Study on the Fauna Associated with *Nautilus belauensis* in the Area off the Southeast Coast of the Palau Islands

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Introduction

Many scientists have investigated and reported on the biological, physiological, embryological, and morphological aspects of *Nautilus*. In a recent year, paleontological and biological knowledge of *Nautilus* was also reviewed (Saunders and Landman, ed., 1987); however, there are relatively few field studies on benthic fauna associated with *Nautilus* (Saunders, 1984; Hayasaka. ed., 1985; Suzuki and Hayasaka, 1987; Suzuki *et al.*, 1988). Since 1980, a research group of geologists and biologists from Japan has carried out ecological field studies on the habitat of *Nautilus pompilius* in the Philippines and Fiji (Hayasaka *et al.*, 1982, Hayasaka ed., 1983, 1985, 1988). These studies reported that sea urchins (in the Philippines) or pandalid shrimp (in Fiji) inhabited abundantly with *Nautilus*. Of the result of these studies, it is interesting to note that the number of individual *Nautilus* closely correlate with those of some shrimp species (Shinomiya *et al.*, 1985).

In the Palau Islands, some investigators have studied the systematical, morphological, and ecological aspects of *Nautilus belauensis* (Saunders, 1981; Saunders and Spinosa, 1978). One of the authors reported in a preliminary study on the associated fauna with *N. belauensis* (Suzuki and Hayasaka, 1987). Saunders and Hastie (1989) researched deep-water shrimp fauna and their vertical distributions, and reported that there were different depth range for each species. The vertical range of *Nautilus* is principally limited by physical and physiological factors, such as water pressure, water temperature, and the probability of shell implosion at great depths. In addition, the vertical distributions of certain organisms, which are either predators of food for *Nautilus*, are thought to restrict the vertical range of *Nautilus*.

The "benthic fauna" treated in the previous studies was based on samples collected by traps with bait and does not represent the substantial or Natural aspects of the fauna. For further progress in the studies on benthic fauna associated with Nautilus and distribution patterns of each organism, it is necessary to conduct not only trapping experiments, but also to use some other methods, such as trawling, sledging, and long-line, in the field concerned.

In this article, the results of trapping, trawling sledging, and long line experiments in the Palau Islands are reported. The vertical distribution of each organism and ecological aspects of the dominant species are also preliminary examined.

Study Area and Methods

Ecological studies on the chambered nautilus were conducted in Mutremdiu Bay, the Palau Islands from early August to the middle of September in 1988, and during early January in 1989. In this field work, trapping experiments on *Nautilus* were carried out at 13 stations in summer (Fig. 1), and 7 stations in winter (Fig. 2). Trawling, sledging, and long-line surveys on macro-benthic fauna were conducted along the reef of Mutremdiu Bay once, three and six times, respectively (Fig. 3). The oceanographic and physiographic features of the bay are reported in the first two papers in this volume.

The stations and lines of all the experiments were on the slope of a barrier reef ranging from 132m to 560m in depth (Table 1). A trap used for collecting samples was made of iron frame covered with 6.4 mm wire-netting. Its size was 86cm X 86cm X 100cm with two entrances at opposite side. Baits for trapping, such as whole body of a frozen sardine, bonito, or small tuna, were suspended inside of the trap. The trap was connected to a buoy and settled on the bottom. It was set in the morning and hauled up the next day (about 24 hrs after setting). Two trapping trails went missing due to a strong current, one of which settled at 50m deep in summer, and another at 200m deep in winter.

A small beam trawl with a string net was used for the trawling experiment. The beam-length was 5m, the total length of the net was 12m , and mesh size of

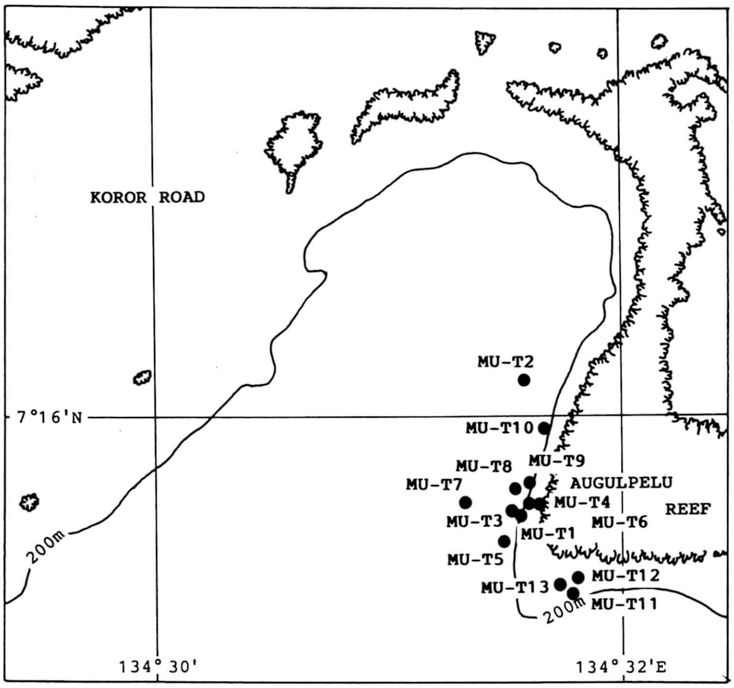

Fig. 1. Map showing the trapping locations in August and September, 1988.

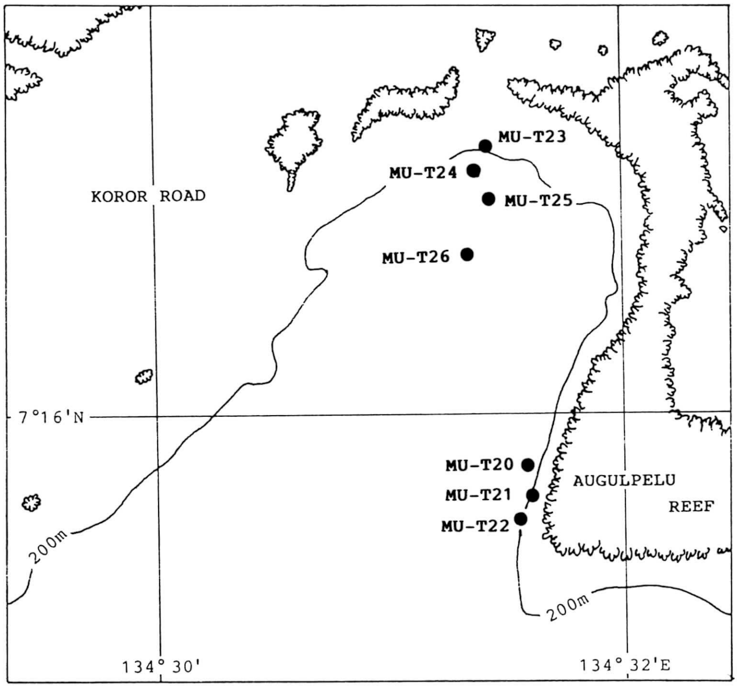

Fig. 2. Map showing the trapping locations on January 6-13, 1989.

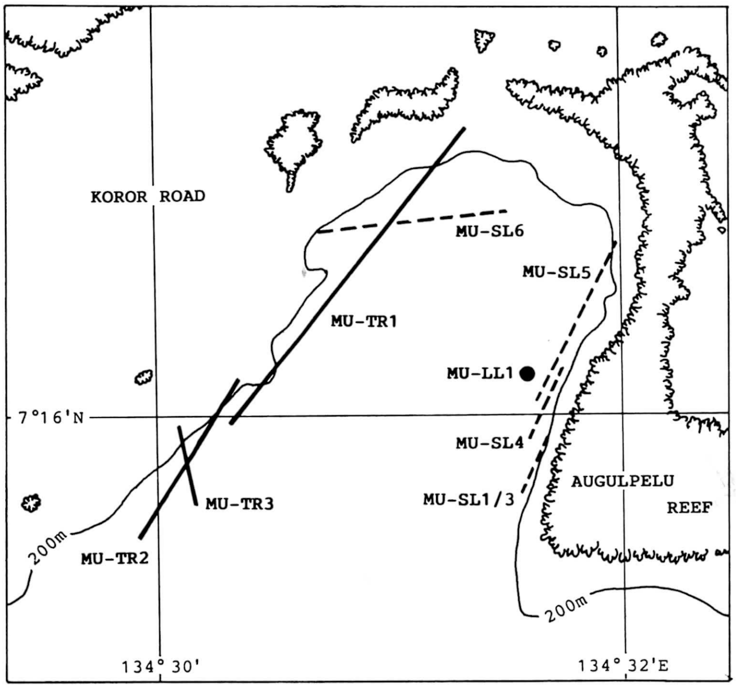

Fig. 3. Map showing the lines of trawling (solid bar) and sledging (broken bar) and the station of the long-line (solid circle).

Table 1. Experimental data of trapping, trawling, sledging, and long-line for *Nautilus belauensis* Saunders in 1988 and 1989.

	Trapping		Trawl	Sledge	Long-line
Year	1988	1989	1988	1988	1988
Date Range for Experiment	Aug.22 : Sep.17	Jan.6 : Jan.13	Sep.1 : Sep.2	Aug.24 : Aug.25	Aug.24 : Aug.25
No. of Trials	13	7	3	6	1
No. of Successful Trials	12	6	1	3	1*
Depth Range of Successful Trials (m)	132 : 560	140 : 450	306 : 366	180 : 400	220

*: A quarter part of the settled line was only hauled up.

the wing net, main net, and cod-end were 50mm, 30mm, and 20mm, respectively. The trawl net was drawn along the reef edge for one to one and a half hours. For collecting the smaller macrobenthos, we used a hand-made sledge with a string net (mesh sizes of the main net and cod-end were 5mm and 2mm, respectively).

The sledge net was drawn for 20 to 40 minutes in a depth range of 180m - 400m. However, two of the trawling and three of the sledging trials failed in hauling due to the floating of gears (light weight), the steep slope of the bottom surface, and the strong current.

A long-line (diameter of main line, about 2mm) was used for collecting demersal fish. In the first trial (at 220m deep in east side of Mutremdiu Bay), however, the main line was cut by certain strong fish, such as shark or a conger, and three quarters of the line remained on the bottom. Thus, only two specimens of fish were obtained by the long-line experiment.

The specimens caught by all experiments were kept in 10% formalin with seawater and brought to the laboratory. These specimens were identified and individual number of each species were counted. Carapace lengths of macro-crustaceans and standard-lengths of fish were measured by slide caliper.

Results and Discussion

1. Benthic Fauna of the Palau Islands

Though all specimens have not been identified to the species level, the specimens collected by all experiments are listed in Tables 2 and 3. There were 37 families, 51 genera and 69 species, of which 19 families were collected by traps, 19 by trawl nets, 6 by sledge net, and 1 by long-line. Amongst the families, 16 and 14 families belonged to the classes Crustacea and Pisces, respectively. Dominant organisms were the pandalid shrimp, of which a total of 381 individuals were captured during the survey period. Predominant creatures were the spider crab (family Majidae), the hermit crab (Diogenidae), the conger ell (Congridae), giant red

Table 2. Numbers of genera, species and individuals of animals collected by trap, trawl, sledge, and long-line in 1988 and 1989.

Family Name	Trapping		Trawl		Sledge		Long-line		Total
	gen.	sp.	gen.	sp.	gen.	sp.	gen.	sp.	inds.
POLYCHAETA									
1. Amphinomidae	1	1							3
GASTROPODA									
2. Cymatiidae	1	1							1
CRUSTACEA									
3. Aegidae	1	1							many
4. Euphausidae					1	1			1
5. Penaeidae			1	1					2
6. Sicyoniidae			1	1					1
7. Sergestidae			1	1					2
8. Pandalidae	2	10	3	7	1	1			381
9. Crangonidae			1	1	1	2			5
10. Diogenidae	4	4							13
11. Paguridae	1	1			2	2			3
12. Galatheidae			2	2	1	2			5
13. Homolidae	2	3	1	1					7
14. Calappidae			1	1					1
15. Leucosiidae	1	1							1
16. Majidae	3	4							17
17. Geryonidae	1	1							9
18. Goneplacidae	1	1							1
OPHIUROIDEA									
19. Ophiomyxidae	1	1							1
20. Ophiuridae			1	1					2
ASTEROIDEA									
21. Astropectenidae			1	1					1
ECHINOIDEA									
22. Temnopleuridae			1	1					1
CRINOIDEA									
23. Colobometridae	1	1							1
PISCES									
24. Muraenidae	1	1							3
25. Muraenesocidae	1	1							1
26. Synaphobranchidae	1	1							4
27. Congridae	1	1							12
28. Moridae	1	1							6
29. Macrouridae			1	1					1
30. Ohidiidae			1	1					1
31. Chaunacidae			1	2					2
32. Ogcocephalidae			2	2					2
33. Serranidae	1	1							4
34. Scorpaenidae			1	1			1	1	3
35. Peristediidae			1	1					2
36. Pleuronectidae			1	1					2
37. Cynoglossidae			1	1	1	1			3

Table 3-a. List of animals collected by trap, trawl, sledge, and long-line, in 1988 and 1989. Numerals indicate the numbers of individuals.

Species	Trapping (1988)	Trapping (1989)	Trawl net	Sledge net	Long line
POLYCHAETA					
Amphinomidae					
1. *Pherecardia* sp.	3				
GASTROPODA					
Cymatiidae					
2. *Distorsio* (*Rhysema*) sp.		1			
CRUSTACEA					
Aegidae					
3. *Aega* sp.	Many	Many			
Euphausidae					
4. *Euphausia* sp.				1	
Penaeidae					
5. *Penaeopsis eduardoi*			2		
Sicyoniidae					
6. *Sicyonia inflexa*			1		
Sergestidae					
7. *Sergia* sp.			2		
Pandalidae					
8. *Heterocarpus ensifer parvispina*	4				
9. *H. gibbosus*		3			
10. *H. laevigatus*	9				
11. *H. sibogae*	143	161	5		
12. *Plesionika edwardsii*	2				
13. *P. ensis*		1	2	1	
14. *P. ocellus*			3		
15. *P. spinensis*			3		
16. *P.* sp.1		2			
17. *P.* sp.2	2	12			
18. *P.* sp.3			1		
19. *P.* sp.4		23			
20. *P.* sp.5	1		2		
21. *Chlorotocus crassicornis*			1		
Crangonidae					
22. *Crangon* sp.1				1	
23. *C.* sp.2				1	
24. *Philocheras* sp.			3		
Diogenidae					
25. *Trizopagurus tenebrarum*	3	5			
26. *Paguropsis typica*	1	1			
27. *Clibanarius* sp.	2				
28. *Dardanus* sp.		1			
Paguridae					
29. *Pagurus* sp.	1				
30. *Pylopagurus* sp.				1	
31. *Cestopagurus* sp.				1	

Table 3-b. Continued.

Species	Trapping (1988)	Trapping (1989)	Trawl net	Sledge net	Long line
Galatheidae					
32. *Munida compressa*			1		
33. *M. squamosa*					
34. *M.* sp.					
35. *Paramunida scabra*			2		
Homolidae					
36. *Homola* sp.1	1	2			
37. *H.* sp.2	2				
38. *Paromola* sp.1		1			
39. *P.* sp.2			1		
Calappidae					
40. *Mursia* sp.			1		
Leucosiidae					
41. *Randallia* sp.		1			
Majidae					
42. *Cyrtomaia curviceros*		2			
43. *C.* sp.	1				
44. *Naxioides mammillata*		13			
45. *Leptomithrax* sp.		1			
Geryonidae					
46. *Geryon qranulatus*	8	1			
Goneplacidae					
47. *Psopheticus stridulans*		1		1	
OPHIUROIDEA				1	
Ophiomyxidae					
48. *Ophiomyxa australis*		1			
Ophiuridae					
49. *Stegophiura* sp.			2		
ASTEROIDEA					
Astropectenidae					
50. *Craspidaster* sp.			1		
ECHINOIDEA					
Temnopleuridae					
51. Temnopleurid sea urchin			1		
CRINOIDEA					
Colobometridae					
52. *Cyllometra manca*	1				
PISCES					
Muraenidae					
53. *Gymnothorax* sp.	2	1			
Muraenesocidae					
54. *Muraenesox cinereus*		1			
Synaphobranchidae					
55. *Synaphobranchus* sp.	4				
Congridae					
56. *Conger* sp.	7	5			

Table 3-c. Continued.

Species	Trapping (1988)	Trapping (1989)	Trawl net	Sledge net	Long line
Moridae					
57. *Physiculus* sp.	6				
Macrouridae					
58. *Ventrifossa macroptera*			1		
Ohidiidae					
59. *Neobythites stigmosus*			1		
Chaunacidae					
60. *Chaunax abei*			1		
61. *C. tosaensis*			1		
Ogcocephalidae					
62. *Malthopsis tiarella*			1		
63. *Halieutaea* sp.			1		
Serranidae					
64. *Plectranthias kamii*	4				
Scorpaenidae					
65. *Pontinus macrocephalus*					2
66. *Setarches longimanus*			1		
Peristediidae					
67. *Satyrichthys amiscus*			2		
Pleuronectidae					
68. *Poecilopsetta plinthus*			2		
Cynoglossidae					
69. *Symphurus orientalis*			1	2	

crab (Geryonidae), and deep-sea cod (Moridae). However, their captured numbers were low, ranging from 6 to 17 individuals. Thus, crustaceans seem to excel in numbers of both families and individuals in benthic fauna of the Palau Islands.

The thirty-five species were collected by trapping experiments in 1988 and 1989 (Table 3). The captured number of *Aega* species was very high, but this species was small in size (20-40mm in total length) and a scavenger. Therefore, this *Aega* species seems to be useless as food for *Nautilus*. Pandalid shrimp, *Hetrocarpus sibogae,* was most abundant in number (143 individuals in 1988 and 161 in 1989) among all captured species. Predominant species were *Plesionka* shrimp, *Naxioides mammillata, Conger* species, *Geryon granulatus, H. laevigatus, Trizopagurus tenebrarum,* and *Physiculus* species. Their total captured numbers were 40, 13, 12, 9, 9, 8, and 6 individuals, respectively. The captured numbers of the other species were below 4 individuals during the survey period.

The species captured by trawling experiment were classified into 19 families and 28 species. Of these, crustaceans (15 species) and pisces (10 species) dominated in number. The shrimp, *H. sibogae* and *Plesioika* species, were also collected by trawl, however, their captured numbers were rather low (below 5 individuals). the species caught by trawl differed from those caught by trap. The species were small fish with a low ability of locomotion, such as *Chaunax abeu, C. tosaensis, Malthopsis tiarella,* and *Halieutaea* species. Their captured numbers were 1 to 2 individuals of each. The difference in the results from the trapping experiment seem to be due to the sampling effect of the trawling experiment.

For collecting the smaller macrobenthos, sledging were carried six times on August 24 and 25, 1988. The specimens captured by sledge were classified into 6 families and 9 species. The majority of them belong to the crustacea class and were small species. Their captured numbers were several different individuals.

Comparing the benthic fauna caught in the present survey with those reported in the previous studies (Hayasaka *et al.*, 1982; Shinomiya *et al.*, 1985; Suzuki and Hayasaka, 1987), it is evident that the Palau Islands' specimens were poorer in number of individuals, but that faunal character is similar to those of the other localities, except for the Philippines, in having the pandalid shrimp as the predominant creature. In Tañon strait, the Philippines, sea urchins (*Malepia cordata* Mordensen) predominate, while in Fiji, the pandalid shrimp are dominant among the creatures associated with *Nautilus* (Hayasaka, *et al.*, 1982; Hayasaka, ed., 1985). Shrimps are also dominant in Palau.

Pandalid shrimps were regarded as one of the favorite foods of *Nautilus* in Fiji (Shinomiya *et al.*, 1985). Shinomiya *et al.* (1985) also showed that the individual number of *N. pompilus* was fairly correlative with that of *H. sibogae*, and suggested that the abundance of *H. sibogae* was one of the most important biotic factors in the habitat of *N. pompilius*. In the present study, the fauna of Palau had many individuals of *H. sibogae* and many nautili were caught by traps in the same area. The pandalid shrimp, *H. sibogae*, therefore, seem to be one of the favorite foods of *N. belauensis* in the Palau Islands.

2) Vertical distribution of each animal

The creatures, including *N. belauensis*, showed a zonation in their vertical distribution (Fig. 4). Many fish (Muraenessocidae, Muraenidae, Congridae, Serranidae, and Moridae) were distributed in region shallower than 200m. Some crustaceans and other invertebrates (*H. ensifer*, Diogenidae, Majidae, Homolidae, Colobometridae, Amphinomidae, Ophiomyxidae, and Cymatiidae) were also distributed in the same region. Of these, three crustaceans, *H. ensifer*, Diogenidae, and Majidae, were rather abundant in number of individuals. Another three crustaceans (*Cyrtomaia* species, Paguridae, and Leucosiidae) were distributed from 200m to 450m in depth. Aegidae and Geryonidae were distributed in the region deeper than 250m, and *H. gibbosus* and *H. laevigatus* were in the region deeper than 350m.

N. belauensis were distributed from 140m to 450m in depth, and this vertical range was about similar to that reported by Saunders (1984). Two types of pandalid shrimp, *Plesionika* species and *H. sibogae*, were also distributed in the same depth range. The former was abundant in number at 140m deep, while the latter was abundant in the range of 250-350m deep.

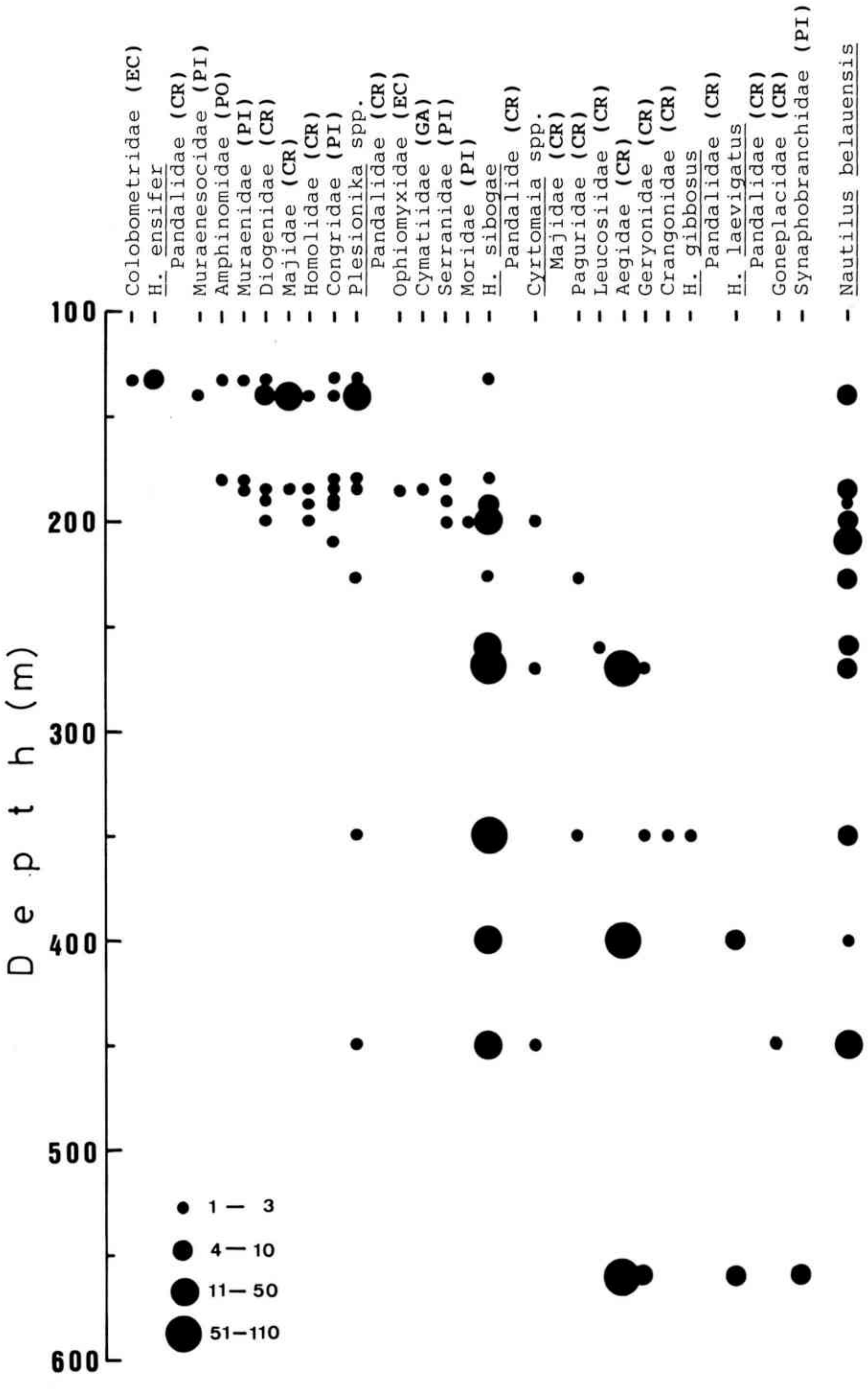

Fig. 4. Vertical distributions of each family and species collected by traps. (PO), (GA), (CR), (EC), and (PI) indicate Polychaeta, Gastropoda, Crustacea, Echinodermata, and Pisces, respectively.

Thus, the individual numbers of *H. ensifer*, majid crab (*Naxioides mammillata*), and *Plesionika* species were high in the region shallower than 200m. In the region from 200m to 400m deep, *H. sibogae* was abundant in number, and deeper than 400m, giant red crab and *H. laevigatus* were distributed in large numbers. The vertical ranges of these crustacean species were about similar to those reported by Saunders and Hastie (1989). These crustaceans, therefore, especially *H. sibogae*, are thought to be favorite foods for *N. belauensis* from the viewpoint of their vertical distributions.

3) Preliminary examination of the *H. sibogae* population

As *H. sibogae* was regarded as an important species in a study on fauna associated with *Nautilus*, some ecological aspects of this species were preliminary examined. *H. sibogae* had a wide range in their carapace length in the summer of 1988 and winter of 1989 (Fig.5). Females having a carapace longer than 25.0mm were

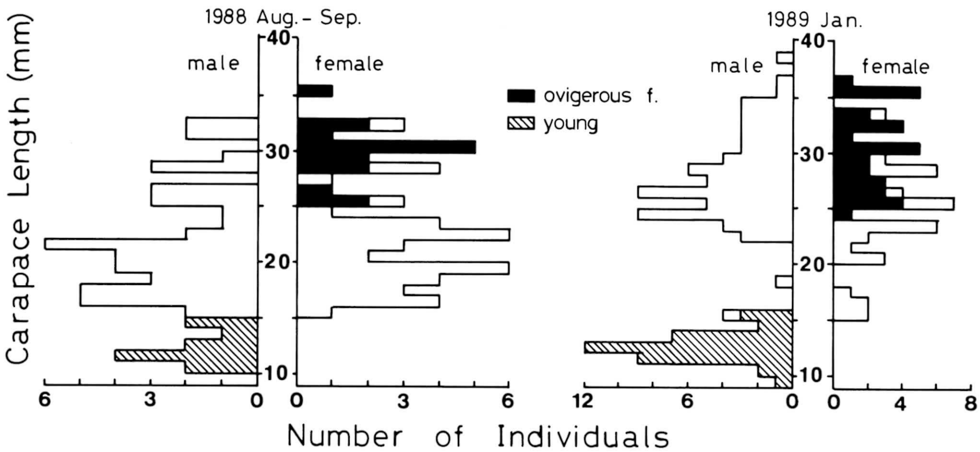

Fig. 5. Size-frequency distributions of *Heterocarpus sibogae* captured by traps in August and September of 1988, and in January of 1989.

Table 4. Total captured numbers and average carapace length (mm) of *Heterocarpus sibogae* for each trapping experiment. Y, M, and F indicate young, male, and female, respectively.

Year & Month	Trap No.	Captured no.			Average carapace length (STD)			Depth (m)
		Y	M	F	Y	M	F	
'88 Sep.	MU-T3		9	9		22.56(5.55)	27.73(3.86)	400
〃	T4	1			12.40(− −)			132
〃	T5	9	35	41	12.29(1.73)	22.19(4.57)	22.84(5.05)	270
〃	T9		1	1		21.10(− −)	19.15(− −)	228
〃	T10	1			12.00(− −)			180
'89 Jan.	T20	14	3	4	12.16(1.34)	27.35(3.40)	22.83(5.31)	260
〃	T25	9	47	51	12.75(1.38)	28.28(3.82)	28.07(4.85)	350
〃	T26	13	15	5	12.75(1.36)	26.37(4.91)	20.76(1.97)	450

mostly ovigerous in both seasons. Young shrimp with a carapace length below 15.0mm were collected in both seasons. Considering the appearance of young and ovigerous shrimp in summer and winter, the reproductive and mating seasons seem to be long.

Except for young shrimp, the size-frequency distribution in the summer of 1988 showed a bimodal shape with the modes around 21mm and 30mm in both sexes. On the contrary, that in the winter of 1989 is composed of shrimp larger than 22.0mm in carapace length. The summer of 1988, the majority of *H. sibogae* were collected at the bay mouth station (MU-T5; 270m deep, Table 4), while in the winter of 1989, most shrimp were collected in the inner bay (at MU-T25 and T26; 350m to 450m deep). Therefore the difference in size-frequency between the two seasons seems to be due to the different locations or depths, but not to substantial growth, considering that the water temperature is below 13℃ throughout the year. There is a possibility of different habitats between the population of small size shrimp and that of large size. For clarifying this point, however, it is necessary to make a much more detailed survey of the *H. sibogae* population.

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