BIOLOGICAL STUDIES OF A LITTORAL MUSSEL, *HORMOMYA MUTABILIS* (GOULD) III. DISTRIBUTIONS OF *HORMOMYA* AND *MODIOLUS* ON HATAKEZIMA ISLAND[1)]

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With 10 Text-figures

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Introduction

The Seto Marine Biological Laboratory of Kyoto University has launched a long-term project of observations, for a century if possible, on successions of littoral animals and plants on Hatakezima Island which has been conserved as an experimental field of the laboratory since the spring of 1969 (TOKIOKA, 1969). Among the most prominent sessile animals throughout the rocky shore on the island are there two kinds of mussels *Hormomya mutabilis* (GOULD) and *Modiolus agripetus*

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(IREDALE), of which the separation of habitat has been noted already in my previous paper (SENAWONG, 1971). As I have been asked for clearing their exact distributions on the island as one of the basic data for the above-mentioned project, I am going to present this report to show their ranges of distribution and exact sites, together with the details of natural environments of their respective habitats on Hatakezima Island, such as the topography, nature of the substratum, water quality, wave action, water flows, amount of silt, growth of sea weeds in some season and their enemies; all are the accumulation of my observations in these one and a half years.

Method of observations

The observations were started in the beginning of April 1970 and closed in the end of August 1971, and made mostly at low tides. A preliminary general survey was done first to find out the most populated areas where further studies are to be made on the details of natural environments. Each area was designated then into several sections according to the different occurrences of these two mussels and differences in circumstances. The results of surveys in respective sections in each area were plotted in signs in the map of the area; these maps are seemingly not only very helpgul to see the general

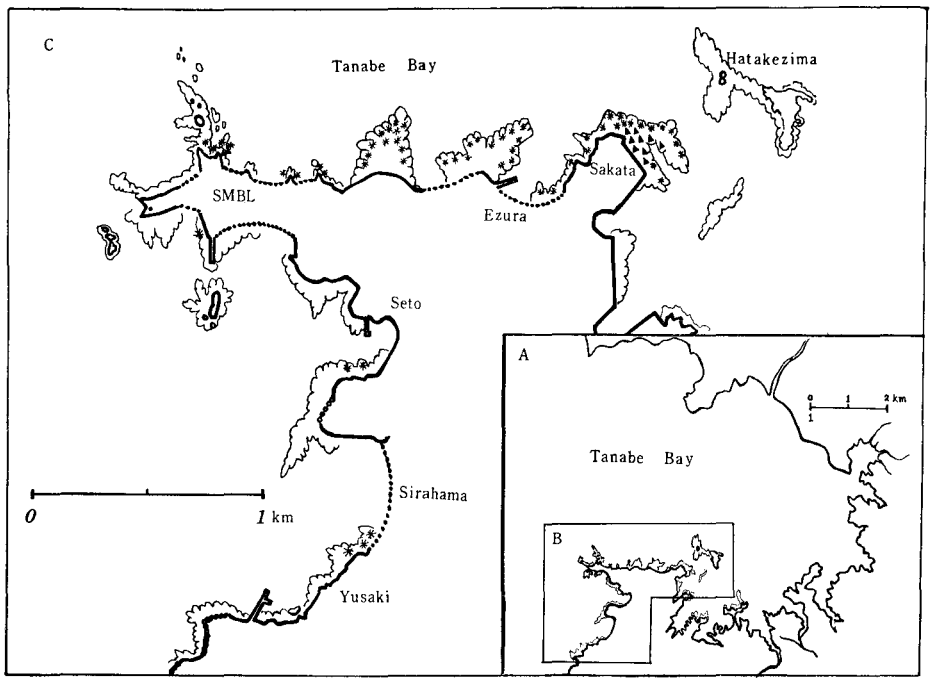

Fig. 1. Distributions of *Hormomya* and *Modiolus* in other parts of Tanabe Bay near Hatakezima Island. The inset A is to show the location of the island in Tanabe Bay, the observed area B is enlarged to C. For signs, see Fig. 2.

aspect of the distributions of the two mussels in respective areas but also facilitate much to compare the distributions among areas to obtain a general thought on the distributions of these mussels throughout the studied areas.

Other prominent sessile animals, especially other mytilids, and plants found in the intertidal zone of the island were also noted. Hitherto, I have not yet been able to learn nor think of any practical way to measure the wave strength, though by studying the occurrences of some animals and plants the comparative degree of wave action at a certain site may be roughly recognized. In the present paper such indicatory organisms were used, together with the direction of dominant wind and waves sighted actually, to show the wave strength in all sections designated. Another problem concerns the difficulty of expressing exactly the population size in respective sections. Different numbers of colonies of different sizes are distributed in different patterns in different sections, thus it seems to me practically impossible to express the population size or the density of mussels in any section. All that I was able to do were to show the rough number of *Hormomya* in some small unit areas and to give the approximate extension of mussel beds in some sections or areas, which may be seen on maps. In addition, some supplementary surveys were made in the adjacent areas of the island in Tanabe Bay, such as the shores at Ezura and Sakata, in order to see the reality of the supposed conclusive trends in the distributions of *Hormomya* and *Modiolus* on Hatakezima Island.

Results of observations

a. Distributions of *Hormomya* and *Modiolus* on Hatakezima Island.

The general survey of Hatakezima Island reveals that *Hormomya* and *Modiolus* will never live on the sand or gravel beach, but with a few exceptions. Furthermore they hardly inhabit on any very steep rocky shore as represented by the north side and northern half of the east side of the Hatakezima Island proper. Only very limited colonies of *Hormomya* and *Modiolus* are spotted along these two sides. For these reasons, the distributions of the two mussels and environmental factors of their habitats are described in detail in the four most inhabited areas designated as Area A, B, C and D respectively (fig. 2), all of which are submerged at high tide. The detailed maps of these areas in this paper (fig. 3 to 6) are intended to show roughly the habitats of the two mussels which usually range from the mid-eulittoral to sublittoral zone. Of these areas, Area A (on its west coast) and B are apparently facing the strong wave action and wind from the north-west. On the other hand, Area C and D are more or less protected from the wind and waves from the same direction. The oceonographic data at the Seto Marine Biological Laboratory (Fuse et al., 1971) shows that the wind, which is virtually effectual to raise waves or enhance the wave action, mostly blows from the north-west throughout the year, especially from November to March. As to the quality of water, Area A, B and C are washed by pure or almost oceanic water, while the

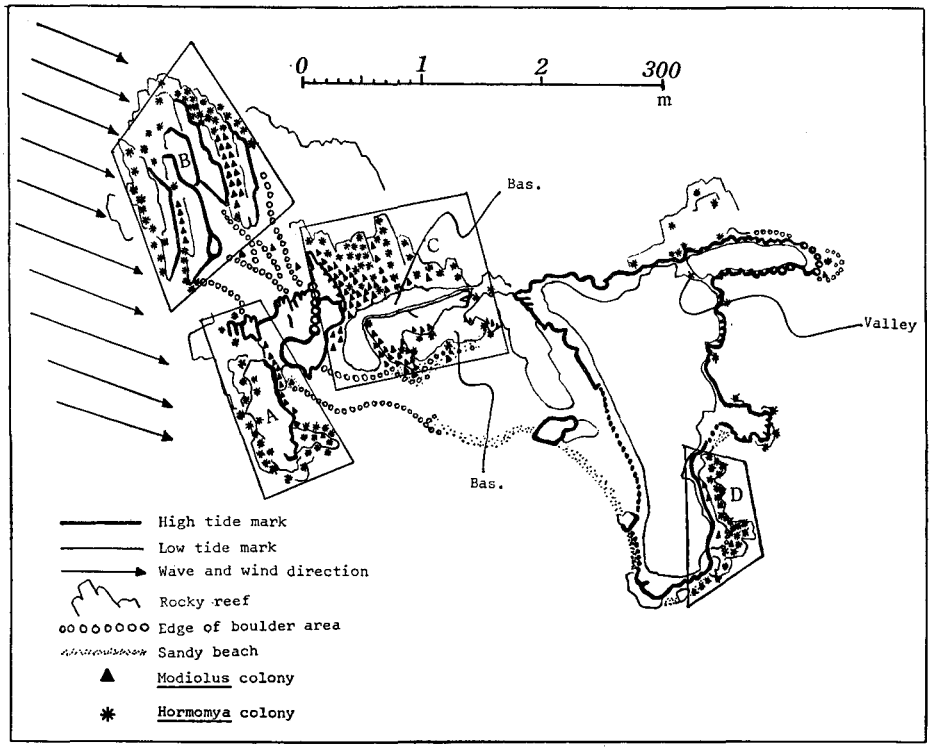

Fig. 2. Hatakezima Island, showing the four most populated areas, Bas.——Basins seen at spring low tides.

ambient water of Area D is reported as being polluted to some extent (KOBAYASHI, 1971). The rocky substratum throughout the areas consists of the tertiary sand stone (TOKIOKA, 1969), variable in the physical nature from place to place as will be described later in detail.

Area A The area is an elongate rocky reef located in the south south-west of Komaruzima Islet and the east edge of the reef, together with the gravel beach south of the islet, embraces a small cove on one side, while the lower west edge of the reef faces the strong wave action on the other side. The area is divided into 7 sections according to differences in circumstances (fig. 3).

Section 1 (Text-fig. 3 ,*1*): This section forms a low narrow reef projected out from the distal end of the main reef to the east. The substratum surface is generally flat, but with some small or big pits at much different levels. The site, particularly the north edge of the section facing a very still water of the cove at low tide, is well protected. The water of the cove will easily become turbid when it is disturbed. There is a small, about one meter in diameter, shallow pool approximately the low tide level along the north edge; it is very silty and occupied by a moderate number of *Modiolus* (fig. 7).

The rest of this section is inhabited mostly by *Hormomya* and seems better to be divided into two major levels according to different populations of this mussel.

I) The top level is occupied scatteringly by many small colonies, round or irregular in outline, the smallest colony has only about 4 cm in diameter while the biggest irregularly shaped colony may cover an area of about 900 cm^2. The mussel itself is of a smaller size, too, usually less than 2 cm in length. There are as many as 600 mussels or more in a small unit area of 20 cm × 20 cm.

II) The bottom level is occupied by many colonies of medium to big-sized mussels. Colonies are scattering and separated along the south edge of the section but tend to aggregate one another to form a wide carpet-like mass extending along the north edge of the section. There, the mussels seem to build a network of byssi holding one another firmly to secure their attachment to the substratum. It is found that underneath this carpet of mussels there is a thick layer of mud and fragments of worn shells, which probably intervene in the direct attachment of byssus to the rocky surface. There are only 242 living mussels in the same unit area of 20 cm × 20 cm, due to their big size.

Section 2 (Text-fig. 3, *2*): This section is the southernmost point of the main reef of the Area A. The substratum surface is somewhat flat but become uneven by many small pits which are partly inhabited by echinids, mainly *Anthocidaris crassispina* (A. AGASSIZ) and *Echinostrephus aciculatus* A. AGASSIZ. The wave action is not so strong here as compared with section 3 and 4 which are to be described later. The ambient water is rather clear, only with a small amount of fine sandy silt. Small-sized *Hormomya* are found in a few small colonies mostly around the east side of the section; *Modiolus* rare.

Section 3 (Text-fig. 3, *3*): The substratum surface may be explained as flat, but sloping down to the west edge from the oyster (*Saxostrea*) zone fringing the upper level of the section. The wave action is stronger than in the section 2; the ambient water is clear and without silt. Colonies of small-sized *Hormomya* are found here and there in this section a little below the oyster zone and down to the sublittoral zone. In the sublittoral zone, there are a group of boulders, on the upper surface of which are found several colonies of rather big-sized *Hormomya*. No *Modiolus* is seen here.

Section 4 (Text-fig. 3, *4*): The floor is very rough due to numerous jagged rocks covering the section. The site is exposed to the strong wave action from the north-west, and the ambient water contains no silt. Some small colonies of small-sized *Hormomya* are found in the upper part of the intertidal zone, while colonies of bigger ones are seen at some places in the sublittoral zone.

Section 5 (Text-fig. 3, *5*): This section is composed of many huge boulders standing on the exposed north-west side of the main reef of Area A. On the land side to these boulders, the low rocky floor is scattered with a number of small or medium-sized

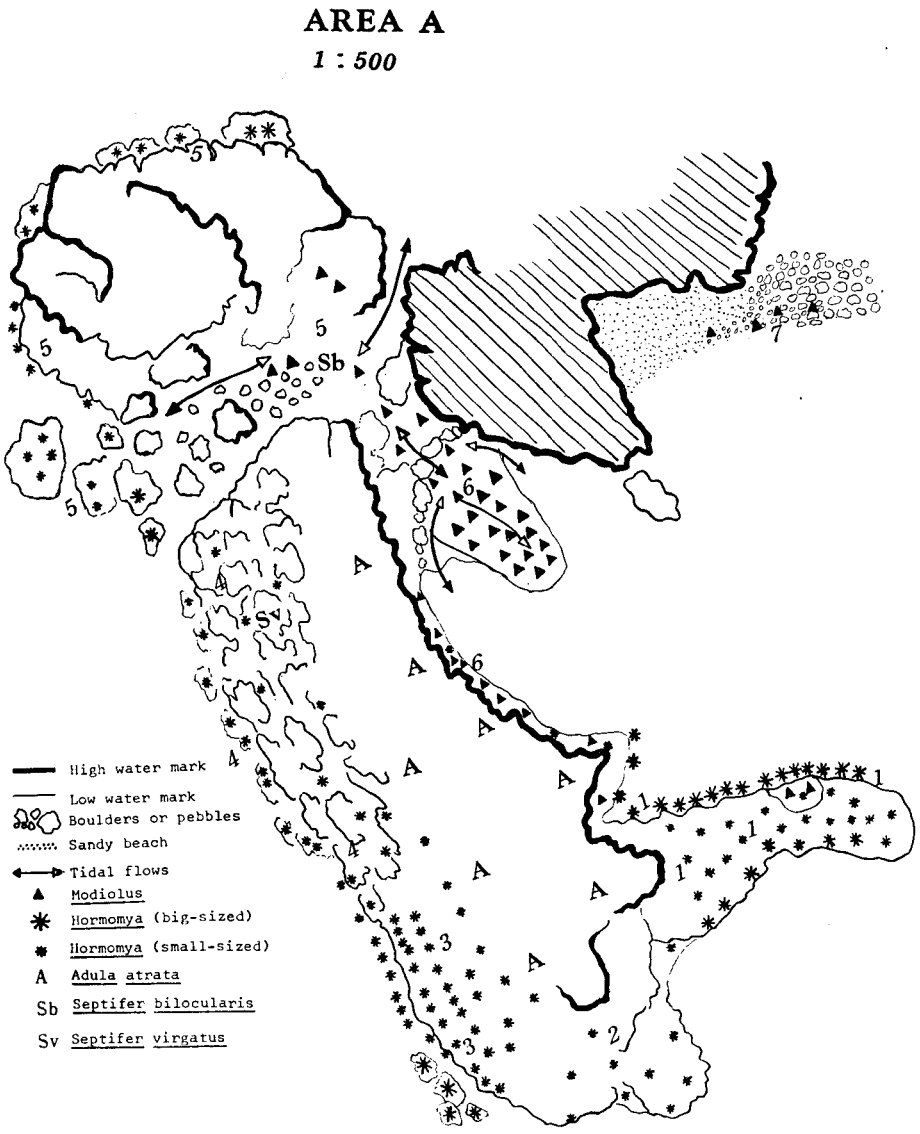

Fig. 3. Detailed map of Area A; ◀—— - direction of the water going out at ebb tide, ◁—— - direction of the water coming in at flood tide.

boulders. The wave action is very strong along the edge of the section, but reduced much in the inner part protected enough by those huge boulders scattered complicatedly. There are a few places in this sheltered part, where the silt, fine sand and dead coralline algal pieces are accumulated by sweeping waves. *Modiolus* is found in a moderate number, together with small groups of *Septifer bilocularis*, in such places. *Hormomya* is found attaching to the flat top-surface of rocks at the sublittoral level on

the sea side to those big boulders mentioned above. This mussel does not occur here in large colonies on the floor as the available substratum is very limited there by pits inhabited by sea urchins.

North to this section, the shore is covered with boulders and gravel and concaved a little to form a slight embayment partly protected from the direct wave action from the north-west by reefs of Area B. No *Hormomya* nor *Modiolus* occurs there; only a brown alga, *Padina* sp. (?), grows there abundantly upon boulders (fig. 2).

Section 6 (Text-fig. 3, *6*): This section is situated at the inner part of the still cove embraced southerly by the reef of Area A and then is the most protected part in the area. The reef edge of Area A in this section is sloping down very steeply to the cove, but forming on the way only a narrow-flat substratum in the sublittoral zone. At the innermost end of the cove, there is a rather wide flat substratum, roughly round in outline and slightly up-raised toward the east and gradually slanted down proximally toward the main reef. This ground is approximately just above the sublittoral level, covered with much silt and many worn shells, and densely inhabited by *Modiolus*; apparently this is the most populated *Modiolus* bed in Area A. *Hormomya* population which is very big along the north edge of section 1 becomes smaller and smaller towards the inner part of the cove along the narrow-flat substratum in the sublittoral zone mentioned above, while the population of *Modiolus* increases steadily towards the inner part till finally it attains the maximum at the above-mentioned *Modiolus* bed at the end of the cove.

Section 7 (Text-fig. 3, *7*): This is a small but interesting area as it is found here that *Moliolus* can survive even on such a sandy beach as this section. The section is covered with coarse sand or gravel, embedded with small to big pebbles, and will submerge under the still water of the cove mentioned above at high tide. *Modiolus* occurs here in groups of a few shells attached limitedly to big pebbles in the section (fig. 8). However, a few groups are found buried in coarse sand, attaching to bits of rocks of approximately 5 to 8 cm in diameter and embedded in sand. Such buried *Modiolus* usually has a striking character of having clean shells with long hairy conchiolin projections, while exposed *Modiolus* has less hairs and, as a rule, is covered with algae on its shell surface.

Area B This area consists of five big reefs, respectively extending in the north-south direction and arranged one another in the east-west direction in a stepped series; for conveniences' sake they are numbered respectively I to V from the west to the east. As compared with other areas, this area is subjected to the strongest wave action coming directly from the mouth of Tanabe Bay in the north-west (fig. 1, 2). However, there are some well sheltered places just behind the elevated east edges of respective reefs. These protected places are usually available by *Modiolus*, but only two of them are found most suitable for its existence, as in others the substratum level is perhaps too high for the mussel to survive. *Hormomya* in this area is small in size, never over 2 cm in

shell length through the whole time of observation, either at low or high level. The shell color is white, pinkish white or yellowish white; this may be due to the attachment of certain stony species of coralline algae which form a thin calcium film on the shell surface. The similar phenomenon also occurs in other places, particularly on the exposed shore at the sublittoral level. The Area B is devisible into 9 sections (fig. 4) as follows.

Section 1 (Text-fig. 4, *1*): The section is located at the southernmost tip of the area and at the south tip of the reef II, projected out from the reef as a small ledge at a lower level. The substratum is almost flat, partly become uneven by pits of echinids, slanting down toward the west, and occupied by echinids and colonies of *Hormomya* only.

Section 2 (Text-fig. 4, *2*): This is a somewhat well protected long but narrow place sited between the reef I and II just north to the section I. The floor is flat, smooth, and silty, especially in the middle part. It is elevated a little on the east side, slopes down to the eastern cliff of the reef I, and at the same time slants down to the south. Thus, when the tide is going out of the area, streams will flow from the east to the west across the width of the section and then down to the south along the length of the section. *Hormomya* covers here only a small part around the south extremity where the substratum is clean, semi-exposed to the wave action and merged in the sublittoral zone. From this southern extremity to the north end of the section, the higher the floor level is the fewer the number of *Hormomya* and on the contrary the more is the number of *Modiolus*. And in the middle part of the section, which is more silty than other parts, *Modiolus* covers almost all the surface of the substratum. Occurrence of *Hormomya* at higher levels in this section is limited mostly to its east edge.

Section 3 (Text-fig. 4, *3*): This is the sinking west side of the reef I. The substratum is generally flat and encrusted by dense communities of coralline algae at the sublittoral level, though it is roughened at some places by pits of sea urchins. This section is exposed most directly to the wave action and also to the wind from the north-west. *Hormomya* is distributed in many colonies along the entire length of this reef edge, but interrupted at places occupied by sea urchins or coralline algae.

Section 4 (Text-fig. 4, *4*): There are many big and medium-sized boulders in this section which is located between the northern ends of the reef I and II and continuous southerly to the section 2 protected by the east ridge of the reef I. Colonies of *Hormomya* are seen covering the top surfaces of these boulders which remain usually submerged or nearly submerged at low tide. The boulders which are exposed highly above the low tide level are covered at the top by oysters (*Saxostrea*).

Section 5 (Text-fig. 4, *5*): The section is defined at and around the north tip of the reef II. The general appearance of this section is almost the same as in section 3. There are *Hormomya* in a moderate number, scattered around, and a few *Modiolus* are behind the east ridge of the reef II near the low water mark.

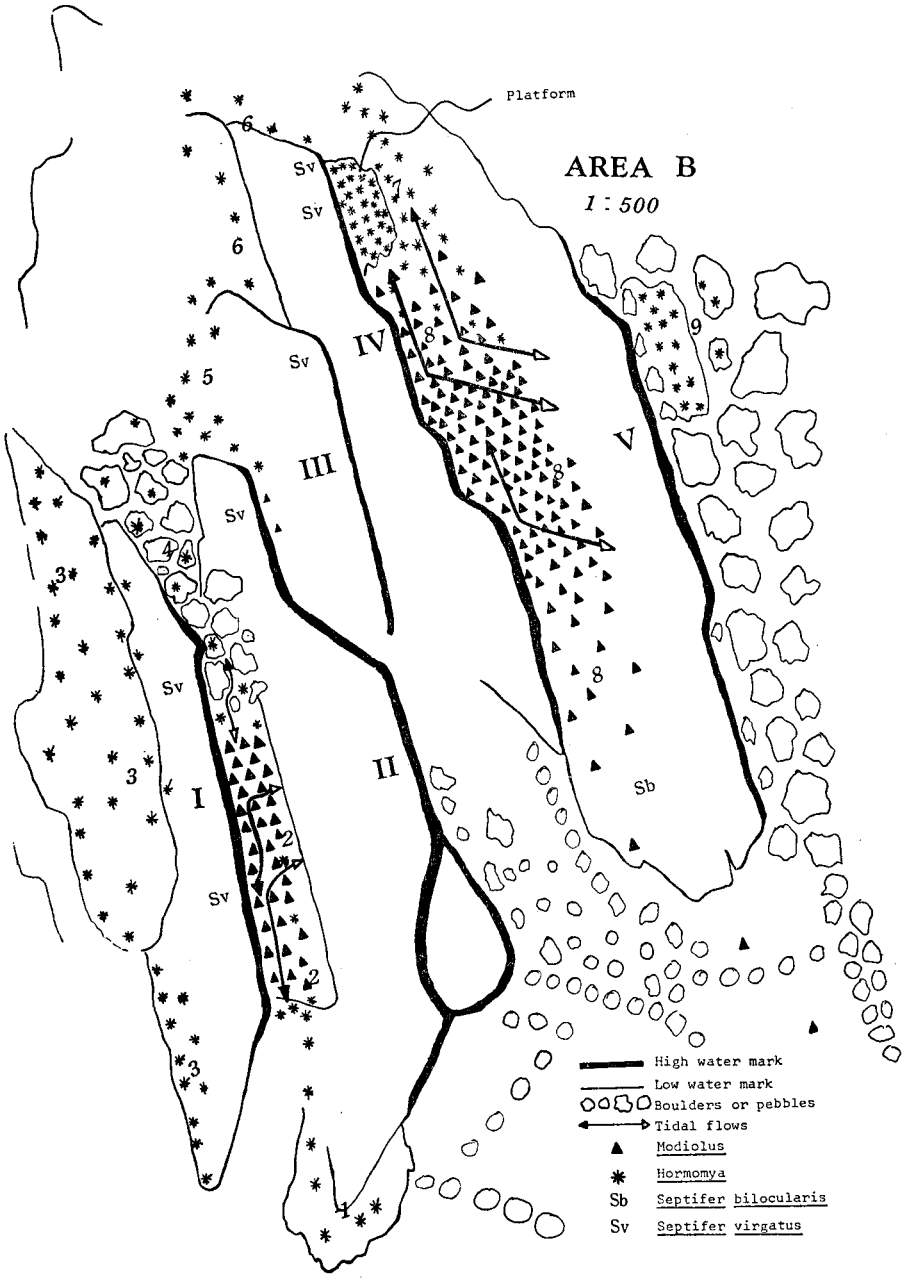

Fig. 4. Detailed map of Area B; ◀—— - direction of the water going out at ebb tide, ◁—— - direction of the water coming in at flood tide, I–V - designate reef numbers.

Section 6 (Text-fig. 4. *6*): The section is located at the north tip of the reef III and provided generally with a similar environmental appearance as in section 3 or 5. There occur, however colonies of *Hormomya* and no *Modiolus*.

Section 7 (Text-fig. 4, *7*): This section is designated to the range around the north tip of the reef V and protected by the northern part of the east edge of the reef IV. The section is remarkably settled by *Hormomya*, evidently this is the most populated section in Area B. The substratum is fairly flat and smooth and partly protected by the reef IV towards the west, though it is exposed to waves coming from the north, which are, however, virtually not so strong as those from the north-west. The most populated spot in the section is seen on a small platform projected out eastwards from the foot of the cliff bordering the northern east edge of the reef IV.

Section 8 (Text-fig. 4, *8*): This section is sited on the side of the reef V protected by the east edge of the reef IV and represents one of the most crowded *Modiolus* beds in Hatakezima Island. The circumstances are similar to those of the section 2 described previously, but differ only in that the inclination of the substratum is tilted here toward the north. Thus the section is in continuation with the section 7, and then the overlapping between *Modiolus* and *Hormomya* territories is inevitable around the border between the two sections. *Modiolus* decrease gradually as the substratum level becomes higher little by little toward the south, till lastly almost disappear in the boulder area south of the Area B. They are found gathering in crevices or clefts, southerly together with a few *Septifer bilocularis*.

Section 9 (Text-fig. 4, *9*): This is a small habitat of *Hormomya* found near the northern range east of the east ridge of the reef V and protected by it from the wave action from the north-west. The substratum consists of many huge or medium-sized boulders, exposed only at low tide. These boulders provide not a few substrata which are small but flatly surfaced and suitable for the settlement of *Hormomya*, though the individual number on them is very limited.

Area C: The Area C is a very vast area, consisting of a series of rocky reefs in the north, a big L-shaped rocky reef in the middle, and a boulder beach in the south, and is spreading wide between Komaruzima Islet and the Hatakezima Island proper. The area is heavily and extensively settled by both *Hormomya* and *Modiolus*. As its topography is very complicated it may be better described in two separate divisions, the north and south divisions (fig. 5).

The north division : The west half of this division forms roughly a horizontal substratum consisting of a series of uniformly north-southerly running platforms which are generally in or near the sublittoral zone, but slightly lowered northwards and stepped down to the east. The division is sheltered well by a high rocky ridge projected out from Komaruzima Islet northerly, by a boulder area adjacent to the ridge and by the big reefs of Area B. Being, thus, free from the wave action from the north-west, the division is affected only by rather weak wave action from the north. The silt is

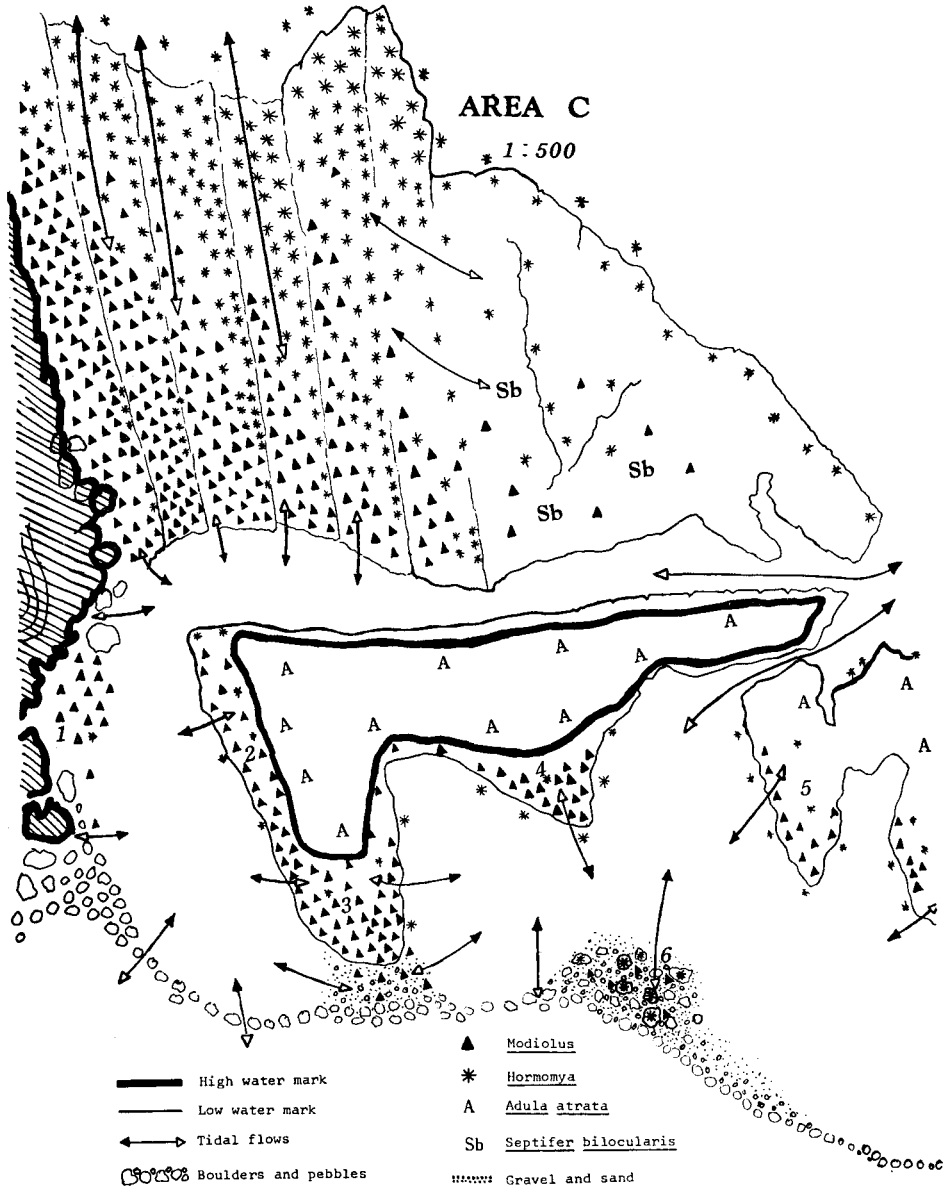

Fig. 5. Detailed map of Area C; ◀—— - direction of the water going out at ebb tide, ◁—— - direction of the water coming in at flood tide.

accumulated considerably in the raised southern part of the west half and a heavy growth of algae is seen on the lower rather exposed substratum in the north. *Modiolus* is seen most crowded on the westernmost platform next to the high rocky ridge from Komaruzima Islet, covering almost all the entire length of the platform. Its population

decreases little by little with platforms eastwards, while the *Hormomya* population increases more and more with platforms eastwards and at the same time towards the northern lower end of respective platforms. Thus, there occurs an overlapping of the two mussels around the middle of the west half, and as a rule *Hormomya* colonies are found on the raised east margin of respective platforms (fig. 9).

In the eastern half of the division, the substratum becomes uneven and is raised more highly than in the west half mentioned above. Here, populations of both mussels decrease considerably, while a moderate number of *Septifer bilocularis* are found clustering in crevices.

Hormomya in this division is generally small-sized, but in a few places at lower levels where it is considerably bigger than usual.

Further north to this north division of Area C, there is another series of flat platforms with the same appearance as the mentioned one, but it lies at deeper levels (fig. 2). These platforms are covered with a few colonies of *Hormomya*, which are found only at the shallowest site near the north division of Area C, and heavily with many kinds of algae.

The south division: This devision is separated from the north division by a deep water passage along the north edge of a big reef which looks like the letter "L" lying in the east-west direction at high tide (fig. 2, 5). The north long straight edge of this reef is very steep and the top is as high as the high water mark, so the reef will be washed at high tide only. The division is the best protected site in Hatakezima Island, no direct wave action from any directions here. At low spring tides, there appears a shallow basin between Komaruzima Islet and the foot of the L-shaped reef and another bigger one is formed between the south edge of the reef and a gravel shore extending on the opposite side across the latter basin. The possible directions of the water coming in (empty triangle) and out (solid triangle) in this division respectively at the rise and fall of the tide are shown by arrows in the detailed map of Area C (fig. 5). The division can be divided into 6 sections according to the occurrences of the mussels and different circumstances.

Section 1 (Text-fig. 5, *1*): This is a small place located near the base of Komaruzima Islet and just protected by a huge rock. The substratum is flat, but slightly convex, covered with much silt and almost wholly dominated by *Modiolus*.

Section 2 (Text-fig. 5, *2*): The section is designated to a long but narrow slope, just opposite the section 1, along the foot of the L-shaped reef. The substratum is flat, tilted to the west till it submerges into the sublittoral zone of the basin. A few colonies of small-sized *Hormomya* are found on the northernmost edge of the section, the colonies become fewer and fewer towards the south as the substratum becomes more and more silty. The section is mostly inhabited by *Modiolus*; *Hormomya* lives only sparsely and limitedly in less silty upper zone or sublittoral zone.

Section 3 (Text-fig. 5, *3*): This is the section around the southern tip of the foot of the

L-shaped reef. The substratum is roughened by many small pits in the upper part near the high tide level marked by oysters, noted as the oyster zone. The lower part is quite flat and smooth, gently sloping down to join southerly the gravel shore at a very low level. The section is very heavily covered with silt and debris, as the site is very excellently protected. *Modiolus* occurs in this section in a great number even in the upper zone where it is dwelling in small pits mentioned above. Further, its territory extends southerly to the gravel shore. This special site is virtually the same as section 7 of Area A described already, with some *Modiolus* found buried in coarse sand and gravel.

Quite a few colonies of *Hormomya* are seen scattered in this section; for instance, along the east edge. This mussel is small-sized usually less than 2 cm long, when it is found at higher levels, but much bigger, about 3 cm in shell length on an average, in or near the sublittoral zone just below the *Modiolus* bed. However, it should be noted that there are found many worn or empty shells of *Modiolus* throughout this section, especially abundantly on the eastern side.

Section 4 (Text-fig. 5, *4*): This is a triangular section projected out from the middle of the south edge of the vertical bar of the L-shaped reef and exposed at low tide only, thus rendering the reef a reverse F-shape at low tide. The substratum and environments of the section are similar to those of the section 3, but here big-sized *Hormomya* is found clumping below the *Modiolus* zone in a moderate number and very rarely in the upper zone.

Section 5 (Text-fig. 5, *5*): The section is composed of two slanting parts projected out southerly from a big reef extending around the north-west corner of the Hatakezima proper and separated from the L-shaped reef by a very narrow but rather deep water passage. The general appearance of this section is almost the same as in the previous sections, but with a little more roughened surface. This section is also regarded as a *Modiolus* bed, however colonies of small-sized *Hormomya* are seen increased in both the less silty upper and lower zones. At the densiest spot, there are about 30 small roundish colonies of *Hormomya* in a square meter.

Section 6 (Text-fig. 5, *6*): This is a small but interesting section of the gravel shore roughly opposite the sections 4 and 5 across the basin. The section is grounded by coarse sand, gravel and pebbles, together with many big or small boulders laid on them. *Hormomya* is spotted on the top surface, or in a few cases clinging to the steep wall of these boulders. *Modiolus*, on the contrary, attaches to pebbles or big gravel embedded in coarse sand at the ground level. Both mussels, however, occur in small numbers.

Area D This is an area as small as Area A, with a few reefs projected out from the southern half of the east land-side coast of the Hatakezima proper. No direct strong wave action is seen here, since the area is facing the stagnant water of Tanabe Bay. The water is not so clean as that of the sea-side areas of the island (KOBAYASHI, 1971), quite turbid as apparently observed when it is disturbed at typhoons. It seems that the ambient water is much enriched with organic materials which are perhaps available

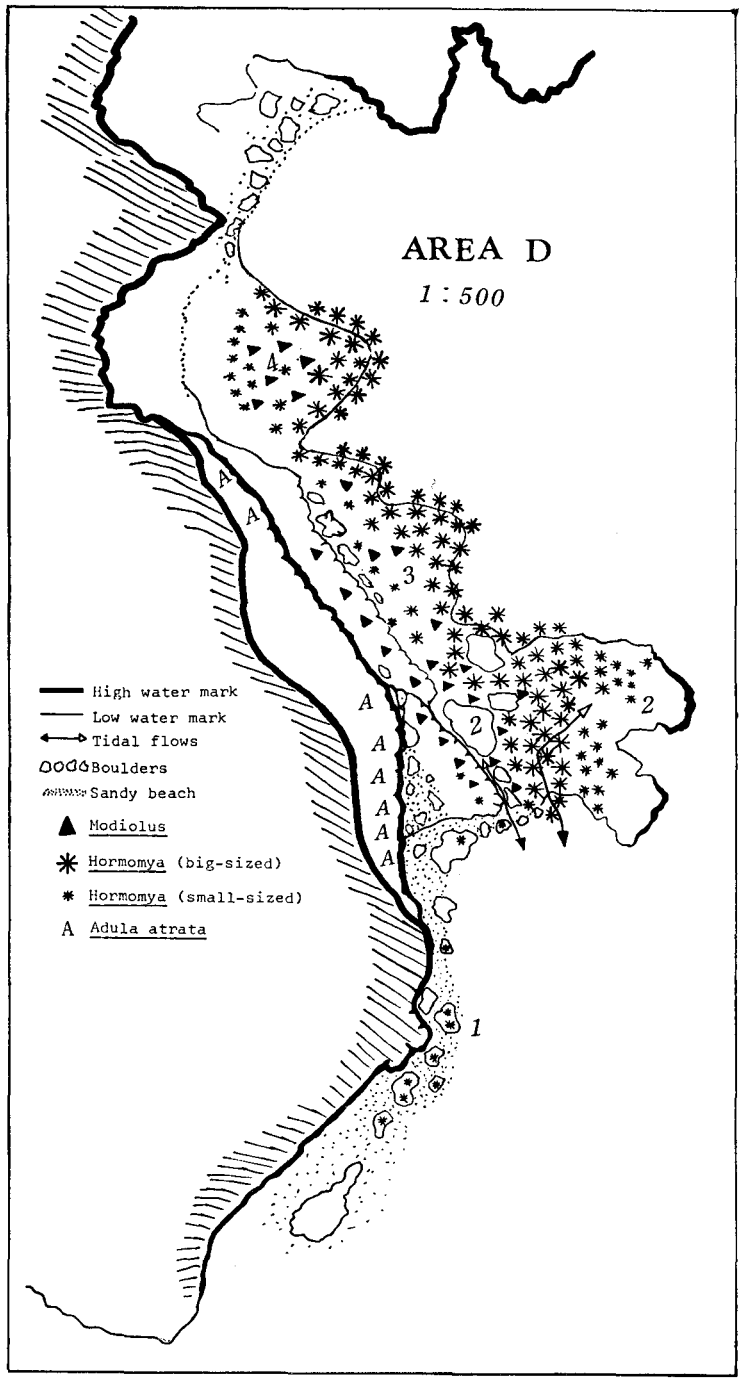

Fig. 6. Detailed map of Area D; ◀—— - direction of the water going out at ebb tide, ◁—— - direction of the water coming in at flood tide.

as nutrients for *Hormomya* which is here virtually much bigger in most places. The area is divisible into 4 sections.

Section 1 (Text-fig. 6, *1*): This southernmost section is a group of big boulders scattered near the steep coast of the Hatakezima proper. They are half embedded on the sandy beach at the sublittoral level. *Hormomya* is seen in clusters on the top surface or clung to the wall of these boulders, just similarly as in section 6 of Area C. No occurrence of *Modiolus* has been confirmed in this section.

Section 2 (Text-fig. 6, *2*): The section is designated to the biggest reef in the area north to section 1. The reef is raised up at the eastern edge almost to the high tide level and sloped down toward the island as well as to the south and then elevated perpendicularly near the island to form a roughly surfaced terrace which is still at the low tide level. The substratum is generally flat from the reef tip to the terrace foot, with several big or small boulders in the lowest part near the terrace. The section is crowded in the lower part of the slope with big-sized *Hormomya*, the biggest throughout the shore and surrounding reefs of Hatakezima Island, some of them may be longer than 4 cm, while the higher part near the reef tip with smaller ones. In the lowest part next to the terrace, there are accumulated much silt and mud and piled up numerous empty worn shells, under which a moderate number of *Modiolus* are seen half embedded in mud. More *Modiolus* are found living in small excavations on the rough surface of the terrace, too, together with a few colonies of small-sized *Hormomya*.

Section 3 (Text-fig. 6, *3*): This smaller section, north to section 2, is sloped down from the island as a flat and less silty substratum, but retaining along the base of the island a terrace actually continuous from the terrace in section 2. *Modiolus* is seen moderately on this roughly surfaced terrace and a few ones among the *Hormomya* community on the slope. Small-sized *Hormomya* is scattered in many colonies at higher levels of the slope near the terrace, but much bigger ones are found distally in colonial patches at or near the sublittoral zone.

Section 4 (Text-fig. 6, *4*): This triangular section is the northernmost part of Area D, the section is sloped down from the island as in section 3, but there is no terrace at the island base and the uppermost flat part is covered thinly with sand, then continues downward the higher part of the slope, which is more uneven than in section 3 and inhabited by *Modiolus* and some colonies of small-sized *Hormomya*. The lower part of the slope is occupied solely by big-sized *Hormomya* as in section 3.

Other areas of the island A few *Hormomya*, mostly of smaller sizes, may be seen in small colonies along the north shore and in the northern half of the east shore of the island, which are all very steep (fig. 2). They are found settled on small ledges or clung to cliffs, but in so small number that it is not worthy to mention the details of their occurrences. An insignificant number of *Hormomya* and *Modiolus* occur around the north-east corner of the island, too. The only place to be mentioned specially is an area near the middle of the north shore of the island just infront of the entrance to a

deep valley. Here are several flatly topped boulders and small-sized *Hormomya* occurs in several big colonies on these boulders. *Modiolus* and *Hormomya* are rarely seen on rocks lying on the sandy beach south-west of the island.

b. Enemies

There occur some carnivorous snails of the families Muricidae, Fasiolariidae and Mitridae on Hatakezima Island, which may be harmful to *Hormomya* and *Modiolus* as these smails are known to graze on newly settled spats and youngs of other sessile animals. However, the starfish seems to be the direct predator on adult mussels, especially the most abundant is *Asterina pectinifera* (MÜLLER & TROSCHEL) which is found frequently invading the mussel beds and actually eating the mussels. A commensal pinnotherid crab is occasionally found inside the shells of big-sized *Hormomya* or *Modiolus*.

c. Other prominent mytilids and some sessile shore animals and plants on Hatakezima Island.

1. *Septifer bilocularis* (LINNÉ) This mussel shows a very wide range of distribution, from about the mid-eulittoral zone down to the sublittoral zone. It is found almost everywhere, exposed or protected, silty or unsilty, so far as the substratum is hard and provided with clefts or crevices, usually in small numbers in almost all sections of every area described above. However, it occurs in a rather big number in such sections as section 5 of Area A or higher places of the north division of Area C.

2. *Septifer (Mytilisepta) virgatus* (WIEGMANN) This species dwells in Hatakezima Island at higher levels, particularly exposed to the strong wave action. Generally it forms clumps in dense communities of *Tetraclita squamosa japonica* PILSBRY and *Balanus tintinnabulum volcano* PILSBRY in the uppermost zones of section 4 of Area A and sections 3, 5 and 6 of Area B. The densiest spot is seen on the reef IV of section 6 in Area B. The occurrrence of this mussel is perhaps one of the best biological indicators to show the strong wave action around that site.

3) *Adula atrata* (LISCHKE) This is probably the smallest mytilid found on Hatakezima Island. It is seen usually in small colonies mostly on the flat substratum with very even and clean surfaces, always at the high tide level. Seemingly, it shows a special preference to somewhat protected sites, tiny and very shallow depressions or narrow crevices, and sometimes is found mingled with *Chthamalus challengeri* HOEK or *Saxostrea echinata*. This mussel is seen abundantly on the main reef of Area A, the L-shaped reef of Area C and on a big ledge lining the east coast of the Hatakezima proper in Area D. It is also found on big rocks located on sandy beach south and south-west of the Hatakezima proper.

4. *Tetraclita squamosa japonica* PILSBRY This big barnacle is spotted in dense masses at the top level of respective reefs in Area B and section 4 of Area A, all are facing the

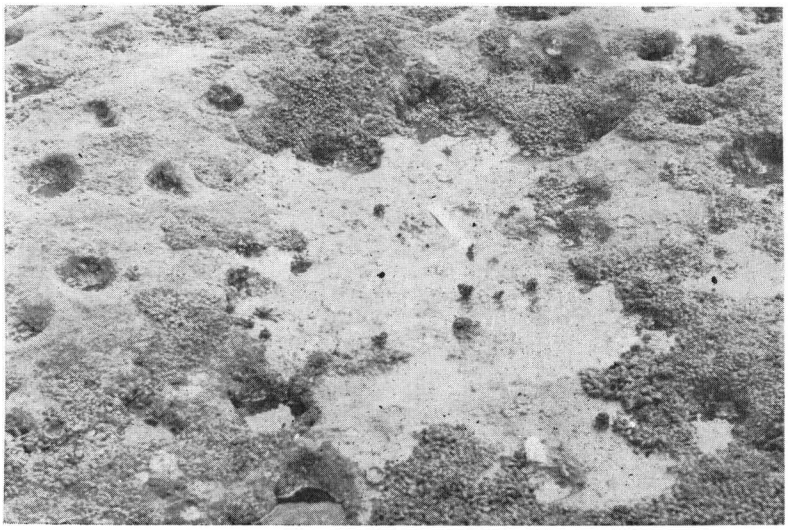

Fig. 7. Section 1 of Area A, showing a small very silty tide pool located among *Hormomya* colonies at the low tide level. *Modiolus* is found living in the pool, a ruler placed in the pool is 20 cm long.

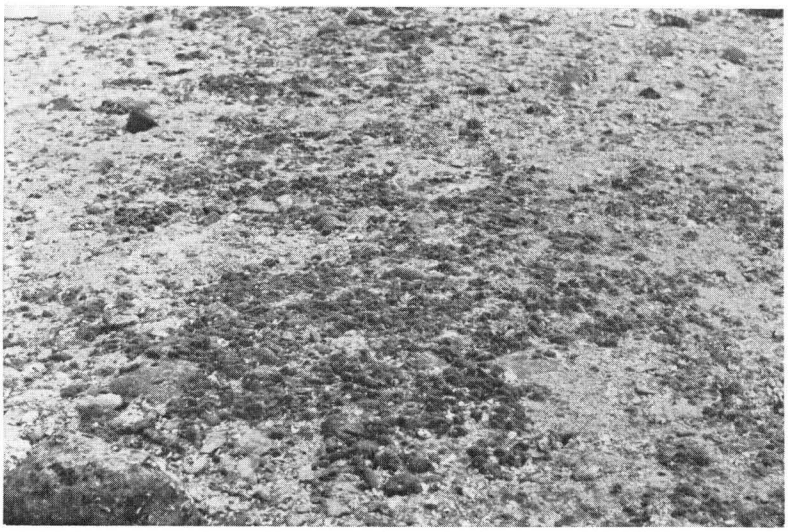

Fig. 8. Section 7 of Area A, showing *Modiolus* settled on pebbles or small boulders, some of them are buried in coarse sand.

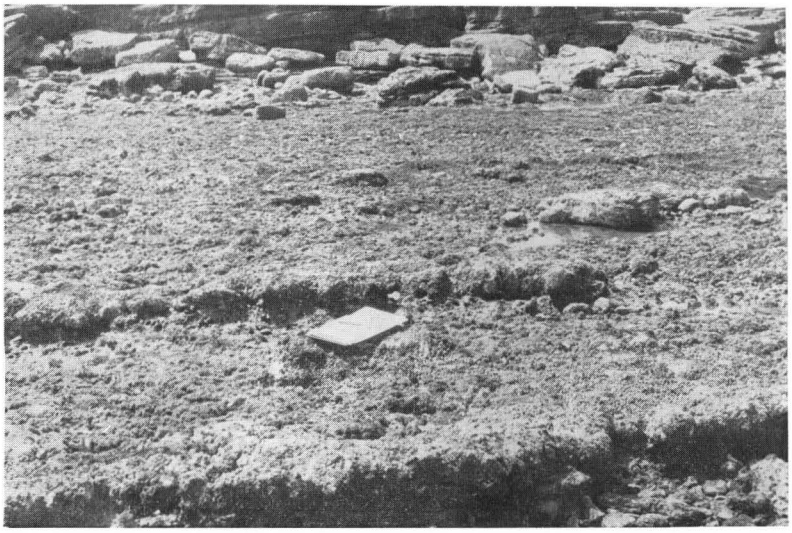

Fig. 9. The north division of Area C, showing two terraces near Komaruzima Island, covered almost completely by *Modiolus; Hormomya* are seen limitedly on the edge of respective terraces.

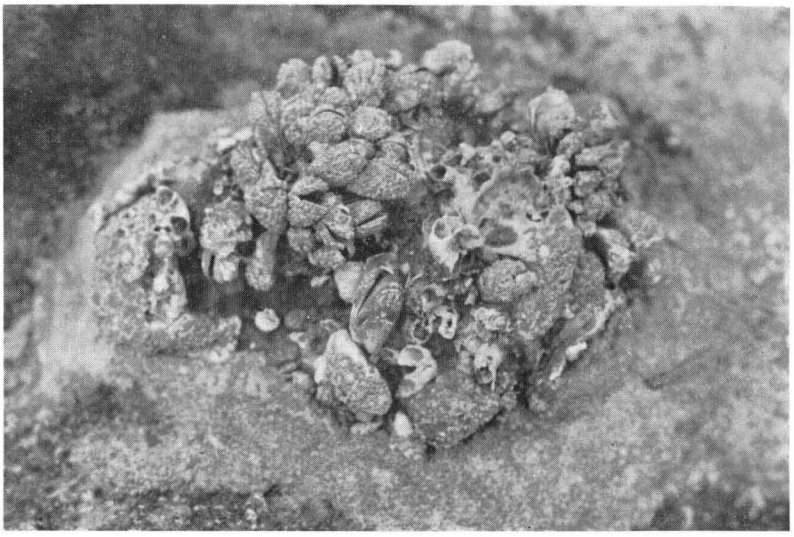

Fig. 10. A colony transplanted to a level 120 cm higher than its original site in the sublittoral zone; showing many dead *Hormomya* and some still alive, with *Chthamalus challengeri* settled heavily on their shells.

strong wave action. It may be seen in other places exposed to rather weaker wave action, but there much less densely. The occurrence and density of this barnacle may be available as an indicator to show the wave strength in respective sites.

5. *Saxostrea echinata* (QUOY et GAIMARD) This is the commonest oyster on Hatakezima Island, existing limitedly on the upper fringe of the intertidal zone, especially on rocky reefs of protected or semi-protected sites. Actually it is seen in a moderate quantity at the high level of the main reef of Area A, the L-shaped reef of Area C and scatteredly on the top surface of boulders in section 4 of Area B. It may be found widely in a small quantity in other places, but the most populated part must probably be around the north and west edges of the big flat reef between the L-shaped reef of Area C and the Hatakezima proper (fig. 2). Further, a considerable number of this oyster are seen in white bands marking the high tide level on all rocks well exposed on the sandy beach south or south-west of the Hatakezima proper.

6. *Hizikia fusiforme* (HARVEY) OKAMURA This edible brown alga occurs only on such exposed sites as sections of Area B except some protected parts of sections 2 and 8, sections 3, 4, 5 of Area A and the whole north shore of the Hatakezima proper. It grows very thickly along the low water level of those sites, but only in winter and early spring, gradually disappearing towards the warm season. At its peak of growth in winter, therefore, *Hormomya* along the low water level of those sections are concealed almost completely by this alga. *Hizikia* is also a good indicator to the strong wave action and has been employed throughout the present observations to define the exposed sites.

7. *Sargassum thunbergii* (MERTENS) O. KUNTZE This brown alga is distributed widely over the rocky flats and slopes in almost all sections, though the vegetation is drastically reduced in well protected silty sites such as the south division of Area C and section 6 of Area A. It grows at a little higher level than the *Hizikia* zone in exposed sites, covering completely the upper part of the intertidal zone inclusive of *Hormomya* colonies around the vicinity from winter to the beginning of spring.

8. *Colpomenia sinuosa* (ROTH) DERBES et SOLIER and *Hydroclathrus clathratus* (BORY) HOWE These two brown algae, the majority is *Colpomenia,* are seen limitedly in well protected silty sites such as section 6 of Area A, and north and south divisions of Area C, especially in section 3 of the latter division. It grows moderately, too, in sections 2, 3, and 4 of Area D. These sac (*Colpomenia*) or basket (*Hydroclathrus*)-shaped algae occur only in winter and completely disappear around the end of March. Their structure is delicate and tends to be destroyed easily by even moderate wave action, hence the significant wave action can be ruled out in any places where they grow. In the cold season all the *Modiolus* beds in Hatakezima Island are covered by these algae.

9. Coralline algae There are several algae of the family Corallinaceae growing on Hatakezima Island, perhaps the major species are *Corallina* sp. and *Amphiroa* sp.

encrusting the substratum most thickly at the sublittoral level generally in exposed sites. They compete with *Hormomya* to gain the substratum surface at the sublittoral level, some species of these algae are found attached to *Modiolus* shells in certain sites, too. They are seemingly growing throughout the present observations.

d. Distributions of *Hormomya* and *Modiolus* in other parts of Tanabe Bay, near Hatakezima Island

There are many coves at the inner part of Tanabe Bay, but most of them are fringed with artificial high and steep banks as resulted from land reclamations. The bottom of these coves is thickly covered with mud and scattered with boulders of various sizes. This, together with a rather high degree of water pollution, must affect much the survival of marine animals and plants, especially the sessile forms. As to *Hormomya* and *Modiolus,* they are seldom seen in these coves; if they do occur there, only in an insignificant number. Going out from the southern coves toward the mouth of Tanabe Bay, the first place crowded by these two mussels is found on the reef at Sakata (fig. 1). The area is very close to Hatakezima Island and covered by *Hormomya* along the outer margin of the reef. *Modiolus* beds are spotted in the inner part of the same reef, protected on the northwest side partly by a bank and some big highly raised parts of the reef. Another big *Hormomya* bed is seen at Ezura, just west to Sakata. This area consists of several big reefs, mostly formed of a stepped series of rocky platforms as in the north division of Area C in Hatakezima Island. The reefs are exposed to the direct strong wave action from the north-west from the mouth of Tanabe Bay. As usual, *Hormomya* is found in a great number along the sublittoral zone of respective reefs, but no *Modiolus* bed is seen there; only a small number of this mussel are seen in pits or in some small sheltered places near the sublittoral zone. Other habitats of *Hormomya* in the vicinity of Sirahama are shown in signs on the map (fig. 1).

In addition, in July 1970, I visited certain coasts of Kii Peninsula, they were Sabiura, Sionomisaki, Nagasima, Hunakosi and Sugasima Island near Toba. Only at Hunakosi, I could find a considerable amount of *Hormomya* attaching to flat rocks exposed on the gravel beach. During another trip to Kyusyu in May, 1971, to see the distribution of this mussel, I saw a rather big *Hormomya* bed at Tuyasaki near the fishery laboratory of Kyusyu University. No *Hormomya* was observed around the Amakusa Marine Biological Laboratory of Kyusyu University, at the land side of Sakurazima Island near Kagosima and around Aosima, a small island in Miyazaki Prefecture. Anyhow, these observations were made there at sites and in time very limited.

Considerations

It seems needless to mention that the distribution of *Hormomya* is limited firstly only to the rocky substratum. However, this mussel seemingly can not compete with

Modiolus in the silty condition, as the latter is provided with a more effective cleaning mechanism (SENAWONG, 1971). Against the wave action, *Hormomya* has a better adaptation in forming compact aggregations, which *Modiolus* lacks. Moreover, while collecting these two mussels, I have noticed that *Hormomya,* despite its smaller size, seems to possess stronger byssal threads than those of *Modiolus.* These factors are probably enough to eliminate *Modiolus* from the sites exposed to the strong wave action, while only the lack of efficient cleaning mechanism in *Hormomya* may be insufficient to explain its absence in protected and silty areas, because this seems to be a secondary character observed in adults only. It is very likely that some vital burdens have happened to the spats of *Hormomya* since the very beginning of their settlement in such an unfavorable condition. For instance, it is quite possible that in the silty condition, at least it is more difficult for its spats to crawl about in an effort to escape from being buried in silt or to aggregate in order to form a compact colony. Natural silt and other turbidity-creating substances such as kaolin (aluminium silicate), powdered chalk and FULLER's earth have been proven as harmful to survival of eggs and larvae of different species of bivalves with different percentages of mortality and at different concentrations (LOOSANOFF and DAVIS, 1963). Even though it seems unnecessary for *Hormomya* to form any compact aggregations in such silty-protected sites, this intrinsic behavior might have some mysterious vital effects to this mussel. So far as I am aware this mussel has never been seen attaching solitarily to the substratum, either in the exposed or protected sites. Such an intrinsic behavior was observed already in juveniles and adults of *Hormomya* in laboratory condition (SENAWONG, 1970), which had been virtually collected mostly from silty-protected sites. However, this gregarious habit has not yet been confirmed in spats of *Hormomya* in natural environments nor in the laboratory, though it was already noted in brief in larvae of *Adula californiensis* (PHILLIPI) (LOUGH and GONOR, 1971). The exact behaviors of *Hormomya* spats will be investigated in future.

It has been shown in many places on Hatakezima Island that *Modiolus* is distributed in a more limited vertical range, while *Hormomya* occurs vertically more widely from the mid-intertidal level down to the sublittoral level. *Modiolus* is found in a narrow range below the mid-intertidal level but never below the low water mark in general. It should be noted also that a significant difference in size of *Hormomya* is seen between the individuals living at higher levels and those at lower levels in such protected sites as section 1 of Area A and most sections of Area D. On the contrary, in exposed sites the shells from different levels do not differ much in size. This may be because in protected sites there is a big gap in period of exposure, especially at spring tides. An observation supplementarily made in Area D reveals that *Hormomya* at the highest level will be exposed for about 6 hours or more, while the lowest colonies in the sublittoral zone will be exposed only for 2 hours or less during the spring low tides. It is a well known fact that any mussels at lower levels can feed more continuously than the higher level dwellers. The gap of exposure period will be reduced much in

exposed sites, as the surges or ocean swells will sweep over the higher level as well. The difference in duration of exposure will concern, at the same time, the tolerance against drying inevitably. A sudden change in much reduction of submergence period seems to be fatal to *Hormomya* as it was shown by a simple supplementary experiment performed in section 1 of Area A. On April 26, 1971, two colonies of big-sized *Hormomya* (51 and 74 mussels respectively) growing each on a medium-sized boulder were transferred from the upper sublittoral zone of the north edge of the section to the higher levels about 90 cm and 120 cm above their original sites respectively and fixed there to the substratum by special cement. On the other hand, two colonies of small-sized *Hormomya* (30 and 60 mussels respectively) scraped off from the levels, where the colonies of bigger-sized mussels were just transplanted, safely together with some part of the substratum were brought down to the places in the upper sublittoral zone, where the colonies of bigger-sized mussels were growing formerly, and fixed there to the substratum amidst the carpet of big-sized *Hormomya*. About two and a half months later on July 9, 1971, 50% of big-sized mussels moved upwards to the higher level (120 cm above the original site) and 20% of mussels moved upwards to the lower level (90 cm above the original site) were found dead. Of dead ones, empty shells were seen weakly attached to boulders with a few byssal threads. It should be noted at this stage that these two colonies transplanted upwards were heavily settled upon by a great number of small barnacles, *Chthamalus challengeri* which is generally found abundantly in that area (fig. 10). Finally in the beginning of August, all the mussels on the boulders transplanted upwards were dead and disappeared. While, a control colony of about 250 mussels at their original sites showed an extremely low mortality, as only a few mussels were seen dead. On the contrary, *Hormomya* which had been transferred from the upper to the lower level were seemingly enjoying their new habitat with shorter exposure period, as almost all of them were found still alive at the above-mentioned times of examination and even at present (November, 1971).

Furthermore, it seems very strange that, during the present observations, *Hormomya* in exposed sites are all, throughout the vertical range, as small as those at higher levels in protected sites. If these discernible sizes are accepted to represent their maximum growth in respective sites, then, the factor which might be responsible for the bigger size of *Hormomya* in protected sites should be the greater supply of food particles in the water of the protected sites. Such protected sites are more or less silty than the usual exposed sites, for instance as seen in Area D. However, the quality of silt in such places seems to differ somewhat from that in such *Modiolus* beds as section 3 of Area C or section 8 of Area B. The silt in Area D is seemingly composed mostly of light, floating decomposed organic particles and clay, while in *Modiolus* beds of section 3 of Area C and others, it is composed mainly of fine sand and other mineral particles which perhaps have derived from dead coralline algae, growing thickly in the sublittoral zone of exposed sites near by. Another possible factor may be the impact of waves tapping *Hormomya* in exposed sites, which might interrupt its feeding rather

rhythmically. There is no such size difference in *Modiolus*, as bigger and smaller shells of this mussel occur mingledly; further it is rather difficult to discriminate the smaller from the bigger ones because of the silty condition of the habitat, moreover all *Modiolus* are covered thickly with algae which make their real size very obscure.

Modiolus buried in sand or gravel in section 7 of Area A, and section 3 of Area C should be in a temporary state which might be brought about in such special sites as those sections perhaps by some big waves swept there over occasionally at high tide.

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