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Distribution Patterns of Animals and Plants on the Rocky Shores of Hahajima in the Ogasawara Islands

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Abstract Distribution patterns of animals and plants are described at 16 stations on the rocky shores of Hahajima in the Ogasawara Islands. The splash zone is characterized by three littorinids *Nodilittorina pyramidalis, N. miliaris* and *Littorina pintado*. The zones from splash to middle intertidal are occupied mainly by the oyster *Saccostrea mordax,* the plumonate limpet *Siphonaria subatra,* the barnacle *Chthamalus challengeri,* and so on. The lower intertidal zone is characterized by the presence of vermetid shells, tube-dwelling polychaetes, sea urchins and coralline algae. Corals are attached to rocks in lower intertidal and subtidal zones at a few restricted sites.

Key words : zonation, rocky shore, splash zone, intertidal zone.

The Ogasawara (Bonin) Islands are subtropical, oceanic islands, located in the northwest Pacific (Lat. 27° N, Long. 142° E) (Fig.1). They are quite isolated, being more than 1,000 km away from the main Japanese Islands. Ogasawara consists of two major island-groups: the northern Chichijima group and the southern Hahajima group, separated by about 50 km from each other (Fig. 1), and Hahajima is the largest island in the latter group. They are ancient volcanic islands formed during the Paleogene time, as early as 40, 000,000 years ago (Yoshiwara, 1902; Umino, 1985). More than 50% of the terrestrial forms there are endemic, as are also several of the marine forms (Shigei, 1970; Hirohito, 1974; Habe *et al.,* 1978). The isolation of marine organisms has been achieved as a result of the fact that no major oceanic current flow around the islands (JODC, 1969, 1975; Kurata *et al.,* 1975; Hasunuma and Yoshida, 1978).

To date, four major marine-biological surveys have been conducted: the Toba Aquarium and Mie University (Toba Aq. and Asahi. Publ., 1970); the Ministry of Education (Shigei, 1970); officials from the Ministry of Health and Welfare and the Tokyo Metropolitan Government (Imajima, 1970); and the National Science Museum (Imajima, 1977; Habe *et al.,* 1978, etc.). These studies were, however, mainly taxonomic in scope, and very little ecological information on marine organisms is available. Thus, ecological studies would be expected to assist us in understanding biogeographical and evolutional aspects of the fauna and flora on these isolated island.

This report provides the first record of distribution patterns of animals and plants on the rocky shores of Hahajima.

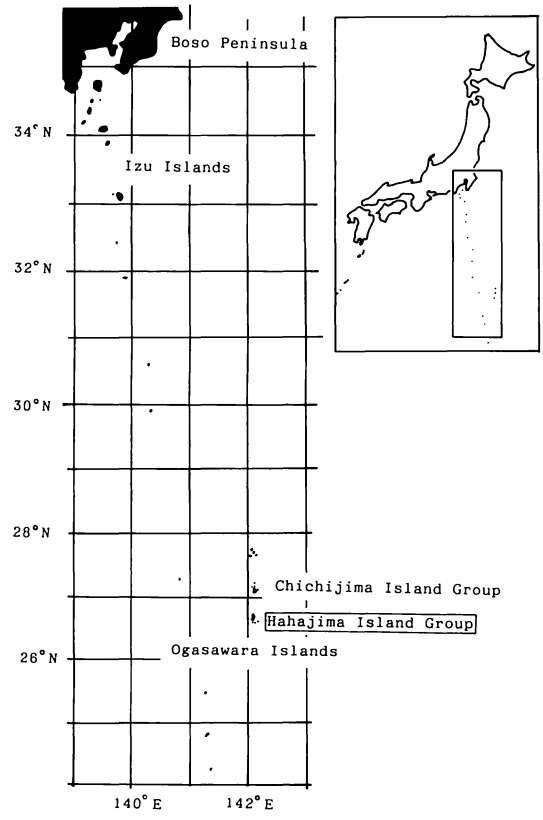

Fig. 1. Location of the Ogasawara Islands and other related islands.

Fig. 2. Typical vertical cliffs on Hahajima (Houraine-hama).

Fig. 3. A typical boulder beach on Hahajima (Nishiura).

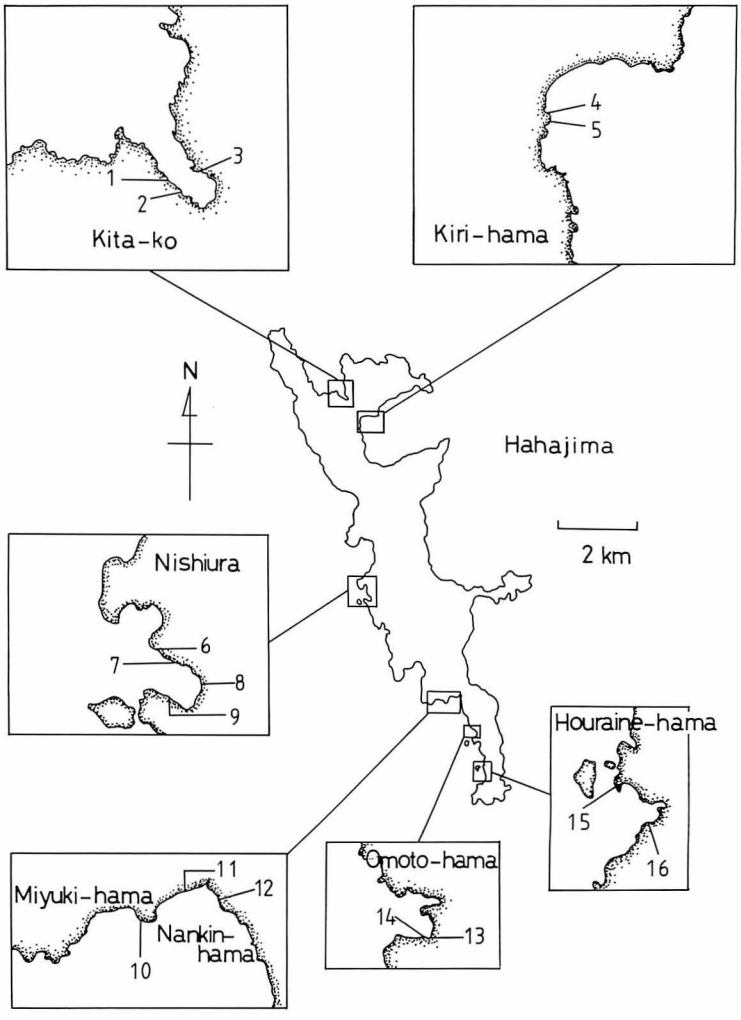

Fig. 4. Location of the study stations along the coast of Hahajima.

Study Sites and Methods

Since Hahajima is an old volcanic island, most of the shores consist of thick piles of lava and related pyroclastic rocks. As the shores have long been exposed to marine erosion, the coastal topography is dominated by precipitous cliffs (Fig. 2) with only small-scale boulder beaches found between them (Fig. 3).

For this study, 16 stations on the rocky shores were selected at 6 sites on Hahajima (Fig. 4). Observations were made at low tide of the spring tide in May, 1989. At each station, the topographical profile was traced, a quadrat (15 cm × 15 cm to 30 cm × 30 cm) was delineated at several points on a transect from the splash zone to the intertidal zone, animals in the quadrat were counted, and coverage of algae in the quadrat was measured.

Qualitative observations were also made on animals and plants at the various stations, and their characteristics were recorded. At some stations, the general features of the shallow subtidal zone were examined by diving.

The nature of substratum, such as rock types and texture of the substratum, was examined to clarify the relationship between the substratum and the distribution of animals and plants.

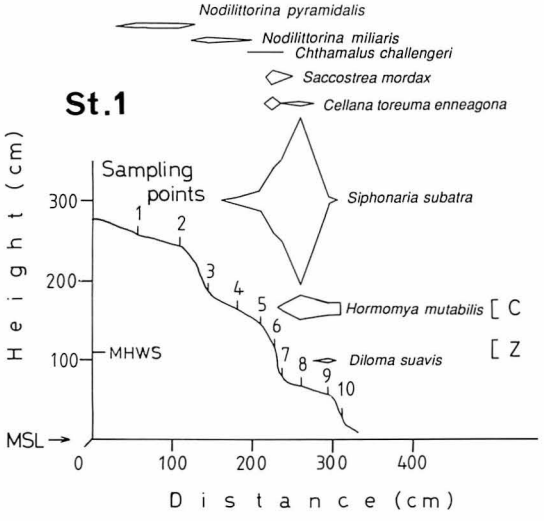

Fig. 5. Topography and distribution of animals and plants at St. 1 in Kita-ko. Each scale and abbreviation indicate: A, coverage of algae, 100%/900cm²; C, density of *Chthamalus challengeri*, 100 individuals/900cm²; and Z, the animals except for *C. challengeri*, 10 individuals/900cm². MSL: mean sea water level.

In this report, tidal level is represented by the height above the mean sea water level (abbreviated as MSL). The term "intertidal zone" is used to indicate a zone between MSL and 1.10 m above it, since the mean tidal amplitude is 1.10 m in Ogasawara. The "upper" intertidal zone is defined here as the upper one third of the intertidal zone, and the middle and lower zones are defined in the same manner.

Species diversity (excluding algae because of the difficulty in identifying and discriminating between individuals) was calculated in terms of Shannon-Weaver's function (H′) and Pielou's evenness component diversity (J′) (for calculation methods, see Kimoto, 1976);

$$H' = -\frac{n_i}{N}\log_2\frac{n_i}{N}$$

$$J' = \frac{H'}{\log_2 S}$$

where n_i is number of individuals of species i, N is the total number of individuals of all species observed, and S is the total number of species observed.

Results

1. Kita-ko (Sts. 1-3); an inlet situated near the northernmost part of Hahajima. The inner part of the inlet was formerly used as a port, but is no longer in use.

St. 1 (Fig. 5) has a steep volcanic rock wall; the littorinids *Nodilittorina pyramidalis* and *N. miliaris* (Fig. 6) are found in the splash zone, a small barnacle *Chthamalus challengeri* (Fig. 7) and a small pulmonate limpet *Siphonaria subatra* are abundant in the splash, upper, and middle intertidal zones, and colonies of a byssally-attached small mytilid *Hormomya mutabilis* (Fig.

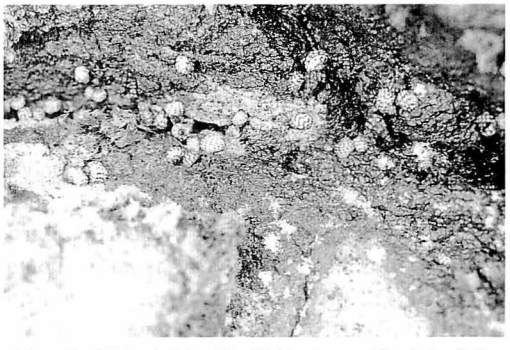

Fig. 6. Littorinids, *Nodilittorina miliaris* (×0.4).

Fig. 7. Barnacles, *Chthamalus challengeri* (×0.7).

Fig. 8. Patches of the byssally-attached bivalve, *Hormomya mutabilis* (×0.3).

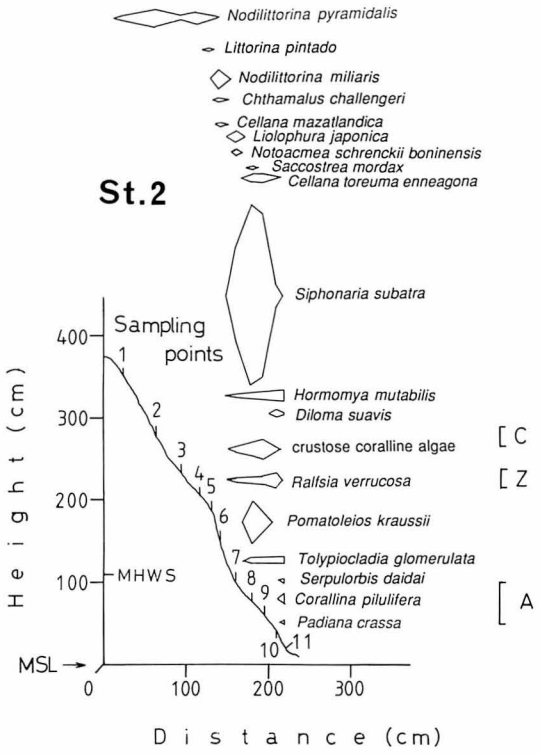

Fig. 9. Topography and distribution of animals and plants at St. 2 in Kita-ko. See the abbreviations in the explanation of Fig. 5.

8) are found in the middle and lower intertidal zones.

St. 2 (Fig. 9) has steep volcanic rock walls; *N. pyramidalis, N. miliaris,* and *Littorina pintado* are found in the splash zone, *S. subatra* is abundant in the upper intertidal zone, and patches of *H. mutabilis* are found in middle intertidal zone.

St. 3 (Fig. 10) has a rock platform, which slopes steeply in the splash zone and gently in the intertidal zone; species diversity is high (Table 1), the above-mentioned 3 species of the littorinids are found in the splash zone, cemented oysters *Saccostrea mordax* are conspicuous (Fig. 11), distributed vertically over a range of about 40 cm in the upper and middle intertidal zones, a trochid gastropod *Diloma suavis* is abundant in the tide pool at point 10, and colonies of corals are found the area below MSL.

A zonal distribution pattern is clearly observed on a wall of a pier that projects from the boulder beach (Fig. 12). A large number of *S. mordax* are firmly attached to the wall, showing a distinct zonal distribution between 60 and 90 cm above MSL. The distribution of a calcareous tube-dwelling polychaete *Pomatoleios kraussii* partly overlaps with that of *S. mordax* about 60 cm above MSL. Sand tubes of the polychaete *Idanthyrusus pennatus* occupy a narrow zone from 0 to 20 cm above MSL.

In the lower intertidal zones of the inner part of the inlet, many individuals of the cemented bivalve *Chama reflexa* are found on the rock surface at the bottom of the tide pools, and a boring polychaete *Boccardia* sp. is commonly found in the cemented left valves of *C. reflexa* near the rock surface.

In the subtidal zone of the inner inlet, the giant bivalve *Tridacna maxima* and the polychaete *Spirobranchus corniculatis* commonly found attached to corals, and on the sea bottom large foraminiferans (ca 1.0 cm in diameter) are quite common on the algae-covered surfaces of the rock wall and boulders.

2. Kiri-hama (Sts. 4 and 5); a boulder beach with rocky shores at its southern end where the

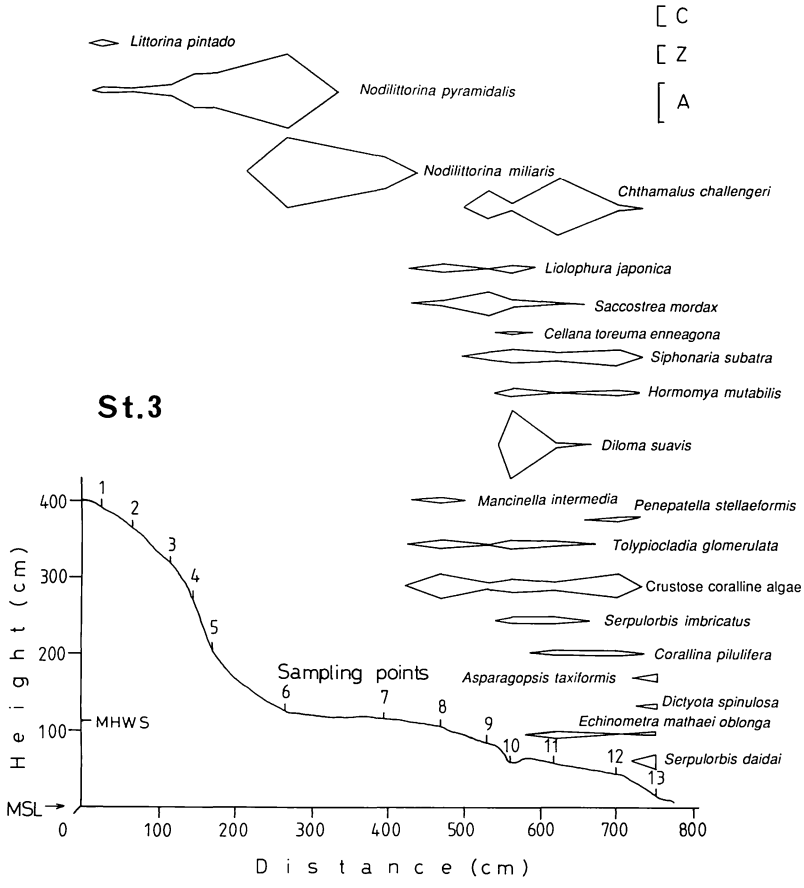

Fig. 10. Topography and distribution of animals and plants at St. 3 in Kita-ko. See the abbreviations in the explanation of Fig. 5.

Table 1. Number of animal species and diversities (H′ & J′) at each station.

Place	Kita-ko		Kiri-hama			Nishiura				Miyuki hama	Nankin-hama		Omoto-hama		Houraine-hama	
Station no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
No. animal species	8	14	14	6	7	11	12	13	9	10	5	7	11	8	8	8
H′	1.408	1.938	1.945	0.940	1.182	2.935	2.406	2.428	1.953	1.140	0.412	1.427	1.496	1.959	1.240	1.689
J′	0.469	0.509	0.511	0.364	0.421	0.848	0.671	0.656	0.611	0.343	0.177	0.508	0.432	0.653	0.414	0.653

observation points are situated. These stations are the only easily accessible sites on the east coast of Hahajima.

St. 4 (Fig. 13) has a moderately gentle slope and is highly wave-exposed; *Nodilittorina pyramidalis* extends to a level 520 cm above MSL, *Siphonaria subatra* reaches more than 190 cm above MSL, animals are scarce around pt. 9, the upper intertidal zones are inhabited by *Chthamalus challengeri,* and the lower intertidal zone is inhabited by several species of algae.

St. 5 (Fig. 14) has some terraces; the littorinids are distributed as far as 350 cm above MSL, and *C. challengeri* and *S. subatra* are abundant in the splash zone and the intertidal zone.

3. Nishiura (Sts. 6-9); a small cove situated near the central part of the west coast of Haha-

jima. The northern shore consists of alternating beds of andesitic lava and pyroclastic rocks, both being highly consolidated. In contrast, much less consolidated limestone, consisting of fossil fragments of foraminiferans and bivalves, is distributed on the southern shore.

St. 6 (Fig. 15) has a steep rock wall; species diversity is the highest of all sites examined (Table 1), *Nodilittorina pyramidalis* extends more than 450 cm above MSL, the number of species is low between pts. 8 and 9, a chiton *Liolophura japonica* and an oyster *Saccostrea mordax* are

Fig. 11. Oysters, *Saccostrea mordax* (×0.2).

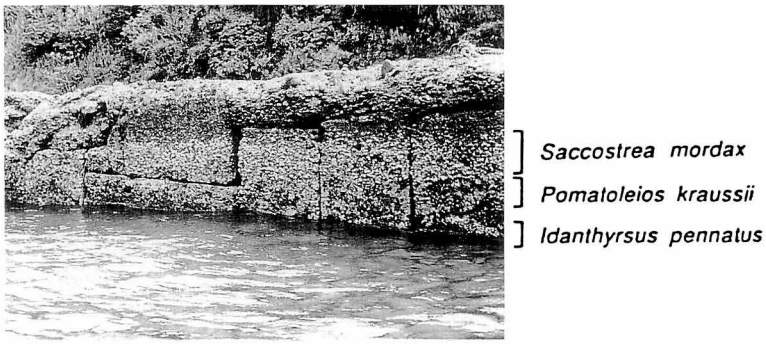

Fig. 12. Zonation pattern of organisms seen on a vertical wall of the pier in the inner part of Kita-ko.

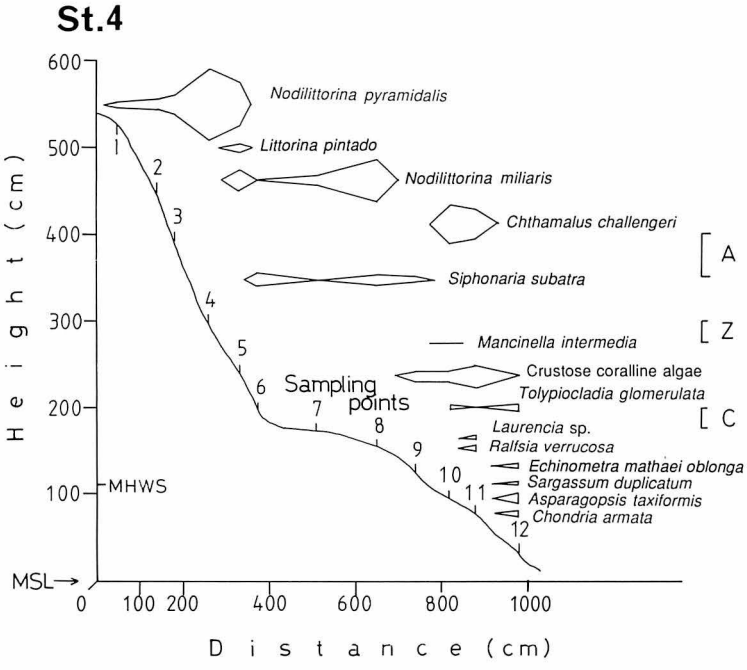

Fig. 13. Topography and distribution of animals and plants at St. 4 in Kiri-hama. See the abbreviations in the explanation of Fig. 5.

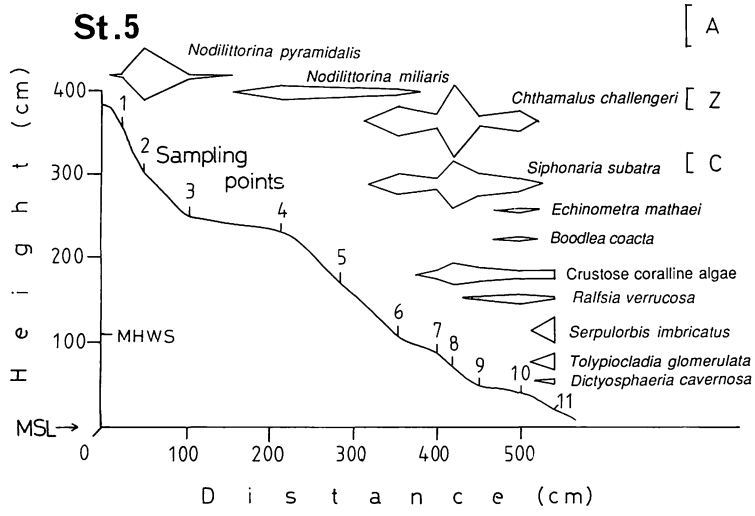

Fig. 14. Topography and distribution of animals and plants at St. 5 in Kiri-hama. See the abbreviations in the explanation of Fig. 5.

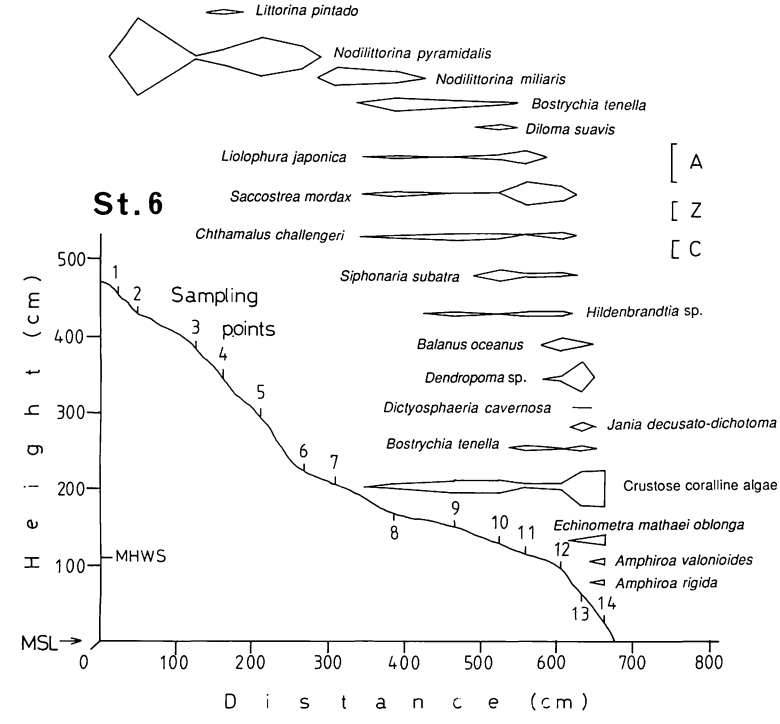

Fig. 15. Topography and distribution of animals and plants at St. 6 in Nishiura. See the abbreviations in the explanation of Fig. 5.

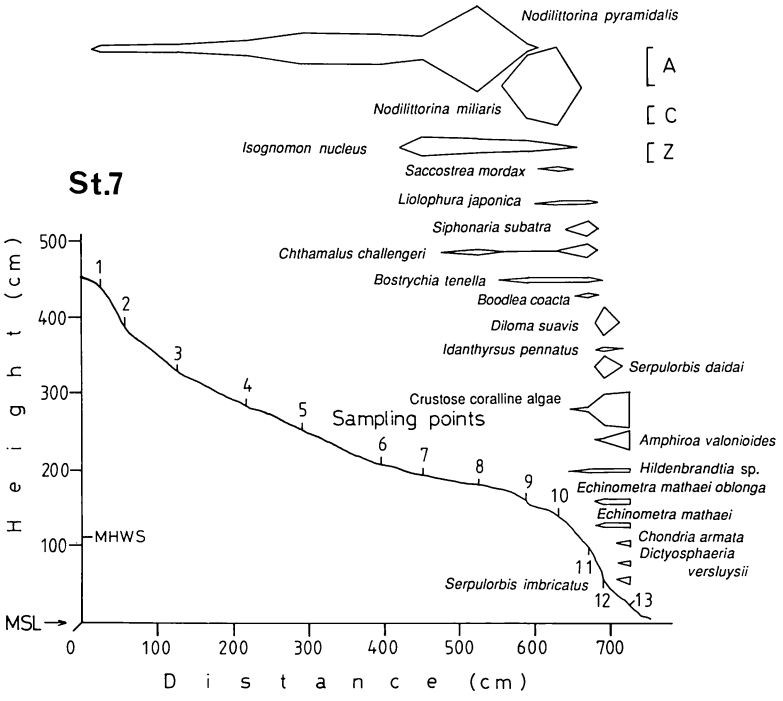

Fig. 16. Topography and distribution of animals and plants at St. 7 in Nishiura. See the abbreviations in the explanation of Fig. 5.

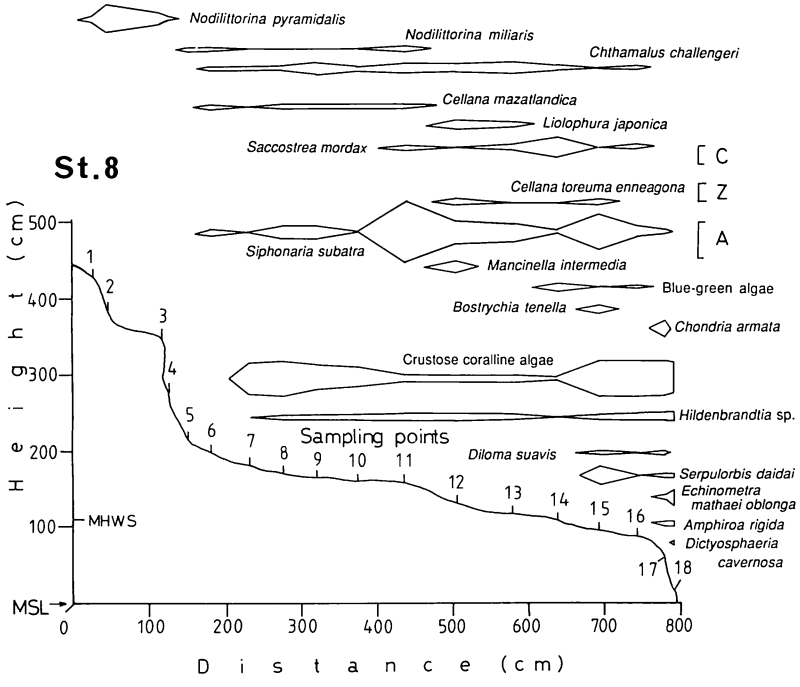

Fig. 17. Topography and distribution of animals and plants at St. 8 in Nishiura. See the abbreviations in the explanation of Fig. 5.

abundant in the splash and upper intertidal zones, and cemented shells of a vermetid *Dendropoma* sp. and a sea urchin *Echinometra mathaei oblonga* are distributed in the middle and lower intertidal zones.

St. 7 (Fig. 16) has a moderately steep rock platform; species diversity is high (Table 1), the littorinids are abundant in the splash zone, a byssally - attached small bivalve *Isognomon nucleus* is distributed in the splash and upper intertidal zones, which the large individuals (>2 cm in shell length) occur in the splash zone while the small individuals (<2 cm in shell length) are

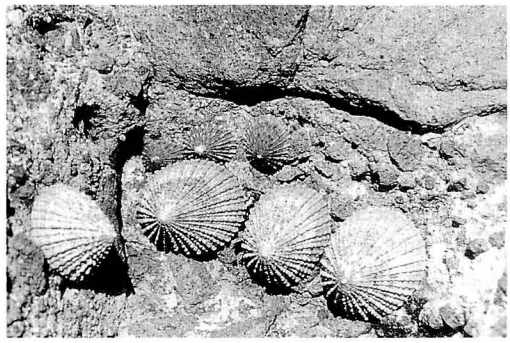

Fig. 18. Endemic giant limpets, *Cellana mazatlandica* (×0.13).

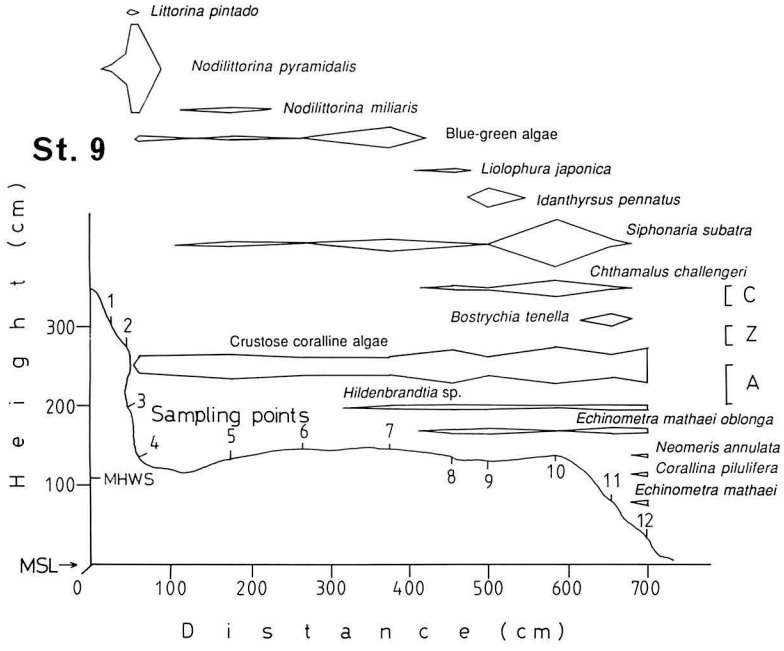

Fig. 19. Topography and distribution of animals and plants at St. 9 in Nishiura. See the abbreviations in the explanation of Fig. 5.

limited to the intertidal zone. *Diloma suavis, Serpulorbis* sp., *Echinometra mathaei,* and *E. mathaei oblonga* are found in the lower intertidal zone and in the subtidal zone.

St. 8 (Fig. 17) is situated on the wave-exposed face of a large rock, which projects from a boulder beach; *Chthamalus challengeri* is found from the splash zone to upper intertidal zone, and the endemic, giant limpet *Cellana mazatlandica* is found in the splash zone (Fig. 18).

St. 9 (Fig. 19) has a vertical wall on the landward site and a long platform with deep tide pools at pt. 9 in the splash zone; these are made up of limestone. The entire surface of the rocks below pt. 9 is deeply bored by the sea urchins *E. mathaei* and *E. mathaei oblonga,* both of which make similar deep grooves (Fig. 20).

4. Miyuki-hama (St. 10); Miyuki-hama and Nankin-hama are situated about 1 km southeast of Oki-ko, the only port in current use in Hahajima.

St. 10 (Fig. 21) has a wide platform consists of black, hard, andesitic lava. The splash zone is

represented by a nearly vertical wall of loosely consolidated limestone. The large platform of lava is apparently the result of the preferential erosion of the overlying less resistant limestone. Owing to the presence of a large platform with the small-scale relief of the lava surface, large tide pools occur at this station. *Chthamalus challengeri* and *Siphonaria subatra* are abundant, surface of the limestone rock below pt. 13 is bored by *E. mathaei,* and the subtidal zone is abundantly inhabited by sea cucumbers *Holothuria atra, H. pervicax,* and *H. moebii,* a cone shell *Virroconus ebraeus,* and the sea urchins *E. mathaei* and *E. mathaei oblonga.*

Fig. 20. Deep grooves bored by sea urchins, *Echinometra mathaei* (×0.1).

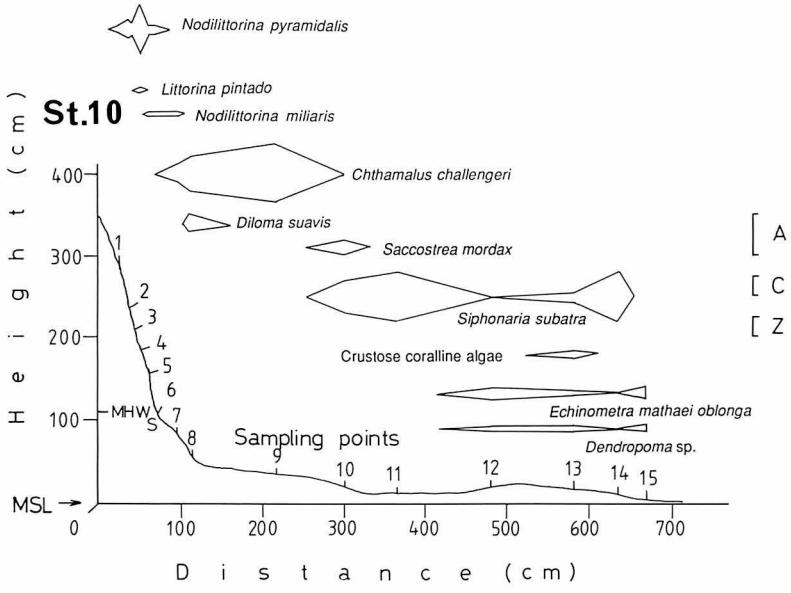

Fig. 21. Topography and distribution of animals and plants at St. 10 in Miyuki-hama. See the abbreviations in the explanation of Fig. 5.

5. Nankin-hama (Sts. 11 and 12); Miyuki-hama continues eastward to Nankin-hama, and they are separated by the projection of rocks of the *Nummulite*-bearing limestone exposure.

St. 11 (Fig. 22) has moderately steep rock walls; species diversity is low (Table 1), densities of the littorinids are distinctly low, the calcareous tubes of *Dendropoma* sp. are abundantly distributed in the areas below pt. 6, several patches of *Hormomya mutabilis* are found in the subtidal zone, where the substratum is completely covered with algae. The presence of *Dendropoma* sp. is recognized by the coiled, worm-like shells cemented to the substrata.

St. 12 (Fig. 23) has moderately steep rock walls; species diversity is low (Table 1), only one species of littorinid is found. Densities of all species at this station are low.

6. Omoto-hama (Sts. 13 and 14); a very small boulder beach with a rocky shore at both ends.

St. 13 (Fig. 24) has steep rock walls; species diversity is low, tubes of the polychaetes *Idanthyrsus pennatus* and *Pomatoleios kraussii* are distributed below the middle intertidal zone, which the cylinder-like tubes of *I. pennatus* made of

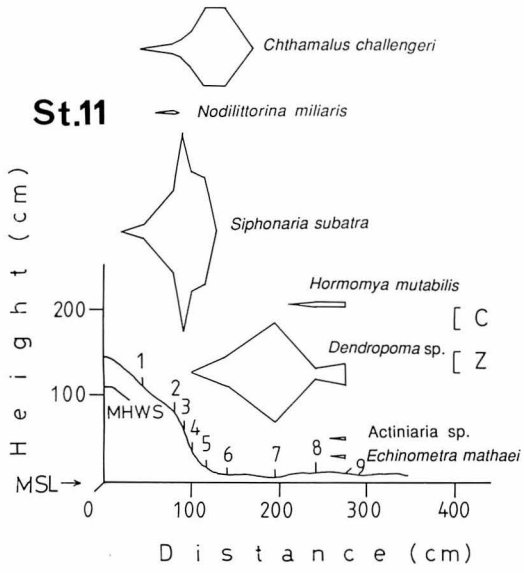

Fig. 22. Topography and distribution of animals and plants at St. 11 in Nankin-hama. See the abbreviations in the explanation of Fig. 5.

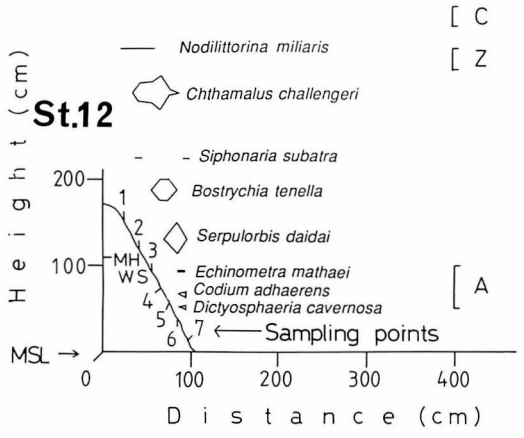

Fig. 23. Topography and distribution of animals and plants at St. 12 in Nankin-hama. See the abbreviations in the explanation of Fig.5.

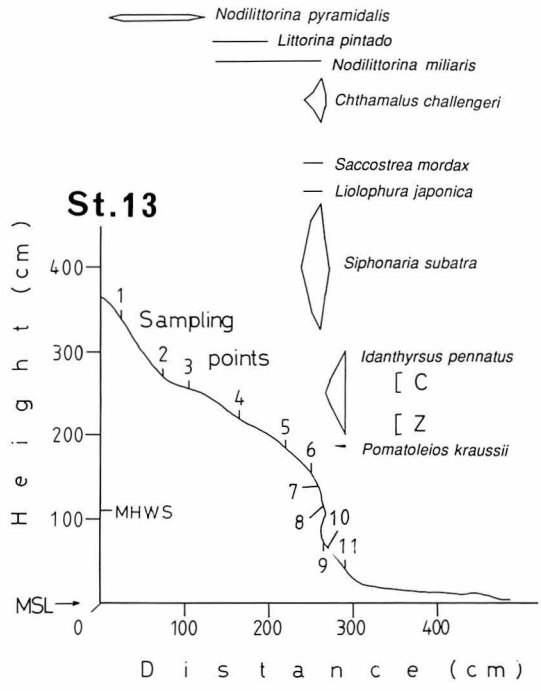

Fig. 24. Topography and distribution of animals and plants at St. 13 in Omoto-hama. See the abbreviations in the explanation of Fig. 5.

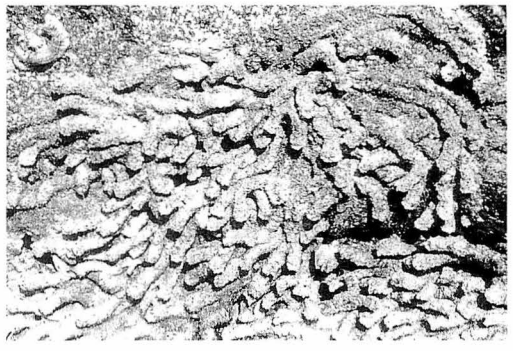

Fig. 25. Sand tubes of the polychaete, *Idanthyrusus pennatus* (×0.4).

sand grains are attached to the substrata (Fig. 25), the lower intertidal zone is covered with algae, and the subtidal zone is occupied by large colonies of *Hormomya mutabilis*.

St. 14 (Fig. 26) has a steep rock wall; species diversity is low, *S. subatra* inhabits upper and middle intertidal zones, tubes of the polychaete *Pomatoleios kraussii* are distributed in the lower intertidal zone, and patches of *H. mutabilis* are found in lower intertidal and subtidal zones.

7. Houraine-hama (Sts. 15 and 16); a small inlet with a rocky shore on each side, situated near the southern end of Hahajima.

St. 15 (Fig. 27) is highly exposed. The long platform is characterized by colonies of *Saccostrea mordax* and *Chthamalus challengeri* and, in lower intertidal and subtidal zones, *Echinometra mathaei* and *E. mathaei oblonga* are abundant, making numerous deep grooves on the rock surface. Many patches of corals are seen in the

subtidal zone.

St. 16 (Fig. 28) is situated at the inner part of the inlet and the species diversity there is low (Table 1). *Nodilittorina pyramidalis* is found in the splash zone, *C. challengeri* and *S. mordax* are distributed in the splash and upper intertidal zones, and *E. mathaei* inhabits the lower intertidal zone at low density.

Discussion

1. General characteristics of zonation

No major differences in zonal distribution patterns were found between the stations because of the relatively monotonous nature of the coastal topography. Some minor differences were, however, recognized probably due to differences in the nature of substratum, the degree of exposure to waves, and coastal topography, although these differences were not examined quantitatively in this study.

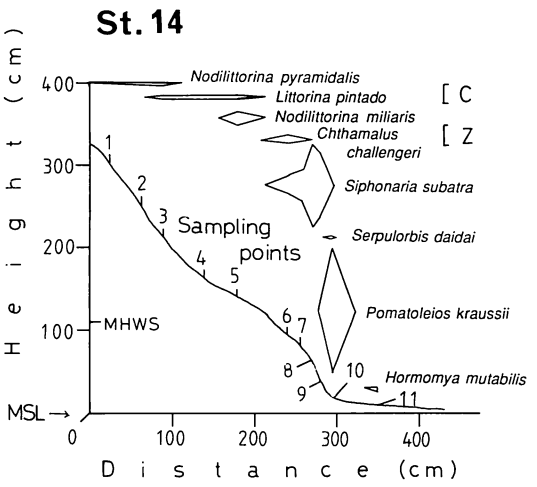

Fig. 26. Topography and distribution of animals and plants at St. 14 in Omoto-hama. See the abbreviations in the explanation of Fig. 5.

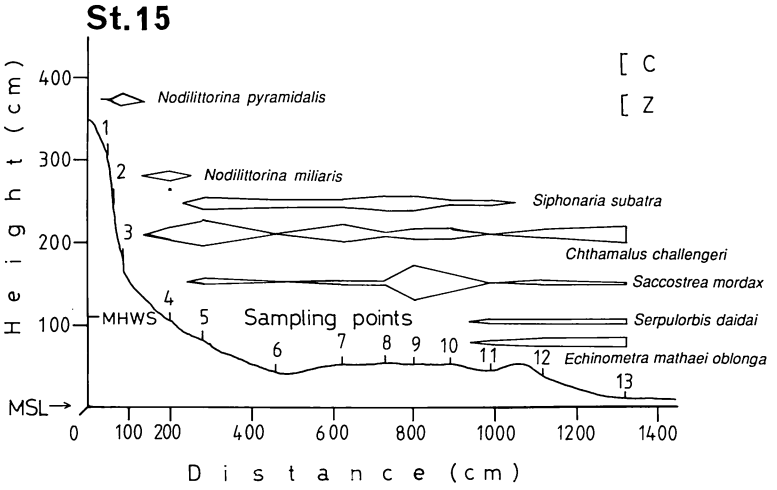

Fig. 27. Topography and distribution of animals and plants at St. 15 in Houraine-hama. See the abbreviations in the explanation of Fig. 5.

The basic pattern of zonal distribution of fauna and flora on the rocky shores of Hahajima can be summarized as follows.

The splash zone is characterized by three littorinids, *Nodilittorina miliaris* (at all stations except St.19), *N. pyramidalis* (Sts. 9-10 and 13-16), and *Littorina pintado* (Sts. 2-4, 6, 9, 10, 13, and 14). *N. pyramidalis* dominates in the splash zone, and it also shows highest vertical distribution, extending as much as 520 cm above MSL. The distribution of *N. miliaris* did not extend beyond that of *N. pyramidalis,* and its density is much lower than that of *N. pyramidalis. L. pintado* occupies, in most cases, a lower vertical position than the above two species, but upper extend of its distribution sometimes overlaps with the lower extend of that of *N. pyramidalis.* The boundary between the splash zone and the upper intertidal zone is well-defined at most of the stations, in particular, at those with steep walls. However, at stations

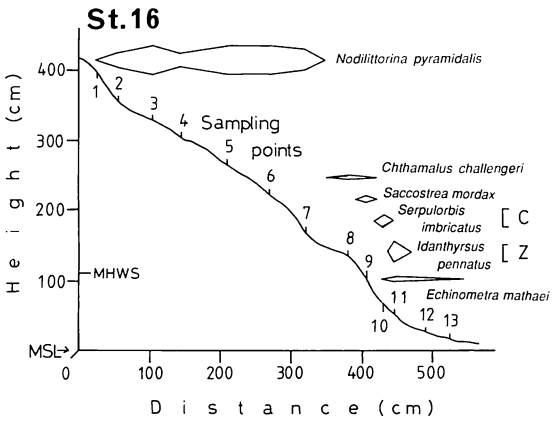

Fig. 28. Topography and distribution of animals and plants at St. 16 in Houraine-hama. See the abbreviations in the explanation of Fig. 5.

with gentler slopes, the littorinids, in particular *N. miliaris,* occur in the presence of some species typical of the splash or upper intertidal zone.

Zones from the lower splash to the middle intertidal are characterized by a pulmonate limpet *Siphonaria subatra* (all stations except for St. 16), a small barnacle *Chthamalus challengeri* (all stations), and an oyster *Saccostrea mordax* (Sts. 1-3, 6-8, 10, 13, 15, and 16).

The middle and lower intertidal zones are characterized by vermetid shells *Serpulorbis daidai, S. imbricatus,* or *Dendropoma* sp. (Sts. 2, 3, 5-8, 10, 12, and 14-16), sea urchins *Echinometra mathaei* and *E. mathaei oblonga* (Sts. 3, 4, 5-9, 10-12, 15, and 16), coralline algae (all stations), and sometimes tube-dwelling polychaetes *Pomatoleios krausii,* and *Idanthyrsus pennatus* (Sts. 2, 7, 13, 14, and 16) and patches of *H. mutabilis* (Sts. 1, 2, 3, and 14).

2. Substratum control on distributions of rocky shore organisms

Most of shores of Hahajima consist of volcanic substrata. We found limestone in only restricted areas: on the southern shore of Nishiura, Miyuki-hama and Houraine-hama. The limestone, which is much less resistant to marine erosion than lava, provides distinctive habitats for some forms of marine life.

At the southern shore in Nishiura (St. 9), the limestone surface of the lower intertidal zone is extensively covered with very deep grooves and is inhabited by many sea urchins. Sea urchins are also common on the volcanic substrata at most of the stations (ex. Sts. 1, 2, 3, etc.). They use small crevices on the surface of the volcanic rocks as diurnal retreat, because they cannot bore easily into the lava. Thus, the general appearance of the lower intertidal zone is quite different between laval substrata and limestone substrata.

Another example of substratum control is infrequent occurrence of littorinids at St. 11 and 12 in Nankin-hama. The splash zone of these stations consists of loosely consolidated sandy limestone. Such grainy surface are considered to be incapable of holding algae, on which the littorinids feed, and they are unsuitable for animals to attach.

3. Comparison of the features of zonation to those in other Japanese localities

The features of the zonation of organisms in Hahajima are more like those on shores in temperate Japanese waters than those in the subtropical islands of Okinawa, even though Ogasawara is situated in subtropical waters.

Osako *et al.* (1982) recognized four zones of organisms on the intertidal rocky shores of Shirahama, Wakayama, i.e., *C. challengeri* zone, *Tetraclita squamosa* zone, *H. mutabilis* zone, and calcareous red algae zone, and splash zone is inhabited by a littorinid, *Nodilittorina exigua.* Similarly, Mori *et al.* (1985) reported four zones on the intertidal rocky shore of Amakusa, Kyushu, i.e., *C. challengeri* zone, *T. squamosa* zone, a low coverage zone, and calcareous red algae zone, and splash zone is inhabited by *N. exigua.*

Hahajima lacks *T. squamosa* zone but has littorinids zone, *C. challengeri* zone, calcareous algae zone, and, sometimes, *H. mutabilis* patches.

By contrast, in Okinawa, Nakasone *et al.* (1974) found several zones (referred to by them as 'belts') in the coral reefs of Sesoko Island, which were entirely different from the above-mentioned cases. For example, *Ophiocoma* zone in the middle intertidal region and *Acropora* zone in the lower intertidal region and so on. The only zone in common with those in Hahajima was the littorinid *N. pyramidalis* zone found along most part of the shores of Okinawa (Nishihira, 1974).

4. Poor assemblages in rocky shores of Hahajima

The numbers of animal species ranged from 5 to 14 in Hahajima (Table 1), while, Nishihira (1974) reported more than 30 species of animals on the rocky shores of Okinawa, and Mori *et al.* (1985) recorded 33 species of animals on the rocky shores of Amakusa.

The low number of animal species on Hahajima appear to be the result of, at least, three features of the island.

(1) Hahajima is a highly isolated place, which means the low possibility of immigration of species from other areas (MacArthur and Willson, 1967; Williamson, 1981). Lawrence and McClintock (1987) reported, similarly, the low diversities of invertebrate species (H'= 0.318-1.841) on the rocky shores of the isolated oceanic islands of Kerguelen in the South Indian Ocean.

(2) Most of the shores of Hahajima consist of volcanic substrata, unlike those of many other subtropical or tropical islands, which most of the shore lines consist of coral reefs or raised limestone. Kuwamura *et al.* (1983) reported a lack of reef-associated or reef-inhabiting fish in Ogasawara. Vermeij *et al.* (1983) reported that shores of the northern Mariana Islands, situated south of Ogasawara, were almost volcanic and lacked at least 22 gastropod species inhabiting coral reefs.

(3) The intertidal zone of Hahajima is rather narrow. The difference of tidal level at spring tide is about 1.10 m in Hahajima, but it is more than about 2 m in Okinawa and more than about 3 m in Amakusa (JMA, 1985). In addition, most of shores of Hahajima incline steeply to the sea. The horizontal extend of littoral zones was 0.75-14 m in this study, but littoral zones sometimes develop horizontally for more than 50 m in Amakusa (Mori *et al.*, 1985) and 100 m in Okinawa (Nishihira, 1974). Furthermore, volcanic rocks present a more monotonous habitat to organisms than coral reefs which have reef flats, lagoons, spur-groove systems and so on (Kuwamura *et al.*, 1983). Thus, the narrow and topographically monotonous intertidal zone may restrict many animals inhabit.

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小笠原諸島母島岩礁海岸の生物の分布パターン

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小笠原諸島母島の岩礁海岸に生息する，動植物の分布パターンを16地点で調査した．

飛沫帯は，３種類のタマキビ類，即ちイボタマキビ・オガサワラタマキビ・コウダカタマキビの分布で特徴づけられる．飛沫帯から潮間帯中部にかけては，オハグロガキ・クロカラマツガイ・イワフジツボ等が分布する．潮間帯下部は，オオヘビガイ・管棲多毛類等の付着動物，ウニ，石灰藻が分布する．サンゴは，非常に限られた地域の潮間帯下部から潮下帯に生息している．