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On the ecology of sand shrimp *Crangon affinis* DE HAAN, as a prey of the damersal fishes in Sendai Bay

by Masaya Kosaka

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On the ecology of the sand shrimp, Crangon affinis DE HAAN, as a prey of the demersal fishes in Sendai Bay*

Masaya KOSAKA

* Publication No. A42 from the Faculty of Oceanography, Tokai University. Received on November 20, 1969. A portion of this study was presented at the Annual Meeting of the Japanese Society of Scientific Fisheries which was held in Tokyo on April 6, 1960.

(p.59)

Abstract

The sand shrimp, *Crangon affinis* DE HAAN, is a small sized shrimp inhabiting coastal waters surrounding Japan. Though little used for human consumption, the sand shrimp seems to support biological production of many demersal fishes. Manifestation of the ecological properties of the shrimp, therefore, is required understanding prey-predator relationships in the demersal animal community.

The shrimps sampled by a small trawl net from estuary of the Natori River, located at north-western coast of Sendai Bay, during February 1959 through February 1960.

Investigations of the predatory species are based on stomach contents of 37 fish species taken from the estuary during 1959 through 1960, and 95 fish species and one hybrid fish from Sendai Bay during 1961 through 1964.

The major results are summarized as follows :

1. The shrimp population consists of short-term generation for about ten months and long-term generation for about fourteen to nineteen months.
2. The short-term generation is spawned in August and September by the large-sized adult members of the long-term generation having occurred early in the year. Members of the short-term generation grows continuously until they mature in the spring. Females bearing eggs are found during late January through April. The adults females are 30 mm, and males 20 mm on the average.
3. Both the long and short-term generations in a year produce the long-term generations of the next year.

The spawning season extends between late November and May. The parent stocks comprise large-sized adults of the long-term generation and small-sized ones of the short-term generation. The long-term generation consists of three groups ; early, middle, and late born ones. Each group grows rapidly in spring and early summer. The growth rate decreases with rise of temperature. The shrimps grow only little during July through October when the water temperature rises above 16°C, but again rapidly in November to January.

The egg bearing females, 42—53 mm in body length, appear from the end of November to May. They increase in number in December, February, April. Average body lengths of the largest members of each group are as follows ; 49 mm, 42 mm, 38 mm in females, and 33 mm, 30 mm, 27 mm in males respectively.

4. The shrimp mainly eat small sized benthic animals, namely amphipods, isopods, and polychaetes throughout the year. Sand and mud particles occur in all the stomachs with food.
5. The feeding activity seems to decrease in summer season.
6. The predators are eight species among 37 species from estuary of the Natori River, and 29 species among 95 species and one hybrid from the Sendai Bay.

   The most important predatory fishes are *Acanthogobius flavimanus* in the estuary, and *Lepidotrigla microptera, Liparis tanakai, Eopsetta grigorjewi* in Sendai Bay.
7. Rearing experiments show that the shrimp is of nocturnal habit. But the trawl net catch does not differ between day-time and night.
8. The shrimps changes their habitat from season to season. They move from the inshore to offshore waters during April through June, stay in the offshore waters during July through September, immigrate into the inshore waters during October through December, and are concentrated there during January through March.

I Introduction

(p.6(

The sand shrimp Crangon affinis DE HAAN is a small-sized shrimp and is widely distributed in coastal waters of Japan, especially in inland seas and bays. This species is found in the largest number among all species of shrimps in Tokyo Bay (KUBO, et al., 1957). In Kasaoka Bay of the Inland Sea of Seto, not only the number but also the weight of C. affinis are the largest among all shrimps (YASUDA, 1957).

In Sendai Bay sand shrimp are commonly seen in the area of less than a depth of 70 m and are reported to be found in Matsushima Bay and the inlet of Bankoku (SATO, 1957; KURATA, 1963), both of which are located inshore in Sendai Bay. Sand shrimp, though their number shows considerable seasonal variations, are also found throughout the year in the estuary of the Natori River that runs into Sendai Bay.

Every year in July and August small fisherboats (3-5 tons) operate in the area of less than a 40-m depth in Sendai Bay, and sand shrimp are caught together with young flatfish, *Rhinoplagusia* spp. and other species of shrimps. According to the statistical data of the fish catch for a 12-year period between 1949 and 1960 at Port Tokiage, the annual haul of shrimp by small fisherboats varied from 1 to 7 tons. Although the data on the catch of individual species of shrimps are not available, our surveys of the shrimp which were caught in the neighboring sea areas have shown that *C. affinis* is in the largest number, followed by *Metapenaeopsis dalei*. These two species of shrimps represented about 80-90% of the shrimp species caught. Other species of shrimp found were *Trachypenaeus curvirostris* and *Alpheus japonicus*, but *Penaeus japonicus* was caught in very small number.

Despite its abundance, *C. affinis* is of low commercial value, since it is small and is covered with hard shell, and thus is not considered important from the viewpoint of fishery. Nevertheless, this species may serve as a prey of a number of useful benthic fish inhabiting Sendai Bay, since sand shrimp have been frequently found in the stomach of these fish. Indeed, *C. affinis* can be a species of importance to form a fundamental food chain among the benthic animal community. Therefore it was deemed necessary to study ecological characteristics of this species of shrimp to analyse the nature of the chain formed between C. affinis and benthic fish; i.e., the prey-predator relationship.

The present report describes the results of the ecological study in which spawning, growth, feeding habit, species of predators, diurnal activity and seasonal migration of C. affinis were examined. (p.61)

The author is grateful to Dr. M. Hatanaka, Professor of Tohoku University, and to the late Dr. I. Kubo, Professor of Tokyo Fisheries College, for their guidance and to Dr. J. Nakai, Professor of Tokai University for his critical reading of the manuscript.

II Materials and Methods

When a commercial fisherboat operating in Sendai Bay was hired to sample sand shrimp, meshes of the fishing net were too coarse so that only a small number of large-sized individuals were collected along with large quantities of large-sized benthic animals such as starfish and sea urchins. Although a large number of samples of various sizes could be secured from the hauls obtained in small fisherboats, it was impossible to collect the samples throughout the year, since the operation of these small fisherboats is limited to only two months of a year, July and August. These limitations necessitated the selection of a few sampling stations in a rather wide test area containing the inlets of Ido and Hiro, both of which are located in the estuary of the Natori River, and the main course of the Natori River (Fig. 1).

The inlets of Ido and Hiro were formed as a result of meandering of the Natori River, are largely less than 1.5 m deep and become less than 1 m deep at low tide. Useful fishes inhabiting in these areas are an icefish Salanx microdon, a dace Leucisus hakonensis, an eel, a gray mullet Mugil japonicus, a sea bass Lateorabrax japonicus, a black porgy Mylio macrocephalus, Acanthogobius flavimanus, a flathead Platycephalus indicus, a halibut Paralichthys olivaceus, a spotted plaice Verasper variegatus, Platichthys stellatus and Kareius bicoloratus. However, freshwater fish are seldom found. These species of fishes are the object of commercial or recreational fishing. Of the shell (p.(

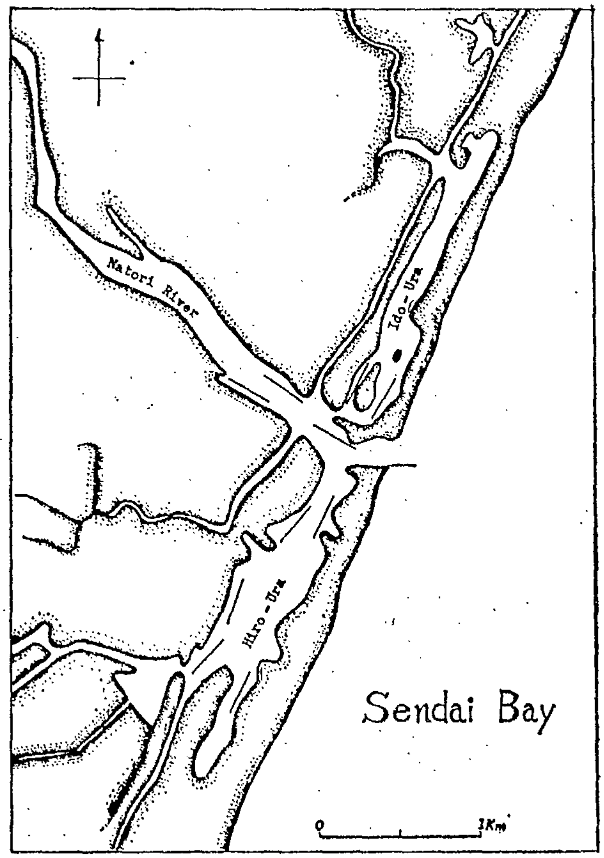

Fig. 1 Map of estuary of the Natori River showing the sampling station of materials.

fish, a Japanese littleneck Tapes japonica, an oyster Osterea gigas and Corbicura atrata are commonly found. Every year from fall to winter the operation of commercial laver culture is conducted in the inlet of Hiro. Judging from the distribution pattern of these many forms of life, considerable quantities of sea water appear to be flown into these estuarial areas.

Sampling of sand shrimps in the test area was conducted twice a month for a one-year period between February 1959 and February 1960. A Japanese minnow net with 3 mm meshes was trawled at a distance of approximately 300 m. At each sampling time one trawling was carried out at 7-10 sites in each one of the three areas; i.e., the inlets of Ido and Hiro and the main course of the Natori River. Also on November 20 and 21, 1959, sampling was hourly conducted in the inlet of Hiro to examine the difference in the catch between day and night. All the sand shrimps collected were immediately fixed in 10% formalin.

A total of 53,273 sand shrimps were sampled during this period. The sex of individual shrimps was determined by the shape of the first and second inner pleopods. The body length (distance from the rear rim of the eye-socket to the tip of the telson) which was determined on 9,720 shrimps, varied from 5.8 to 53.9 mm. Portions of the 9,720 shrimps were also used for the measurement of the body weight, examination of the stomach contents and counting of the number of eggs held by a single female.

In order to examine the species of the predators of C. affinis, large numbers of fish were caught in the estuary of the Natori River at the same time as sand shrimp were sampled and at different times by other means. Also fish were collected in Sendai Bay by a few chartered commercial fisherboats. Patterns of the seasonal distribution and migration of sand shrimp were estimated from the feeding habit of the main predatory fish of C. affinis. Furthermore, the diurnal activity was examined by observation of a few sand shrimps reared in an aquarium.

III Results

III-1 Spawning

The spawning season of C. affinis was estimated by examining the occurrence of those female shrimps which were bearing eggs. The number of egg-bearing females and the occurrence rate of these females (the number of egg-bearing females/the number of total females) at each sampling time are described in Table 1. The occurrence rate of egg-bearing females was 3.9% on August 3 and 1.4% each on September 3 and 7. Examinations of individual eggs held by the females revealed that most of the eggs had not developed the eyes and hence were considered immature ones. The body length of the egg-bearing females on these dates was 30-31 mm. Judging from the growth curve of C. affinis (which will be described later), these females appeared to be among the largest of members belonging to L_2 group of a long-term generation. The

Table 1. Change of the occurring condition of the females bearing eggs by date and by body length.

Date \ Body length (mm)	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	No. of egg bearing females	Total number of females	Occurring percentages of egg bearing females
Ⅱ-13			1														1	1	1		1			1		6	228	2.6
Ⅱ-27		1																1				1				3	278	1.1
Ⅲ-10																										0	134	0.0
Ⅲ-20																										0	133	0.0
Ⅳ-15		1													1			3	1		1		1			8	212	3.8
Ⅳ-27																										0	242	0.0
Ⅴ-15																		1								1	210	0.5
Ⅴ-27														1												1	124	0.8
Ⅵ-13																										0	65	0.0
Ⅵ-25																										0	60	0.0
Ⅶ-16																										0	4	0.0
Ⅷ-3		2	1																							3	78	3.9
Ⅷ-17																										0	53	0.0
Ⅸ-3·7		1																								1	74	1.4
Ⅸ-25·30																										0	17	0.0
Ⅹ-9																										0	85	0.0
Ⅹ-26																										0	136	0.0
Ⅺ-12																										0	299	0.0
Ⅺ-20															1	1										2	237	0.8
Ⅻ-2																										0	31	0.0
Ⅻ-10															1				2	2	2		1			8	260	3.1
Ⅻ-25																	1									1	94	1.1
Ⅰ-12																										0	120	0.0
Ⅰ-14																				1						1	282	0.4
Ⅰ-26			1														1		1			2			1	6	209	2.9
Ⅱ-16		1	1																							2	144	1.4

water temperature in the months of August and September was $22-24^{o}$ C, and the number of eggs born by a single female ranged from 531 to 658.

After September 7 no egg-bearing female was seen until mid November. Thereafter egg-bearing females reappeared in the sample population and the occurrence of these females continued, though intermittent, until late May of the following year. These females were fallen into two categories according to their body length; 30-31 mm and 42-53 mm. Those individuals in the second category apparently belong to either one of groups L_1, L_2 and L_3 of the long-term generation (see the section of Growth - Translator's note). The water temperature between November and May varied from 3 to 14^{o} C. The number of eggs carried by one female ranged from 1,623 to 3,197 and these numbers are much higher than those counted for the egg-bearing females found in August and September. The occurrence rate of egg-bearing females showed high values in December, February and April. This suggests that during the period between November and May there are three peaks of spawning. The presence of the three spawning peaks appear to correspond to the presence of three different growth groups in the population of the long-term generation. Also during the same period small-sized egg-bearing females appeared from late January to April. These females must have developed from the eggs spawned in summer and are likely to be the members of a short-term generation (see the section of Growth - Translator's note). The number of eggs born by a single small-sized female ranged from 481 to 763. The water temperature during the period between late January and April varied from 5 to 12^{o} C.

These observations indicate that the spawning season of C. affinis extends over a rather long period starting August and ending May of the following year. However, this spawning season consists of a few periods during which each of females of different generations and/or development spawn. In August and September female members of group L_2 of the long-term generation spawn. It is reasonable to assume that spawning by the members of L_3 group also takes place at this (p.64) time. However, since the members of L_3 group migrate offshore from the test area in summer, no individual of this group was sampled, and accordingly this assumption could not be confirmed. Between November and May females belonging to each one of the three groups of the long-term generation and those of the short-term generation spawn. Judging from the size composition of the sample population and from the number of eggs borne by a single female, the main spawning season of C. affinis appears to be in a period between December and April. The low over-all occurrence rate of egg-bearing females in the test area may indicate that spawning of C. affinis takes place seldom in the estuary but mainly in the offshore area of Sendai Bay.

III-2 Growth

The growth pattern of C. affinis was estimated by examining the frequency distribution of the body length of a total of 9,720 male and female shrimps at each sampling date. However, the pattern of the distribution was found very complex due to the long spawning season during which apparently more than one spawning took place. Hence calculations of the mean or mode values from the original data were deemed meaningless. Since in the present case the pattern of a single frequency distribution was likely to consist of a few distributions arising from groups of different development, the original data were arranged using normal probability graph papers according to the method of HARDING (1949) to separate individual constituent normal distribution curves. The mean value of each curve was calculated for each sampling date to produce growth curves which are demonstrated in Fig. 2.

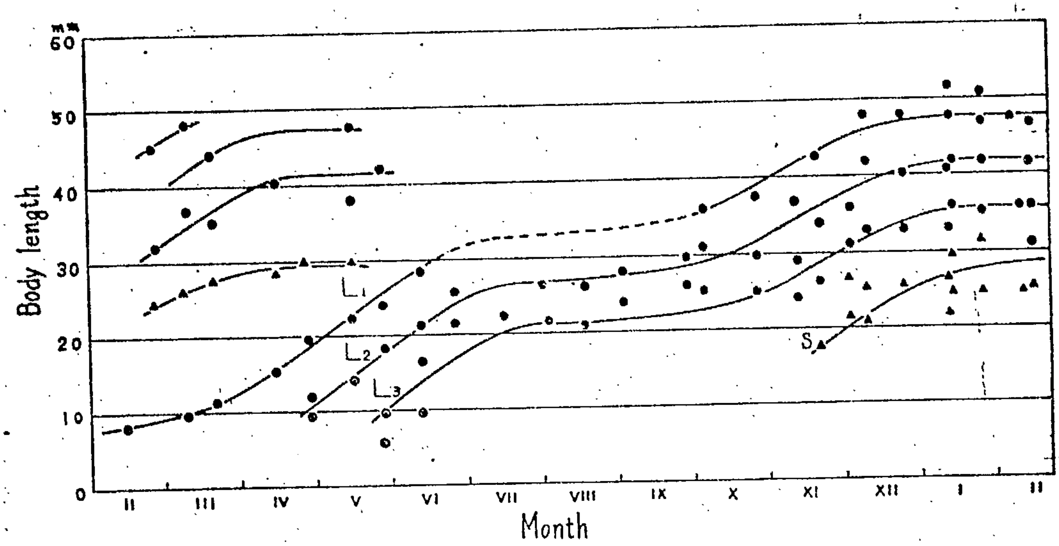

Fig. 2-1 The growth curve of female *Crangon affinis* based on the average body-length of the two generations and each group, separated by using Harding's method.

●: the long-term generation. ▲: the short-term generation.

⊙: sex uncertain. L_1, L_2, L_3 ; early, middle and late born group found in the long-term generation

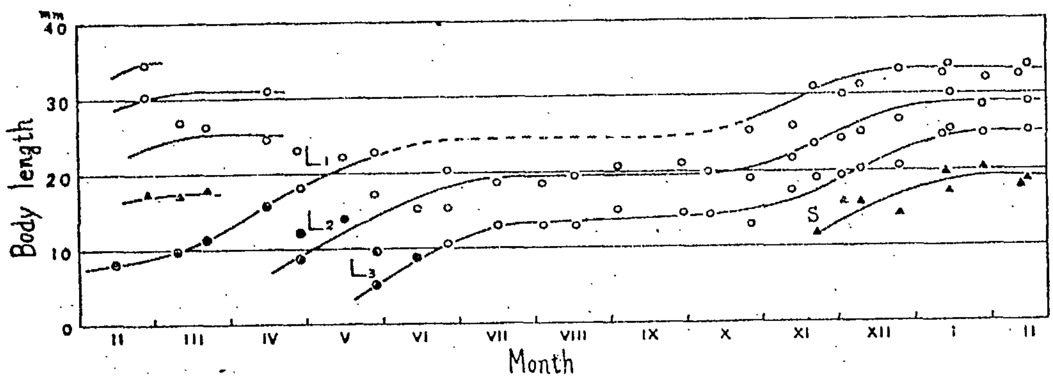

Fig. 2-2 The growth curve of male *Crangon affinis*.
Others are the same as in the case with the Fig. 2-1.

Young shrimp, 6-13 mm in body length, appeared at first on February 13, then on April 27 and again on May 27. At the times of the first appearance all of these young were in the sexless form in which no secondary sex characteristic is apparent. These individuals are herein grouped into L_1, L_2 and L_3, according to the order of the date of the appearance. At the time when the secondary sex characteristics of these individuals became distinct, the average body lengths of groups L_1, L_2 and L_3 were more than 15 mm, more than 13 mm and more than 9 mm, respectively. Also at the same time in each group there was a clear difference in the body length between the male and female; the female being larger than the male. When the water temperature reached 16-18° C in June, members of L_2 group moved from the test area to Sendai Bay (p.65) and no sample of this group was obtained. The growth rate of the members of the other two groups became extremely slow. Since the number of individuals belonging to these two groups sampled during summer months showed the lowest value of all year, many of them were considered also to move offshore. When the water temperature cooled to 15-17^{0} C in October, the numbers of shrimps of groups L_1, L_2 and L_3 were increased, indicating their return to the test area. Females showed a rapid growth from October to November and thereafter their growth appeared to be halted. Males also showed a rapid growth from November to mid January and then became extremely slow in growth. In each group the time when the growth of the members declined, corresponded to the spawning season. Such a life cycle is termed herein 'a long-term generation'.

Young shrimp hatched from the eggs which were produced in August and September appeared after November 20. At the time of the first appearance these already possessed distinct secondary sex characteristics. They continue to grow until mid January and female members spawn from late January to late April. This life cycle is called a 'short-term' generation.

Apparently the population of C. affinis consists of individuals of long and short-term generations, and the growth pattern is different between the two. Furthermore, three groups of different development, L_1, L_2 and L_3, were recognized among the sample population of the long-term generation. The average body lengths of full-sized female and male members were 49 mm and 33 mm in group L_1; 42 and 30 mm in L_2; and 38 and 27 mm in L_3, respectively. On the other hand, the corresponding values for those of the short-term generation were

30 and 20 mm, respectively.

The life-span of *C. affinis* was estimated to be 1.3-1.7 years for the long-term generation but about 0.9 years for the short-term generation.

Of all the individuals sampled, 8,511 (87.6%) were those of the long-term generation, whereas 1,209 (12.4%) belonged to the short-term generation, indicating the predominance of the former in the population.

In the population of the long-term generation the numbers of females and males were 2,952 and 4,864, respectively, the sex ratio being 1.65. However, those were 857 and 352 in the short-term generation and thus the sex ratio becomes 0.41. No reasonable explanation can be offered at present for this large difference in the sex ratio between the long and the short-term generation.

III-3 Feeding Habit

In March, April, May, July, September, October, December and January 20-30 shrimps (total number was 220) were chosen from those individuals in which stomach contents were recognized, and used for the analysis of their stomach contents. Throughout the observation period benthic amphipods and isopods were the main constituents of the stomach contents, both of which representing 58%, followed by polychaetes (20%). Other animals found were mysid shrimp (3%), copepods (3%), squillae (2%) and fish eggs (*Chaenogobius castanea* ?, 1%). The contents of plant origin represented 12% and consisted of

4% each of Myxophyceae, diatoms and algae. In large numbers of the samples, in addition to these forms of life, sand and mud particles were always seen in the stomach along with food. (p.66)

As described above, C. affinis eats a variety of animals and plants. However, it feeds on small-sized benthic crustaceans such as amphipods and isopods, and polychaetes. No seasonal variation was recognized in the feeding habit of sand shrimp.

The diurnal feeding activity of C. affinis was examined on those individuals which were hourly sampled on November 20 and 21, 1959. At each sampling time 50 shrimps were chosen, the number of those which contained food in the stomach was counted and the rate of occurrence of food-ingested shrimp was calculated (Fig. 3).

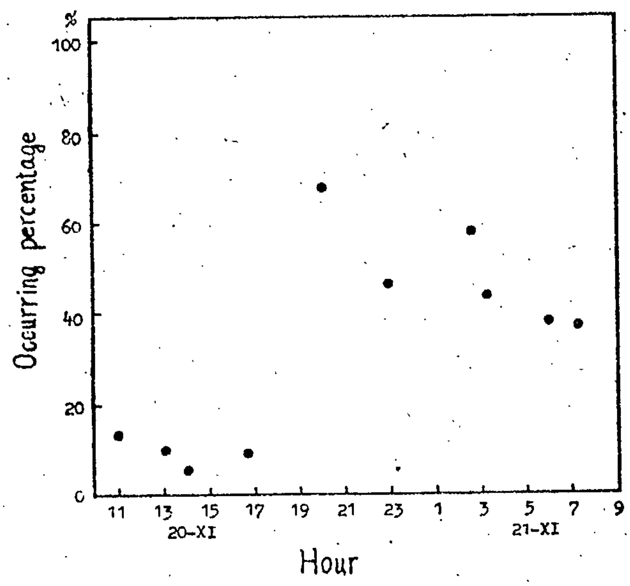

Fig. 3 Diurnal change of the occurring percentage of the stomachs containing food against the total number of the stomachs examined.

The rate remained low between 11 and 17 hours, the values being 6-13%, but rose to high values ranging from 37 to 68% between 21 hours and 7 hours of the following day. The highest value occurred about 20 hours, then the rate tended to decrease toward morning. It appears that C. affinis feeds seldom in the daytime but actively between dusk and dawn.

The daily feeding activity of the sand shrimp was observed in those individuals which were reared in an aquarium. During the day they hid themselves in the sand and stayed resting but moving only the antennae. About one hour before sunset they appeared on the sand surface and 1-2 hours after dark briskly walked on the sand or actively swam in the water. At this time no individual was seen hiding itself in the sand. Also some of the shrimps were observed eating food. Thereafter these activities subsided, and at midnight a majority of the individuals were staying motionless on the sand. In the morning after sunrise all individuals were seen again hiding themselves in the sand. Hence it is reasonable to assume that under natural conditions sand shrimp rest in the sand in the daytime but are active and feed in the nighttime, especially 1-2 hours after sunset.

The occurrence frequency of those shrimps which contained food in the stomach varied from 20 to 75% between February and June, from 3 to 26% between July and early October and from 26 to 55% between late October and January. The feeding activity was less in the period between July and October, during which no active growth was seen, than in any other period of the year.

III-4 Predators; Species and Status (p.67)

The species of fishes which were sampled in the inlets of Ido and Hiro and the main course of the Natori River between February 1956 and February 1960, amounted to 37. Analyses of the stomach contents of these fishes have shown that the following 8 species prey on C. affinis: a black porgy Mylio macrocephalus, Tridentiger obscurus, Aboma lacticeps, a goby Acanthogobius flavimanus, Chaenogobius castanea, a dragonet Platycephalus indicus, Platichthys stellatus and Kareius bicoloratus. Of these 8, M. macrocephalus was caught for a period of 4 months between August and November, T. obscurus for 7 months (March - June and September - November), Platichthys stellatus for 6 months (March - August), K. bicoloratus for 9 months (January - July and September - October), whereas other four species of fishes were caught throughout the year as C. affinis.

When the occurrence frequency and the occurrence rate of each one of the 8 species of fishes were calculated from the data of a total of 158 trawlings between February 1959 and January 1960, the following results were obtained: Aboma lacticeps 89 (56.0%), Acanthogobius flavimanus 129 (81.1%), C. castanea 79 (50.0%), Platycephalus indicus 40 (25.1%), M.

macrocephalus 24 (15.1%), T. obscurus 32 (20.1%), Platichthys stellata 20 (12.5%), and K. bicoloratus 48 (30.2%). Considering from the period and rate of the occurrence, Acanthogobius flavimanus appears to be the most important predator of C. affinis, followed by Aboma lacticeps, Chaenogobius castanea and Platycephalus indicus in decreasing order of importance.

When the monthly occurrence frequency of each species was examined from the 1959-1960 data, M. macrocephalus appeared only in September, T. obscurus in May and October, Aboma lacticeps in May and June, Acanthogobius flavimanus every month of the year, C. castanea in March, April, September and November, Platycephalus indicus in May, September and November, Platichthys stellatus in May and October, and K. bicoloratus from April to June. The occurrence frequency rate of these predators was high in spring (April to June) and fall (September to November). Only one species of fish, Acanthogobius flavimanus, preyed on C. affinis throughout the year. The body length of those sand shrimps which had been ingested by the predators varied from 5 to 33 mm, but no individual which was larger than 33 mm, was found in their stomach. In each of these predators the fish tended to eat larger sand shrimp as the size of the fish increased. However, in M. macrocephalus, T. obscurus, Aboma lacticeps and C. castanea all of the shrimp found in the stomach were less than 20 mm in body length.

These findings clearly indicate that Acanthogobius flavimanus is the most important predator of C. affinis in the test estuarial area. When the occurrence frequency rate of fish which had ingested sand shrimp [(no. of sand shrimp-ingested fish/no. of food-ingested fish) x 100] was calculated on the monthly basis for this species, the results were as follows: 4.8% in February, 4.4% in March, 16.3% in April, 14.8% in May, 11.6% in June, 6.3% in July, 31.4% in August, 13.8% in September, 5.4% in October, 6.1% in November, 4.8% in December and 2.1% in January. The values between April and October were considerably higher than those during the rest of the year, indicating that in this species the predatory activity is high during the former period.

None of the 8 predatory species of fishes completes its life in the test area. In other words, these species utilize the area only at a certain stage of their life cycle probably as a spawning ground, a growing ground for the fry or a habitat for the mature individuals. Hence their predatory period and degree will be determined by both the time at and the extent to which the living territories of the sand shrimp and the predators overlap, by the stage of development of the two parties in that particular period and by the availability of other species of living food.

In order to examine the species of predatory fish of <u>C. affinis</u> in Sendai Bay that is considered the main habitat of the sand shrimp, a few surveys were conducted between 1959 and 1964. The results have shown that the following benthic fishes prey on the sand shrimp: <u>Mustelus manazo</u>, a horse mackerel <u>Trachurus japonicus</u>, a sea bass <u>Lateolabrax japonicus</u>, Nibea mitsukurii, Argyrosomus argentatus, Sebastes vulpes, S. oblongus, Hexagrammos otakii, a dragonet Platycephalus indicus, Hemitripterus villosus, Occa iburia, Chelidonichthys kumu, a gurnard Lepidotrigla microptera, Liparis tanakai, a halibut Paralichthys olivaceus, Pseudorhombus pentophthalmus, Cleisthenes pinetorum herzensteini, Eopsetta grigorjewi, a spotted plaice Verasper variegatus, V. moseri, Limanda herzensteini, L. yokohamae, Platichthys stellatus, Kareius bicoloratus, Tanakius kitaharai, Rhinoplagusia japonica, Areliscus joyneri, Lottella maximowiczi and a cod Gadus macrocephalus. These predatory fish amount to 29 species which represent 30.5% of all the benthic fish species inhabiting in the trawling ground of Sendai Bay. (p.68)

From the results of surveys conducted between April 1962 and March 1964, the monthly occurrence of the predatory fish species were found to be in 1962, 8 species in April, 9 species in May, 7 in July, 13 in August, 9 in September, 4 each in October and November, 3 in December; in 1963, no species in January and February, 3 in March, 11 in August, 8 in September, 4 in October, none in November, 7 in December; and in 1964, 2 in Janaury, 1 on February and 2 in March. Hence in a period between April and September a large number of predatory fish species appeared but in another 6-month period the occurrence was low.

Since these predatory fish species varied considerably in body length and in predatory activity, the size of the sand shrimp ingested by the predators also showed large variations, ranging from 6 to 58 mm in length. In other words, individuals of all developmental stages were ingested by the predators.

In order to analyze the relationship between the sand shrimp and those predators, the inhabiting density and season of each predatory species in the trawling ground of Sendai Bay were estimated from the data collected between April 1962 and March 1963. The average number of individual fish in a single haul was taken as an index of the density, whereas the frequency of the appearance as an index of the season. These results were combined and arranged by the quadrant graph method of ONO (1961) to produce Fig. 4. According to this figure, the 29 predatory fish species are classified into 3 groups; those in group 1 showed higher than average values in both the number of individuals per haul and the appearance frequency and these are Limanda herzensteini, L. yokohamae, Lepidotrigla microptera and Kareius bicoloratus. The species in group 2 had a lower than average value in the number of individuals per haul but a higher than average value in the appearance frequency, and contain 8 species, Paralichthys olivaceus, Eopsetta grigorjewi, Areliscus joyneri, Liparis tanakai, Hemitripterus villosus, Platycephalus indicus, Hexagrammos otakii and Verasper variegatus. The rest of the species is included in group 3 in which both the number of individuals per haul and the appearance frequency are lower than the average values. Hence the predators which have

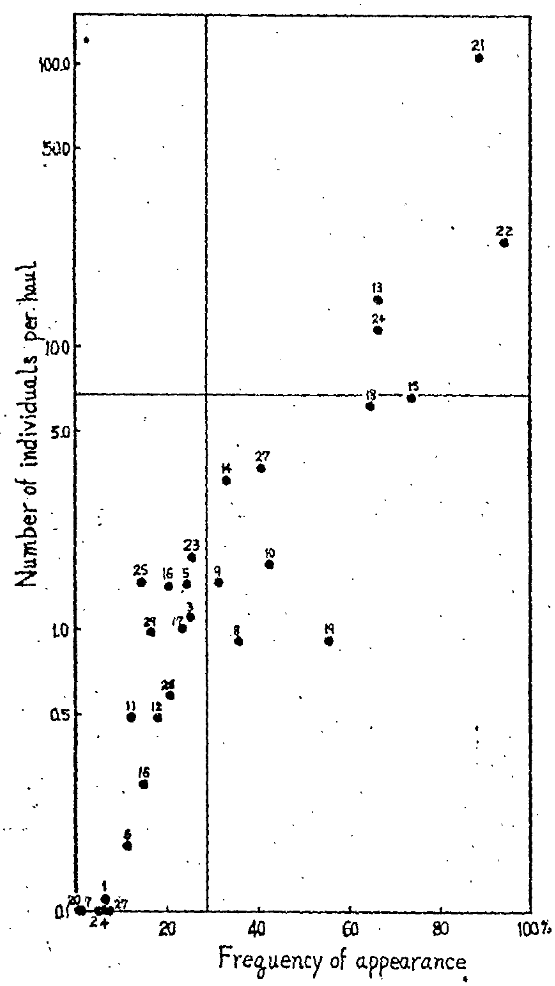

Fig. 4 Quadrant graph of the abundance and frequencey of the 29 predatory fish species for the *Crangon affinis* in Sendai Bay.

Species :

1. *Mustelus manago*
2. *Trachurus japonicus*
3. *Lateolabrx japonicus*
4. *Nibea mitsukurii*
5. *Argyrosomus argentatus*
6. *Sebastes vulpes*
7. *Sebastes oblongus*
8. *Hexagrammos otakii*
9. *Platycephalus indicus*
10. *Hemitripterus villosus*
11. *Occa iburia*
12. *Chelidonichthys kumu*
13. *Lepidotrigla microptera*
14. *Liparis tanakai*
15. *Paralichthys olivaceus*
16. *Pseudorhombus pentophthalmus*
17. *Cleisthenes pinetorum herzensteini*
18. *Eopsetta grigorjewi*
19. *Verasper variegatus*
20. *Verasper moseri*
21. *Limanda herzensteini*
22. *Limanda yokohamae*
23. *Platichthy stellatus*
24. *Kareius bicoloratus*
25. *Tanakius kitahari*
26. *Rhinoplagusia japonica*
27. *Areliscus joyneri*
28. *Lottella maximowiczi*
29. *Gadus macrocephalus*

a close relation with C. affinis are fishes of groups 1 and 2.

When the predatory status of each one of the 12 species of fish belonging to groups 1 and 2 was examined (Table 2), the occurrence frequency rate of sand shrimp-ingested fish varied from 0.09% for Limanda herzensteini and L. yokohamae to 49.6% for Lepidotrigla microptera. Since Lepidotrigla microptera, Liparis tanakai and Eopsetta grigorjewi showed considerably high values for the rate, these three are considered the most important predators of C. affinis. An ecological chain ring formed between these three predatory fish species and the sand shrimp and its seasonal changes will be described elsewhere.

III-5 Seasonal Migration

Since the pattern of seasonal migration of C. affinis could not be easily searched by any direct means, an indirect approach was made in which the monthly data of the average number of sand shrimps per haul and those of the occurrence of sand shrimp in the stomach contents of the main predatory fish species which were caught at known sites of Sendai Bay, were combined.

In the present study sampling of C. affinis in the estuary of the Natori River was conducted in the daytime throughout the year except for February in which the specimens were collected in the nighttime (at flowing tide). Since it was deemed possible that the hour of sampling, especially the tidal level, might affect the catch of the specimens, the data

Table 2. Predatory status of the dominant and common species for the *Crangon affinis* in Senday Bay.

Predatory species	Total number of fish examined	Number of fish with food	Number of fish eaten *Crangon affinis*	Occurring percentage of fish eaten *Crangon affinis*
Limande herzensteini	2,665	1,120	1	0.09
Limanda yokohamae	2,145	1,074	1	0.09
Lepidotrigla microptera	795	621	308	49.60
Kareius bicoloratus	599	115	1	0.87
Paralichthys olivacens	425	190	1	2.11
Eopsetta grigorjewi	349	242	4	37.60
Arcliscus joyneri	254	22	91	4.54
Liparis tanakai	253	227	100	44.05
Hemitripterus villosus	108	57	1	1.75
Platycephalus indicus	96	21	6	28.50
Hexagrammos otakii	61	58	5	8.60
Verasper variegatus	81	60	18	30.00

obtained on November 20 and 21, 1959, were supplemented with the statistical data of the tidal levels on the same days to yield Fig. 5. In the daytime the catches at ebbing tide, low tide and flowing tide ranged from 306 to 485 shrimps per haul and did not show any significant difference among the different tidal levels. On the other hand, in the nighttime the catch at ebbing tide varied from 641 to 781, the value being about 1.3 - 2.6 times those at the same tidal levels in the day. At low tide and also an early part of flowing tide the catches were minimal, the number of shrimps being 102 - 118, and were only from 0.21 to 0.39 times those in the daytime. In other words, the catch increased at ebbing tide but decreased (p.71

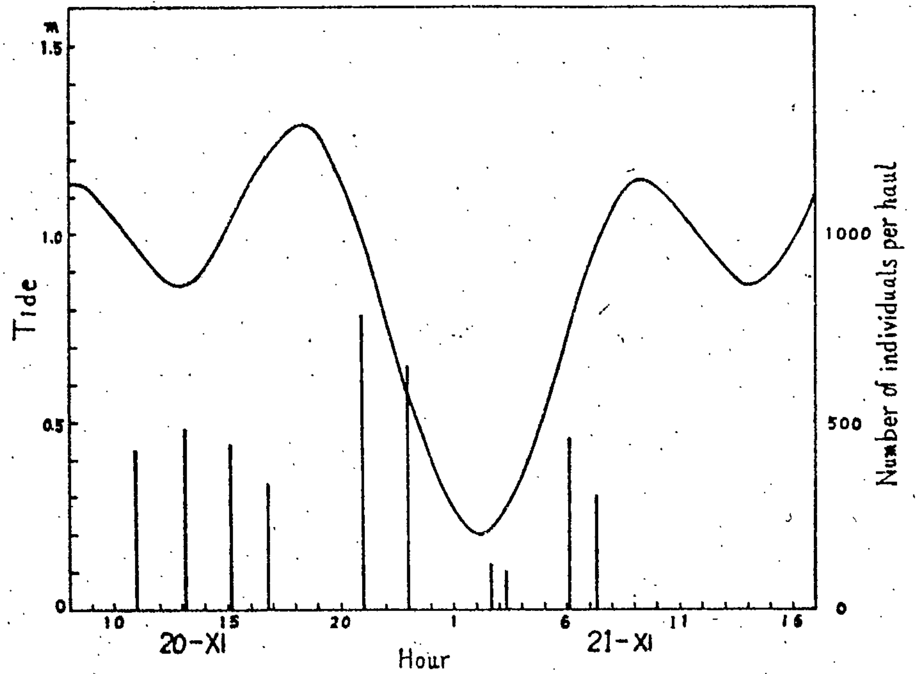

Fig. 5 Variations in the catch of the *Crangon affinis* with a small trawl trawl net in relation to tidal level and time of the day.

at low tide in the nighttime. However, the catches at other times of the day remained almost unchanged regardless of the tidal level. Hence the number of shrimps found in a single haul at any time of the day can be regarded as the number of individuals inhabiting in the sampling area at that time.

The average number of individual shrimps per haul was relatively small between May and early November, thereafter showed an increase toward February, decreased in March and rose to the highest value in April (Fig. 6). It appears that these changes are controlled by the life cycle of C. affinis itself as well as by alterations in nonbiological environmental conditions, especially water temperature. The number

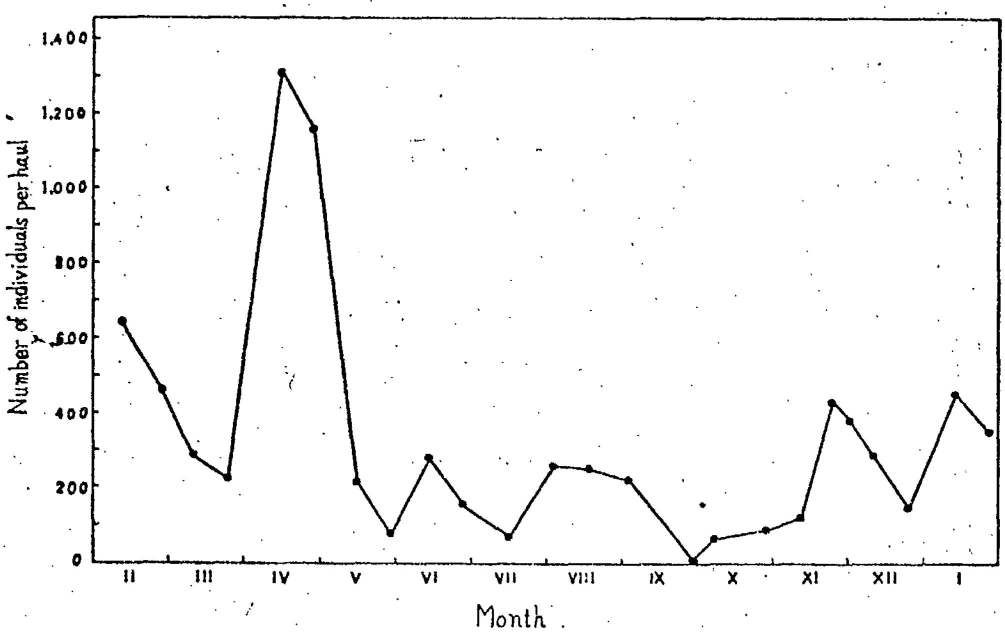

Fig. 6 Month-to-month change of the number of the shrimp catch per haul from estuary of the Natori River, during February 1959 through January 1960.

of sand shrimps inhabiting the test area was small during a period between May and late November when the water temperature remained relatively high. As has already been described under section III-2 (Growth), the members of group L_1 of the long-term generation move offshore to disappear completely from the test area between June and October. Also those of other groups of the same generation were found only in small numbers and the growth of these individuals was markedly reduced during this period. Hence a majority of the sand shrimp in the area presumably moves from the estuary of high temperature to offshore waters of cool temperature. This migration has been considered one of the ecological characteristics of the northern species of C. affinis (YOKOYA, 1933). The increased catch of sand shrimp in the test area between late November and February may have resulted from an increased number of individuals of the long-term generation returning to shallow estuary where the water temperature was sufficiently lowered, as well as from the appearance of new individuals of the short-term generation. On the other hand, the decline in the catch in March may have reflected the death of a number of mature individuals following spawning, whereas the sharp elevation in April was probably caused by the appearance of large numbers of young shrimp originating from eggs produced by mature females of both long and short-term generations.

From these findings the seasonal migratory pattern of

C. affinis can be divided into two phases; distribution in offshore waters between May and the first half of November and inshore waters between the last half of November and April.

In order to examine in detail the distribution pattern of C. affinis in offshore waters, the results of the investigations in Sendai Bay will be described below. A survey was conducted in Sendai Bay between April 1962 and March 1963, in which a few commercial trawlers were chartered to collect fish, and all of these fish were examined for the stomach contents. Table 3 shows the ratio of the number of sand shrimp-ingested fish species to that of shrimp-ingested fish species and the rate of the occurrence frequency of sand shrimp-ingested individuals in each one of the three main predators; i.e., gurnard Lepidotrigla microptera, Eopsetta grigorijewi and Liparis tanakai, at each sampling date along with the depth of the sampling location (expressed as the average depths of the spots where the net was cast and the spots where the net was drawn up). It was assumed that each fish which was caught, had ingested sand shrimp in the neighborhood of the sampling station and/or location. Hence a high value for the occurrence frequency rate of sand shrimp-ingested fish can be interpreted to be due mainly to an increase at the sampling site in the number of those shrimps which were proper in size to be ingested by that species of fish rather than to ecological changes in the predator species

Table 3. Predatory status of the most important predators for the *Crangon affinis*, taken from Sendai Bay during April 1962 through March 1963.

Dete	Depth (m)	Occurring percentage of individuals eaten *Crangon affinis*			Occuring percentage of species eaten *Crangon affinis* against the total species with shrimps in stomach
		Lepidotrigla microptera	*Eopsetta grigrorijewi*	*Liparis tanakai*	
13-IV'62	85-105	0.0 (2)			0.0
14-IV	36- 44				100.0
15-IV	23- 24				66.7
17-IV	64- 76	0.0 (19)	0.0 (1)		0.0
25-IV	33- 51				100.0
30-IV	30- 36				100.0
1-V	36- 36	35.3 (17)	100.0 (1)		100.0
2-V	27- 41				100.0
9-V	27- 41	23.3 (30)	100.0 (1)		100.0
13-V	33- 35	28.0 (25)	100.0 (1)		80.0
21-V	30- 43	33.3 (6)			50.0
28-V	35- 46				50.0
31-V	40- 52	33.3 (3)	66.7 (3)		80.0
1-VI	33- 40			51.3 (39)	100.0
7-VII	27- 30	71.4 (14)			75.0
25-VII	32- 43			77.8 (18)	100.0
27-VII	33- 38	0.0 (3)			33.3
31-VII	33- 36				33.3
2-VIII	43- 75	50.0 (6)			100.0
3-VIII	36- 38	40.0 (10)		42.1 (19)	60.0
6-VIII	47- 49	73.3 (15)			100.0
8-VIII	41- 73	48.8 (43)	100.0 (9)		80.0
11-VIII	43- 65	86.7 (60)	80.0 (5)		81.8
15-VIII	68- 68	83.3 (24)	90.0 (10)		66.7
18-VIII	52- 61	76.0 (25)	100.0 (1)		100.0
25-VIII	49- 58	41.5 (41)	86.4 (22)		100.0
30-VIII	46- 58	76.8 (43)	100.0 (8)		100.0
31-VIII	44- 56	76.2 (21)	100.0 (15)		100.0
3-IX	52- 73	100.0 (2)	100.0 (4)		66.7
12-IX	41- 56	73.3 (30)	50.0 (2)		75.0
16-IX	32- 43	100.0 (9)	50.0 (2)		100.0
20-IX	87- 90	0.0 (1)	0.0 (1)	0.0 (40)	0.0
23-IX	30- 41	68.8 (16)			40.0
28-IX	44- 68	34.1 (41)			66.7
7-X	71- 75	0.0 (24)	0.0 (10)		0.0
14-X	64- 75	0.0 (4)	0.0 (10)		0.0
18-X	46- 58	33.3 (27)			25.0

24-X	65- 76	0.0 (5)	0.0 (5)	0.0 (5)	0.0
29-X	44- 70	0.0 (44)		0.0 (2)	0.0
3-XI	55- 55	0.0 (2)	0.0 (4)		0.0
11-XI	43- 70	0.0 (13)		0.0 (9)	0.0
14-XI	35- 41			50.0 (2)	50.0
20-XI	35- 44	12.5 (8)		50.0 (2)	60.0
26-XI	44- 49	10.0 (10)		0.0 (9)	12.5
29-XI	27- 35	5.9 (17)		0.0 (17)	12.5
3-XII	32- 43	42.9 (7)	0.0 (1)	42.9 (7)	33.3
8-XII	58- 64	0.0 (2)			0.0
13-XII	36- 36			41.7 (12)	100.0
16-XII	30- 44			40.0 (5)	100.0
19-XII	20- 41			28.6 (7)	33.3
23-XII	27- 40	0.0 (7)			0.0
25-XII	46- 52	0.0 (2)	0.0 (2)	0.0 (4)	0.0
29-XII	68- 78	0.0 (25)		0.0 (5)	0.0
3-I '63	47- 61		0.0 (10)	0.0 (7)	0.0
6-I	65- 70	0.0 (8)	0.0 (6)	0.0 (7)	0.0
12-I	52- 64	0.0 (1)	0.0 (15)	0.0 (9)	0.0
16-I	53- 64			0.0 (2)	0.0
18-I	62- 65	0.0 (2)	0.0 (5)	0.0 (6)	0.0
31-I	24- 43		0.0 (1)		0.0
3-II	90- 96	0.0 (9)	0.0 (5)		0.0
12-II	55- 87		0.0 (4)		0.0
17-II	30- 43				0.0
22-II	159-167				0.0
26-II	27- 46				0.0
3-III	76- 87	0.0 (1)	0.0 (22)		0.0
6-III	154-159				0.0
11-III	24- 33				10.0
17-III	33- 46				0.0
20-III	30- 35				50.0

Numerals placed before parentheses represent the occurring percentage of individuals eaten *Crangon affinis.*

Numerals in parentheses represent the number of individuals examined.

or prey animals other than C. affinis.

When the results of Table 3 were analyzed with special reference to the migratory behavior of C. affinis, from April to May the maximal depth of water at which the main predatory fish were caught, increased from 28.5 m to 46.0 m. During the same period the occurrence frequency rate of sand shrimp-ingested gurnards was increased from 0 to 35.3%, suggesting that this period corresponds to a season in which *C. affinis* moves to deep waters. Although only one sampling was carried out in June in the 1962-1963 survey, the occurrence frequency rate of sand shrimp-ingested gurnard in the 1960-1961 survey showed similar values in the month of june to those obtained in the month of May 1962. Thus this migratory season may extend to June.

In August and September the depth of the sites at which the predators of *C. affinis* were caught extended to 60 m, and the rate of the occurrence frequency of sand shrimp-ingested gurnard at this depth was considerably increased (p.74) (86.7-100%). Hence in these two summer months *C. affinis* inhabits deep waters. Since four samplings in July were carried out at depths of less than 43 m, nothing was known on the distribution of sand shrimp at depths of more than 43 m in this month. However, since the feeding activity of gurnard has been shown to be similar in July and August, it can be safely concluded that between July and September sand shrimp inhabit deep waters.

From November to December the depth of the sampling sites for the predators decreased from 52.0 to 37.5 m and the occurrence feequency rate of sand shrimp-ingested individuals was also reduced. Therefore during this period *C. affinis* migrates to shallow waters.

In Janaury and February no predatory fish species was caught at a depth of more than 33.5 m. However, since no sampling was carried out in shallow waters, no information is available on the exact distribution territory of C. affinis during these two months. In March the appearance of the predatory fish was seen at a depth of 28.5 m. However, in no gurnard the presence of sand shrimp was found in the stomach. It appears that between January and March sand shrimp are distributed in shallow waters. (p.75

These findings indicate that C. affinis inhabits shallow waters during the cold-water season between January and March but in deep waters during the warm-water season between July and September. It is noteworthy that the direction of this seasonal migration is opposite to that observed in other species of shrimps. However, around the shallow distribution territory such as the estuary of the Natori River this species of shrimp can be seen throughout the year and only the number of the individuals undergoes seasonal variations. It is to be noted that the depth of the distribution territories also undergoes marked seasonal variations.

IV Discussion

The fauna of shrimp inhabiting inland seas and bays of Japan has been studied by many investigators; e.g., Mutsu Bay (YOKOYA, 1930), Onagawa Bay (YOKOYA, 1939), Matsushima Bay (Sato, 1957), Tokyo Bay (KUBO et al., 1957), the bays of Mikawa and Ise (Aichi Prefectural Fisheries Experimental Station, 1942), Kasaoka Bay (YASUDA, 1957), the Inland Sea of

Seto (YASUDA et al., 1957), the Sea of Yatsushiro and Kagoshima Bay (URYU, 1921), Tachibana Bay (Nagasaki Prefectural Department of Commerce and Industry, 1958), the Sea of Ariake (MIYAKE, 1961; IKEMATSU, 1963) and Lake Naka-umi (HARADA, 1968).

Of these inland seas, the bays of Mikawa, Ise and Kagoshima are the only three areas where the presence of sand shrimp has not been described. According to YOKOYA (1933), the southern limit of the distribution territory of C. affinis in coastal waters of Japan lies in the Inland Sea of Seto on the Pacific side and in the Goto Islands on the side of the Sea of Japan. Hence it is reasonable to accept that no collection of sand shrimp has been recorded in Kagoshima Bay (since Kagoshima Bay is located further south of the Inland Sea of Seto - Translator's note). However, it is not known whether the conclusion that no distribution of sand shrimp is found in the bays of Mikawa and Ise (the two bays are located north of the Inland Sea of Seto - Translator's note), may have been formed on the basis of insufficient evidence or on other grounds. Apart from these exceptions, it is obvious that C. affinis is one of the shrimps which are widely distributed in coastal waters of Japan. Those inland seas and bays in which the population of sand shrimp is known to surpass that of other species of shrimps are Tokyo Bay, Kasaoka Bay and an inshore area of Hiroshima Bay. In this study it has been shown that Sendai Bay also can belong to this category.

The spawning season of C. affinis in Sendai Bay extends over a considerable long period ; i.e., August - September and November - May. Spawning itself is also carried out in a complex manner. KURATA (1963), in his ecological study of shrimp in a laver culture ground in the inlet of Bankoku, Miyagi Prefecture, has classified this species into a summer-spawning group. However, the findings of the present study have clearly shown that summer-spawning females hold smaller numbers of eggs than the spring-spawning females and that the population of shrimp developed from summer-spawned eggs is smaller than that produced by spring-spawned eggs. Hence the summer-spawning is of less importance for the reproduction of this species than the spring-spawning in Miyagi Prefectural waters. As KURATA pointed out, the total number of shrimp sampled in his study may have been insufficient to conduct detailed analyses of the shrimp population during the winter and spring seasons, thereby leading to this incorrect conclusion.

The ecological characteristics of C. affinis inhabiting in Kasaoka Bay have been reported in detail by YASUDA (1956; 1957). Thus attempts will be made to comapre the results of the present study with those of his studies, thereby clarifying certain ecological characteristics of this species inhabiting in Sendai Bay. Spawning of sand shrimp in Kasaoka Bay (herein called 'Kasaoka' sand shrimp) takes place in November - December and in January - July, the main season being between late February and late April. However, the spawning season of the same species in Sendai Bay (herein called Sendai sand shrimp) has been found to be in August - September and in November - May, the height of the season falling between December and April. It is evident the spawning season starts earlier in the north (Sendai Bay) than in the south (Kasaoka Bay).

Summer-spawning females of Sendai sand shrimp are 30-31 mm in body length during the spawning season. Judging from the growth pattern of *C. affinis*, these females appear to be the members of L_2 group of the long-term generation. Although it is not known whether these died following spawning, no significant difference in the body length composition of the sample population was seen before and after spawning.

Females spawning in November and December in Kasaoka Bay are medium-sized (21-28 mm in body length) and show the growth pattern similar to that of the long-term generation. These appear to die after spawning, thereby, according to YASUDA, forming a short-term generation that is distinct from the long-term generation. The life-span of this short-term generation is believed to be about 6 months.

However, in those species of shrimps the population of which consists of individuals of both long and short-term generations, the time of the appearance and the growth pattern of young shrimp are in general known to show significant differences between the long and short-term generation. Also it is not known whether the females of the short-term generation classified by YASUDA died after spawning, and the body length composition of the population of Kasaoka sand shrimp was hardly altered before and after the spawning in November and December. Hence within the limits of knowledge available at present, it appears more reasonable to conclude that the November - December spawning females of Kasaoka sand shrimp are the members of the long-term generation rather than that they belong to another generation. (p.76)

The spawning females is larger in body length in Sendai Bay than in Kasaoka Bay. This is probably due to the fact that the former was hatched earlier (and accordingly, has undergone more advanced developmental stages) than the latter. Sendai sand shrimp certainly have experienced a longer growing season in spring prior to the summer non-growing season than Kasaoka sand shrimp.

In Sendai Bay spawning between November and May is carried out by females of the long-term generation. A majority of the egg-bearing females at the early and late stages of this spawning season is 42-44 mm in body length but most of those at the mid stage are more than 45 mm long. The body length throughout the spawning season ranged from 42 to 53 mm. The occurrence of egg-bearing females during this season has been found discontinuous. Judging from the occurrence rate of egg-bearing females, the appearance time of young shrimp and the body length composition of the population of the long-term generation, the main spawning appears to take place three times during this season.

However, in Kasaoka Bay spawning of the long-term generation takes place between January and June. The body length of egg-bearing females is small at the beginning but increases as the spawning season advances, and varied from 37 to 58 mm during the whole season. The occurrence of egg-bearing females is continuous throughout the season, the peak appearing in late March.

In Sendai Bay during the main spawning season females of the short-term generation which have developed from summer-spawned eggs spawn from late January to April. These egg-bearing females are 30-31 mm in body length and are considerably smaller than those of the long-term generation at the same time of the spawning season. The number of eggs born by a single female is also less in the short than in the long-term generation. In Kasaoka Bay females of the short-term generation spawn from late April to late July. The body length of these egg-bearing females ranges from 27 to 37 mm.

When the spawning habit is compared between Sendai and Kasaoka sand shrimp, there is a difference in the spawning season. However, the mode of reproduction is essentially the same beteeen the two and consists of spawning by middle-sized females of the long-term generation, that by full-sized females of the long-term generation and that by females of the short-term generation.

In Sendai Bay young shrimp of the long-term generation appear three times; i.e., mid February, late April and late May. These young individuals have average body lengths of 8, 9 and 6 mm, respectively, at the time of their first appearance. It appears that the three have developed from eggs spawned in mid December, mid February and mid April, respectively. In other words, the eggs produced in mid December have grown to reach a length of 8 mm for about 60 days, those in mid February to 9 mm for 75 days and those in mid April to 6 mm for about 40 days.

According to the results of rearing experiments of *C. affinis* (YAMANOUCHI, 1965). larvae of about 1.7 mm length were seen 1-5 days after egg-bearing females had been placed in an aquarium. The larvae led a benthic life at stage VI after 5 ecdyses and were about 2.6 mm in body length at stage V, the last stage of development in the plankton period. The water temperature in the aquarium was $18-21^{\circ}$ C. Ground meat of Japanese littleneck *Tapes japonica* was given as a feed. In one case only 3 of the newly hatched 3,850 larvae developed into stage VI after 25 days. However, in four other cases no ecdysis took place and none of the hatched larvae survived for more than 5 days. The failure was attributed by the author to deterioration of the quality of the culture water which was caused by the ground meat. Therefore the state of growth between hatching and stage VI reported in this study is likely to be different from that which is expected to occur under natural conditions. Since the increment of the body length during each stage between stage II and V of plankton larvae was 0.2-0.3 mm, the body length at stage VI would be about 3 mm. Hence the estimates made for the early growth of Sendai sand shrimp can be regarded as appropriate, when the difference in the water temperature between the aquarium used in the rearing experiments of YAMANOUCHI and Sendai Bay is considered.

Young shrimp of the long-term generation at the time of the first appearance are in the sexless form but soon develop the secondary sex characteristics. This development depends on the birth date and earlier-born individuals have a larger body length than later-born ones at the time of the first appearance of the secondary sex characteristics. Active growth is seen during the season of from spring to summer. However, when the water temperature rises above 16° C, no increase in the body length is recognized. In November and December when the water temperature is decreased below 16° C active growth is resumed. No growth is apparent during the spawning season and the death occurs after spawning. The life-span of the long-term generation varies from 1.4 to 1.7 years and full-grown shrimp of females and males are 49 mm and 30 mm in body length, respectively.

On the other hand, in Kasaoka Bay spawning of the long- (p.77 term generation takes place continuously between January and June. The composition of the body length among the male and female population at each sampling time has shown a normal distribution curve, and in each sex deviations between the minimal and maximal length are reported to be less than 10 mm. During the spawning season should all of the young shrimp developing from spawned eggs survive and should they be sampled, the body length composition of the population would not be likely to show a normal distribution. Therefore in

Kasaoka Bay it seems that only those larvae which were hatched from eggs spawned at a particular stage of the 6-month spawning season would survive and form the following generation. Young shrimp appear from late May onward and are about 10 mm in body length at the time of the first appearance. They continue to grow for about one month until late June. During a period when the water temperature remains above 20° C; i.e., between late June and early October, hardly any increase in the body length is observable. Until the end of the high-water temperature period all young individuals are in the sexless form. However, when the growth resumes as the water cools, the secondary sex characteristics are developed. A rapid growth is seen from January to February, and the death occurs following spawning. The life-span of the long-term generation is about one year and full-sized female and male shrimp are 48 mm and 36 mm in length, respectively.

Young shrimp of the short-term generation in Sendai Bay appear in November and possess already the secondary sex characteristics at that time. Shrimp of this generation spawn between January and April and die in about May. In contrast to the long-term generation, members of the short-term generation maintain uniform growth throughout the life and their life-span is 0.9 years. The average body length of full-grown individuals is 36 mm for females and 20 mm for males.

In Kasaoka Bay young shrimp of the short-term generation appear in mid February in the sexless form, develop the secondary sex characteristics in March, continue to grow thereafter until May. The life-span is estimated to be 0.5 years, and the average body lengths of full-sized female and male shrimp are 33 and 27 mm, respectively.

The growth patterns of the long-term generation of Sendai and Kasaoka sand shrimp show certain seasonal differences which have been brought about by the differences in both the spawning season and the water temperature. The upper limit of the water temperature beyond which the growth is nearly completely halted, is 16° in the north but 20° in the south. Apparently Sendai sand shrimp are less resistant to high temperatures than Kasaoka shrimp. This is one of the ecological characteristics of the Sendai species.

The life-span of Sendai sand shrimp is longer than that of Kasaoka shrimp in both long and short-term generations. Although the body length of full-sized females does not show any marked difference between the two, full-sized males are larger in Kasaoka than in Sendai Bay. Therefore the growth speed is faster in the former than in the latter.

As for the feeding habit of C. affinis, KURATA (1963) has described that this species feeds on animals. The findings of this study have shown that of the animals, small-sized, benthic amphipods, isopods and polychaetes are the main food.

As other species of shrimps, C. affinis is nocturnal and feeding activity takes place also in the nighttime. During the summer non-growing season the feeding activity decreases.

The predatory fish species of C. affinis in the Inland Sea of Seto have been reported by Yasuda (1957) to be 3 including Hexagrammos otakii, though no details were given. The results of the present study have revealed that a large number of fish species (8 species in the estuary of the Natori River and 29 species in Sendai Bay) prey on C. affinis. The species of importance are Acanthogobius flavimanus in the estuary; and Lepidotrigla microptera, Liparis tanakai and Eopsetta grigorjewi in Sendai Bay. The occurrence frequency of these predators varies with season and increases in a period between April and September during which sand shrimp migrate to and inhabit deep waters. However, the occurrence frequency becomes minimal during the main spawning season of between December and March, indicating that the loss of the population of sand shrimp due to predators becomes reduced during the main spawning season of the shrimp. This is of extreme interest, since it offers an example to show the existence of a certain mutual relationship between a predator and a prey animal.

Diurnal changes in the catch of C. affinis have been examine by HARADA (1968) who used a small bag net for sampling in Lake Naka-umi. It was observed that the maximal catch was obtained at ebbing tide in the nighttime but that almost no catch was recorded at flowing tide in the night or at any tidal hour in the daytime. The results of the present study in the estuary using a trawl net have shown that the maximal catch is obtained at ebbing tide at night and that the minimum is at low tide at night. At other tidal hours in the night- (p.78) time and at any tidal hour in the daytime the catches are about the same and medium. The discrepancies between the two studies are in part due to the difference in the fishing tool (net). A bag net is stationary and utilized a natural tidal current, whereas a trawl net is transportable. Hence the latter is able to collect those sand shrimp which are hidden in sand in the daytime. However, the reasons why sand shrimp which are active at night were caught in the bag net only at ebbing tide in the nighttime and why the trawling catch of sand shrimp was maximum at ebbing tide in the nighttime, are not clear.

According to the available record of the maximal depth at which sand shrimp have been sampled along coastal waters of Japan (YOKOYA, 1933), two sites (north of Tsushima and east of Sado) on the side of the Sea of Japan had a depth of 219 m and one site (east of Aomori Prefecture) on the Pacific side was 172 m deep. Thus the distribution territory of C. affinis extends from an inland sea and bay to a continental shelf. In Sendai Bay the deepest site at which sand shrimp were collected is 68 m deep and that is 54 m deep in Tokyo Bay.

Kasaoka sand shrimp do not show as marked a seasonal migratory habit as Sendai shrimp. According to YASUDA (1956), the former inhabits at the center of the bay between June and September, moves inshore between October and December and is distributed in the entrance area of the bay between January and May. In Tokyo Bay the population density of sand shrimp is reported to be high throughout the bay in late spring and fall but to become extremely low in late summer (KUBO *et al.*, 1957). However, re-examinations of Tables 16-18 in their original paper showed that the maximal density occurred at a depth of 47 m in late spring (from May 27 to June 1) and at a depth of 54 m in late summer (August 30 - September 5) but at a depth of 33 m in late fall (December 7 - December 12), indicating that this species of shrimp tends to inhabit in deep waters during a period of high-water-temperature but in shallow waters during a cool-water period within Tokyo Bay. Sendai sand shrimp show a similar but distinct seasonal migratory habit; *i.e.*, moving inshore during a low water-temperature period but offshore during a high water-temperature period. Hence seasonal migration of *C. affinis* takes place in the opposite direction to that which has been observed in many other species of shrimps and can be considered one of the ecological characteristics of the northern species.

Judging from the results of the present study as well as those of other investigators', *C. affinis* is a small-sized shrimp and is distributed widely along coastal waters of Japan. The spawning season, the duration of the spawning season, seasonal variation of the growth pattern and the seasonal migratory behavior, all of which clearly indicate that this species has ecological characteristics unique to the northern species. Sand shrimp in Sendai Bay may be of little importance as a fishing object but may play an important role as a prey in the maintenance of the reproduction of useful benthic fishes such as Lepidotrigla microptera and Eopsetta grigorjewi.

V Summary

A few measurements and observations were made on sand shrimp Crangon affinis which were sampled in the estuary of the Natori River, Miyagi Prefecture, between February 1959 and February 1960. Also, in order to determine the species of predatory fish, stomach contents of fish which were caught in the same estuary and in the trawling ground of Sendai Bay were examined.

The results obtained are summarized as follows:

1. The population of sand shrimp consists of individuals of a short-term generation, the life-span of which is about 10 months, and those of a long-term generation which have a life-span of 14-19 months.

2. Individuals of the short-term generation are reproduced in August and September by large-sized females of the long-term generation and appear in the catch at first in November. These grow continuously until early January, spawn from late January to April and survive until about May. The average body length of full-sized shrimp of this generation is 30 mm in females and 20 mm in males.

3. Individuals of the long-term generation are

reproduced by those of the long and short-term generations produced in the previous year. The long-term generation consists of three groups developed at different times; large numbers of young shrimp appear in the catch three times; i. e., in February, April and May. These young shrimp grow rapidly from spring to early summer but show little growth between June and October when the water temperature rises above 16° C. The growth resumes after November until the spawning season.

Egg-bearing females, 42-53 mm in body length, appear between late November and late May, but in large numbers in December, February and April, suggesting the presence of three spawning peaks. This corresponds to the presence of three (p.79) groups of development among the population of the long-term generation. The average body lengths of the largest members of each one of the three groups are 49, 42 and 38 mm in females, and 33, 30 and 27 mm in males.

4. The sand shrimp lives on small-sized benthic animals, especially amphipods, isopods and polychaetes, throughout the year. Sand and mud particles are always seen in the stomach along with food.

5. The feeding activity decreases in summer when the water temperature is high.

6. Eight of the 37 fish species caught in the estuary of the Natori River, and 29 of the 96 fish species including one hybrid caught in the trawling ground of Sendai Bay, are found to be the predators of C. affinis. Of these, Acanthogobius

flavimanus in the estuary, and Lepidotrigla microptera, Liparis tanakai and Eopsetta grigorjewi in Sendai Bay, are considered of importance.

7. C. affinis is of nocturnal habit. However, no significant difference is seen in the trawling catch between night and day.

8. The sand shrimp shows a seasonal migratory behavior; it moves from inshore to offshore waters between April and June, inhabits offshore between July and September, returns to inshore waters between October and December and inhabits there between January and March.

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