ECOLOGICAL OBSERVATIONS ON THE JAPANESE SPINY LOBSTER, *PANULIRUS JAPONICUS* (VON SIEBOLD), IN ITS LARVAL AND ADULT LIFE[1)]

EIJI HARADA[2)]

Zoological Institute, Faculty of Science, Kyoto University

With Plates VI–VII, 5 Tables and 6 Text-figures

Introduction

The Japanese spiny lobster, *Panulirus japonicus* (VON SIEBOLD), is one of the most dominant crustaceans on the Pacific coast of southern Japan. The spiny lobster fishery takes a most important part in the inshore fishery of this area during the open season of the winter through early spring.

The Japanese spiny lobster has been studied on the embryonic development by NAKAZAWA (1917), TERAO (1929), and SHIINO (1950); on its larvae by NAKAZAWA (1917), KINOSHITA (1934), OHSHIMA (1941), and OKADA and KUBO (1948, 1950); and in regard to its adult life by many authors, such as KINOSHITA (1931, 1934), OHSHIMA (1935, 1941, 1948), NAKAMURA (1940), OKADA and KATÔ (1946), OKADA and KUBO (1946), OKADA, KUBO and TAKAGI (1947), KUBO and HATTORI (1947), INO (1947, 1950), etc. However, the ecological studies of the larvae are very scarce, and the true life of the adult might be expected to be made clear through direct observations under water, though the study along this line has not been fully developed yet owing to its practical difficulty.

Although its landing is not so great as of other marine food animals like fishes, cuttlefishes or prawns in this country, the species concerned is of considerable economic value in providing for the fishermen's income in certain areas. It has become desirable for the problem of conservation or increase of its natural stock to obtain a thorough knowledge of the life history of this animal, especially of the ecology of the larvae when recent development of the fishery using the fish-attracting lamp has brought a new problem into the coastal fishery. Many fishermen are convinced that the evil effect of intense light of the lamp on the larvae of the Japanese spiny lobster leads them to die and consequently results in the remarkable decrease of the adult population.

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1) Contributions from the Seto Marine Biological Laboratory, No. 296.
2) Present address: Seto Marine Biological Laboratory, Sirahama.

The present paper deals with some aspects of lives of the larvae and the adult of the Japanese spiny lobster. The distribution of the larvae and the effect of the fish-attracting lamp upon the larvae were examined by the plankton sampling procedures in relation to the distribution and breeding of the adult lobster and the developmental stages of the larvae.

The present work was defrayed in part by a grant from the Foundation in Support of the Seto Marine Biological Laboratory to which I wish to express my hearty thanks. Furthermore, I am indebted to Professor Denzaburo MIYADI for his instructive advice and to Dr. Huzio UTINOMI for his guidance and suggestion given to me throughout the whole course of my investigation. Mr. Shinichiro FUSE and Mr. Ryônosuke OKUNO cared nothing about to give advice and to help me in the field investigation, to whom my sincere thanks are due. To Mr. Syûzi URA and Mr. Syôzô SAKAI, I am especially grateful for the practice of the field work on board. Mr. Syôzô SAKAI also generously afforded his record of the catch of the spiny lobster to me. Lastly, I would like to extend my special thanks to Mr. Chiyozi KANAYA and Mr. Hidematsu TOYAMA for providing me with some samples of the larvae taken by them, and to Mr. Shigeru IWAHASHI for providing at my disposal with the facilities of examining the landing of the spiny lobster at the Sirahama Fishery Market.

Methods of Collecting and Study

The following observations were carried on during about one year and a half period from July, 1955 to January, 1957, in the neighbouring waters of the Seto Marine Biological Laboratory at Sirahama, Wakayama Prefecture.

With the purpose to observe the occurrence and distribution of the planktonic larvae of the species concerned, hauls were made using a large and a small plankton net. The large one was 1 m in diameter at the mouth and 2.6 m long with silk bolting cloth at the upper and middle part (29 meshes/inch) and at the bottom (39 meshes/inch). The net was entered into the water, and immediately hauled behind the research boat for 3 minutes duration with the constant speed, keeping it in such a position that the upper edge of the opening lies just beneath the water surface. The current meter was attached to the centre of its opening ring to be able to estimate the volume of water flowed into the net. A volume of about 78 m^3 of water was usually filtered at each haul. The small net was 0.5 m in diameter at the mouth and 1 m long with silk bolting cloth (39 meshes/inch). The net was usually hauled from the bottom to the surface during the 24-hour period on several occasions at two stations. On several occasions, a series of horizontal hauls at various depths were made using this net.

For the collection of the smaller larvae on and beneath the rocks or among the algae, the pump was used in summer-time, water pumped up being filtered at each time with silk bolting cloth (72 meshes/inch). In this case, the hose was kept by me under water with the aid of the "scuba". Direct observations and collections were made while diving with the "scuba".

To test the effects of the fish-attracting lamp on the larvae, the experimental lightings were made to capture the light-attracted larvae.

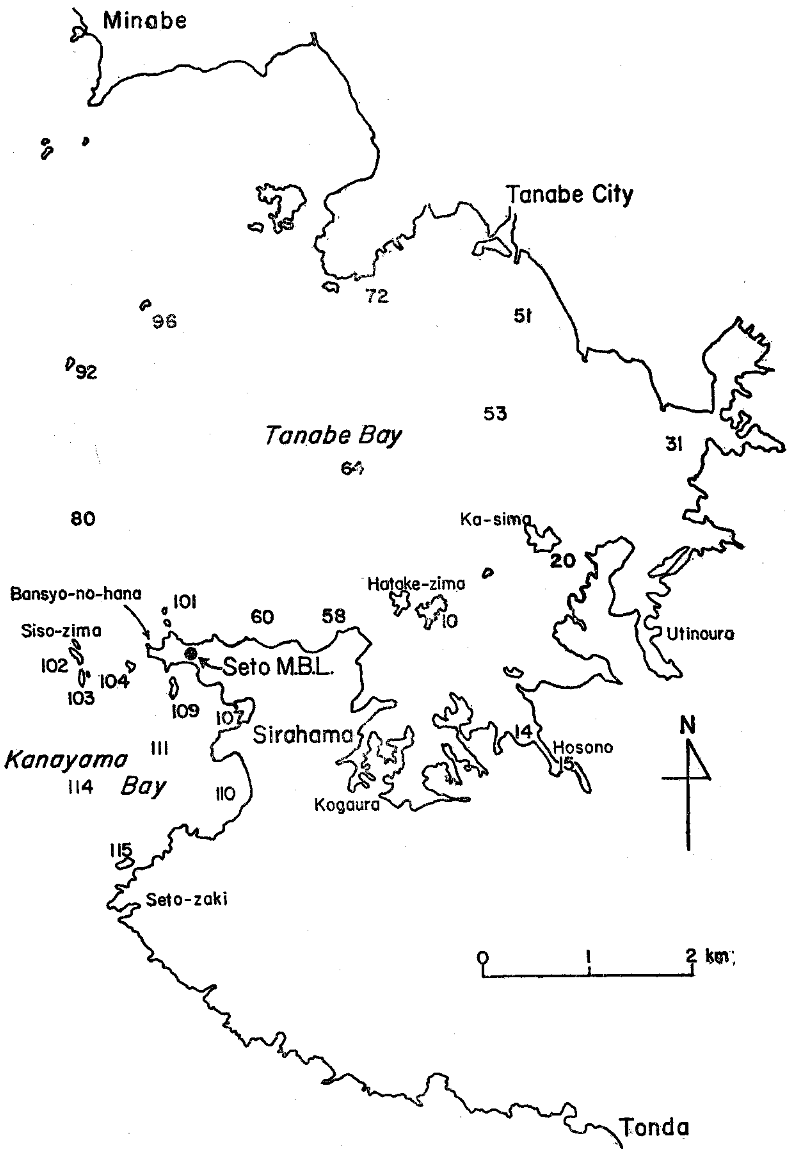

Fig. 1. Map of the area studied, showing stations mentioned in the text.

Several stations were chosen in Kanayama Bay, Tanabe Bay and off Bansyo-no-hana. Plate VI shows the area chiefly investigated. These stations are shown in Fig. 1 and Table 1 (p. 117).

The samples of the commercial spiny lobster landing were examined at the Sirahama Fishery Market as often as it was possible. The gear used for the commercial spiny lobster fishery is the anchor gill net, usually called "ebi-ami" in Wakayama Prefecture. The fishermen set the net at evening along rocky shores and reefs and pull it up next morning. The net with the mesh size of about 5 cm is commonly employed, but it may allow the escape of some smaller adult or subadult lobsters than of the legal size ("short"), although a considerable number of "shorts" are taken.

Distribution and Abundance of the Adult

Distribution. The Japanese spiny lobster ranges in rocky areas throughout the Pacific coast of southern Japan, northward to Ibaragi Prefecture.

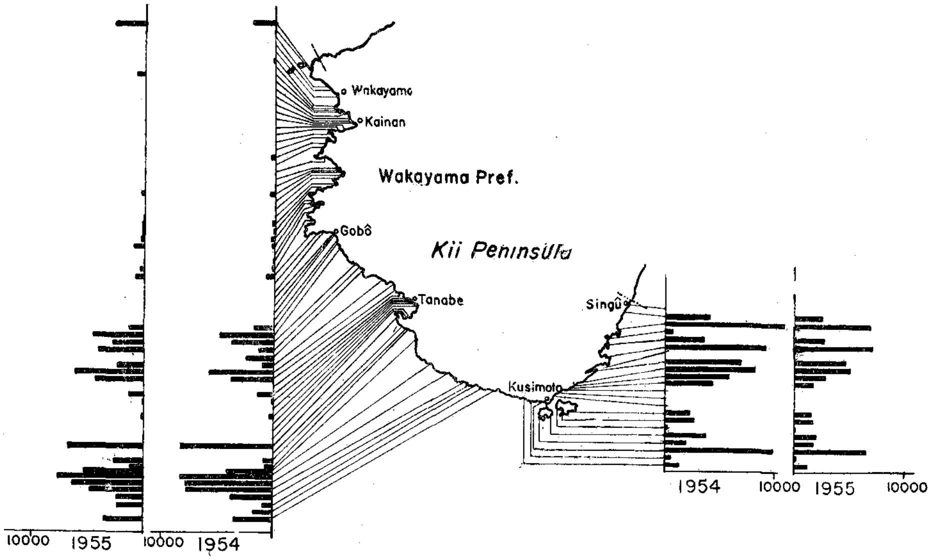

Fig. 2. Quantity per annum of spiny lobsters landed at each fishery market in Wakayama Prefecture, 1949–1950. Quantities are shown by their weight in kg.

All along the west coast of Kii Peninsula, the commercial spiny lobster fishery is effectively working as far north as Kada, facing the entrance to Osaka Bay. Fig. 2 shows the total landings of the spiny lobster at each fishery market during two years of 1949 and 1950. The total landing increases to its maximum as going southwards and this is likewise in the case of the catch per unit effort represented in terms of that per one fisherman. It must be noted that relatively high landings are represented at Kada, where the benthic fauna has rather southern characters. The remarkable difference in total landings between the areas northward and southward from Hinomisaki clearly indicates that the spiny lobster occurs in abundance in the southern areas directly washed by the warm current of Kurosio.

The daily average numbers of the catch per one fisherman at various fishing grounds near the Seto Marine Biological Laboratory are shown in Table 2. It seems reasonable to conclude from this data that the better yields are expected, in general, from where faced to the open sea of warm water than from in the bay throughout the whole commercial season.

The daily records of the number of the catch and the locality are highly useful to make clear the relative abundance and activity of the lobster. Localities where fishing nets were placed and the points where the lobsters were caught were recorded and plotted on the map every day by one fisherman, Mr. Syôzô SAKAI, when he fished during the commercial season from November, 1955, to April, 1956, except January, 1956. The data were available from the northern part of Kanayama Bay, which is for the sake of convenience divided into several regions topographically. Relative abundance in each region is presented monthly in Fig. 3 in terms of the average number of the catch per unit effort (i.e. per one sheet of the fishing net). Variations from region to region are apparent, being always low in the innermost part of the bay.

The similar tendency is noted in Tanabe Bay too. The spiny lobsters reduce their number considerably in the innermost part of the bay, where the rocky reefs are covered by mud and the water is generally shallower.

Habitat. Considering that rocky areas may hardly be said to be uniform environments and must afford various habitats, it seems that the lobsters are distributed in close relation to topographical features of underwater reefs or rocks. Moreover, they have a tendency to aggregate to a greater or less extent, as in the findings of LINDBERG (1955) for *Panulirus interruptus.* By diving at the point where one or two catches were recorded every day for four days, more than twenty lobsters wers found in a large rock cave. There were many holes or crevices available to them as shelters within 10 metres from this rock cave, but little were found there. Furthermore, some lobsters were utilizing small holes on the roof of the cave or small space under small boulders in the cave, whereas such holes were rarely utilized as their shelter in open areas with abundant habitats (Plate VII, figs. 1 & 2). On other occasions, three to five lobsters were observed for about one month of August, 1955, in a vertical rock crevice, the upper part of which was usually exposed to the air at the ebb tide. Almost the same number of lobsters were found there during the summer of the next year. On another occasion, as many as ten or twelve lobsters inhabiting in one large ledge were observed, and neighbouring smaller sheltering ledges were also occupied by lobsters. These facts suggest that lobsters tend to aggregate, but the aggregation of the lobster occurs in the way of utilizing every shelter in their neighbourings.

Seven diving localities were chosen in Tanabe Bay in November, 1956, to investigate the outer-inner distribution of the lobsters in relation to their habitat. At Station 102 (the outer side of the rocky reef of Sisô-zima), where the lobster fishing is intensively made, a number of lobsters were found at various situations, such as rock caves, sheltering ledges, small holes, rock crevices, or under boulders, and they were almost concentrated to small areas. At a reef (Kanatoko-zima) just north of Station

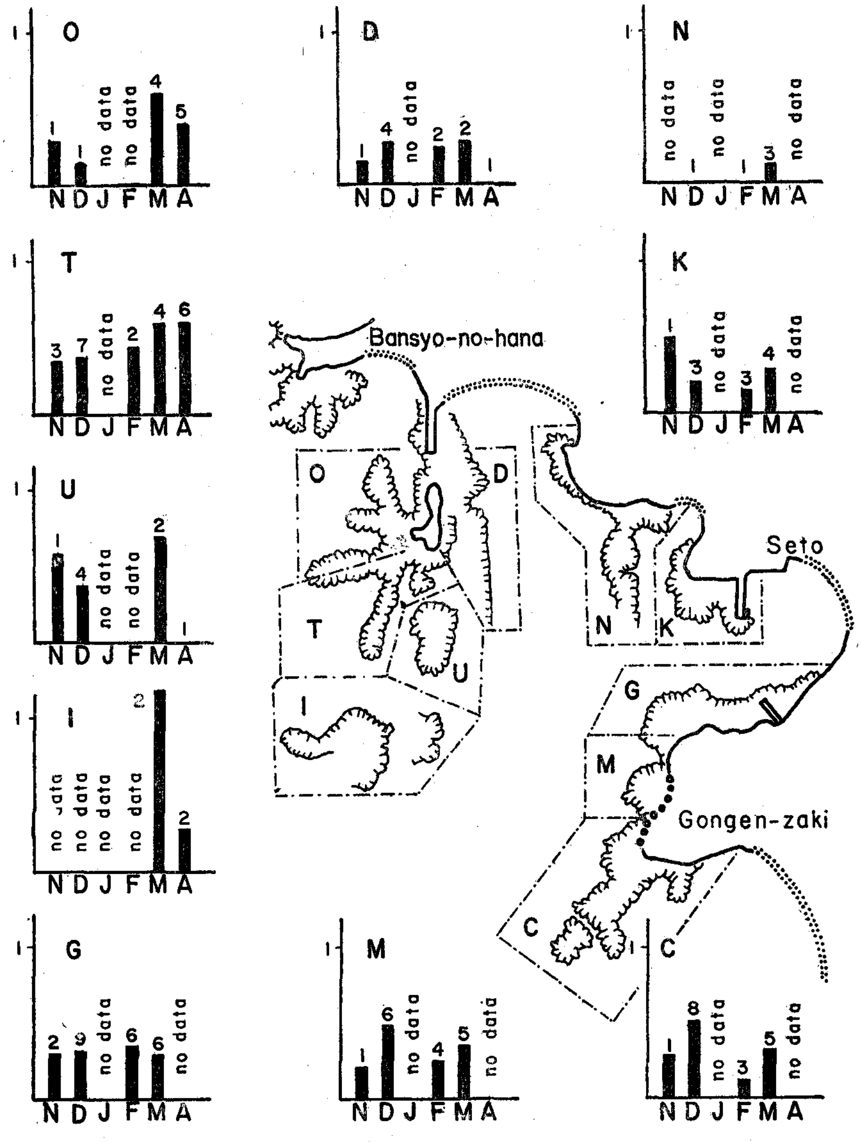

Fig. 3. Monthly average numbers of the catch per one sheet of fishing net in various regions of northern part of Kanayama Bay in the commercial season of 1949–1950, as recorded by one fisherman.

101, there was little rock crevice or rock cave along the cliff which extends downward to some 15 m depth from the sea surface, and consequently existed no or little lobster. Although sufficient available rock crevices, small caves, sheltering ledges, of holes were afforded at the east side of Hatake-zima, which is in an area lightly fished, mud covered all over the bottom, and lobsters were aggregated and utilizing only deep caves, deep ledges or deep crevices, innermost parts of which had little mud covering. At Kanô-zima, which is situated between Hatake-zima and Ka-sima, the mud covering was thicker than at Hatake-zima, and only one lobster was found in a small hole. At innermost two localities of Utinoura and Kogaura, mud was deposited thicker and only one lobster was found in a small hole at the depth of 5 m at Utinoura.

The large population of the spiny lobster may be expected at somewhat offshore and deep reefs where various types of shelters are abundantly available and not at the innermost parts of the bay where mud deposits thicker.

Population Composition. A total of 2,444 lobsters were measured. The monthly frequency distribution of carapace length is shown in Fig. 4 by each 5 mm. The range is 21 mm to 112 mm. The minimum size of the catch is associated with the mesh size of the net, so it must be noted that data cited above does not provide random samples of the natural lobster community.

In general, there is a remarkable difference in the range of size between male and female, that is, large lobsters are mainly found in males. The number of the male also exceeds that of the females in every monthly sample.

It was hoped that the age groups would be indicated by a series of modes of the carapace length frequency, and that the successive progression of these modes month by month would indicate the average growth increment of the age groups. NAKAMURA (1940) and OHSHIMA (1941) have stated that there is a clear indication of two size groups in the frequency distribution of carapace length in the sample of August. One mode is at about 36 mm and the other is at about 52 mm. They also followed the shiftings of these modes over a year and decided that the former is of the two-years-old[1)] and the latter of the three-years-old[2)]. For *Panulirus argus*, DAWSON and IDYLL (1951) detected a shifting of one mode of the length frequency indicative of annual growth, but the number and complexity of the modes failed them in identifying the various age groups and in tracing the growth rates of each. LINDBERG (1955) also was unable to show well-defined size groups in *Panulirus interruptus*. These are all the same as is the case of the present data. No well-defined size groups could be detected. One dominant mode is apparent in most of the months, shifting slightly to the right as the season progresses. Although KUBO and HATTORI (1947) say that the ecdysis never occur till May, the lobsters were found frequently in the state of just preparing the moult or in the soft-shelled condition after the moult. The shift of the mode may possible be the result of the growth.

Seasonal and Daily Variations. The monthly commercial landing records at the Sirahama Fishery Market between the years 1949 and 1950 are presented in

1)2) OHSHIMA (1948) corrected thus in his paper later published.

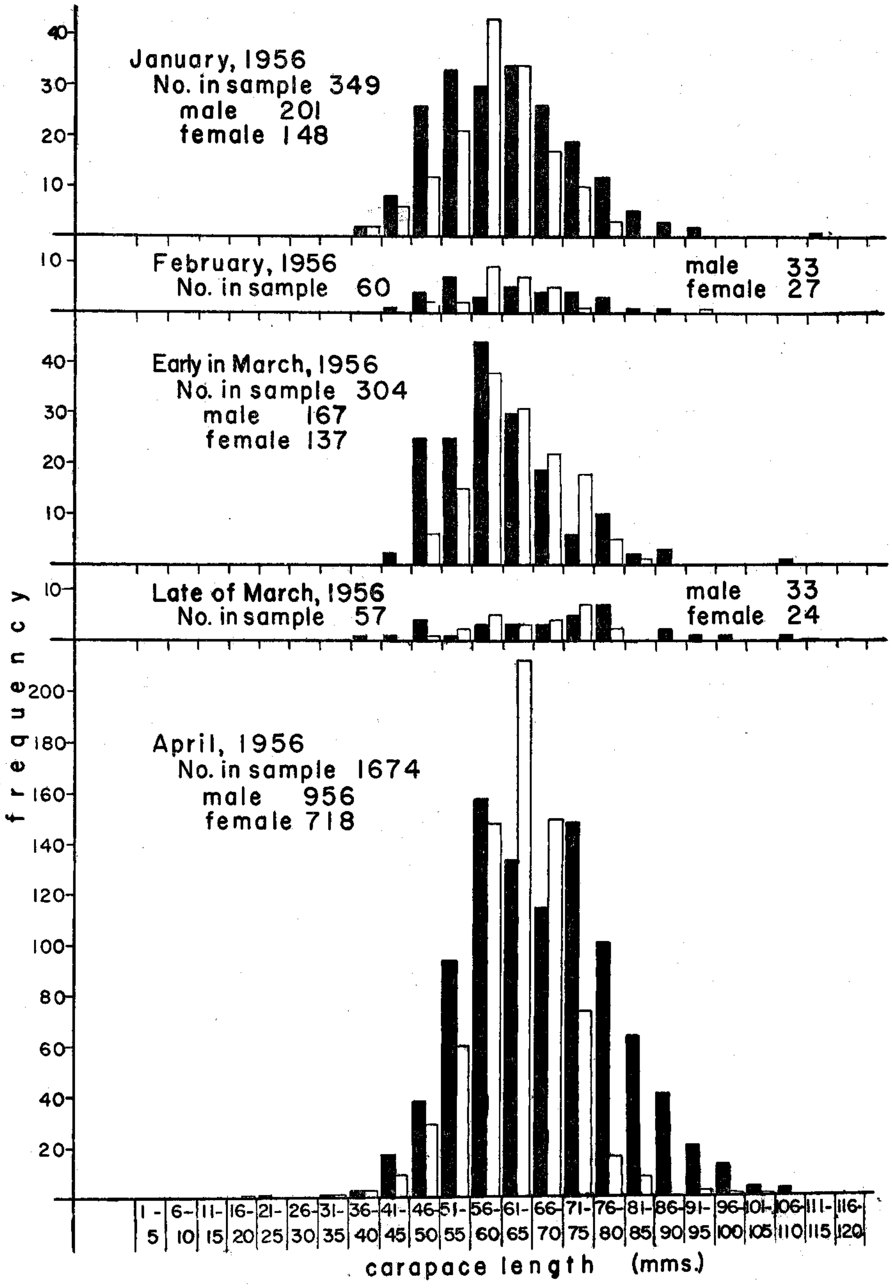

Fig. 4. Frequency distribution of carapace length in monthly samples from the catch landed at the Sirahama Fishery Market in the period from January to April, 1956.

Fig. 5. The landing diminishes considerably in the winter months of January and February, being followed by remarkable increases in the spring months of March and April. The same tendency is also shown in Table 2 and Fig. 3.

Daily yields vary much according to the condition of the sea. Fishermen say that heavy surge during night often yields a great catch. A possible explanation for this evidence may be that the lobsters are captured by the net swinging and pushed to them by the action of surge when they are out of their shelters. Full moon at night results in little or no yield (Table 2 and 3).

Migration and Activity. The evidence of migration of the spiny lobsters has been described by many authors for many members of the Family Palinuridae. OHSHIMA

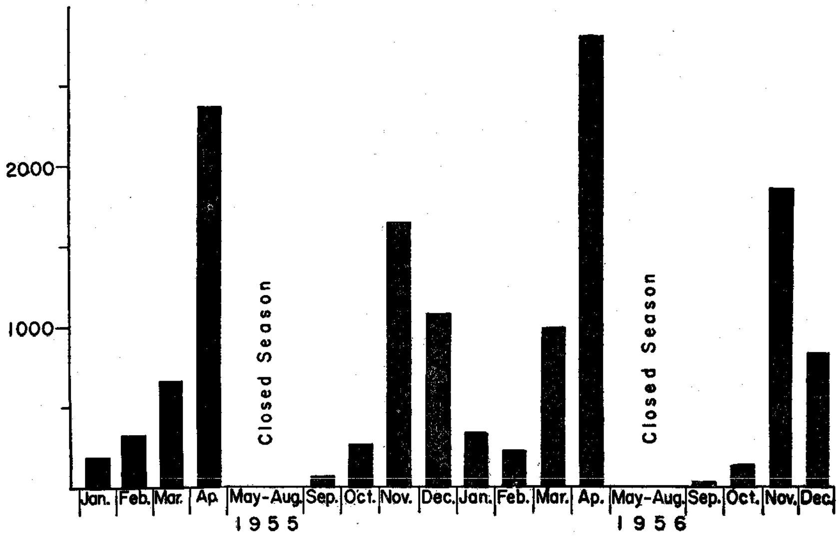

Fig. 5. Monthly landings at the Sirahama Fishery Market. Quantities are shown by their weight in kg. In September and October, the fishing is restricted to only around Oki-no-sima and Nada-no-sima.

(1935) says for *Panulirus japonicus* that the lobsters migrate from deep water to shallow water in spring and that this is associated with the increase of water temperature. The same is said for *Jasus lalandii* by ANDERTON (1907). SMITH (1948) recognized three types of movement for *Panulirus argus*: 1) that caused by the change in physical condition, 2) that concerned with search for food, and 3) regular seasonal movements associated with breeding habits. DAWSON and IDYLL (1951), showing the sex ratios by month for the same species, reported that the proportion of female in the population is at its lowest point in the months at the height of the spawning season, presumably because they move into deeper water to spawn. By comparing the length frequencies and sex ratios at various localities, SUTCLIFFE (1952, 1953) also found for *Panulirus argus* that the great majority of mature females and smaller mature males migrate to the periphery of the reefs in the breeding season. For *Panulirus interruptus*, LINDBERG (1955) reported the same as recognized by SMITH above cited. On the other hand, OKADA and KATO (1946) reported the migratory power of *Panulirus japonicus* to be relatively small. KINOSHITA (1933) showed their stay in the same fishing ground by tagging experiment.

As has been described and shown in Fig. 5, the commerical landing tends to increase toward spring, but this evidence is more than could be accounted for by spring onshore mass movement. There has been no considerable change in the number of fishermen of Sirahama engaging in the spiny lobster fishery, nor in the number of fishing grounds, excluding two months of September and October when the fishing ground is restricted to only around Oki-no-sima and Nada-no-sima. Changes in the monthly average numbers of the catches per one sheet of the fishing net at various regions in Kanayama Bay (Fig. 3) and in the daily average numbers of the catches per one fisherman at various fishing grounds show the same tendency and no indication of the increasing number of the lobster in shallow water. Furthermore, relatively high yields have been recorded in February and early March, when water temperature is at its lowest. The increasing landing in spring may, therefore, primarily due to the change in activity of the spiny lobster, in relation to increasing temperature and possibly to its breeding behaviour.

Other Members of Palinurids. On the south-west coast of Kii Peninsula, of the genus 6 species *Panulirus japonicus*, *P. longipes*, *P. versicolor*, *P. penicillatus*, *P. homarus* and *P. ornatus* are known to occur (KUBO, 1954). Of these, *Panulirus japonicus* is predominant, and *P. longipes* is often found in the samples of the commerical landing, while the record of the catch of the other four species is very rare. By the examination of the commercial catches at the Sirahama Fishery Market during the fishing season 1955–1956, only three individuals of *Panulirus longipes* were found. Of the allied Palinurid forms, *Scyllarides squamosus* (=*S. sieboldi*), *S. haani* and *Parribacus antarcticus* (=*P. ursus-major*) are common, but less than *Panulirus japonicus*. Of these, the first two Scyllarids are of commercial value as food lobsters.

Some Aspects of Life in Larval Stages

I) PHYLLOSOMA STAGE

A number of the newly hatched phyllosome of *Panulirus japonicus* were collected by the horizontal surface hauling of a large plankton net. It occurs in the plankton from the middle of June to the late of August. Its horizontal distributions in Kanayama Bay and in Tanabe Bay are shown in Table 4 and Fig. 6. In Kanayama Bay, its occurrence in the surface plankton varies irregularly from time to time and from station to station. During daytime on August 1st, 1955, it occurred in large number at Station 102, while there were comparatively few catches from neighbouring Stations 103 and 104. On August 19th, 1955, the catch during daytime from Station 102 was less than that from Station 103. While many were taken at Station 103 during daytime on June 21st, 1956, there were only few taken on later days during the summer of 1956, when the catches from other stations were somewhat high. On August 10th, 1956, hauls were made at just before dawn and during daytime. Many were caught in the former case, but only two were captured in the latter. The catches from Stations 110, 107 and 115 were very few throughout the period investigated. Although the number of

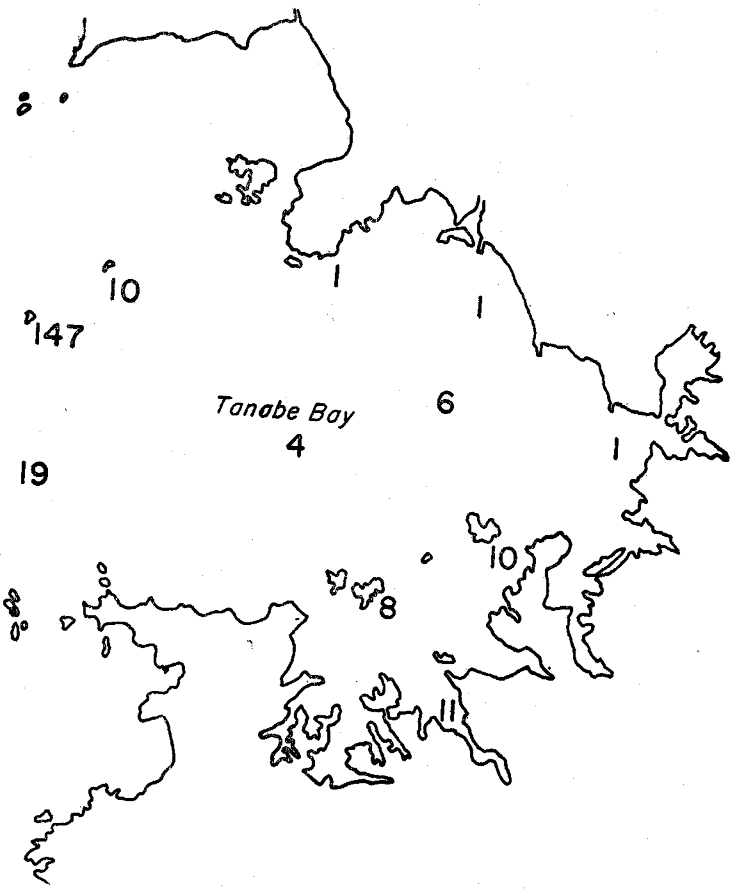

Fig. 6. Horizontal distribution of the newly hatched phyllosomes of *Panulirus japonicus* (VON SIEBOLD) on July 26th, 1956, in Tanabe Bay.

the newly hatched phyllosomes in the collections from stations at Kanayama Bay is too small to afford a true picture of the horizontal distribution, and besides there are considerable unevenness and fluctuation in their number, it appears that their occurrence in the plankton in the surface layers is, on the whole, restricted mainly to the vicinities of rocky reefs, where high populations are expected to be present as inferred from the data of the commercial landings. Irregularity of their occurrence is possibly due to the uneven occurrence of hatching out.

In Tanabe Bay, the newly hatched phyllosomes occur at various stations in sufficient numbers to bring evidence on their horizontal distribution. During daytime on June 26th, 1956, hauls were made at eleven station and the phyllosomes were found in every sample from these stations (Fig. 6). However, there were marked difference in number between a group of Stations 92, 82, 96, 53, 20, 10 and 14 and a group of Stations 51, 72, 31 and 64. Stations belonging to the former group are all in the vicinities of the rocky reefs and the number of the phyllosomes in the collection from these stations is higher than that from stations of the latter group. Especially, at those stations of innermost part of the bay such as Stations 31 and 51, only one was caught at each. At Station 64, which is situated nearly at the center of the bay and has no rocky reef in its vicinity, four phyllosomes were captured, and this fact indicates that the phyllosomes are brought away by the mechanical action of water movement. On September 3rd, 1956, hauls were made at seven stations (92, 51, 20, 10, 15, and 58), but none were caught.

On June 26th, four stations (81, 02, 03 and 04) were visited to make hauls during daytime. No phyllosome was, however, captured except at Station 81, where only one newly hatched phyllosome was captured.

On July 14th, just before the sunrise, a small plankton net was towed horizontally at four depths (surface, 1–1.5, 2.5–3, and 6–7 m) over about 150 m along the underwater cliff at Station 109. Three newly hatched phyllosomes were taken at the surface (0–0.5 m), but none at other depths. After the sunrise, none were caught at the surface too. Thus, the number of the catch of the phyllosome is too small to obtain an indication of its vertical distribution. However, considering with the fact that many were caught by the horizontal surface hauls of the large plankton net just before the dawn on August 10th at various stations, it seems highly probable that the newly hatched phyllosomes are more abundant at the surface at dawn and diminish after the sunrise.

This smaller number of the catch of the newly hatched phyllosomes by these procedures seems to suggest that their stay in the water as plankton is very short. KINOSHITA (1931) observed the newly hatched phyllosomes in the aquarium and described that they stay at the surface for two days and then descend to the bottom, producing no moult. SHIINO reared the newly hatched phyllosomes for about one month producing no moult (personal communication). If this stage is prolonged in the aquarium, the newly hatched phyllosomes will sink to the bottom before two days will elapse.

It was then hoped to collect the phyllosomes descended to the bottom using the pump. Collections were occasionally made at various situations, such as on the rock surface, among algae, in the rock crevice and rock ledge where the adult lobsters inhabit, but none were found in these samples. If a considerable number of the eggs carried by one female, approximately from 29,000 to 554,000 (INO, 1947), is taken into account, the probable explanation of this fact is that most of the newly hatched phyllosomes are carried away for some distance by the mechanical action of water movement, if their mortality rate is not too high.

II) PUERULUS STAGE

It was hoped to collect the pueruli using the beam trawl and the "Manga" dredge. Station 110 and 107 were mainly visited during daytime and at night, but no puerulus was captured. The results of trawlings of the beam trawl made by Mr. Siro TAKAMATU on September 2nd, 1956, at several stations of innermost part of Tanabe Bay, where *Zostera nana* or *Z. marina* is growing on the bottom, show no catch of the puerulus. On January 23rd, 1956, the "Manga" dredge was used at the muddy deep part and at the innermost muddy part of Tanabe Bay, and no puerulus was taken.

Some fishermen captured pueruli that were attracted to the fish-attracting lamp and were swimming at the surface of water under the lamp. These pueruli were all of *Panulirus japonicus* and the measurements of them are shown in Table 5. These were all caught in the area where rocky reefs lie on the bottom and about 10–20 m in depth. Some fishermen say that the pueruli are attracted only when the fish-attracting lamp is lighted near the rocky reefs in the period between September and October. Other fishermen say that when they trawled at muddy areas of innermost part of Tanabe Bay at night many pueruli have been captured. Other fishermen say that when he was diving in June a number of pueruli were observed among algae. These evidences are also reported by many investigators (KINOSHITA, 1931; OHSHIMA, 1941; OKADA and KUBO, 1950). It may probably be said that the pueruli are living normally in the rocky area as in the adult.

Some descriptions on the attraction of pueruli by the light will be mentioned under the article of "Effect of the Fish-attracting Lamp on the Larvae."

III) YOUNG LOBSTER

One young lobster of *Panulirus japonicus* was captured in a small hole on the rock at 2 m in depth near Station 109 on July 24th, 1956. The hole was as large as its body, so that the animal was in a situation with its 2nd antennae completely exposed outside of the hole.

While diving, three young lobsters (sub-adult) were observed, each inhabiting in one small hole on the rock and in the same situation mentioned above. These animals are a little larger than that mentioned above; one on September 4th, 1956, at 5 m in depth near Station 109 by me, two on December 15th, 1956, at 2–3 m in depth at northern shore of the Laboratory by Mr. Ryônosuke OKUNO. Measurements of one of those are shown in Table 5. In the latter case, they were also observed on the following day. It is thus undoubted that the young lobsters are inhabiting in small holes on the rock.

Comparing the measurements of the first and the last shown in Table 5, some differences are noticed. These increments are presumably due to the growth in the period between they were found.

Effect of the Fish-attracting Lamp on the Larvae

Many fishermen of Sirahama emphasize that the fish-attracting lamp of "Bôuke-ami" fishery affects on the larvae of the spiny lobster with its intensity of light and leads them to come to the surface, swimming restlessly around far enough to die. They indicate, also, that it occurs from July to October, the majority being seen in September. But this evidence has not been perceived by most of fishermen of Tanabe, Minabe or Sakai. Here arise some questions whether the larvae of the spiny lobster, so fishermen report, are true larvae of *Panulirus japonicus* or not, and whether they are seen frequently in great number or not.

It was, therefore, asked in 1955 for fishermen of Sirahama engaging in the "Bôuke-ami" fishery to record the occurrence of the larvae with the date, locality, depth, and condition of the sea when they were found, and to collect the larvae attracted. But, unfortunately, only a few records and collections were available. Only one puerulus of *Panulirus japonicus* was attracted and captured near Tonda on September 22nd by Mr. Chiyozi KANAYA. Other fishermen made collections of the larvae of the spiny lobster, as they call so, but these were in fact all the Alima larvae of stomatopods, excluding one which is alike the puerulus but species is undeterminable. In 1956, fisherman of Sirahama state that they have never seen the larvae, though they fished for about a month and a half from the middle of May to the end of June in Kanayama Bay.

In 1956, Mr. Hidematsu TOYAMA at Minabe captured fifteen larvae during the period from the beginning of September to the end of October. Unfortunately, five specimens collected on September 30th were lost away. These were all pueruli of *Panulirus japonicus* (Table 5). He reported that when fished off the coast where depth is over 40 m, many large long-spined transparent larvae were taken. But when fished in the vicinities of the rocky reefs ranging from 10 to 15 m in depth, many transparent larvae with long slender antennae and without long spines were captured. The formers in his information are the Alima larvae and the latters are the pueruli.

It is not certain from these observations made by the commercial fishermen whether the phyllosomes are attracted to the fish-attracting lamp or not. To test this, the fish-attracting lamp was lighted at some stations and the organisms attracted to the lamp were collected using the plankton net. The observation was carried out in two manners. One was designed to make a comparison between the station close to rocky reefs and the station somewhat off the rocky reefs. Three stations were chosen in Kanayama Bay, namely Stations 107, 109 and 111. These stations were visited in the same night, making tows from 1 m depth to the surface under the lamp before and 20 minutes after it was lighted. But no phyllosome was caught at all.

Another observation was attempted to know the change in number of the lamp-attracted phyllosomes during night. Vertical tows were made under the lamp at intervals of two or three hours. One newly hatched phyllosome was taken at midnight on July 21st, 1956, at Station 10, and this is the only one case that the newly hatched phyllosome was captured under the lamp. It can hardly be said that the newly hatched phyllosomes are attracted to the lamp.

Thus, it may be concluded that the pueruli of *Panulirus japonicus* are attracted to the lamp when it is lighted in the vicinities of the rocky areas, but this is not the case of its newly hatched phyllosomes.

Discussion

Many investigators have written as to the occurrence of the phyllosomes of various spiny lobsters. CUNNINGHAM (1892) described as follow: "These larvae (the phyllosomes of *Palinurus vulgaris*) do not occur near shore, for we have never taken them before in our ordinary tow-nets worked within a mile or two of the coast. On two occasions on which I obtained the larvae, I captured them only when towing the net at the surface, not when it was sunk to some depth." But RUSSELL (1927), comparing his results on the vertical distribution of marine macroplankton with that of CUNNINGHAM, says: "These results are opposed to mine, but it may be that the catches were made much nearer the Eddystone, where up-welling currents might upset the normal distribution of the plankton in more quiet water." According to his conclusions of three papers (1925, 1927, 1928), the phyllosomes of *Palinurus vulgaris* appear to have been very near the bottom during the daylight; at dusk they are distributed rather evenly in all layers and great in number; at midnight and dawn the numbers are somewhat reduced. On the other hand, ANDERTON (1907) observed the vast number of the first embryo[1] of *Palinurus edwardsii* swarmed in the large tank, swimming freely near the surface. GILCHRIST, in his two papers (1913, 1916) on the larval stages of *Jasus lalandii*, says that on hatching the naupliosoma rapidly ascends to the surface; in a few hours (4–6) the phyllosoma stage is assumed; later, the phyllosomes avoid the light and seem to descend from the upper layers of the water on ecdysis. Moreover, he took a series of two-nettings at more or less regular intervals in Table Bay from January, 1913, to May, 1914, and found the first phyllosomes in abundance in the inshore waters during the summer months, and much smaller number of more advanced stages in the deep waters.

NAKAZAWA (1917) consented with this description of GILCHRIST, but he made an assumption that the newly hatched phyllosomes may stay near the bottom when they released in quiet waters and not move upward to the surface by themselves, and their occurrence at the surface may be merely due to upwelling movement of water. Later, KINOSHITA (1931) made the observations on the newly hatched phyllosomes of *Panulirus japonicus* reared in the aquarium and reported that the phyllosomes descend to the bottom after 2 days duration of the surface life, producing no moult. Thus, although RUSSELL and NAKAZAWA opposed to the opinion that the phyllosomes swim upward to the surface, it seems probable that the newly hatched phyllosomes pass a

1) THOMSON (1907) described that this has the characteristic *Phyllosoma* appearance, and later GILCHRIST (1913) named this larvae as *naupliosoma*. The species name of *Palinurus edwardsii* was corrected as *Jasus lalandii* by ARCHEY (1914) and GILCHRIST (1916).

surface planktonic life, though it is for a short period of time. In the present investigations, a number of the newly hatched phyllosomes of *Panulirus japonicus* were taken at the surface in the vicinities of rocky reefs even during the daytime.

Considerable variations are seen in the number of the newly hatched phyllosomes of *Panulirus japonicus*, that occur in the surface plankton, from time to time and among stations. This variations or fluctuations seem to be closely related to the unevenness of occurrence of the hatching. KINOSHITA (1931) suggested that the hatching occurs at night or dawn. The vast number of eggs carried by one female, on hatching, may possibly result in producing great number of the newly hatched phyllosomes in the surface layers when they are released. The shortness of their duration in the surface layers caused their distribution being restricted in the vicinity of the place where they are released from their mother, thus preventing the even distribution throughout the area.

In their stay in the surface layers, though for a short period of time, the newly hatched phyllosomes may disperse wider from where they are released. This dispersal is probably due to the mechanical action of water movement, because their swimming power seems to be too small to migrate over such a distance as will be mentioned below within a short period of time, for some are captured at the centre of Tanabe Bay, where no rocky reef is expected within 2 km. However, none were caught far off the coast (Stations 02, 03, 04), though there is one at Station 81 which is situated over the underwater reef. Thus, this dispersal in the newly hatched phyllosoma stage may ordinarily not extend far over several miles.

It is not certain whether the majority of the newly hatched phyllosomes disperse and reach the bottom far from where they are hatched out or settle down to the bottom in the vicinities of the places where they are released from their mothers.

LINDBERG (1955) described on large and intermediate-sized phyllosomes of *Panulirus interruptus* taken during the mid-water trawling operations and says: "It is perhaps significant, however, that phyllosomes are taken at greater frequency during these operations than when surface samples alone are made. The presence of these advanced larval stages at these suggested depths in the month of March leads us to think that the larvae spend a minimum of six to nine months in the plankton. This fragmentary evidence suggests that the settling of larval forms may occur in deep water and that the metamorphosed bottom stages then migrate to shallow water." It is, however, not certain if these assumptions are applicable to the larval life of *Panulirus japonicus*, for I have no evidence to support it.

Summary

1. The present paper deals with the results of the investigations on the larval and adult Japanese spiny lobster, *Panulirus japonicus*, carried out between July, 1955, and January, 1957, in the neighbouring waters of the Seto Marine Biological Laboratory, Wakayama Prefecture.

2. The samples of the catch of the adult spiny lobster were examined and their population composition was analysed in terms of carapace length and sex ratio. They are more abundant in the fishing grounds facing the open sea. The monthly commercial landings, the monthly catches per unit effort and the daily catches per one fisherman increase toward the warmer months of spring, probably due to the increasing activity of the species concerned. There is an apparent progression of the mode of carapace length by month, but age groups are not discernible.

3. The newly hatched phyllosomes of *Panulirus japonicus* occur from the middle of June to the end of August, generally in accordance with the period of spawning season of this species. They are found in abundance in the surface layer in the vicinities of the rocky reefs, but their numbers vary irregularly.

4. No phyllosome in advanced stage was captured in the surface layer. These evidences suggest that the newly hatched phyllosomes may spend a short planktonic life in the surface layer. The pueruli of *Panulirus japonicus* are mostly captured in the shallow waters of rocky areas. It is not certain whether the newly hatched phyllosomes that ascend to the surface are brought away far off the coast or not.

5. From the horizontal surface towings, it seems highly probable that the newly hatched phyllosomes are most abundant at the surface at dawn and diminish after the sunrise.

6. The larvae of *Panulirus japonicus* in the puerulus stage only are attracted to the fish-attracting lamp when it is lighted close to the rocky reefs.

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APPENDIX

Table 1. List of stations chosen for this study in Kanayama Bay, Tanabe Bay and off Bansyo-no-hana. (Also see Fig. 1)

St. No.	Substratum	Depth (m)	Remarks
1) Kanayama Bay			
102	rock	5–7	close to the rocky reef of Sisô-zima
103	rock	8–10	close to the rocky reef of Sisô-zima
104	rock	9–11	near the rocky reef of Sisô-zima
107	boulders	4–6	close to the rocky reef of Seto
109	boulders	6–8	close to the rocky reef of Taka-sima
110	sand	4–5	at the bottom of the arched sandy shore
111	rock	3–8	over the underwater reef
114	sand	20	over the deep
115	sand	8–10	near the rocky reef
2) Tanabe Bay			
10	mud	9–12	near the rocky reef of Hatake-zima
14	mud	2–4	close to the rocky reef of the mouth of Hosono
15	*Zostera marina*	2–3	innermost part of Hosono
20	mud	8–10	near the rocky reef of Ka-sima
31	mud	8	
51	sand	4–5	near the sandy shore
53	rock	2–6	over the underwater reef
58	rock	10–15	near the rocky reef of Ezura
60	sand	6–7	
64	mud	23–25	over the deep
72	rock	9–12	near the rocky reef
82	sand	31–34	
92	rock	11–20	close to the rocky reef of Oki-no-sima
96	rock	4–12	close to the rocky reef of Nada-no-sima
101	boulders	4–9	near the rocky reef of Tô-sima
3) Off Bansyo-no-hana			
81	rock	16–18	1 mile off, over the underwater reef of Seto-ga-se
01	mud	60	1.5 mile off
02	mud	80	3 miles off
03	mud	100	6 miles off

Table 2. Daily average numbers of the catches per one fisherman at various fishing grounds.

Date	Date of lunar month	Condition of the sea	Fishing grounds		
			Kanayama Bay	Southern coast of Seto-zaki	Sisô-zima
Jan. 13	0	very smooth	2.0	4.8	2.0
15	2.0	smooth	—	10.3	1.3
16	3.0	slight	2.5	3.3	4.0
17	4.0	smooth	2.5	3.6	1.3
18	5.0	very smooth	2.2	2.1	—
19	6.0	moderate swell	—	—	5.0
Feb. 15	3.2	very smooth	3.6	2.8	—
Mar. 8	25.2	slight	9.0	—	—
9	26.2	slight	5.8	6.0	—
22	9.5	smooth	1.5	—	2.0
Apr. 4	22.5	slight swell	4.7	20.0	—
5	23.5	very smooth	4.0	6.8	—
6	24.5	very smooth	4.2	9.1	—
7	25.5	very smooth	4.5	9.3	—
8	26.5	slight swell	5.0	8.5	1.0
11	0	moderate swell	8.0	—	—
12	1.0	moderate swell	9.8	10.5	4.0
14	3.0	rather rough swell	8.5	9.9	—
15	4.0	smooth	6.7	—	—
16	5.0	slight swell	7.3	8.0	—
17	6.0	very smooth	2.5	—	4.0
18	7.0	very smooth	3.5	5.6	—

Table 3. Daily average numbers of the catches per unit effort (per one sheet of net) at various regions in Kanayama Bay in the years 1955–1956. (see Fig. 3)

Date	Date of lunar month	Conditions of the sea	Regions		
			T	G	C
Nov. 18	3.6	smooth	—	0.21	—
19	4.6	smooth	0.43	—	—
20	5.6	smooth	0.43	0.43	0.29
21	6.6	smooth	0.24	—	—
Dec. 3	18.6	smooth	0.18	—	—
5	20.6	smooth	0.43	—	—
6	21.6	smooth	0.28	—	—
7	22.6	moderate swell	—	0.14	0.79
8	23.6	smooth	0.30	0.22	—
9	24.6	moderate swell	—	—	1.00
10	25.6	smooth	—	0.08	0.21
11	25.6	smooth	0.08	0.71	0.19
13	28.6	smooth	—	—	0.03
14	29.6	slight swell	—	0.87	0.37
15	0.8	smooth	—	0.21	—
16	1.8	moderate swell	0.68	—	—
17	2.8	rather rough swell	—	0.25	—
18	3.8	slight swell	—	—	1.27
19	4.8	smooth	—	0.20	—
20	5.8	smooth	0.00	—	—
22	7.8	slight swell	—	0.71	0.62
Feb. 2	20.0	smooth	0.28	—	—
3	21.0	smooth	—	0.20	0.10
6	24.0	smooth	0.57	0.43	—
9	27.0	moderate swell	—	0.50	—
11	29.0	slight swell	—	0.60	—
14	2.2	smooth	—	0.21	0.08
15	3.2	very smooth	—	0.08	0.23
Mar. 2	19.2	smooth	—	0.21	0.15
3	20.2	very smooth	—	0.21	0.20
5	22.2	very smooth	—	0.28	0.00
6	23.2	smooth	0.50	—	—
9	26.2	slight swell	0.71	—	—
10	27.2	slight swell	—	0.47	—
11	28.2	very smooth	—	0.00	—
16	3.5	moderate swell	0.33	—	—
18	5.5	slight swell	—	—	1.10
19	6.5	slight swell	0.70	—	—
21	8.5	smooth	—	0.38	0.42
Apr. 1	19.5	smooth	0.64	—	—
3	21.5	smooth	0.95	—	—
5	23.5	very smooth	0.59	—	—
7	25.5	very smooth	0.54	—	—
8	26.5	slight swell	0.53	—	—

Table 4. Numbers of the newly hatched phyllosomes of *Panulirus japonicus* (VON SIEBOLD) caught in the surface layer at various stations in Kanayama Bay in the period between August, 1955, and January, 1957. Numbers in a volume of 78 m^3 of water.

Date	103	107	109	110	111	114	115	101	102	104
1955										
Aug. 1 (dt)	2	—	—	—	—	—	—	—	14.5	1.6
Aug. 19 (dt)	6	—	—	—	—	—	—	—	2	—
Sept. 2 (dt)	—	0	0	—	—	—	—	—	—	0
Sept. 4 (n)	—	0	0	—	—	—	—	—	—	—
Oct. 5 (dt)	—	0	0	—	—	—	—	—	—	—
Oct. 22 (dt)	—	0	0	—	—	—	—	—	—	0
Oct. 22 (n)	—	0	0	—	—	—	—	—	—	—
Nov. 29 (dt)	—	0	0	—	0	—	—	—	—	—
Dec. 2 (n)	—	0	0	—	0	—	—	—	—	—

Table 4. (continued)

Date	103	107	109	110	111	114	115	101	102	104
1956										
Jan. 17 (dt)	—	0	0	—	0	—	—	—	—	—
Jan. 17 (n)	—	0	0	—	0	—	—	—	—	—
Feb. 15 (dt)	—	0	0	—	0	—	—	—	—	—
Mar. 10 (dt)	—	0	0	—	0	—	—	—	—	0
Mar. 10 (n)	—	0	0	—	0	—	—	—	—	—
Apr. 13 (dt)	—	0	0	—	0	—	—	—	—	—
May 12 (dt)	0	0	0	0	0	0	0	—	—	—
May 24 (dt)	—	—	—	—	—	—	—	0	0	—
May 25 (dt)	0	0	0	0	0	0	0	—	—	—
May 28 (n)	0	0	0	0	0	0	0	0	—	—
June 6 (dt)	0	0	0	0	0	0	0	0	—	—
June 15 (n)	0	0	0	0	0	0	0	0	—	—
June 21 (dt)	16	0	0	0	3	3	1	2	—	—
June 28 (dt)	0	1	0	0	1	0	0	0	—	—
July 9 (dt)	1	0	0	0	0	0	0	0	—	—
July 22 (dt)	0	0	0	1	0	0	—	5	—	—
Aug. 10 (dw)	0	0	3	0	2	4	0	1	—	—
Aug. 10 (dt)	1	0	0	0	0	0	0	0	—	—
Aug. 19 (dt)	—	0	0	—	0	—	—	—	—	—
Sept. 1 (dt)	0	0	0	0	0	0	0	0	—	—
Oct. 2 (dw)	0	0	0	0	0	0	0	0	—	—
Oct. 2 (dt)	0	0	0	0	0	0	0	0	—	—
Oct. 30 (dt)	0	0	0	0	0	0	0	—	—	—
Nov. 18 (dt)	0	0	0	0	0	0	0	0	—	—
Dec. 16 (dt)	0	0	0	0	0	0	—	0	—	—
1957										
Jan. 23 (dt)	0	—	0	—	—	—	—	—	—	—

dt: daytime, n: night, dw: dawn.

Table 5. Measurements of specimens of the pueruli, the young and the sub-adult lobsters of *Panulirus japonicus* (VON SIEBOLD).

Date	Locality	Depth (m)	Method	Measurements* (mm)				
				bl	cl	bw	bh	al
I) Puerulus								
Sept. 22, 1955	off Tonda	—	light	20.2	7.0	5.0	3.8	17.2
Sept. 1, 1956	off Senri, Minabe	10	light	20.8	7.2	5.0	4.0	21.5
" " "	"	"	"	27.0	9.8	6.7	4.8	31.5
Sept. 30, 1956	off Nakayama, Iwasiro	20	light	20.5	7.1	5.7	4.1	16.2
" " "	"	"	"	20.8	7.3	5.2	4.0	23.0
" " "	"	"	"	20.9	7.2	5.2	3.4	22.0
" " "	"	"	"	21.0	7.3	5.2	3.8	22.2
" " "	"	"	"	24.6	8.1	6.9	5.6	20.6
Oct. 3, 1956	off Nakayama, Iwasiro	20	light	26.5	9.9	6.8	4.8	28.5
Oct. 4, 1956	off Nakayama, Iwasiro	20	light	26.8	9.8	6.8	5.0	27.6
II) Young (Sub-adult)								
July 24, 1956	near Taka-sima	4	diving	26.2	8.5	6.8	6.1	42.4
Dec. 12, 1956	northern shore of the Laboratory	2	diving	70.0	20.8	17.0	15.8	141.2

* bl: body length, cl: carapace length, bw: body weight, bh: body height, al: 2nd antennal length.

EXPLANATION OF PLATES VI–VII

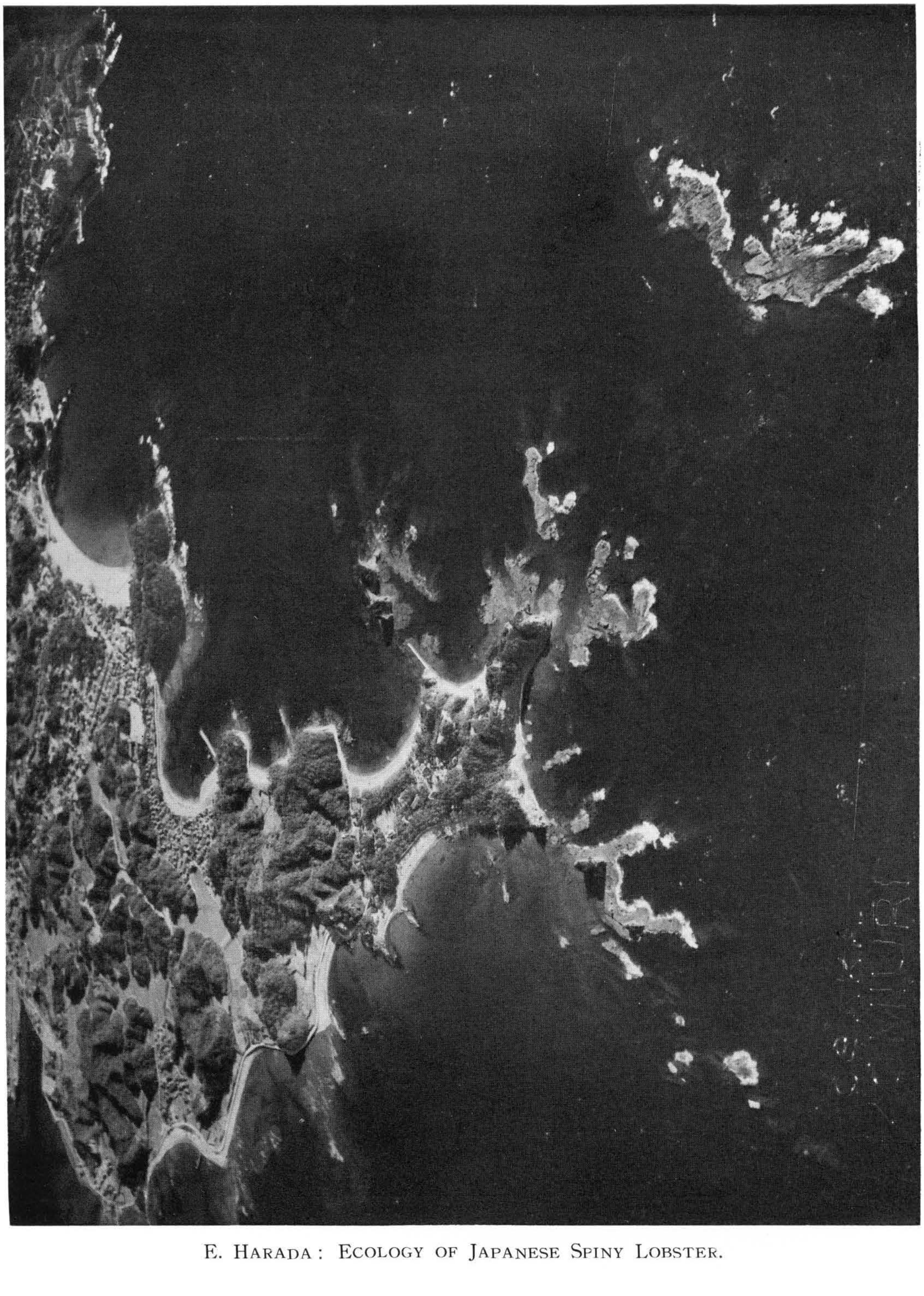
PLATE VI

Fig. 1. Aerial view of Bansyo-no-hana and Kanayama Bay looking southeastward. Underwater reefs are clearly seen. Photo by Osaka Yomiuri Shinbun, Nov. 1956.

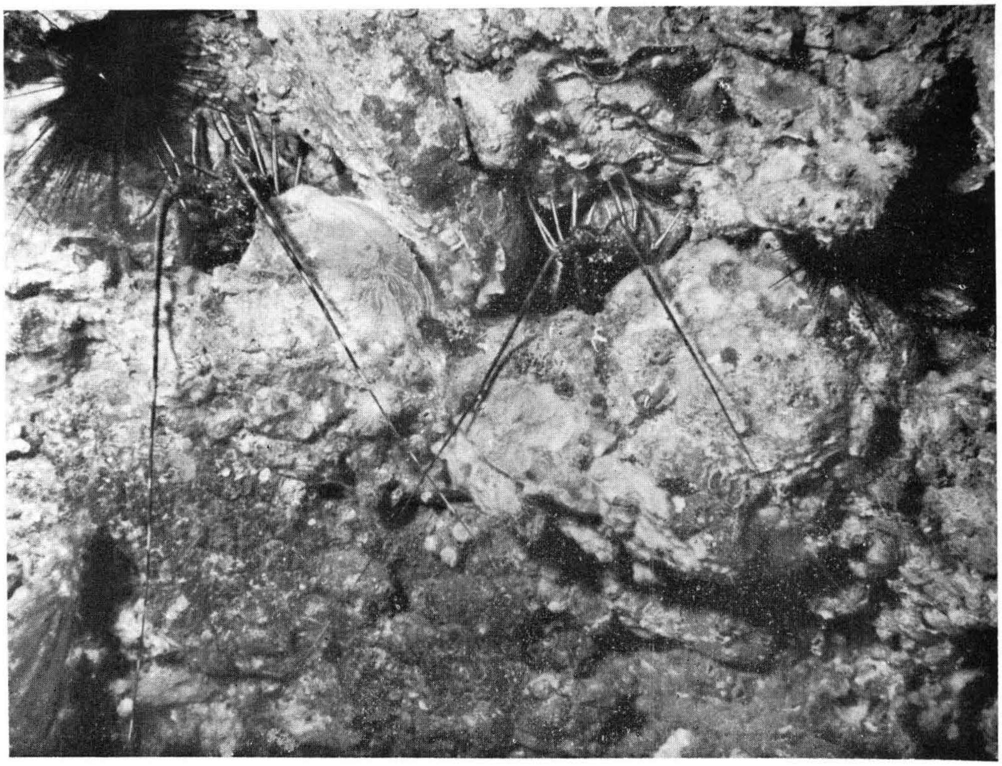
PLATE VII

Fig. 1. Two lobsters sheltered in small holes on the roof of a large rock cave. Photo under water by E. HARADA, Nov. 1956.

Fig. 2. A lobster sheltered in a ledge at the bottom of a large rock cave. Photo under water by E. HARADA, Nov. 1956.



E. HARADA: ECOLOGY OF JAPANESE SPINY LOBSTER.



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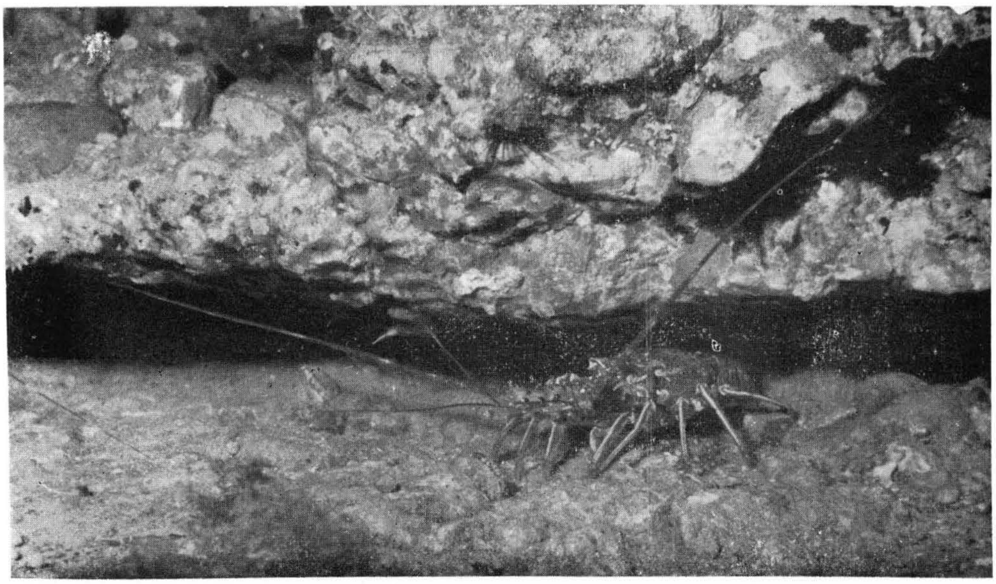

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