plants along the coastline had recovered their leaves; however, many dead trees were also reconfirmed. They also mentioned the potential for alien species to invade into the gaps caused by natural disturbances such as typhoons.

The seagrass *Z. japonica*, an underwater plant, drastically decreased in abundance on the western sandy shore of the island in 2019 (Fig. 5). The typhoons possibly damaged the *Z. japonica* bed since the colony was usually observed during this season, even in May 2018 (Fig. 5). Considering that a large amount of sand was pushed up onto the upper shore, we speculate that the sand either removed the colony or covered the surface of the colony. As the recovery of the colony may take several years, this area requires continuous observation.

4.7. Significance of long-term monitoring survey

Human-mediated ecological drivers such as climate change and eutrophication could significantly influence ecosystems and the population structures of marine organisms (Bellard et al., 2012; Haase et al., 2016). Long-term research and monitoring can provide valuable insights for managing ecosystems and natural resources. Therefore, long-term ecological studies have become more important due to increasing anthropogenic impacts (Robertson et al., 2012; Ohgaki et al., 2019). However, long-term surveys are not so common. Long-term surveys more than 20 years are available on marine benthic fauna and are limited to small areas in places such as England (Southward, 1995a, b; Southward and Crisp, 1954), Netherland (Beukema, 1974, 1976), Africa (Evance et al., 1993), USA (Barry et al., 1995), and Australia (De'ath et al., 2012). In Japan, long-term surveys were also conducted in Seto Inland Sea (Yuasa, 1995), Osaka Bay (Yamanishi, 2018), Mikawa Bay (Nishikawa and Maeda, 1991), Amakusa (Tamaki, 1994; Flach and Tamaki, 2001), and Tanabe Bay. Especially, there are four long-term monitoring sites, namely, Hatakejima Experimental Field (e.g., Tokioka, 1969; Ohgaki, 2011), Cape Bansho (Ohgaki et al., 2011; Ishida et al., 2018), Uchinoura and Torinosu (Koga et al., 2018), in Tanabe Bay. Monitoring surveys at the latter two sites were conducted in tidal flats based on the Monitoring 1000 Sites Project. All long-term surveys in Tanabe Bay are still ongoing. Therefore, Tanabe Bay is one of the most documented areas in the world.

Despite the importance of long-term surveys, many monitoring surveys have failed because of the unclear object, poor planning and method's poor repetition (Lindenmayer and Likens, 2009), and come to an end due to the lack of fund (Duarte et al., 1992), or suspended due to the lack of next-generation researchers (Ohgaki et al., 2019). We hope a "Century of Research Project at Hatakejima" can be successfully completed in the next 50 years. We must train the next generation of researchers to take over these methods and knowledge of long-term surveys.

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Literature cited

Abe, N. 1980. Extinction of the population of *Heminerita japonica* (Dunker) in the inner part of Tanabe Bay. The Nanki Seibutsu, 22, 21–25. (in Japanese)

Abe, N. 1985. Two forms of *Thais clavigera* (Küster, 1858). Venus, 44, 15–26.

Abe, N. 1994. Growth and prey preference of the two forms in *Thais clavigera* (Küster) under rearing. Venus, 53, 113–118.

Abe, H., Kobayashi, G. and Sato-Okoshi, W. 2015. Impacts of the 2011 tsunami on the subtidal polychaete assemblage and the following recolonization in Onagawa Bay, northeastern Japan. Marine Environmental Research, 112, 86–95.

Araga, C. 1972. A record of *Colobocentrotus mertensi*. The Nanki Seibutu, 14, 59. (in Japanese)

Arakaki, Y., Uehara, T. and Fagoonee, I. 1998. Comparative studies of the genus *Echinometra* from Okinawa and Mauritius. Zoological Science, 15, 159–168.

Barry, J.P., Baxter, C.H., Sagarin, R.D. and Gilman, S.E. 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. Science, 267, 672–675.

Bellard, C., Bertelsmeier, C., Leadly, P., Thuiller, W. and Courchamp, F. 2012. Impacts of climate change on the future of biodiversity. Ecological Letters, 15, 365–377.

Beukema, J.J. 1974. Seasonal changes in the biomass of the macro-benthos of a tidal flat area in the Dutch Wadden Sea. Netherlands Journal of Sea Research, 8, 94–107.

Beukema, J.J. 1976. Biomass and species richness of the macrobenthic animals living on a tidal flat area in the Dutch Wadden Sea: effects of a severe winter. Netherlands Journal of Sea Research, 13, 203–223.

Darwin, C. 1854. A monograph on the subclass Cirripedia, with figures of all species. The Balanidae, (or Sessile Cirripedes), the Verrucidae, etc., etc., etc. Ray Society, London, 1854, pp. 30–300.

De’ath, G., Fabricius, K.E., Sweatman, H. and Puotinen, M. 2012. The 27–year decline of coral cover on the Great Barrier Reef and its causes. Proceedings of Natural Academy Science U.S.A., 109, 17995–17999.

Duarte, C.M., Cebrián, J. and Marbà, N. 1992. Uncertainty of detecting sea change. Nature, 356, 190.

England, K. W. 1992. Actiniaria (Cnidaria: Anthozoa) from Hong Kong with additional data on similar species from Aden, Bahrain and Singapore. In Morton, B. (ed), The Marine Flora and Fauna of Hong Kong and Southern China III. Hong Kong University Press, Hong Kong, 49–95.

Evance, S.M., Gill, M.E., Hardy, F.G. and Seku, F.O.K. 1993. Evidence of change in some rocky shore communities on the coast of Ghana. Journal of Experimental Marine Biology and Ecology, 172, 129–141.

Flach, E. and Tamaki, A. 2001. Competitive bioturbators on intertidal sand flats in the European Wadden Sea and Ariake Sound in Japan. In Reise, K. (ed). Ecological comparisons of sedimentary shores. Springer, Berlin, pp. 149–171.

Haase, P., Frenzel, M., Klotz, S., Musche, M. and Stoll, S. 2016. The long-term ecological research (LTER) network: Relevance, current status, future perspective and examples from marine, freshwater and terrestrial long-term observation. Ecological Indicators, 65, 1–3.

Hashimoto, I., Kashiyama, Y. and Kubota, S. 2009. A living subadult of *Lambis* (*Harpago*) *chiragra* (Discopoda, Strombidae) collected at Shirahama town, Wakayama Prefecture, Japan. The Nanki Seibutu, 51, 58. (in Japanese)

Headquarters for Earthquake Research Promotion. 2013. Long-term evaluation of Nankai earthquake (2nd edition). 13 pp. (in Japanese)

Imahara, Y. (ed.) 2016. A color guide to the rocky shores of Japan, field edition, revised edition. Tombow Publishing, Osaka, 279 pp. (in Japanese)

Ishida, S., Iwasaki, K. and Kuwahara, Y. 2005. Initial invasion history and process of range expansion of *Mytilus galloprovincialis* – Inferred from the specimens collected by T. Furukawa. Venus, 64, 151–159. (in Japanese)

Ishida, S., Komemoto, K. and Funayama, N. 2018. An outline of 'Cape Bansho Malacofauna Research' and some issues associated with its long-term continuation. Bulletin of Kansai Organization for Nature Conservation, 40, 143-152 (in Japanese)

Iwasaki, K. 2007. Non-indigenous organisms introduced into Japanese waters and their impacts on native ecosystems and industries. Nippon Suisan Gakkaishi, 73, 1121–1124. (In Japanese)

Iwasaki, K. 2018. Non-indigenous marine organisms and their impacts on industries and native ecosystems. Yaseifukki, 6, 1–5. (in Japanese)

Jaramillo, E., Dugan, J.E., Hubbard, D.M., Melnick, D., Manzano, M., Duarte, C., Campos, C. and Sanchez, R. 2012. Ecological implications of extreme events: Footprints of the 2010 earthquake along the Chilean coast. PLoS ONE, 7.

Jung, J., Jung, J. and Kim, W. 2018. Subdividing the common intertidal hermit crab *Pagurus minutus* Hess, 1865 (Decapoda: Anomura: Paguridae) based on molecular, morphological and coloration analyses. Zoological Studies, 57, 1–20.

Kanaya, G., Suzuki, T. and Kikuchi, E. 2015. Impacts of the 2011 tsunami on sediment characteristics and macrozoobenthic assemblages in a shallow eutrophic lagoon, Sendai Bay, Japan. PLoS ONE, 10, 1–18.

Kato, T., Harada, K. and Yamauchi, H. 2018. The Population density of the macrobenthos (sea urchins). In: National Astronomical Observatory of Japan (ed.). Chronological Environmental Tables 2019–2020. Maruzen Publishing, Tokyo, p. 197.

Koga, T., Aoki, M., Kohda, Y. and Watabe, T. 2018. Temporal change in the tideland macrobenthos in Tanabe Bay: based on the Monitoring 1000 Project. Bulletin of Kansai Organization for Nature Conservation, 40, 129–141. (in Japanese)

Komai, T., Akatsuka, K. and Ikari, J. 1927. The Seto Marine Biological Laboratory of the Kyoto Imperial University, its equipment and activities, with remarks on the fauna and flora of the environs. Memories of the College of Science, Kyoto Imperial University, Series B, 3, 281–306.

Komai, T. and Mishima, S. 2003. A redescription of *Pagurus minutus* Hess, 1865, a senior synonym of *Pagurus dubius* (Ortmann, 1892) (Crustacea: Decapoda: Anomura: Paguridae). Benthos Research, 58(1), 15–30.

Koyama, Y. 1992. Marine mollusks new to Japan 3. The Nanki Seibutu, 34, 71–74. (in Japanese)

Kubota, S. 1997. Annihilation record of a blue mussel in summer of 1994 in Tanabe Bay, Wakayama Prefecture. The Nanki Seibutu, 39, 73–74. (in Japanese)

Kubota, S. 2007. Decrease of *Mytilus galloprovincialis* population and increase of *Perna viridis* population in Tanabe Bay and its adjacent waters, Wakayama Prefecture, Japan. The Nanki Seibutu, 49, 81–82. (in Japanese)

Kubota, S. 2011. Sharp decrease of *Mytilus gallovincialis* population and a marked increase of *Perna viridus* population in Tanabe Bay and its adjacent waters, Wakayama Prefecture, Japan. Bulletin of the Biogeographical Society of Japan, 66, 75–78. (in Japanese)

Kubota, S. 2018. Sharp decrease of *Mytilus gallovincialis* population and a marked increase of *Perna viridus* population in Tanabe Bay and its adjacent waters, Wakayama Prefecture, Japan (follow-up report). Bulletin of the Biogeographical Society of Japan, 72, 223–225. (in Japanese)

Landry, C., Geyer, L.B., Arakaki, Y., Uehara, T. and Palumbi, S.R. 2003. Recent speciation in the Indo-West Pacific: rapid evolution of gamete recognition and sperm morphology in cryptic species of sea urchin. Proceedings of the Royal Society of London. Series, B, 270, 1839–1847.

Lee, T. and Shin, S.A. 2012. A new record of sea urchin (Echinoidea: Camarodonta: Strongylocentrotidae) based on morphological and molecular analysis in Korea. Animal Systematics, Evolution and Diversity, 27, 213–219.

Lindenmayer, D.B. and Likens, G.E. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends in Ecology and Evolution, 24, 482–486.

Maesako, Y., Watanabe, S. and Nakano, T. 2019. Vegetation of Hatakejima Island in Tanabe Bay, Wakayama Prefecture, Japan. Bulletin of Kansai Organization for Nature Conservation, 41, 131–142. (in Japanese)

Miura, O., Sasaki, Y. and Chiba, S. 2012. Destruction of populations of *Batillaria attramentaria* (Caenogastropoda: Batillariidae) by tsunami waves of the 2011 Tohoku earthquake. Journal of Molluscan Studies, 78, 377–380.

Mooney, H.A. and Cleland, E.E. 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences of the United States of America, 98, 5446–5451.

Nakano, T., Takahashi, K., Ozawa, T. 2007. Description of an endangered species of *Lunella* (Gastropoda: Turbinidae) from the Ogasawara Islands, Japan. Venus, 66, 1–10.

Nakano, T., Kawamura, M., Satoh, T.P. 2019. First record of tropical sea urchin *Echinometra* sp. C from Honshu, Japan. Japanese Journal of Benthology, 73, 109–117. (in Japanese)

Nishikawa, T. 2018. Enteropneusts of the Nara Woman's University, collected in 1911 by Prof. Hisato KUWANO from Tanabe, Wakayama Prefecture, Japan. The Nanki Seibutu, 60, 154–159. (in Japanese)

Nishikawa, T. and Maeda, K. 1991. Report on a biota survey of the mediolittoral rocky zone in Sakushima Island, Mikawa Bay, Central Japan, in 1990. Nagoya University, Research Bulletin Series. B. Natural Sciences and Psychology, 35, 17–27.

Nishimura, S., Suzuki, K. and Utinomi, H. 1971. Common seashore animals of Japan in color. 196 pp. (in Japanese)

Nishimura, S. (ed.) 1992. Guide to seashore animals of Japan with color pictures and keys, vol. I. Hoikusha Publishing, Osaka, 425 pp. (in Japanese)

Nishimura, S. (ed.) 1995. Guide to seashore animals of Japan with color pictures and keys, vol. II. Hoikusha Publishing, Osaka, 663 pp. (in Japanese)

Nomoto, A., Watanabe, T., Tokumaru, N., Sakai, S., Ishimura, M., Koda, Y., and Wada, K. (2020). The changes in distribution of four ghost crabs (genus *Ocypode*) on the sandy shore along the Kinki District, western Japan, in 2002, 2010 and 2019. Bulletin of Kansai Organization for Nature Conservation, 42, 45–59.

Nygren, A. 2014. Cryptic polychaete diversity: A review. Zoologica Scripta, 43, 172–183.

Odendaal, L.J., Haupt, T.M. and Griffiths, C.L. 2008. The alien invasive land snail *Theba pisana* in the West Coast National Park: Is there cause for concern? Koedoe, 50, 93–98.

Ohgaki, S. 1984. Intertidal fauna and flora on the west coast of Hatakejima Island in 1969 and 1984. The Nanki Seibutu, 26, 77–85. (in Japanese)

Ohgaki, S. 1989. Long-term change in the coastal biota of Hatakejima Island. Japanese Journal of Ecology, 39, 27–36. (in Japanese)

Ohgaki, S. 1997. Population fluctuation in *Mytilus galloprovincialis* Lamarck in Tanabe Bay, with reference to the pea crab, *Pinnotheres sinensis* Shen. The Nanki Seibutu, 39, 1–8. (in Japanese)

Ohgaki, S. 2001. Distribution of intertidal macrobenthos around Hatakejima Island, 1993. Argonauta, 5, 32–47. (in Japanese)

Ohgaki, S. 2002. Distribution of intertidal macrobenthos around Hatakejima Island, 1998. Argonauta, 6, 15–31. (in Japanese)

Ohgaki, S. 2003. Distribution of intertidal macrobenthos around Hatakejima Island, 2003. Argonauta, 9, 21–34. (in Japanese)

Ohgaki, S. 2011. Long-term dynamics of coastal marine biota: a scientific natural history of Tanabe Bay. The Nanki Laboratory of Coastal Marine Ecology, Tanabe. 136 pp.

Ohgaki, S. 2012. Distribution of intertidal macrobenthos around Hatakejima Island, 2008. Argonauta, 20, 23–36. (in Japanese)

Ohgaki, S. and Tanase, H. 1984a. Intertidal animals found on Hatakejima Island, 1949-1983, part 1. The Nanki Seibutu, 26, 56–61. (in Japanese)

Ohgaki, S. and Tanase, H. 1984b. Intertidal animals found on Hatakejima Island, 1949-1983, part 2. The Nanki Seibutu, 26, 105–111. (in Japanese)

Ohgaki, S., Abe, N., Takegami, T. and Wada, K. 1985. Spacial occurrence of 91 intertidal animal species on Hatakejima Island, 1983. Publications of the Seto Marine Biological Laboratory, 30, 325–332.

Ohgaki, S., Komemoto, K. and Funayama, N. 2011. A record of the intertidal malacofauna of Cape Bansho, Wakayama, Japan, from 1985 to 2010. Publications of the Seto Marine Biological Laboratory, Special Publication Series, 11, 1–198.

Ohgaki, S., Takenouchi, K., Hashimoto, T. and Nakai, K. 1999. Year-to-year changes in the rocky-shore malacofauna of Bansho Cape, central Japan: rising temperature and increasing abundance of southern species. Benthos Research, 54, 47–58.

Ohgaki, S., Yamanishi, R., Nabeshima, Y. and Wada, K. 1997. Distribution of intertidal macrobenthos around Hatakejima Island, central Japan, in 1993, compared with 1969 and 1983-84. Benthos Research, 52, 89–102.

Ohgaki, S., Kato, T., Kobayashi, N., Tanase, H., Kumagai, N.H., Ishida, S., Nakano, T., Wada, Y. and Yusa, Y. 2019. Effects of temperature and red tides on sea urchin abundance and species richness over 45 years in southern Japan. Ecological Indicators, 96, 684–693.

Okutani, T. (ed.) 2020. Marine Mollusks in Japan. 2nd Edition. Tokai University Press, 1375 pp. (in Japanese)

O'Loughlin, P.M. and Waters, J.M. 2004. A molecular and morphological revision of genera of Asterinidae (Echinodermata: Asteroidea). Memoirs of Museum Victoria 61(1), 1–40.

Otani, M. 2006. Important vectors for marine organisms unintentionally introduced to Japanese waters. In Koike, F., Clout, M.N., Kawamichi, M., De Poorter, M., Iwatsuki, K. (eds). Assessment and Control of Biological Invasion Risks. IUCN, Gland and SHOUKADOH Book Sellers, Tokyo, pp. 92–103.

Pilsbry, H.A. 1895. Catalogue of the marine mollusks of Japan. 196 pp., 11 pls.

Rahman, S. and Uehara, T. 2004. Interspecific and intraspecific variations in sibling species of sea urchin *Echinometra*. Comparative Biochemistry and Physiology, Part A, 139, 469–478.

Robertson, G.P., Collins, S.L., Foster, D.R., Brokaw, N., Ducklow, H.W., Gragson, T.L., Gries, C., Hamilton, S.K., McGuire, A.D., Moore, J.C., Stanley, E.H., Waide, R.B. and Williams, M.W., 2012. Long-term ecological research in a human-dominated world. BioScience, 62, 342–353.

Sasaki, T. 2000. The family Trochidae. In Okutani, T. (ed.) Marine Mollusks in Japan. Tokai University Press, pp. 54–101. (in Japanese)

Salazar-Vallejo, S.I., Carrera-Parra, L.F. and León-González, J.A. De 2011. Giant eunicid polychaetes (Annelida) in shallow tropical and temperate seas. Revista de biological tropical, 59, 1463–1474.

Schulze, A. 2011. The Bobbit worm dilemma: a case for DNA. Revista de biological tropical, 59, 1475–1477.

Seike, K., Shirai, K. and Kogure, Y. 2013. Disturbance of shallow marine soft-bottom environments and megabenthos assemblages by a huge tsunami induced by the 2011 M9.0 Tohoku-Oki Earthquake. PLoS ONE, 8.

Senawong, C. 1972. Biological studies of a littoral mussel, *Hormomya mutabilis* (Gould). III. Distribution of *Hormomya* and *Modiolus* on Hatakejima Island. Publications of the Seto Marine Biological Laboratory, 19, 269–291.

Seto Marine Biological Laboratory 1969. Hatakejima Experimental Field. Seto Marine Biological Laboratory, Shirahama. 12 pp. (in Japanese)

Simon, C.A., van Niekerk, H.H., Burghardt, I., ten Hove, H.A. and Kupriyanova, E.K. 2019. Not out of Africa: *Spirobranchus kraussii* (Baird, 1865) is not a global fouling and invasive serpulid of Indo-Pacific origin. Aquatic Invasions, 14, 221–249.

Southward, A.J. 1995a. The importance of long time-series in understanding the variability of natural systems. Helgoländer Meeresunters, 49, 329–333.

Southward, A.J. 1995b. Seventy year's observations of changes in distribution and abundance of zooplankton and intertidal organisms in the western English Channel in relation to rising sea temperature. Journal of Thermal Biology, 20, 127–155.

Southward, A.J. and Crisp, D.J. 1954. Recent changes in the distributions of the intertidal barnacles *Chthamalus stellatus* Poli and *Balanus balanoides* L. in the British Isles. Journal of Animal Ecology, 23, 163–177.

Takeda, M., Marumura, M. 1994. Rare crabs from the west coast of the Kii Peninsula, central Japan. The Nanki Seibutu, 36, 26–30. (in Japanese)

Tamaki, A. 1994. Extinction of the trochid gastropod, *Umbonium* (*Suchium*) *moniliferum* (Lamarck), and associated species on an intertidal sandflat. Research on Population Ecology, 36, 225–236.

Tanaka, K., Kohtsuka, H. and Oosaku, K. 2019. The handbook of sea urchins. BunichiSogo Publishing, 128 pp.

Tanase, 1986. Two species of the genus *Arothron* collected at Shirahama. The Nanki Seibutu, 28, 124. (in Japanese)

The Japan Meteorological Agency. 2020. https://www.jma.go.jp/jma/indexe.html

The Sessile Organisms Society of Japan (ed.) 2017. Research tips for sessile organisms, new edition –Species identification on major sessile organisms–. Kouseisha Kouseikaku, Tokyo, 278 pp. (in Japanese)

Tokioka, T. 1963. Supposed effects of the cold weather of the winter 1962–63 upon the intertidal fauna in the vicinity of Seto. Publication of the Seto Marine Biological Laboratory, 11: 415–424.

Tokioka, T. 1969. Hatakejima Island will successfully be conserved for marine biological researches. Publications of the Seto Marine Biological Laboratory, 17, 1–6.

Tokioka, T. 1982. Fauna in Shirahama coastal area. Shirahamachoshi, 3, 169–205. (in Japanese)

Tsuchiya, K. 2017. Family Muricidae. In Okutani, T. (ed.) Marine Mollusks in Japan. 2nd Edition. Tokai University Press, Kanagawa, 282-310, 946–972.

Uchida, H. 1992. Hexacorallia. In: Nishimura, S. (ed.), Guide to Seashore Animals of Japan with Color Pictures and Keys, vol. I. Hoikusha, Osaka, 118–147 (in Japanese).

Uchida, H. and Soyama, I. 2001. Sea anemones in Japanese waters. TBS Britannica, Tokyo, 160 pp (in Japanese)

Uehara, T. 1990. Speciation of *Echinometra mathaei*. Iden 44, 47–53. (in Japanese)

Wada, K. and Watanabe, T. 2019. Records of 4 species of the ghost crabs (genus *Ocypode*) around the coast of Tanabe Bay, Wakayama Prefecture in 2010. Wadatsumi, 1, 11–12.

Wada, K. and Yamamoto, Z. 1989. Records of the number of fecal mounds of the enteropneust *Balanoglossus carnosus* at Hatekejima Island during 1981-1988. Annual report of the Seto Marine Biological Laboratory, 3, 47–50.

Wakayama Prefecture (ed). 2019. List of alien species in Wakayama Prefecture. Wakayama Prefecture, Wakayama, 90 pp. (in Japanese)

Watanabe, T., Yodo, S., Kimura, S., Nomoto, A. and Wada, K. 2012. Distribution of four crab species of the genus *Ocypode* along the middle to southern coast of the Kinki District, Japan, in 2002 and 2010. Bulletin of Kansai Organization for Nature Conservation, 34, 27–36.

Williams, S.T., Apte, D., Ozawa, T., Kaligis, F. and Nakano, T. 2011. Speciation and dispersal along continental coastlines and island arcs in the Indo-West Pacific turbinid gastropod genus *Lunella*. Evolution, 65, 1752–1771.

World Register of Marine Species: WoRMS. 2020. http://www.marinespecies.org/

Yamaguchi, T., Prabowo, R.E., Ohshiro, Y., Shimono, T., Jones, D., Kawai, H., Otani, M., Oshiro, A., Inagawa, S., Akaya, T. and Tamura, I. 2009. The introduction to Japan of the Titan barnacle, *Megabalanus coccopoma* (Darwin, 1854) (Cirripedia: Balanomorpha) and the role of shipping in its translocation. Biofouling, 25, 325–333.

Yamaguchi, T. 2014. Geographic distribution on the introduced barnacle *Megabalanus coccopoma* (Darwin 1854) in Japan. Sessile Organisms, 31, 15–23.

Yamamoto, T and Kimura, S. 1987. New record of two species of crabs of the genus *Chlorodiella* (Xanthidae) from Mie and Wakayama Prefectures. The Nanki Seibutu, 29, 121–125. (in Japanese)

Yamanishi, R. 2018. Changes in intertidal fauna and flora of Osaka Bay revealed through long-term monitoring surveys. Bulletin of Kansai Organization for Nature Conservation, 40, 115–128. (in Japanese)

Yamazaki, D., Miura, O., Ikeda, M., Kijima, A., Tu, D.V., Sasaki, T. and Chiba, S. 2017. Genetic diversification of intertidal Gastropoda in an archipelago: the effects of islands, oceanic currents, and ecology. Marine Biology, 164, 184.

Yanagi, K. 2006. Sea anemones around the Sagami Sea with the list of Japanese species. Memoirs of the National Science Museum, Tokyo 40, 113–173. (in Japanese with English abstract).

Yoshida, Y. 1983. Methods using biological indices. In Yoshida, T. (ed.) Environmental Assessment for Coastal Fisheries, Koseisha-koseikaku Co. Ltd., Tokyo, pp. 25–46.

Yuasa, I. 1995. Alert from the change of ecosystem in Seto Inland Sea. Journal of Human Environmental Studies, 21, 73–79. (in Japanese)

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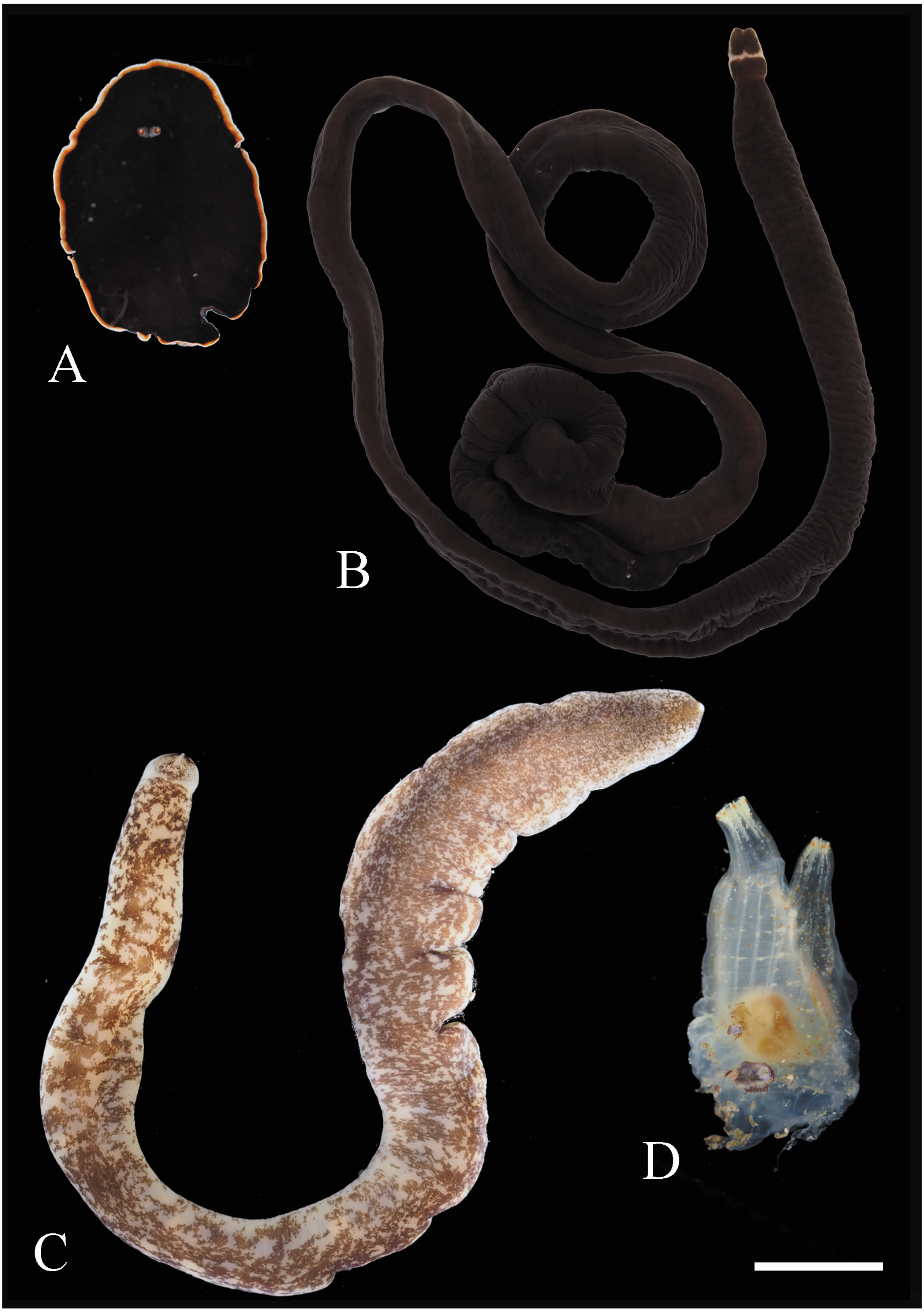

Plate 1. Representatives of platyhelminthes, nemerteans and chordate species observed in this study. Platyhelminthes: **A**, *Callioplana marginata* Stimpson, 1857. Nemertea: **B**, *Notospermus geniculatus* (Delle Chiaje, 1828); **C**, *Nipponnemertes punctatula* (Coe, 1905). Chordata: **D**, *Ciona savignyi* Herdman, 1882. Scale bar = 1 cm.

Plate 2. Representatives of molluscan species observed in this study. **A**, *Cellana toreuma* (Reeve, 1855). **B**, *Patelloida lanx* (Reeve, 1855). **C**, *Patelloida heroldi* (Dunker, 1861). **D**, *Patelloida pygmaea* (Dunker, 1860). **E**, *Lottia langfordi* (Habe, 1944). **F**, *Lottia kogamogai* Sasaki and Okutani, 1994. **G**, *Nipponacmea schrenckii* (Lischke, 1868). **H**, *Nipponacmea gloriosa* (Habe, 1944). **I**, *Monodonta confusa* Tapparone-Canefri, 1874. **J**, *Turbo stenogyrus* Fischer, 1873. **K**, *Lunella correensis* (Récluz, 1853). Scale bar = 1 cm.

Plate 3. Representatives of molluscan species observed in this study. **A**, *Chlorostoma xanthostigma* A. Adams, 1853. **B**, *Chlorostoma lischkei* (Tapparone Canefri, 1874). **C**, *Omphalius rusticus* (Gmelin, 1791). **D**, *Euplica scripta* (Lamarck, 1822). **E**, *Morula iostoma* (Reeve, 1846). **F**, *Reishia clavigera* (Küster, 1860) form P. **G**, *Reishia clavigera* (Küster, 1860) form C. **H–I**, *Reishia bronni* (Dunker, 1860). **J**, *Arca boucardi* Jousseaume, 1894. Scale bar = 1 cm.

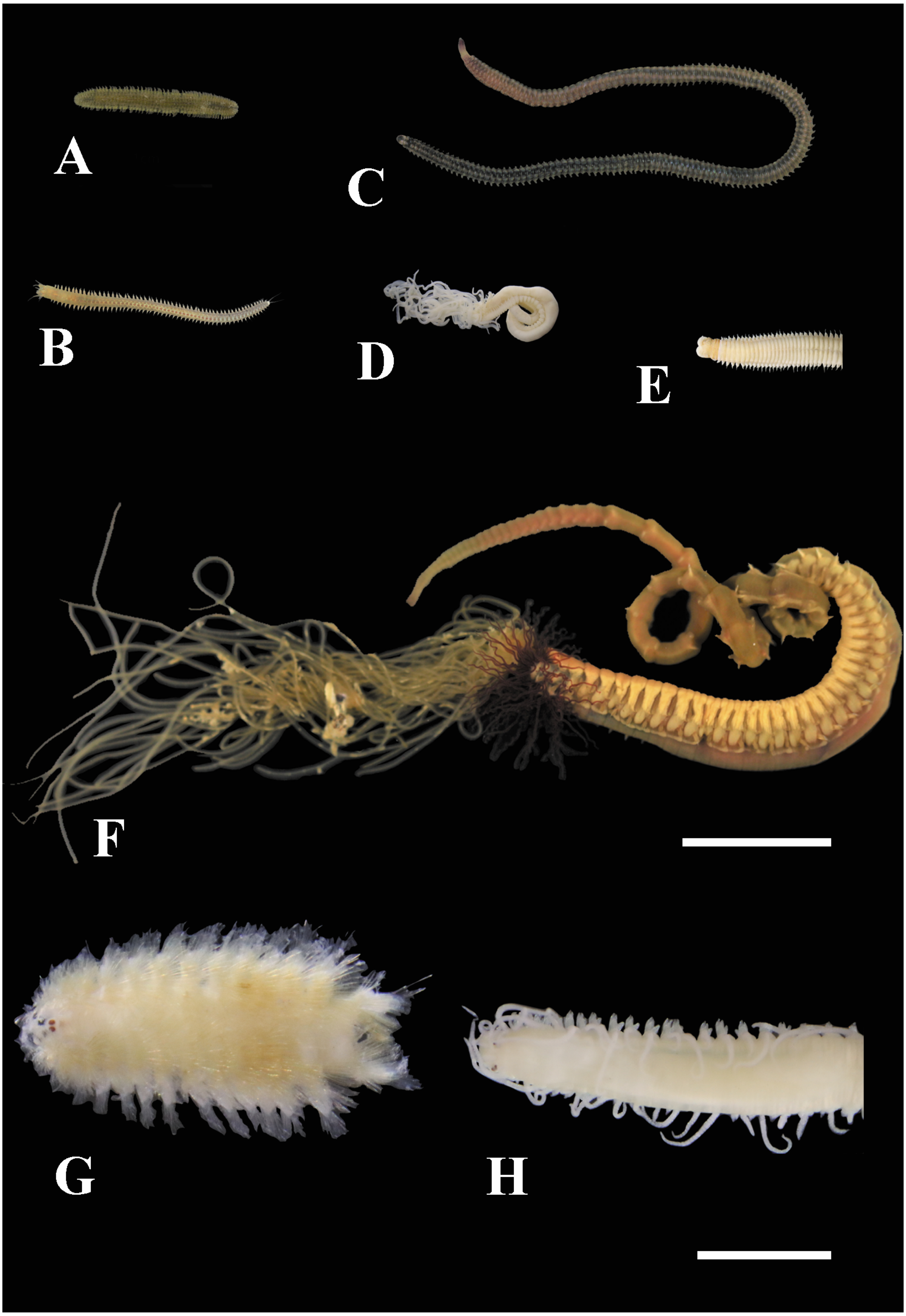

Plate 4. Representatives of annelid species observed in this study. **A**, Chrysopetalidae gen. et sp. 1. **B**, Nereididae gen. et sp. **C**, *Arabella iricolor* (Montagu, 1804). **D**, Terebellidae gen. et sp. 2. **E**, Eunicidae gen. et sp. **F**, Terebellidae gen. et sp. **G**, Chrysopetalidae gen. et sp. 2. **H**, Syllidae gen. et sp. Scale bar = 1 cm for A–F, 1 mm for G–H.

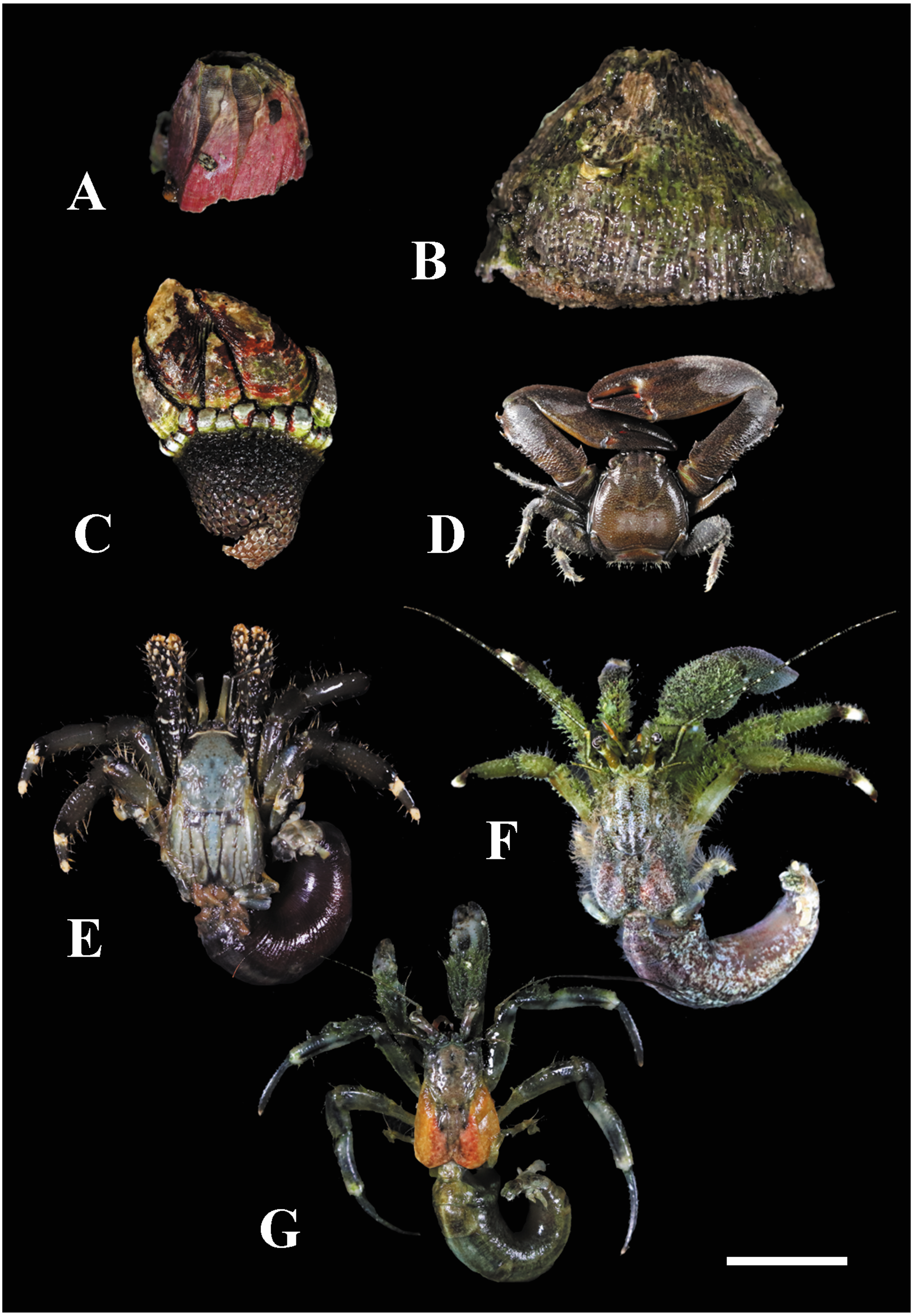

Plate 5. Representatives of arthropod species observed in this survey. **A**, *Megabalanus coccopoma* (Darwin, 1854). **B**, *Tetraclita japonica* (Pilsbry, 1916). **C**, *Capitulum mitella* (Linnaeus, 1758). **D**, *Petrolisthes japonicus* (De Haan, 1849 [in De Haan, 1833-1850]). **E**, *Clibanarius virescens* (Krauss, 1843). **F**, *Pagurus filholi* (de Man, 1887). **G**, *Pagurus minutus* Hess, 1865. Scale bar = 1 cm.

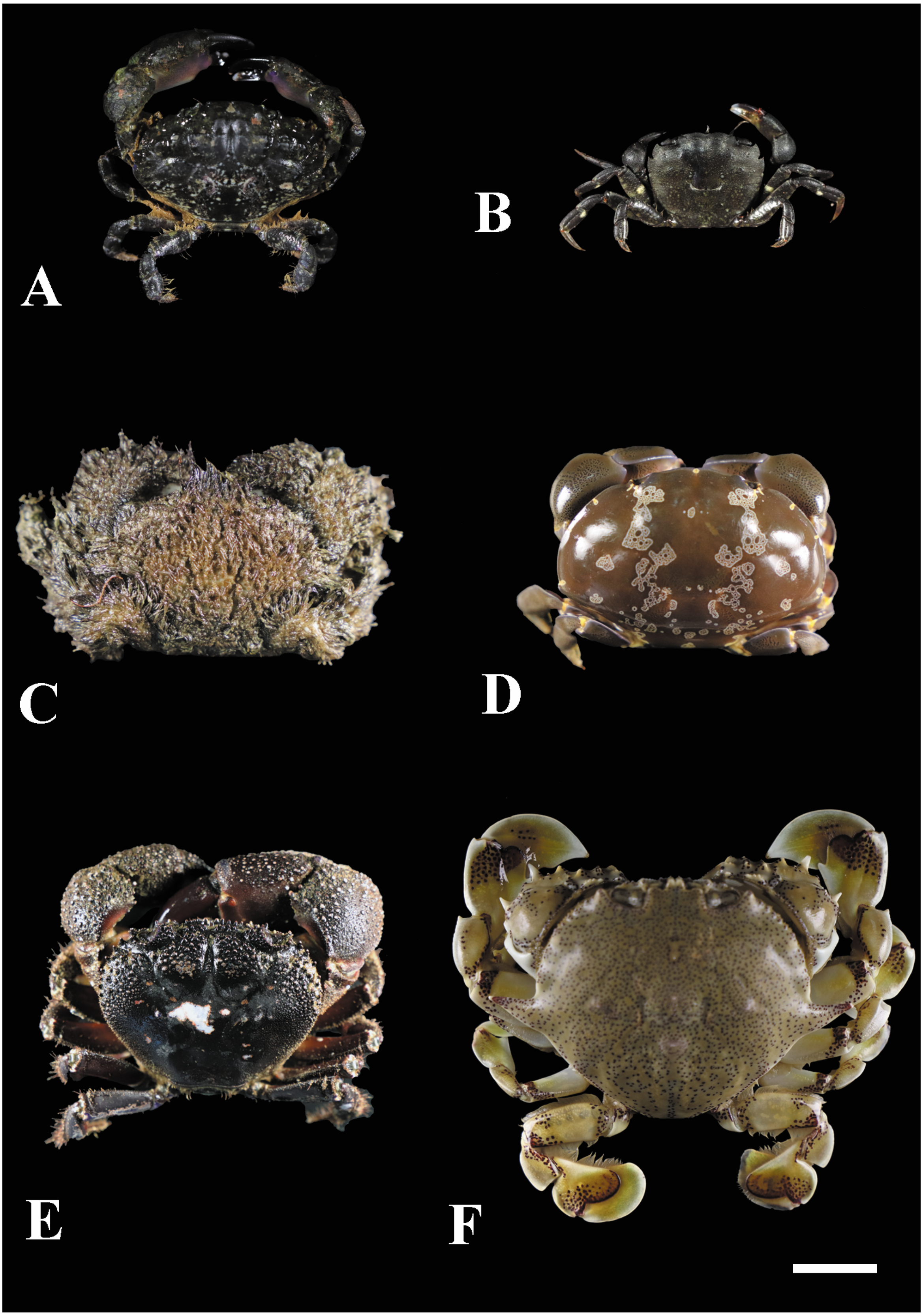

Plate 6. Representatives of arthropod species observed in this survey. **A**, *Leptodius exaratus* (H. Milne Edwards, 1834). **B**, *Gaetice depressus* (De Haan, 1833 [in De Haan, 1833-1850]). **C**, *Pilumnus vespertilio* (Fabricius, 1793). **D**, *Atergatis floridus* (Linnaeus, 1767). **E**, *Eriphia ferox* Koh and Ng, 2008. **F**, *Matuta victor* (Fabricius, 1781). Scale bar = 1 cm.

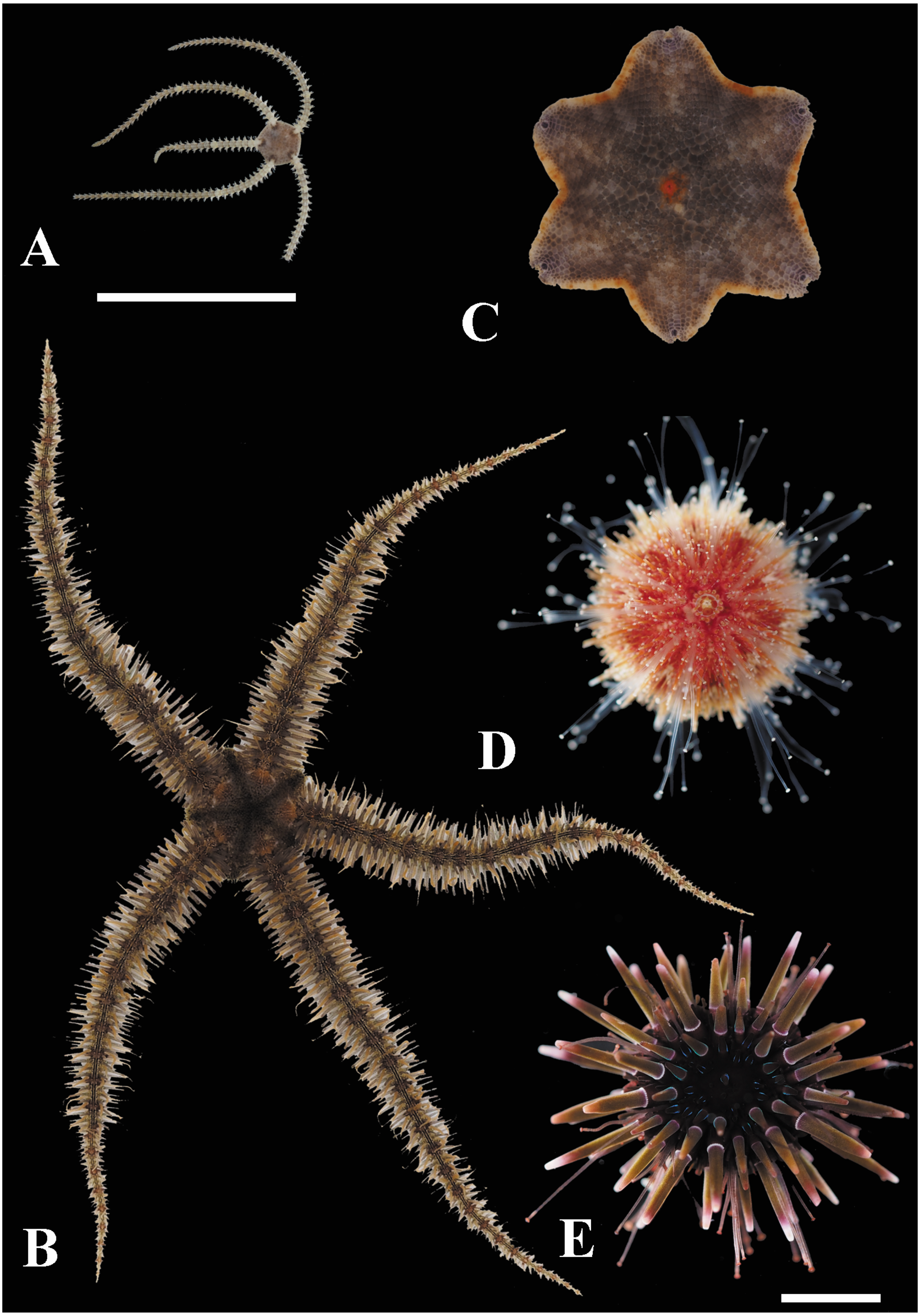

Plate 7. Representatives of echinoderm species observed in this survey. **A**, *Amphipholis squamata* (Delle Chiaje, 1828). **B**, *Ophiothrix (Ophiothrix) exigua* Lyman, 1874. **C**, Asterinidae gen. et sp. **D**, *Temnotrema sculptum* A. Agassiz, 1864. **E**, *Echinometra* sp. A. Scale bar = 1 cm.

Appendix Table 1a. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Porifera, Cnidaria, Platyhelminthes, Nemertea, and Bryozoa.

Phylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Porifera, Demospongiae, Halichondrida								
Halichondria okadai (Kadota, 1922)	Kuro-Iso-Kaimen	1	1			2	on rocks	low
Hymeniacidon sinapium de Laubenfels, 1930	Daidai-Iso-Kaimen	2	2	2		2	on rocks	low
Haliclona cinerea (Grant, 1826)	Murasaki-Kaimen	1	1	1		1	on rocks	low
Cnidaria, Anthozoa, Actiniaria								
Anthopleura inornata Stimpson, 1855	Beriru-Isoginchaku		1	1		1	in tide pools	low to middle
Anthopleura uchidai England, 1922	Yoroi-Isoginchaku		1				in tide pools	middle
Diadumene lineata (Verrill, 1869)	Tatejima-Isoginchaku	1	2	1			in tide pools	low to middle
Cnidaria, Anthozoa, Scleractinia								
Oulastrea crispata (Lamarck, 1816)	Kikumeishi-Modoki	1		2			in tide pools	low
Cnidaria, Hydrozoa, Thecata								
Dynamena crisioides Lamouroux, 1824	Chigaiumisugi		2				rock shade	low
Amphisbetia furcata (Trask, 1857)	Himeumikabi		1		(1)	2	rock shade, under boulders	low
Aglaophenia whiteleggei Bale, 1888	Shirogaya					1	in tide pools	low
Platyhelminthes, Rhabditophora, Polycladida								
Callioplana marginata Stimpson, 1857	Kario-Hiramushi					(1)	in tide pools	low
Planocera reticulata (Gray, 1860)	Tsuno-Hiramushi	(1)		(1)	(1)		under boulders	low
Nemertea, Hoplonemertea, Monostilifera								
Nipponnemertes punctatula (Coe, 1905)	Madara-Himomushi				(1)		under boulders	low
Nemertea, Pilidiophora, Heteronemertea								
Iwatanemertes piperata (Stimpson, 1855)	Ryukyu-Himomushi		(1)				on rocks, under boulders	low
Notospermus geniculatus (Delle Chiaje, 1828)	Misaki-Himomushi			(1)	(1)		under boulders	low
Bryozoa, Gymnolaemata, Cheilostomata								
Watersipora subatra (Ortmann, 1890)	Chigokemushi	3			1	1	under boulders	low

Appendix Table 1b. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Mollusca (Polyplacophora: Chitonida).

Phylum, Class, Order		Section					Habitats	Distribution in intertidal zone
Species	Japanese name	A	B	C	D	E		
Mollusca, Polyplacophora, Chitonida								
Ischnochiton comptus (Gould, 1859)	Usu-Hizaragai			1			under boulders	low
Acanthopleura loochooana (Broderip & G. B. Sowerby, 1829)	Ryukyu-hizaragai		1			2	on rocks	middle
Liolophura japonica (Lischke, 1873)	Hizaragai	1	1	2	1	1	on rocks	middle
Onithochiton hirasei Pilsbry, 1901	Nishiki-Hizaragai			(1)	1		under boulders	low
Placiphorella stimpsoni (Gould, 1859)	Babagaze					(1)	under boulders	low
Acanthochitona achates (Gould, 1859)	Himekehada-Hizaragai	1	1				on rocks	middle
Cryptoplax japonica Pilsbry, 1901	Kemushi-Hizaragai		(1)		2		on rocks	middle

Appendix Table 1c. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Mollusca (Gastropoda: Patellogastropoda).

Phylum, Class, Order / Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Mollusca, Gastropoda, Patellogastropoda								
Scutellastra flexuosa (Quoy & Gaimard, 1834)	Tsutanohagai					1	on rocks	low
Cellana toreuma (Reeve, 1854)	Yomegakasa	1	2	2	1	2	on rocks	low to middle
Cellana nigrolineata (Reeve, 1854)	Matsubagai	1	2				on rocks	middle
Cellana grata (Gould, 1859)	Bekkougasa		2			1	on rocks	high
Patelloida saccharina lanx (Reeve, 1855)	Unoashi		2	1	2	2	on rocks	middle
Patelloida heroldi (Dunker, 1861)	Himekozara	1	1	1	1	2	on rocks	middle
Patelloida pygmaea (Dunker, 1860)	Shiborigai	2					on rocks, on oyster shells	middle
Lottia langfordi (Habe, 1944)	Kikukozara	1	1			2	on rocks	low
Lottia kogamogai Sasaki & Okutani, 1994	Kogamogai		1			2	on rocks	middle
Lottia tenuisculpta Sasaki & Okutani, 1994	Komorebi-Kogamogai	2	2			2	on rocks	middle
Nipponacmea schrenckii (Lischke, 1868)	Aogai				(1)		under boulders	low
Nipponacmea gloriosa (Habe, 1944)	Sakura-Aogai					1	under boulders	low
Nipponacmea fuscoviridis (Teramachi, 1949)	Kusairo-Aogai		1				on rocks	middle to high
Nipponacmea nigrans (Kira, 1961)	Kumori-Aogai				(1)		under boulders	low

Appendix Table 1d. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Mollusca (Gastropoda: Vetigastropoda and Neritimorpha)

Phylum, Class, Order / Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Mollusca, Gastropoda, Vetigastropoda								
Trochus rota Dunker, 1860	Uzuichimonji		1	(1)			in tide pools	low
Tectus pyramis (Born, 1778)	Gintakahama					(1)	in tide pools	low
Monodonta confusa Tapparone-Canefri, 1874	Ishidatami	1	2		3		on rocks	middle to high
Monodonta perplexa Pilsbry, 1889	Kubire-Kurozuke		1				on rocks	high
Pictodiloma suavis (Philippi, 1849)	Irowake-Kurozuke		2			1	on rocks	middle
Broderipia iridescens (Broderip, 1834)	Hanazara					1	on rocks	low
Turbo stenogyrus Fischer, 1873	Koshidaka-Sazae				1		under boulders	low
Lunella correensis (Récluz, 1853)	Sugai	2		1	2		on rocks	middle
Chlorostoma lischkei (Tapparone-Canefri, 1874)	Kubogai				(1)		on rocks	low to middle
Chlorostoma xanthostigma A. Adams, 1853	Kumanokogai		(1)		2		on rocks	low to middle
Omphalius rusticus (Gmelin, 1791)	Koshidaka-Gangara	1	1	1			on rocks	low
Omphalius nigerrimus (Gmelin, 1791)	Hime-Kubogai	1	2		(1)		on rocks	low
Haliotis tuberculata Linnaeus, 1758	Tokobushi					(1)	under boulders	low
Fissurellidae gen. et sp. 1	Sukashigai sp. 1		(1)				on rocks	middle
Montfortia picta (Dunker, 1860)	Susokakegai		1		1	2	on rocks	middle
Mollusca, Gastropoda, Neritimorpha								
Nerita albicilla Linnaeus, 1758	Amaobunegai	1			2	1	on rocks	high
Plesiothyreus cytherae (Lesson, 1831)	Yukisuzume			1		1	in tide pools	low

Appendix Table 1e. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Mollusca (Gastropoda: Caenogastropoda)

Phylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Mollusca, Gastropoda, Caenogastropoda								
Clypeomorus bifasciata (G. B. Sowerby II, 1855)	Kayanomi-Kanimori	3					on rocks	middle to high
Planaxis sulcatus (Born, 1778)	Gomafunina	2					on rocks	middle to high
Peasiella habei Reid & Mak, 1998	Kobito-Urauzugai			1			on rocks	high
Echinolittorina radiata (Souleyet in Eydoux & Souleyet, 1852)	Arare-Tamakibi	2	3			2	on rocks	high
Echinolittorina cecillei (Philippi, 1851)	Ibo-Tamakibi	1					on rocks	high
Littorina brevicula (Philippi, 1844)	Tamakibi		2				on rocks	high
Savia conica (Schumacher, 1817)	Kikusuzume		(1)				on rocks	low
Thylacodes adamsii (Mörch, 1859)	Oohebigai	2	1	2	1	2	on rocks	low to middle
Gyroscala commutata (Monterosato, 1877)	Nejigai					1	in sandy beaches	low
Euplica scripta (Lamarck, 1822)	Futokorogai		1			1	on rocks	low intertidal
Mitrella bicincta (Gould, 1860)	Mugigai				(1)		on rocks	low
Semiricinula fusca (Küster, 1862)	Reishi-Damashi-Modoki	1					on rocks	middle
Drupella margariticola (Broderip, 1833)	Une-Reishi-Damashi	2	2	2	2	2	on rocks	middle
Tenguella musiva (Kiener, 1836)	Shima-Reishi-Damashi	2	2	2	2	2	on rocks	middle
Reishia bronni (Dunker, 1860)	Reishigai					(1)	on rocks	low
Reishia clavigera (Küster, 1860)	Ibonishi	1	1	1		2	on rocks	middle to high
Morula isotoma (Reeve, 1846)	Itomaki-Reishi-Damashi	(1)					on rocks	middle

Appendix Table 1f. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Mollusca (Gastropoda: Lower Heterobranchia, Nudipleura, Euopisthobranchia, and Panpulmonata)

Phylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Mollusca, Gastropoda, Lower Heterobranchia								
Hydatina physis (Linnaeus, 1758)	Misugai	1					on rocks	low
Mollusca, Gastropoda, Nudipleura								
Platydoris ellioti (Alder & Hancock, 1864)	Kumogata-Umiushi	(1)	(1)			(1)	on rocks	low
Discodoris concinna (Alder & Hancock, 1864)	Tsuzure-Umiushi	(1)					on rocks	low
Dendrodoris arborescens (Collingwood, 1881)	Kuroshitanashi-Umiushi	1					on rocks	low
Mollusca, Gastropoda, Euopisthobranchia								
Aplysia kurodai Baba, 1937	Amefurashi		1				on rocks	low
Mollusca, Gastropoda, Panpulmonata								
Siphonaria sirius Pilsbry, 1894	Kikunohanagai	1	2		2	2	on rocks	low to middle
Siphonaria japonica (Donovan, 1824)	Karamatsugai	1	1	2		2	on rocks	middle
Siphonaria acmaeoides Pilsbry, 1894	Shiro-Karamatsugai			1			in tide pools	middle
Peronia verruculata (Cuvier, 1830)	Iso-Awamochi			1			on rocks	low

Appendix Table 1g. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Mollusca (Bivalvia)

Phylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Mollusca, Bivalvia, Arcoida								
Arca boucardi Jousseaume, 1894	Koberuto-Funegai	1	1		2		under boulders	low
Barbatia foliata (Forsskål in Niebuhr, 1775)	Karigane-Egai	(1)			2		under boulders	low
Mollusca, Bivalvia, Mytiloida								
Xenostrobus atratus (Lischke, 1871)	Kuroguchi	4					on rocks	middle to high
Septifer bilocularis (Linnaeus, 1758)	Kujakugai	1	2		1		on rocks	low
Brachidontes mutabilis (Gould, 1861)	Hibarigai-Modoki	3	3	3		3	on rocks	low to middle
Modiolus nipponicus (Oyama, 1950)	Hibarigai		(1)				on rocks	middle
Mollusca, Bivalvia, Pterioida								
Pinctada imbricata Röding, 1798	Akoyagai	(1)					on rocks	low
Magallana gigas (Thunberg, 1793)	Magaki	1					on rocks	low
Magallana nippona (Seki, 1934)	Iwagaki	1					under boulders	low
Saccostrea scyphophilla (Peron & Lesueur, 1807)	Ohagurogaki	3	2	2		2	on rocks	middle to high
Saccostrea kegaki Torigoe & Inaba, 1981	Kegaki	3	1	2		2	on rocks	middle to high
Mollusca, Bivalvia, Carditoida								
Cardita leana Dunker, 1860	Tomayagai	1					under boulders	low
Mollusca, Bivalvia, Veneroida								
Chama japonica Lamarck, 1819	Kikuzaru	1	(1)	1			on rocks	middle
Pseudochama retroversa (Lischke, 1870)	Sarunokashira	1	1				in tide pools	low to middle

Appendix Table 1h. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Annelida (Terebellida, Cirratulida, and Phyllodocida)

Phylum, Order / Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Annelida, Terebellida								
Terebellidae gen. et sp. 1	Fusa-Gokai sp. 1	1					under boulders	middle
Terebellidae gen. et sp. 2	Fusa-Gokai sp. 2		(1)		1		under boulders, in a gap between rocks	middle
Loimia verrucosa Caullery, 1944	Chinchiro-Fusa-Gokai				(1)		under boulders	middle
Annelida, Cirratulida								
Acrocirrus validus Marenzeller, 1879	Kumanoashitsuki		(1)			1	in tide pools, under boulders	middle
Annelida, Phyllodocida								
Chrysopetalidae gen. et sp. 1	Tanzaku-Gokai sp. 1		(1)				under boulders	middle
Chrysopetalidae gen. et sp. 2	Tanzaku-Gokai sp. 2					(1)	under boulders	middle
Nereididae spp.	Gokai spp.		(1)	(1)			under boulders, in a gap between rocks	middle
Leocrates sp.	Otohime-Gokai sp.			(1)			under boulders	low
Eulalia viridis (Linnaeus, 1767)	Samidori-Sashiba		(1)				under boulders	middle
Phyllodoce japonica Imajima, 1967	Ito-Sashiba					(1)	under boulders	middle
Syllidae gen. et sp.	Shirisu sp.				1		in a gap between rocks	middle
Halosydna brevisetosa Kinberg, 1856	Miroku-Urokomushi					(1)	under boulders	low
Harmothoe imbricata (Linnaeus, 1767)	Madara-Urokomushi	1	1		1	(1)	under boulders	middle
Hermilepidonotus helotypus (Grube, 1877)	Sanhachi-Urokomushi				(1)		under boulders	middle
Paralepidonotus ampulliferus (Grube, 1878)	Kobutsuki-Urokomushi			(1)		1	under boulders	middle
Thormora jukesii Baird, 1865	Somewake-Urokomushi	(1)	1		(1)	(1)	under boulders	middle

Appendix Table 1i. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Annelida (Eunicida and Sabellida)

Phylum, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Annelida, Eunicida								
Eunicidae spp.	Isome spp.		(1)		(1)		in a gap between rocks	middle
Eunice aphroditois (Pallas, 1788)	Oni-Isome					(1)	in tide pools, under boulders	middle
Arabella iricolor (Montagu, 1804)	Seguro-Isome		1		(1)		under boulders, in a gap between rocks	middle
Annelida, Sabellida								
Serpulidae gen. et sp.	Kanzashi-Gokai sp.					4	attaching to boulders	middle
Spirobranchus sp. 1 (sensu Simon et al., 2019; previously identified as *Spirobranchus kraussii*)	Yakko-Kanzashi					3	attaching to boulders	middle

Appendix Table 1j. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Arthropoda (Crustacea: Maxillopoda)

Phylum, Subphylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Arthropoda, Crustacea, Maxillopoda, Pedunculata								
Capitulum mitella (Linnaeus, 1758)	Kamenote	3	3			4	on rocks	high
Arthropoda, Crustacea, Maxillopoda, Sessilia								
Chthamalus challengeri Hoek, 1883	Iwa-Fujitsubo	4	4		2	4	on rocks	high
Tetraclita japonica (Pilsbry, 1916)	Kuro-Fujitsubo	1	3			4	on rocks	low to middle
Tetraclita squamosa (Bruguière, 1789)	Minami-Kuro-Fujitsubo					2	on rocks	low to middle
Balanus trigonus Darwin, 1854	Sankaku-Fujitsubo			1	1		under boulders	low
Amphibalanus amphitrite (Darwin, 1854)	Tatejima-Fujitsubo	1					on rocks	high
Fistulobalanus albicostatus (Pilsbry, 1916)	Sirosuji-Fujitsubo	2					on rocks	high
Megabalanus volcano (Pilsbry, 1916)	Ooaka-Fujitsubo		3			3	on rocks	low
Megabalanus coccopoma (Darwin, 1854)	Kokopohma-Aka-Fujitsubo	(1)	1			2	on rocks	low

Appendix Table 1k. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Arthropoda (Crustacea: Malacostraca)

Phylum, Subphylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Arthropoda, Crustacea, Malacostraca, Decapoda								
Hemigrapsus sanguineus (De Haan, 1835 [in De Haan, 1833-1850])	Iso-Gani		(1)	1	1		under boulders	low
Pachygrapsus crassipes Randall, 1840	Iwa-Gani			1			under boulders	low
Leptodius exaratus (H. Milne Edwards, 1834)	Ougi-Gani			1	1		under boulders	low
Pilumnus vespertilio (Fabricius, 1793)	Kebuka-Gani			1	1		under boulders	low
Etisus laevimanus Randall, 1840	Hizume-Gani			1			under boulders	low
Gaetice depressus (De Haan, 1833 [in De Haan, 1833-1850])	Hiraiso-Gani			1	1		under boulders	low
Parasesarma pictum (De Haan, 1835 [in De Haan, 1833-1850])	Kakubenkei-Gani	(1)		1			under boulders	middle
Eriphia ferox Koh & Ng, 2008	Iboiwaougi-Gani			1			on rocks	low
Atergatis floridus (Linnaeus, 1767)	Subesubemanju-Gani	(1)					on rocks	low
Matuta victor (Fabricius, 1781)	Kinsen-Gani			(1)			on sandy beaches	low
Pagurus filholi (de Man, 1887)	Hon-Yadokari	2	1	2	1	1	in tide pools	low
Pagurus minutus Hess, 1865	Yubinaga-Hon-Yadokari			1	1		in tide pools	low
Clibanarius virescens (Krauss, 1843)	Iso-Yokobasami			2	2	1	in tide pools	low
Petrolisthes japonicus (De Haan, 1849 [in De Haan, 1833-1850])	Iso-Kanidamashi		1	1	2		under boulders	low
Palaemon pacificus (Stimpson, 1860)	Isosuji-Ebi	2					in tide pools	low
Upogebia issaeffi (Balss, 1913)	Barusu-Anajako			1			under boulders	low
Alpheus sp.	Teppou-Ebi sp.			(1)			under boulders	low
Arthopoda, Crustacea, Malacostraca, Isopoda								
Ligia (*Megaligia*) *exotica* Roux, 1828	Funamushi	(1)					on rocks	high

Appendix Table 1l. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Echinodermata (Crinoidea: Comatulida; Asteroidea: Valvatida and Paxillosida; Ophiuroidea: Ophiurida)

Phylum, Class, Order Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Echinodermata, Crinoidea, Comatulida								
Anneissia japonica (Müller, 1841)	Nippon-Umishida					(1)	in tide pools	low
Echinodermata, Asteroidea, Valvatida								
Aquilonastra coronata (von Martens, 1866)	Togeitomaki-Hitode			1	1		under boulders	low
Asterinidae gen. et sp.	Itomaki-Hitode sp.				(1)		under boulders	low
Echinodermata, Asteroidea, Paxillosida								
Astropecten polyacanthus Müller & Troschel, 1842	Togemomijigai			(1)			on sandy beaches	low
Echinodermata, Ophiuroidea, Ophiurida								
Amphipholis squamata (Delle Chiaje, 1828)	Isokomochi-Kumohitode			1			under boulders	low
Macrophiothrix longipeda (Lamarck, 1816)	Udenaga-Kumohitode				(1)		under boulders	low
Ophiothrix (Ophiothrix) exigua Lyman, 1874	Nagatoge-Kumohitode			(1)			under boulders	low
Ophiactis savignyi (Müller & Troschel, 1842)	Chibi-Kumohitode					(1)	under boulders	low

Appendix Table 1m. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Echinodermata (Echinoidea: Diadematoida and Camarodonta; Holothuroidea: Aspidochirotida and Dendrochirotida)

Phylum, Class, Order / Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Echinodermata, Echinoidea, Diadematoida								
Diadema savignyi (Audouin, 1809)	Aosuji-Gangaze			(1)		(1)	in tide pools	subtidal
Diadema setosum (Leske, 1778)	Gangaze	(1)	(1)	1		(1)	in tide pools	low
Echinodermata, Echinoidea, Camarodonta								
Echinometra sp. A	Tsumajiro-Nagauni			1			under boulders	low
Echinostrephus aciculatus A. Agassiz, 1863	Tawashi-Uni		1			2	in tide pools	low
Heliocidaris crassispina (A. Agassiz, 1864)	Murasaki-Uni	1	2	1	2	2	in tide pools	low to middle
Hemicentrotus pulcherrimus (A. Agassiz, 1864)	Bafun-Uni			1	2	(1)	under boulders	low
Mespilia globulus (Linnaeus, 1758)	Koshidaka-Uni			1	(1)		under boulders	low
Pseudocentrotus depressus (A. Agassiz, 1864)	Aka-Uni				(1)	(1)	under boulders	low
Temnotrema sculptum A. Agassiz, 1864	Kodemari-Uni			(1)			under boulders	low
Echinodermata, Holothuroidea, Aspidochirotida								
Holothuria (*Lessonothuria*) *pardalis* Selenka, 1867	Iso-Namako			1	1	1	under boulders	low to middle
Holothuria (*Mertensiothuria*) *leucospilota* (Brandt, 1835)	Nisekuro-Namako		(1)	1	1	1	in tide pools	low
Holothuria (*Selenkothuria*) *moebii* Ludwig, 1883	Tetsuiro-Namako				(1)	1	under boulders	low
Aspidochirotida sp.	Aspidochirotida sp.					(1)	under boulders	low
Echinodermata, Holothuroidea, Dendrochirotida								
Afrocucumis africana (Semper, 1867)	Murasaki-Gumi-Modoki				2		under boulders	low to middle
Polycheira rufescens (Brandt, 1835)	Murasaki-Kuruma-Namako			1	2		under boulders	low to middle

Appendix Table 1n. Species of intertidal macrobenthic animals found in the Hatakejima Experimental Field during the survey in 2019. Hemichordata (Enteropneusta: Enteropneusta); Chordata (Ascidiacea: Enterogona and Pleurogona)

Phylum, Class, Order / Species	Japanese name	Section A	B	C	D	E	Habitats	Distribution in intertidal zone
Hemichordata, Enteropneusta, Enteropneusta								
Balanoglossus carnosus Müller in Spengel, 1893	Wadatsumi-Giboshimushi			1			on sandy beaches	low
Chordata, Ascidiacea, Enterogona								
Ciona savignyi Herdman, 1882	Yurei-Boya			1		1	under boulders	low
Chordata, Ascidiacea, Pleurogona								
Pleurogona sp.	Maboya sp.				1		under boulders	low