6. Studies on the Fauna Associated with *Nautilus* in the area off the East Coast of Viti Levu, Fiji in Autumn, 1986

by

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Introduction

Many scientists have investigated and reported on the biological, physiological, embryological, and morphological aspects of *Nautilus*. However, field study and report on the bottom fauna associated with *Nautilus* have been rather few (HAYASAKA, 1985; SUZUKI and HAYASAKA, 1987). Since 1980, a research group of geologists and biologists from Japan has carried out the ecological field studies on the habitat of *Nautilus pompilius* in the Philippines and in Fiji (HAYASAKA *et al.*, 1982; HAYASAKA, 1983, 1985). The most important result of their studies concerning the association of animals is statistically recognized relationship between the biomasses of *Nautilus* and of several shrimp species (SHINOMIYA *et al.*, 1985). The "benthic fauna" treated in their study is based on the samples collected by trapping with bait and does not represent the substantial or natural aspects of fauna. For further progress of the study on the benthic fauna associated with *Nautilus*, it is necessary to conduct not only the trapping experiment but also some other methods, such as trawling, dredging, and so on, in the field concerned.

In this article, the results of additional trapping experiments and of preliminary trials of trawling and dredging in Fiji are reported.

Study Area and Methods

During the field works for the ecological studies on the habitat of chambered nautilus from late August to the middle of September in 1986, the trapping experiments on *Nautilus* were carried out at 14 stations off Suva (Fig. 1, A) and four stations off Ovalau Island (Fig. 1, B). The trawling and dredging surveys on the macro-benthic fauna were practiced several times along two lines off Suva (Fig. 1, A). For the oceanographic and physiographic features of these areas,

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refer to the previous report (HAYASAKA, 1985) and the first paper in this volume.

The trapping stations and lines of trawling and dredging are on the outer slope of a barrier reef ranging from 200 to 500 m in depth except for one trawling line (Fig. 1, A; T1-line) in the 20-30 m deep lagoon near the Lauthala Harbour.

We used the large- and medium-sized traps called "TR-A" in the previous papers (HAYASAKA *et al.*, 1984; HAYASAKA, 1985) for collecting samples. They were made of iron frame covered with 15 mm wire-netting and have been used for the deep sea fishing by the staff of Institute of Marine Resources (IMR). The baits for trapping, such as whole bodies of a few frozen sardine, bonito, or small tuna were suspended inside of each trap. Two large- and two medium-sized traps connected to a buoy were settled on the bottom. The traps were set in the afternoon and hauled up on the next day (17-18 hours after setting). All the animals captured by trapping were identified and the number of individual of each group were counted immediately after the hauling up the trap.

A small beam trawl with string net was used for trawling experiment. The beam-length was 5 m, total length of net was 12 m, and mesh sizes of wing net, main net, and cod-end were 50 mm, 30 mm and 20 mm, respectively. The trawl net was drawn along the line perpendicular to the strike of slope for about 600 m in the lagoon, and for about 1000 m outside the reef.

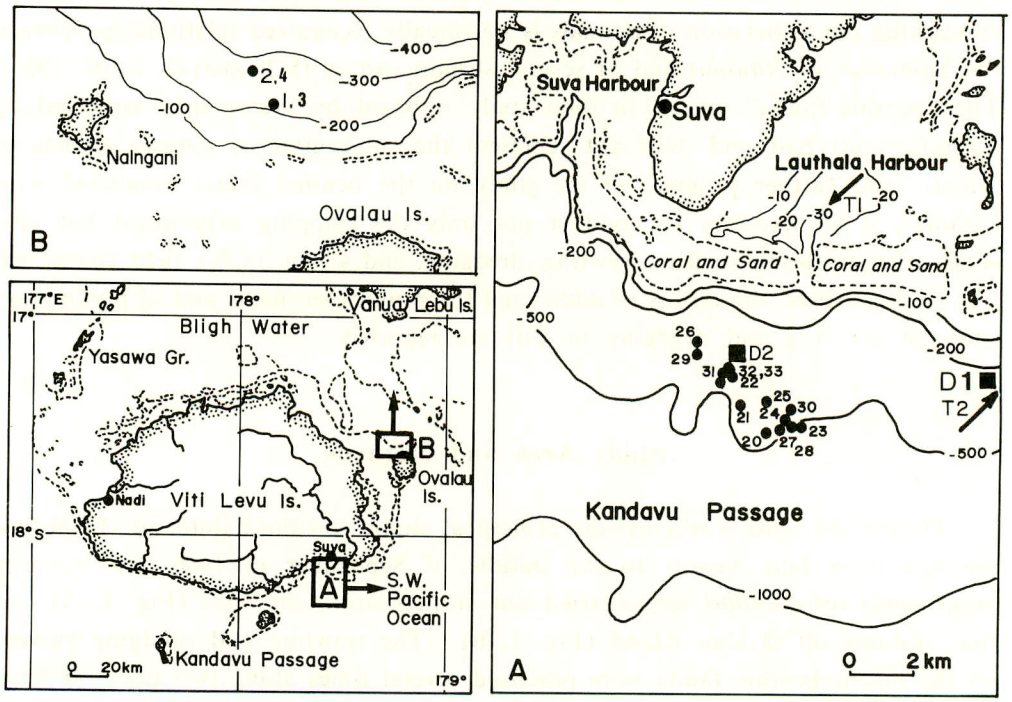

Fig. 1. Maps of the Suva (A) and Ovalau (B) areas, Viti Levu Island, showing the trapping stations (●) and lines of trawling (arrows) and dredging (■).
The numerals indicate the number of stations.

For collecting the small macro-benthos, we used the anchor-dredge which was modified by IMR with the string net (mesh size, about 10 mm). The dredge was dragged for about a few meters at 300-500 m depth within the habitat of *Nautilus*.

The specimens caught by trapping from the stations 32-33 off Suva and 1-3 off Ovalau Island and all the animals captured by trawling and dredging were kept in 10 % formalin with sea water and brought to the laboratory. These specimens were identified and number of individual of each species was counted, and carapace length of macro-crustacea and standard-length of fishes were measured in the laboratory.

Results and Discussion

1. The trapping experiments

The animals collected by trapping are listed in Table 1. There were thirteen crustacean species, of which eleven occurred off Suva and nine off Ovalau Island. Among them collected off Suva, three pandalid species, *Heterocarpus ensifer, H. gibbosus,* and *H. sibogae,* were predominant showing high individual numbers per trap such as 13.71, 4.79, and 77.64, respectively. The sex ratios (male/female) of the three species in the five selected samples (32th and 33th off Suva and 1st to 3rd off Ovalau Is.) were severally 0.66, 1.04, and 1.37 in average. This suggests that the abundance of male and female of each species inhabiting this area is nearly equal. Most females of all the three species were ovigerous. The

Table 1. List of species, catch records, sex ratios, and ovigerous of crustaceans collected by trapping in Fiji, in 1986. Ratios (*) were calculated only on the specimens brought to the laboratory.

Scientific name	Locality					
	off Suva			off Ovalau Is.		
	Individuals per trap(SD)	Ratios* of Sex	Ov.(%)	Individuals per trap(SD)	Ratios* of Sex	Ov.(%)
Aristeidae						
1. Aristeus virilis	0.07(0.17)					
Penaeidae						
2. Penaeopsis eduardoi	0.07(0.15)	0.0	0.0	0.31(0.94)	0.25	0.0
Pandalidae						
3. Heterocarpus ensifer	13.71(14.22)	0.66	34.2	4.69(4.98)		
4. H. gibbosus	4.79(5.89)	1.04	100.0	3.69(3.49)		
5. H. sibogae	77.64(47.84)	1.37	50.8	14.88(13.04)		
6. H. laevigatus	0.14(0.28)					
7. Parapandalus serratifrons	0.48(1.07)					
8. Plesionika longirostris	1.05(1.81)	---	---	3.63(4.83)		
9. P. martia orientis	0.84(0.98)	0.0	100.0	1.81(2.13)	2.22	44.4
Galatheidae						
10. Munida sp. 1	0.04(0.09)			0.06(0.19)	0.0	100.0
11. M. sp. 2				0.06(0.19)	0.0	100.0
Parapaguridae						
12. Parapagurus dofleini				0.13(0.38)	0.0	50.0
Paguridae						
13. Pylopagurus serpulophilus	0.02(0.06)					

other eight species, *Aristeus virilis, Penaeopsis eduardoi, Heterocarpus laevigatus, Parapandalus serratifrons, Plesionika longirostris, P. martia orientis, Munida* sp. 1, and *Pylopagurus serpulophilus* were rather few in number of individuals.

Off Ovalau Island, nine species, i. e., *P. eduardoi, H. ensifer, H. gibbosus, H. sibogae, P. longirostris, P. martia orientis,* two species of *Munida,* and *Parapagurus dofleini,* were caught by traps. *H. sibogae* was most abundant in Ovalau being analogous to the case of Suva.

Three shrimps and one anomura, i. e. *A. virilis, H. laevigatus, P. serratifrons,* and *P. serpulophilus,* occurred only in Suva. Two anomuran crabs, *Munida* sp. 2 and *P. dofleini,* were collected only in Ovalau. On the contrary, the dominant shrimps, such as three species of *Heterocarpus,* appeared in both areas. These results seem to indicate that the benthic fauna off Ovalau Island is mainly similar to that off Suva, though the biomass of Ovalau is poorer.

Comparing the benthic fauna caught by traps in the present study with those reported in the preceding studies (HAYASAKA *et al.,* 1982; SHINOMIYA *et al.,* 1985), it is evident that the Ovalau Island specimens represent poorer fauna in number of individuals, but that the faunal character is similar to those of the other localities in having the three dominant pandalid species. In Tanon strait, the Philippines, sea urchins *(Malepia cordata* MORDENSEN) predominate and in Fiji, shrimps are most abundant among the animals associated with *Nautilus* (HAYASAKA *et al.,* 1982; HAYASAKA, 1985). Shrimps are most abundant in Palau and in Yap[1] as well, but the numbers of captured individuals were very low (SUZUKI and HAYASAKA, 1987).

These shrimps were regarded to be one of the favorite foods of *Nautilus* by SHINOMIYA *et al.,* (1985), and we also have an impression that there is a close relation of coexistence between *Nautilus* and shrimps in this area. SHINOMIYA *et al.* (1985) showed that the individual numbers of *N. pompilius* and *H. sibogae* in each station was fairly correlative with each other, and suggested that the abundance of *H. sibogae* was one of the most important biotic factors in the habitat of *Nautilus.* In the present case, the faunas of Suva and Ovalau had many individuals of *H. sibogae* and many nautili were caught by traps in both areas (see "The Trapping Experiment" in this volume). The important factor as the foods favorable for *Nautilus* may be not only the kind of animal but also the size of individual suitable for easy prey by *Nautilus.*

Table 2 shows the mean, minimum, and maximum carapace lengths of male and female in each dominant species such as *H. ensifer, H. gibbosus, H. sibogae* and *P. martia orientis.* The size distribution of each species is shown in Fig. 2 (a-d).

H. ensifer is rather small shrimp with 19.06 mm mean carapace length among the four dominant species, and maximum carapace lengths of male and female

1) From the Yap Islands, no live *Nautilus* have been found.

Table 2. Table showing the data on the four abundant species collected by trapping in Fiji, in 1986.

Species	Heterocarpus ensifer	H. gibbosus	H. sibogae	Plesionika martia orientis
Mean Carapace Length (mm)				
Male	19.06	29.07	26.4	18.9
Female	19.51	33.12	25.9	19.23
Ovigerous F.	21.16	33.12	30.02	22.49
Minimum C. L. (mm)				
Male	13.6	22.25	13.2	15.9
Female	15.0	27.35	15.65	14.1
Ovigerous F.	19.35	27.35	22.25	21.45
Maximum C. L. (mm)				
Male	23.25	35.0	33.45	23.6
Female	24.6	38.9	35.35	24.6
Ovigerous F.	24.6	38.9	35.35	24.6

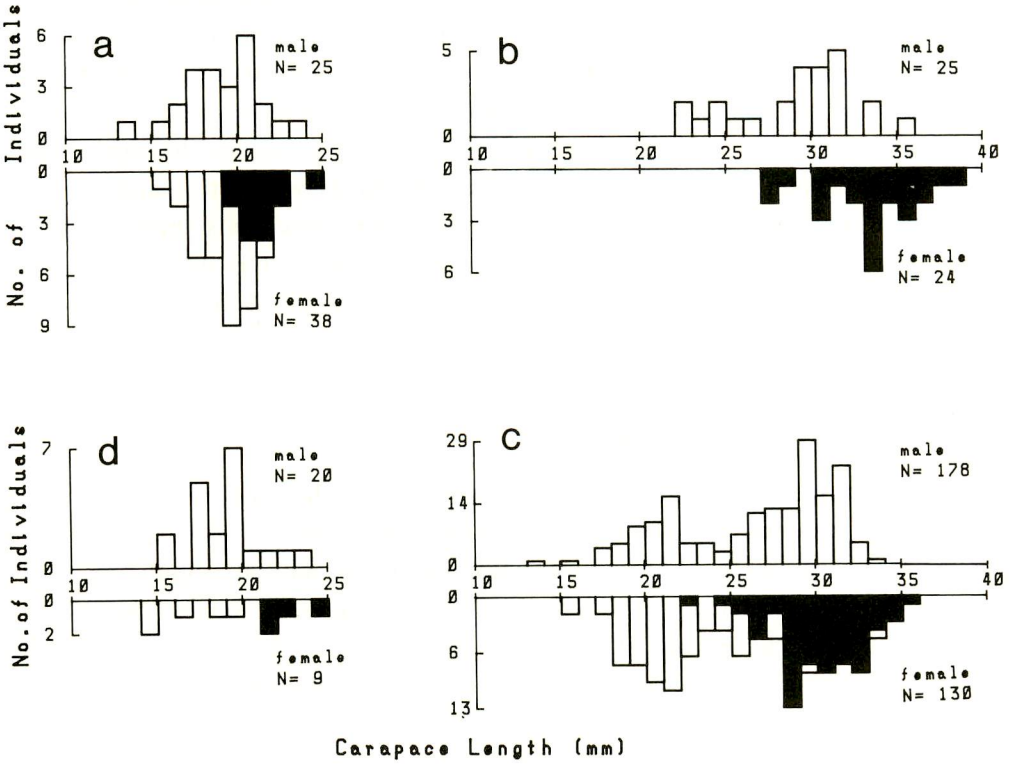

Fig. 2. Size distributions of *Heterocarpus ensifer* (a), *H. gibbosus* (b), *H. sibogae* (c), and *Plesionika martia orientis* (d) captured by traps. Solid bars indicate ovigerous female.

were 23.25 mm and 24.6 mm, respectively. The females of this species having the carapace longer than 19.35 mm were ovigerous. *H. gibbosus* is large and shows the mean length of 29.07 mm in male and 33.12 mm in female. The minimum carapace lengths of male and female are 22.25 mm and 27.35 mm, respectively. These minimum size are nearly equal to or larger than the maximum size of *H. ensifer.* All females of *H. gibbosus* were ovigerous. *H. sibogae* has a wide

range of carapace length; the minimum and the maximum values are 13.2 mm and 33.4 mm in male (mean, 26.4 mm) and 15.65 mm and 35.35 mm in female (mean, 25.9 mm) with the bimodal size-distribution. Each peak was nearly similar to those of *H. ensifer* and *H. gibbosus*. The females having the carapace longer than 22.25 mm were mostly ovigerous. *P. martia orientis* is small shrimp similar to *H. ensifer*. The minimum lengths of male and female are 15.9 mm and 14.1 mm and the maximum 23.6 mm and 24.6 mm, respectively. Each shows a normal size-distribution with modes of 18.9 mm (male) and 19.23 mm (female).

Both populations of *H. ensifer* and of *P. martia orientis* were composed of individuals with carapace smaller than 25 mm in length and their size-distributions show one peak at about 20 mm. The population of *H. sibogae* shows the bimodal size-distribution with the modes around 21 mm and 30 mm. On the contrary, *H. gibbosus* population is composed of rather large individuals longer than 25 mm. SHINOMIYA *et al.* (1985) statistically analyzed the correlation between the individual numbers of *Nautilus* and some shrimp species, and obtained the results that the numbers of *H. sibogae* and *H. gibbosus* show high correlations with those of the captured *Nautilus*. Considering the present results, the species having carapace longer than 25 mm are regarded as the favorite foods of nautili, and this may imply that *Nautilus* can prey more easily on larger individuals than on smaller ones. For further studies on the food habit of *Nautilus*, it is necessary to make much more detailed survey on the benthic fauna within the habitat of *Nautilus* in various places.

2. The trawling experiments

As mentioned in the introduction, sampling method of benthos has been restricted to trapping with baits (HAYASAKA, 1983; 1985). The trawl sampling is one of the useful methods to get information on natural population of the benthic fauna associated with *Nautilus*. In the present survey the trawling experiments were carried out at three localities off Suva. But one of them failed in hauling owing to the complex and extreme undulation of bottom surface. The animals captured by two successful trawling experiments are listed in Table 3.

The animals were classified into nine phylum, 49 families and 62 species. Amongst them, gastropoda (24 species) and crustacea (17 species) predominate in number of species.

Comparing the fauna in lagoon (Stn. T-1) with that on the slope of outer reef (Stn. T-2) where *Nautilus* inhabits, differences were found in both the number of individuals captured and the species composition. The fauna of lagoon had 47 species involving many gastropods which might feed on the fallen leaves of mangrove. The crustacean fauna of lagoon was composed of small species, such as *Solenocera* shrimp, *Portunus longispinosus bidens*, *Macrophthalmus* crab, and

Table 3. List of species and catch records (Carapace or Standard Length ; mm) of animals collected by trawling : M, F, and ov. F indicate Male, Female, and ovigerous Female, respectively.

Scientific name	Localities	
	Outside Reef (T-2)	in Lagoon (T-1)
COELENTERATA		
1. Muggiaeid sp.	1	
NEMERTINEA		
2. Lineid sp.		5
MOLLUSCA		
GASTROPODA		
Turritellidae		
3. *Haustator fascialis*		2
Potamididae		
4. *Royella sinon*		1
5. Carinariid sp.	2	
Cymatiidae		
6. *Distorsio reticulata*		2
Muricidae		
7. *Murex troscheli*		9
8. Buccinid sp.	1	
Nassariidae		
9. *Zeuxis caelatus*		5
10. *Reticunassa* sp.		78
Mitridae		
11. *Vexillum vulpeculum*		11
12. *V.* sp. 1		6
13. *V.* sp. 2		10
Conidae		
14. *Chelyconus pauperculus*		4
15. *C. fulmen*		1
Turridae		
16. *Lophiotoma leucotropis*		11
Epitoniidae		
17. *Globriscala stigmatica*		1
18. Pyramidellid sp.	2	
Chelidonuridae		
19. *Doridium* sp.		1
Akeridae		
20. *Akera* sp.		1
SCAPHOPODA		
21. Dentaliinae sp.	1	
BIVALVIA		
Arcidae		
22. *Diluvarca ferruginea*		4
23. Arcid sp.		2
Veneridae		
24. *Lioconcha* sp.		3

Table 3. Continued.

Scientific name	Localities	
	Outside Reef (T-2)	in Lagoon (T-1)
Gariidae		
25. *Gari maculosa*		2
26. Gariid sp.	3	
ANNELIDA		
Sigalionidae		
27. *Leanira* sp.		3
28. Nephtyid sp.		1
29. Maldanid sp.		1
30. Serpulid sp.		8
ARTHROPODA		
31. Sphaeromid sp.		1
Penaeidae		
32. *Penaeopsis eduardoi*	2F(26.42)	
33. *Solenocera* sp.		4M(6.64) 3F(8.9)
34. *Penaeus semisulcatus*		1M(24.15)
35. *Metapenaeus* sp.		1F(24.0)
Pandalidae		
36. *Heterocarpus sibogae*	1ov.F(26.2)	
37. *Plesionika martia orientis*	1M(12.05) 1F(18.2)	
Polychelidae		
38. *Polycheles* sp.	1(14.8)	
Palinuridae		
39. *Puerulus angulatus*	1(22.6)	
Nephropidae		
40. *Metanephrops* sp.	1(10.25)	
Galatheidae		
41. *Galathea* sp.		1M(3.55)
42. *Munida* sp.	1F(7.75) 1ov.F(15.45)	
Majidae		
43. *Hyastenus* sp.	1ov.F(18.15)	
Portunidae		
44. *Portunus longispinosus bidens*		7M(8.69) 1F(9.0) 2ov.F(8.3)
45. *Charybdis anisodon*		1M(26.35) 1ov.F(25.3)
46. *Podophthalmus vigil*		1M(6.9)
Ocypodidae		
47. *Macrophthalmus* sp.		1M(4.5) 1F(3.65)
SIPUNCULOIDEA		
48. Sipunculid sp.		2

Table 3. Continued.

Scientific name	Localities	
	Outside Reef (T-2)	in Lagoon (T-1)
ECHINODERMATA		
EUASTEROIDEA		
49. Astropectinid sp.		1
OPHIUROIDEA		
50. Amphiurid sp.		6
HOLOTHUROIDEA		
51. Holothuriid sp.		3
PROCHORDATA		
ASCIDIACEA		
52. Ascidiid sp.		9
PYROSOMATA		
Pyrosomatidae		
53. Pyrosoma sp.	1	
THALIACEA		
Salpidae		
54. Iasis zonaria	1	
PISCES		
Bregmacerotidae		
55. Bregmaceros japonicus	1(79.0)	
Macrouridae		
56. Ventrifossa sp.	1(100.0)	
Apogonidae		
57. Apogon lineatus		4(33.76)
Bramidae		
58. Brama sp.	1(43.0)	
Champsodontidae		
59. Champsodon sp.	1(96.0)	
Gobiidae		
60. Oxyurichthys saru		2(56.83)
Callionymidae		
61. Callionymus sp.		3(25.63)
Bothidae		
62. Crossorhombus sp.		2(50.85)

so on, without the shrimp species occurring in the habitat of *Nautilus,* such as pandalids. On the contrary, the fauna in the outer reef area had few gastropods, crustaceans, and pisces appeared in the lagoon. The larger shrimps captured by trap, such as *Heterocarpus sibogae* and *Penaeopsis eduardoi* occurs commonly instead of the small crustaceans. As already mentioned, these larger shrimps may be the favorite foods of *Nautilus.*

The pisces fauna outside the reef also differs from that of lagoon. It comprises the abyssal fishes, such as *Ventrifossa* sp., *Champsodon* sp., and *Bregmaceros japonicus.* These fishes were captured at the first trial of the serial operation in Fiji, and are different from the species recorded by SHINOMIYA *et al* (1985). The defference may be resulted from the sampling effect of trawling experiment conducted in this survey.

Table 4. List of species and catch records (Carapace Length ; mm) of animals collected by dredging : M and F indicate Male and Female.

Scientific name	Stations	
	D-1	D-2
PROTOZOA		
1. Unidentified sp.	7	2
COELENTERATA		
2. Muggiaeid sp.		12
3. Actiniarid sp.		2
NEMERTINEA		
6. Lineid sp.		4
7. Hubrechtid sp.		1
MOLLUSCA		
GASTROPODA		
8. Nassariid sp.	4	
9. Terebrid sp.		1
10. Pyramidellid sp.	1	
11. Atycid sp.	1	
Cavolinidae		
12. *Cavolinia tridentata t.*		2
13. *C. globulosa*	6	
14. *C. longirostris l.*	1	
15. *C. gibbosa*	1	
16. *C. inflexa labiata*	2	
17. *Diacria trispinosa t.*	15	1
SCAPHOPODA		
18. Dentaliinae sp.		1
19. Siphonodentaliid sp.		1
20. Cadulid sp.		1
BIVALVIA		
21. Nuculanid sp.	10	2
22. Amusiid sp.	1	
23. Gariid sp.		1
Tellinidae		
24. *Macoma sectior*	1	1
25. Tellinid sp.	2	1
ANNELIDA		
26. Nereid sp.	3	2
27. Nephtyid sp.	6	2
Glyceridae		
28. *Glycera* sp.	3	1
29. Eunicid sp.	1	3
30. Lumbrinerid sp.		7
31. Opheliid sp.		2
32. Arenicolid sp.		2
33. Maldanid sp.	27	28

Table 4. Continued.

Scientific name	Stations	
	D-1	D-2
ARTHROPODA		
34. Scalpellid sp.		2
35. Aegid sp.		1
36. Gammaridean sp.	3	
Ampeliscidae		
37. Ampelisca sp.		6
Oxycephalidae		
38. Oxycephalus sp.		1
39. broken penaeid shrimp		3
Pandalidae		
40. Pandalus sp.		1(6.35)
Alpheidae		
41. Synalpheus sp.	3(8.93)	1(5.65)
42. broken Callianassa sp.		1
Galatheidae		
43. Munida sp.		1(3.5)
44. Pagurid sp.		1
Goneplacidae		
45. Typhlocarcinops sp.	1M(4.25) 1F(4.8)	
46. Hexaplax megalops		1M(4.7)
Retroplumidae		
47. Retropluma sp.		1M(7.1)
SIPUNCULOIDEA		
48. Sipunculid sp.	2	6
ECHINODERMATA		
OPHIUROIDEA		
49. Amphiurid sp.		1
HOLOTHUROIDEA		
50. Synaptid sp.	3	4
PROCHORDATA		
THALIACEA		
51. Doliolid sp.		11

3. The dredging experiments

For collecting the small macro-benthos, the dredging were preliminarily carried out during the field works for the ecological studies of *Nautilus*. Two experiments were carried out in the habitat of *Nautilus* outside the reef. Table 4 shows the animals captured by the dredge. They were classified into nine phylum, 42 families and 51 species. Most of them belongs to three phylum, such as mollusca, annelida, and arthropoda. Empty shells of *Cavolinia globulosa, C. gibbosa,* and *Diacria trispinosa trispinosa,* representing the major part of the collected gastropods, were found in the dredge samples. Amongst living animals, the polychaetos belonging to Maldanidae, Lumbrineridae, and Nephtyidae were predominant. These species

inhabit the silt-clay sediments with the tube nest. It is also known that *Ampelisca, Synalpheus,* and two goneplacid crabs inhabit the silt-clay bottom creeping on the bottom surface or burrowing the nest.

These results seem to indicate that the silt-clay particles accumulate on the sea bottom of the habitat of *Nautilus,* and that the gastropod shells are sporadically piled up.

Some specimens of *Munida* (Crustacea; Galatheidae) were also collected. The specimens captured by traps seems to be related to Baba's (1969 a, b) description, and the others caught by the trawl are similar to *M. crassa* (BABA, 1982). However, they are a little different from those species in number of spines on the carapace. For the present, it is difficult to identify them definitely since all specimens are of females. These are now under close examination.

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