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STUDIES ON THE BIOLOGY AND POPULATION DYNAMICS OF THE SPINY LOBSTER, *PANULIRUS POLYPHAGUS* (HERBST), OF THE WEST COAST OF THAILAND, WITH NOTES ON EXPERIMENTAL REARING OF *P. VERSICOLOR* (LATRIELLE) IN THE LABORATORY

by

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ABSTRACT

The landings of spiny lobster, *Panulirus polyphagus*, at Phuket on the west coast of Thailand were analyzed for their morphological relationships, size-composition, seasonal fluctuations of size-groups, sex-ratio, sexual maturity, growth rate and observations on spawning season. Nature of their fishery and its seasonal fluctuations are reported. Results of some experiments on rearing another species of spiny lobster, *P. versicolor*, in the laboratory are reported on their growth rate and moulting studied.

GENERAL INTRODUCTION

We are passing through times when demand for seafood is notably increasing while the yield from marine harvests is measurably decreasing. Lobsters of the west coast of Thailand are local examples. There are reports of a remarkable decrease in the landings of lobsters in this area, but we know next to

nothing about the biology and distribution of these lobster populations. Any attempts to search for remedial measures to rectify this situation demands, as a first step, collection of basic background information about the species in question. With this idea in mind, the Department of Fisheries of Thailand initiated a research programme on the biology of lobsters at Phuket Marine Biological Center, the first results of which are presented in this paper. It is hoped that an accumulation of knowledge on the biology and behaviour of the lobsters of this area will ultimately make a positive contribution towards a better understanding of the difficulties and problems relating to the future feasibility for artificial cultivation of these animals.

The planning and initiation of all work pertaining to this programme was exclusively our personal responsibility, and we wish hereby to express our thanks to our superiors in the Department of Fisheries for their deep interest which has been a great encouragement for us in the course of this programme.

I. INTRODUCTION

Spiny lobsters belonging to the family Palinuridae constitute a highly favoured seafood in southern Thailand, particularly along the west coast, and therefore are of great economic importance. Naiyanetr (unpublished) recorded five species of lobsters from the west coast of Thailand, while Bhatia (1974, in press) recorded a sixth species, *P. homarus*, in his recent survey of the distribution of lobsters in this area. The six species are:

1. *Panulirus homarus* (L.)
2. *P. longipes* (Milne - Edwards)
3. *P. ornatus* (F.)
4. *P. penicillatus* (Olivier)
5. *P. polyphagus* (Herbst)
6. *P. versicolor* (Latrielle)

Spiny lobsters are widely distributed in the Indian Ocean region and surrounding areas and are one of the largest and most familiar of the crustaceans in waters around Ceylon, India, Malaysia, South Africa and other regions. This report deals with some observations on the biology and population dynamics of one of these species, *Panulirus polyphagus*.

Very little is known on the ecology of spiny lobsters of the Indo-Pacific region in general. One of the earliest investigations bearing specifically on this subject is that of Kubo (1937), who described sexual dimorphism in the Japanese lobster, *P. japonicus*. Harada (1957) studied the ecology of the same species, which included observations on the distribution of larval stages. Chapgar and Deshmukh (1961) reported on the occurrence of *P. dasypus* in Bombay waters. A short record of *P. penicillatus* from the southwest coast of India was made by Satyanarayana (1961). Charbonnier and Crosnier (1961) reported on the lobster fishery of Madagascar. De Bruin (1962) studied the ecology of *Panulirus* species from waters around Ceylon, their distribution patterns and behaviour. Barnard (1950) made detailed observations on the systematics of South African lobsters, while Berry studied the reproductive and moulting cycles, fecundity, growth and feeding of two species of South African *Panulirus*, *P. homarus* (1971) and *P. delagae* (1973). The ecology and systematics of Australian spiny lobsters was investigated by George (1966 & 1968). Bhatia (1974, in press) recently studied the distribution of lobsters and their fishery along the Indian Ocean coast of Thailand.

The local lobster fishery makes only a very negligible contribution to the total landings of marine animals at the Phuket fishing harbour on the west coast of Thailand. As we have no idea whatsoever of the extent of lobster populations in this area, it was considered essential to study the biology of these animals for the maintenance and possibilities of future expansion of their fishery, also keeping the overall aspects of their conservation in consideration. A research programme on these aspects was initiated at the Phuket Marine Biological Center in 1971. It is hoped that an

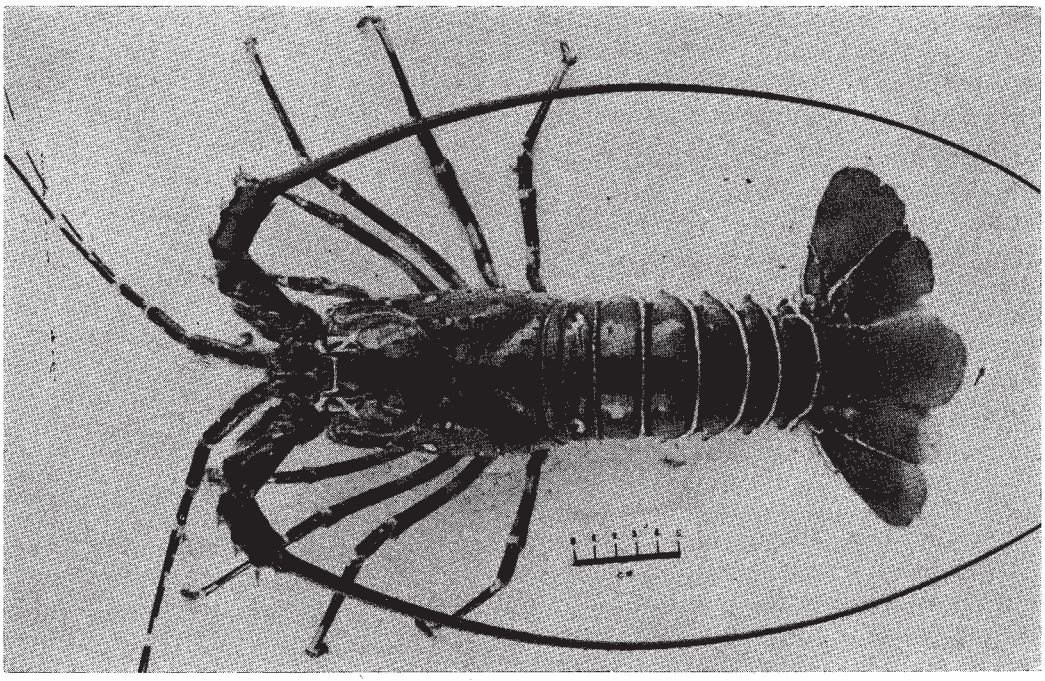

Fig. 1—Spiny lobster, *P. polyphagus* (Herbst).

increase in our knowledge of the biology and behaviour of the spiny lobsters of this area will make a positive contribution towards a better understanding of the difficulties and problems relating to the future feasibility of artificial cultivation of these animals.

The present study reports on the biological observations made on the lobster populations of this area during the first year of study (February, 1971 to January, 1972), and also covers aspects of population dynamics, such as morphological relationships, size composition, sex-ratio, sexual maturity, growth, and observations on the spawning season. Results of a few experiments carried out on the artificial rearing and growth-rate of another species of spiny lobster, *P. versicolor* in the laboratory, are also reported.

II. MATERIALS AND METHODS

(a) Sampling

Most of the marine catches by local trawlers are landed at Phuket fishing harbour every day in the early morning hours. These catches are invariably made by the normal otter-board bottom trawling net and consist mostly of fishes, prawns and crabs, and occasionally a few lobsters also. These specimens mostly belong to the deep-water species, *P. polyphagus* (Fig. 1). The fishing harbour was regularly visited twice a week, every Monday and Friday, during the period from February, 1971, to January, 1972, and all the lobster specimens landed on that day were measured accurately at the harbour itself (all broken and imperfect specimens were rejected). Each specimen was measured for its total length, carapace length, body length, telson length, carapace width, first abdominal segment width and total weight as per definitions given below. Length measurements were made to an accuracy of 0.1 centimeter using vernier calipers while the specimens were weighed to one gram accuracy. The length measurements were grouped into classes of 10 mm. intervals and their monthly fluctuations studied.

There is a minor fishery for lobsters carried out by smaller fishing boats and divers in the coral

reefs and rocky areas around this region. The catches are landed on the local beaches and sold directly to restaurants catering in seafood. As no systematic records of these landings could be kept, they are not considered in the present study.

(b) DEFINITIONS

The length and weight measurements as applied in the present studies are defined as follows:

Total length: The distance along the dorsal midline from the transverse ridge between supra-orbital horns to the tip of the telson.

Carapace length: The distance along the dorsal midline from the transverse ridge between the supra-orbital horns to the posterior end of the cephalothorax. This was used as the standard measurement of length.

Body length: The distance along the dorsal midline from the ridge of the first abdominal segment to the point of the V-shaped base of central uropod of the telson.

Telson length: The distance along the dorsal midline from the point of the V-shape of the central uropod to the tip of the telson.

Width of carapace: The maximum distance between the tergum of the carapace.

Width of the first abdominal segment: The maximum distance between the plural spurs of the first abdominal segment.

Total weight: Weight of the whole animal excluding eggs in ovigerous females.

(c) REARING EXPERIMENTS IN THE LABORATORY

During four cruises of the research vessel *Pramong 8*, live specimens of the spiny lobster, *P. versicolor* (adult and juvenile animals, both male and female), were collected from several areas off Phuket, Phang-nga, Krabi, Ranong and Satun provinces along the west coast of Thailand.

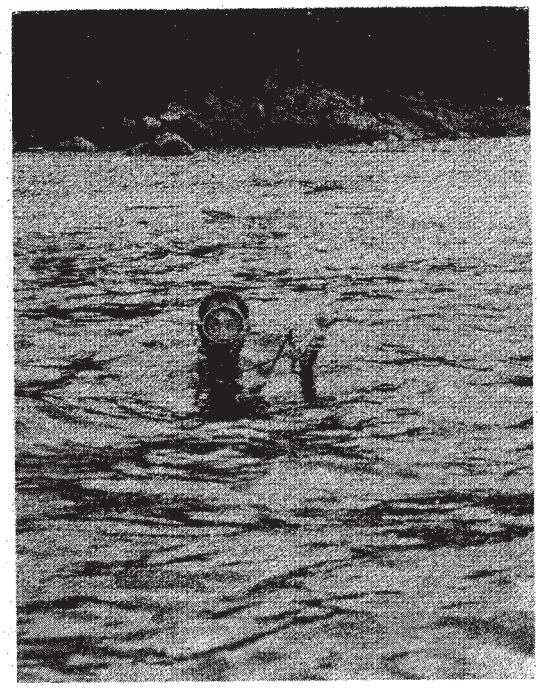

Fig. 2—A spiny lobster caught by a diver around Phang-nga area during the 1st. cruise.

Attempts were made to rear these animals in the laboratory in both glass and cement-tanks with a running seawater system. Untreated and unfiltered seawater pumped from a depth of about 2 meters below the average sea-level in front of the laboratory was used for circulation.

Live specimens were also collected from the coral shores around the Center by diving, using mask and snorkel (Fig. 2). All collections were made using a blunt tip metal hook with a handle. This hook was used by the diver to gently pull the animal out of its hiding places (such as the crevices between and below corals) with one hand, and then the animal was grasped with the other hand. All these collections were made during the daytime when the animals were mostly inactive and in hiding.

The aquarium specimens were fed every day with prawns (*Metapenaeus* spp.) purchased from the landings at the Phuket fishing harbour. These lobsters were measured every 20 days or so on the average and after every moulting, when their total

length, carapace length, body length, telson length, carapace width, first abdominal segment width and total weight were recorded. The moulting specimens were also measured in detail except for the weight.

(d) MORPHOLOGICAL RELATIONSHIPS

The following correlations were calculated from the above measurements.

1. Carapace length (X) / total length (Y)
2. Carapace length (X) / total weight (Y)
3. Carapace length (X) / carapace width (Y)
4. Carapace length (X) / first abdominal segment width (Y)

The regressions were determined by using the equation

$$Y = a + b_{YX} X$$

where, a and b_{YX} are the Y-intercept and the slope of the straight line relating Y to X respectively. For correlation No. 2, the exponential equation

$$W = c. L^n$$

was used, where W is the weight, L is the length and c is the constant.

In the logarithmic form,

$$\log W = \log c + n \log L \quad . . \quad (1)$$

where the constants c and n are determined by the least square method.

If in equation (1)

$$Y = \log W$$
$$X = \log L$$
$$a = \log c$$
$$b_{YX} = n,$$

then the equation would read

$$Y = a + b_{YX} X$$

where $a = \overline{Y} - b_{YX} \overline{X}$

or $\overline{Y} = a + b_{YX} \overline{X}$

$$b_{YX} = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{N}}{\Sigma X^2 - \frac{(\Sigma X)^2}{N}}$$

III. RESULTS

(a) NOTES ON FISHING

Although lobsters are landed in small numbers throughout the year, the highest landings are always recorded during the southwest monsoon months, May to September. As recorded by De Bruin (1962) for Ceylonese waters, unlike other species, *P. polyphagus* is found only in a habitat with muddy bottom, where it gets caught in the bottom trawl net during trawling operations for prawns. In sharp contrast to this, all other species of lobsters are found in coral reefs and rocky areas where they take refuge in crevices between rocks and corals. De Bruin found that they are essentially nocturnal creatures active only during the night mostly for foraging. All the trawling operations for lobsters and prawns in Phuket area are carried out only during the night hours. This is not necessarily to catch more lobsters, but to get a higher yield of prawns, which are also nocturnal in habit, and naturally a larger number of lobsters also get caught in the nets. The lobster landings in this area are therefore not the result of an intentional fishery as in the diving operations. As these trawling operations for prawns are carried out only on muddy bottom (this being the normal habitat for prawns), the predominant species of lobster caught in the nets is *P. polyphagus*, other species being absent or represented only by stray specimens. This agrees with the observations of De Bruin (1962), who found that *P. polyphagus* is the only lobster caught in the nets during trawling operations for prawns on Ceylonese mudbanks. Deshmukh (1964) reports that this species constitutes 99 percent of the commercial landings of lobsters by hoop nets and trawling operations to depths of at least 70 meters on the west coast of India.

(b) SIZE COMPOSITION OF CATCHES

The size-frequency distribution of the monthly samples and their seasonal fluctuations are shown in Fig. 3. The mean carapace length for the total yearly landings was found to be 92.64

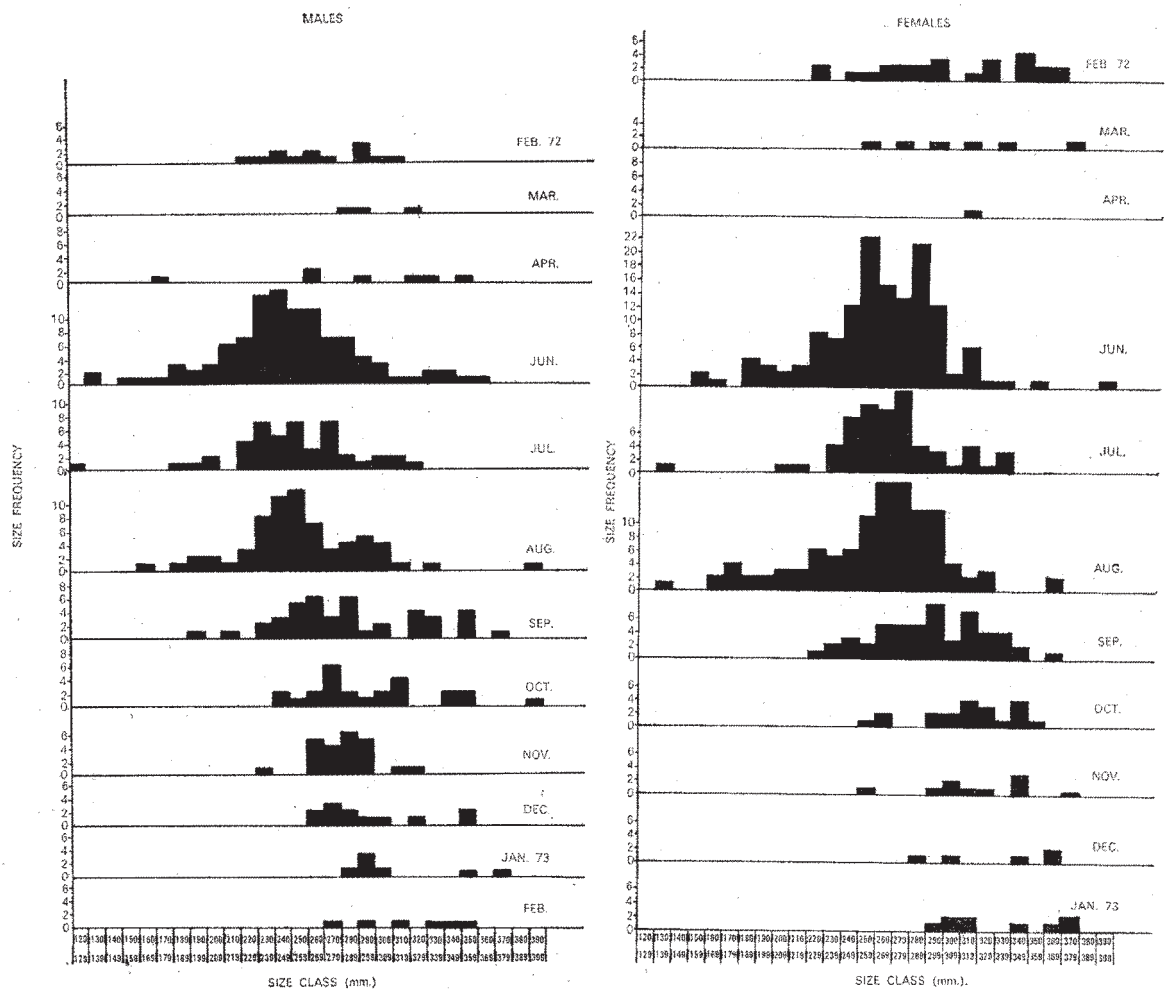

Fig. 3—Monthly size frequency distribution of males and females.

mm. for males and 88.90 mm. for females (Fig. 4). The most predominant size-group landed for the whole year is 240-249 mm. in the case of males and 250-259 mm. in the case of females. On the basis of overall averages, it is found that males are slightly larger than females in the populations fished. The maximum abundance for any size group and for any month was in June for both males and females, which was also the best month for lobster fishery on the basis of total landings. The length of specimens landed fluctuated between 120-399 mm. in males and 130-399 mm. in females. It should here be mentioned that neither the net nor the haul was of quantitative nature for sampling the lobster populations in a systematic way and the sampling error might therefore be of a high order. All these calculations must necessarily be considered to be valid for the landed populations only.

Mean carapace width for the whole year was 68.9 mm. for males and 66.9 mm. for females and the mean width of the first abdominal segment, 56.4 and 58.4 mm. respectively.

(c) Sex-ratio

For the total yearly landings at Phuket and for all the size-groups put together, 44.8 percent

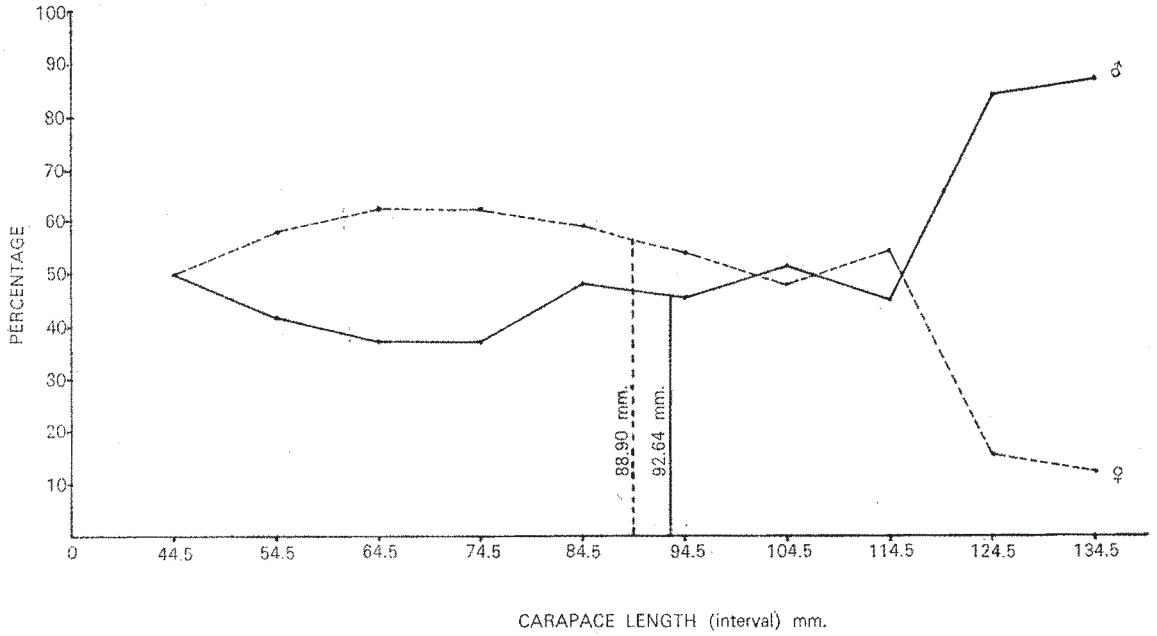

Fig. 4—Size frequency distribution of males and females.

are males and 55.2 percent are females. If the various size-groups are separately considered, in the sex-groups below 99 mm. size, more females were found than males (except for 40-49 mm. size-group which has a sex-ratio of 1:1). Maximum dominance was in the 60-69 mm. size-group where 62.9 percent were females. The condition was exactly the opposite in the two largest size-groups of 120-129 mm. and 130-139 mm. where males constituted 84.2 and 87.5 percent respectively of the specimens. But as some of these size-groups are represented only by a few specimens, the fluctuations in the sex-ratio might be the result of this anomaly and are not quite reliable (see Table 1). On the basis of monthly averages for all size-groups put together, the highest percentage of males was landed in April (87.5 percent) and of females in March (66.7 percent) (see Table 2). The sex-ratio was nearest to that in September when the total landings consisted of 44.5 percent males and 54.8 percent females (see Fig. 5). However, these percentages may not represent a correct picture for comparisons because of the large fluctuations in the number of boats fishing and lobsters landed every month. For example, a total of only 8 specimens were caught in April, while a maximum of 241 lobsters were landed in June, if May is left out of consideration for lack of data. (These numbers represent the total counts during visits to the fishing port and not the absolute total landings during the month).

(d) SEASONAL FLUCTUATIONS OF THE SIZE-GROUPS

The monthly fluctuations of each size-group landed are shown separately for males and females in Fig. 3. It is clearly seen that the monsoon months (June to September) are the best period for abundance in terms of landings. Both males and females of all size-groups of less than 220 mm. total length are landed only during this period, after which they abruptly disappear (the only exception is males in April for the size-group 170-179 mm.). The monsoon landings during the above four months are completely dominated by the size-groups of 220-300 mm. total length. These size-groups also mostly disappear in the postmonsoon landings which are quite clear-cut particularly in the case of females but not so obvious in the

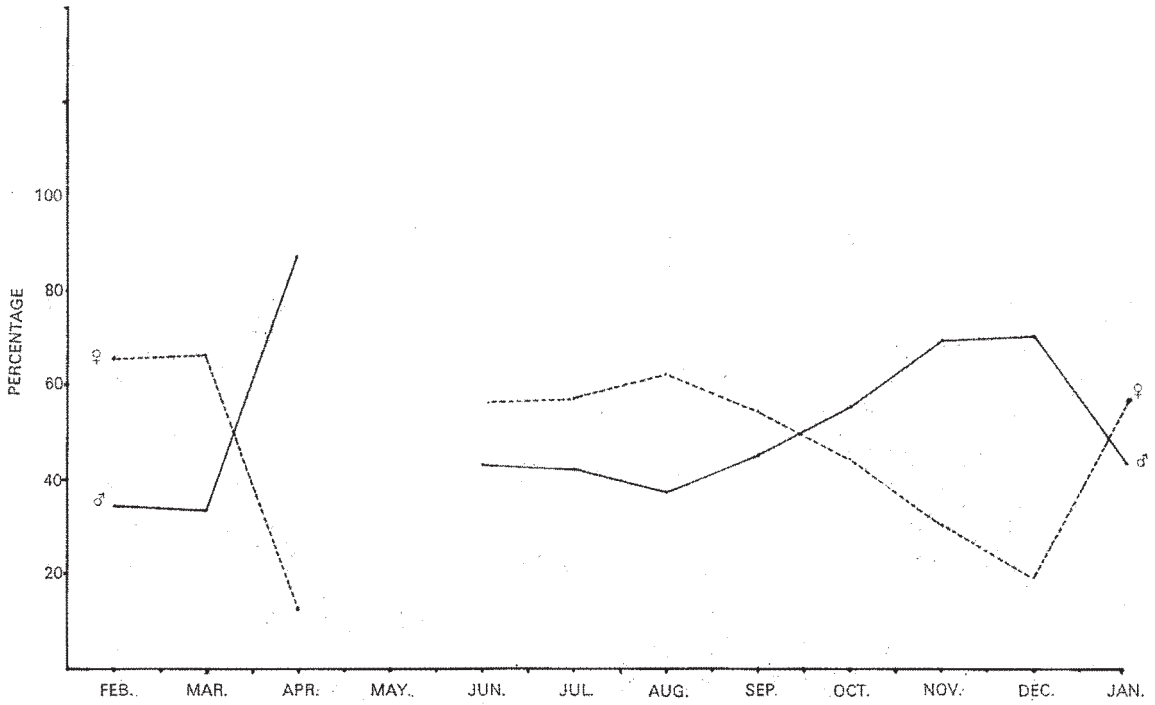

Fig. 5—Monthly variation in sex ratio.

case of males. The size-groups larger than 300 mm. total length predominate in the catches after the monsoon although they are not so abundant in number. Size-groups of less than 250 mm. are not landed at all after October until February in the case of females and less than 260 mm. in the case of males (with only one exception in November in the size-group 230-239 mm.).

(e) MORPHOLOGICAL RELATIONSHIPS

The morphological relationships and correlations of the various length, breadth and weight measurements carried out on the landings are shown in Table 6. The correlations are expressed in diagrammatic form in Figs. 6 to 11, separately, for males and females. It is obvious from the figures that the most significant values in terms of reliability are those which converge close to the mean. These calculations have been carried out as a check to control the reliability of all data on the populations collected during this investigation.

The details of all calculations are given in the Appendix.

(f) FREQUENCY OF OVIGEROUS FEMALES AND THE SPAWNING SEASON

Only females in the size range 70-129 mm. were found to bear eggs and in no case was a female with a carapace length of less than 70 mm. found to carry eggs. The largest number of ovigerous females belonged to the 80-89 mm. and 90-99 mm. carapace length-groups, with a maximum preponderance in the second size-group while only a negligible number of egg-bearing females were found in the other size-groups recorded. The maximum number of ovigerous females was observed during the monsoon months (June to the end of October) with a very clear-cut peak in August. No egg-bearing females were seen during the premonsoon months, March and April (no sampling in May). Thus, starting from an eggless period in the premonsoon season, a clear-cut peak is attained during the monsoon months

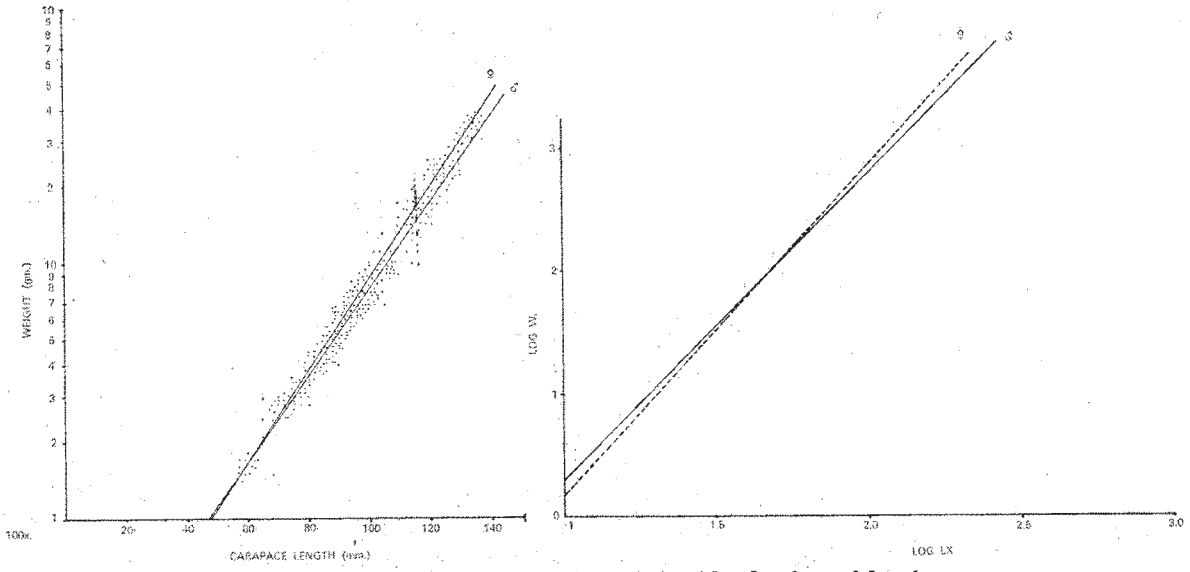

Fig. 6—Carapace length/total weight relationship of males and females.

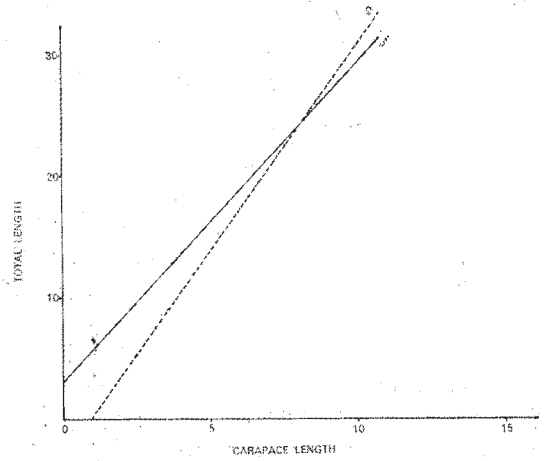

Fig. 7—Carapace length and total length relationship of males and females.

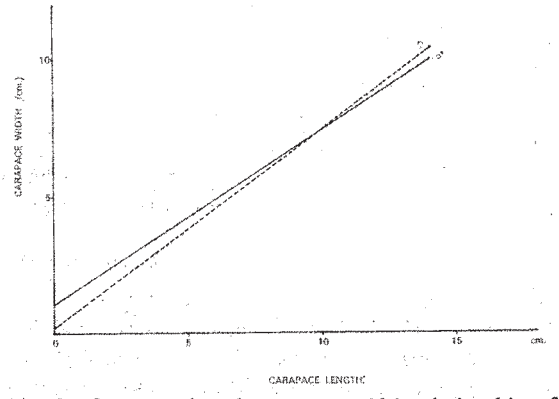

Fig. 8—Carapace length/carapace width relationship of males and females.

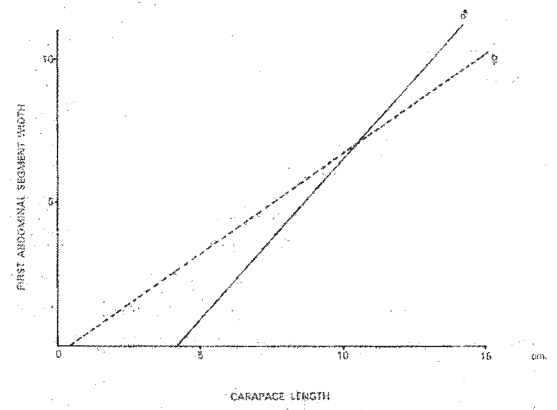

Fig. 9—Carapace length/first abdominal segment width of males and females.

after which it is seen to fall off (see Fig. 10 and Table 4). If we take this attainment of clear-cut peak during monsoon months as an indication of the peak spawning season, we could therefrom conclude that *P. polyphagus* spawns during the monsoon season (June to October) in this area.

(g) Growth studies

Attempts to keep specimens of *P. polyphagus* alive in aquaria for rearing experiments met with

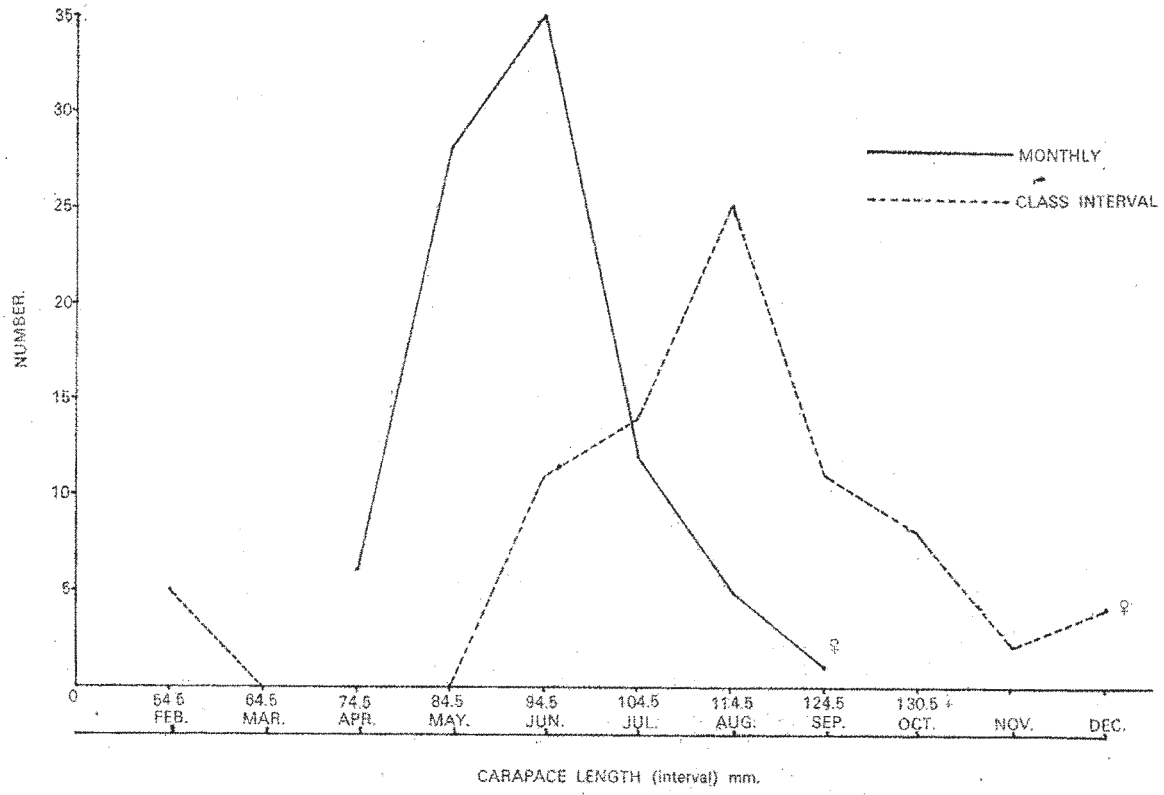

Fig. 10—The monthly relationship between carapace length and the number of egg-bearing females.

failure. Some indication of the average seasonal growth increment of the lobster populations fished is therefore obtained by analysing the fluctuations in the monthly distribution pattern of various size-groups and following any trends in the successive progression in the mode of the dominant size group.

The greatest source of error in such an approach to analyse the growth rate lies in the verification of whether the populations fished month after month remain the same or not. About a hundred fishing trawlers operate from the Phuket fishing harbour, and each trawler generally fishes in a more or less fixed area every month (except in instances of unfavourable weather conditions). This is a custom established by tradition. Because of this fortunate coincidence, it may here be supposed for the sake of our study that the area fished remaining the same, the population fished is more or less the same every month.

The monthly size-frequency distribution of male and female lobster is shown in Fig. 3. In the case of male lobsters, an irregular shift in the mode is apparent from June to October, although the average length increment of the dominant size-group is not found to shift or progress smoothly, apparently due to sampling error. Each month has generally one dominant size-group, but three size-groups have equal dominance in July and two in September. If these two months are left out of consideration, a roughly progressive shift of dominant mode from left to right is seen to occur from June to August through October. If this is of significance and if it represents one and the same population, it could be taken as the average growth rate of the population sampled. The dominant mode in June is at an average size of 244.5 mm. which increases to 254.5 mm. in August, showing apparent increase in size of 10 mm. The basic pattern of progression of the dominant mode

is however not very clear and precludes the possibility of identifying the various age-groups and of tracing the growth-rates.

In the case of females also, each month has one dominant size-group in the catches, but the pattern of progression of a dominant mode again presents a very confusing picture. Thus, the size-group 250-259 mm. dominates in June and 270-279 mm. in July; but August has two dominant modes in the range 260-279 mm. There is a further 20 mm. shift of the dominant mode between August and September which cannot be real. October has again two dominant modes. Therefore, in the case of females also, the number and complexity of the modes confuses the growth pattern considerably and prevents any definite conclusions in tracing growth-rate. Perhaps this indicates that the population sampled every month might not be the same one.

(h) Rearing experiments

Juvenile specimens of *P. versicolor* were grown in the laboratory in aquaria with a running seawater system during the period from September 1971 to February 1972, and the rate of their growth measured from time to time. Not more than two specimens (1 male and 1 female) were kept in each aquarium and fed with prawns of *Metapenaeus* spp. every day. A maximum of four successive moultings took place during this period. The specimens were also measured after each moult and the results are shown in Table 10. Only the total length showed a steady increase, but a progressively diminishing one, from moult to moult (from an increase of 0.95 cm. after the first moult to 0.01 cm. after the fourth moult). It could be said that body length, carapace width and tota weight also showed a similar trend except for a minor insignificant decrease after the fourth moult. Variations after each moult fluctuated as follows: from an increase in body-length of 0.2 cm. after the first and second moults to a decrease of —0.12 cm. after the fourth moult; from an increase in carapace width of 0.2 cm. after the first and second moults to a decrease of —0.01 cm. after the fourth moult; and from an increase in total weight of 3.1 g. after the first moult to a decrease of —0.1 g. after the fourth moult. (This might be an error in measurement, because the animals were always weighed wet). Carapace length showed an increase of 0.25 cm. after the first and second moults and of 0.06 cm. after the fourth moult, while it remained constant after the third moult (see Fig. 11 and Table 5). Lewis, Moore and Babis (1952) found that carapace length is the most reliable measurement for indicating growth-rate of post-larval stages of *P. argus*.

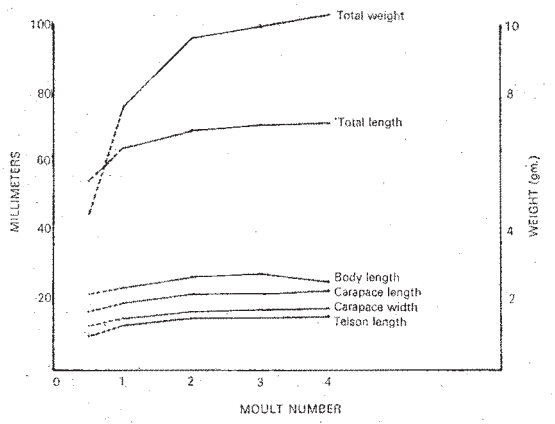

Fig. 11—Growth rate of *P. versicolor* in laboratory.

The lobsters were also measured every 20 days even if they did not moult. Obviously, no increase in size could be expected here, but a very small increase in weight, which was negligible, was recorded. For *P. argus*, Dawson and Idyll (1951) recorded an actual decrease in length after moulting in some cases, after four to five months of holding in an enclosed area in Biscayne Bay. For the same species, Sweat (1968) observed that moulting frequency might vary from individual to individual and show an increase during the summer months when the water temperature is higher.

(i) Moulting

Juveniles moult more frequently than adults, as is the case in other species also. In agreement with the observations of Sweat *(loc. cit)* for *P. argus*, moulting takes place always during the

night. During the moulting process, the animals bend in an inverted U-shaped fashion, when the exoskeleton cracks transversely along the first abdominal segment. The abdominal segments are then slowly pulled out of the exoskeleton along with the telson through this opening, followed by the cephalothorax including the antennule, antennae and walking legs. The complete process of moulting usually takes about 15 minutes. The animal does not ingest any food just before and for a day after moulting. The lobster appears extremely pale in color after moulting; the normal color pattern of the adult lobster and the hardening of the new exoskeleton, which takes about 2-3 days, become apparent simultaneously. Some specimens have remained in the aquaria up to four months without moulting. Occasionally, some animals (both male and female) fail to come out of their exoskeleton during moulting; these animals invariably die or are eaten by their companions.

IV. DISCUSSION AND CONCLUSIONS

Spiny lobsters, particularly *P. polyphagus*, constitute a minor fishery along the west coast of Thailand. Most of the specimens are however caught during trawling operations for prawns, as *P. polyphagus* also occurs in the same habitat as the prawns. In other areas of the Indian Ocean also such as Ceylon, the west coast of India and Australia, this is the predominant species of spiny lobster caught during trawling operations. It might therefore prove worthwhile to search for new fishing grounds for this species of lobster. Bhatia (1974, in press) has recently studied the distribution of this species along the west coast of Thailand. The statement of George (1968) that "its absence in quantities over most of the Indo-West Pacific zone can be regarded as real" requires verification in view of its additional abundance in the present area investigated.

Analysis of the yearly landings and their size composition shows that the smallest lobsters landed are of the (total length) size-group of 120-129 mm. (males) and 130-139 mm. (females). The largest size-group landed was of 390-399 mm. for both sexes. These size-groups show some interesting seasonal fluctuations. Monsoon season was the best period for successful lobster fishery and maximum landings are recorded during June to September. The size-groups of maximum abundance for any month were of 240-249 mm. for males and 250-259 mm. for females both during the month of June. All smaller size-groups of up to 220 mm. in total length (both males and females) appear in the catches only during this period and disappear after the monsoon season. Medium size-groups of 220-300 mm. total length range predominate in the monsoon landings and are the most abundant size-groups contributing to the annual fishery. These size-groups also disappear (in females) or are considerably reduced in quantity (in males) after the monsoon months. Landings during the postmonsoon months consist mostly of size-groups longer than 300 mm. total length, although they are not so abundant in quantity. From this trend it is clear that the lobster fishery of this area is based predominantly on medium size-groups, and not the maximum size. It is left to future investigations to find out whether this points to a gradual degeneration or overfishing of the lobster populations in this area.

If the two sexes are considered separately, the data show that for the populations landed, males are slightly longer than females on the basis of carapace length. Comparing the average total weight for each size-group with the others, it is found that females were slightly heavier than males throughout the year. Crawford and De Smidt (1922) recorded a similar trend in the spiny lobster *P. argus*.

The total yearly landings sampled consisted of 44.8 per cent males and 55.2 per cent females, giving an almost 1 : 1 sex-ratio for the whole year. The populations of Florida spiny lobster, *P. argus* were observed by Dawson and Idyll (1951) to be composed of 53.3 percent males and 46.7 percent females. Berry (1971) found that the sex-ratio of South African populations of *P. homarus* approximated closely a 1:1 ratio. When the various

size-groups are considered separately, a preponderance of females was noticed for the size-range, 20-69 mm., which decreased progressively until a 1:1 ratio was reached in the 70-79 mm. class.

The sex-ratio of the natural lobster populations around Ceylon was estimated by De Bruin (1962) by diving operations to approximate 1:1, but almost twice the number of males are caught in traps, probably because of their greater foraging activity.

Our result in the study on sex-ratio of *P. polyphagus* also confirmed their findings.

Only females of the size-range from 70 to 129 mm. were found to be ovigerous, indicating that the females became sexually mature only after they attain a minimum size of 70 mm. carapace length. The maximum preponderance of egg-bearing females was in the length-groups of 80-89 mm. and 90-99 mm., with the absolute predominance in the second group. They are most abundant during monsoon months, but totally absent during the premonsoon period. An outstanding seasonal trend is thus to be seen in the abundance of ovigerous females, where, beginning from an eggless period during the premonsoon months, a clear-cut peak is attained in August, after which it falls off. This indicates that *P. polyphagus* has a single spawning peak during the monsoon months in the present area of investigation.

For *P. homarus*, Berry (1971) recorded the maximum number of egg-bearing females in the summer months with a peak in January and concluded that along the South African coast this lobster spawns during the summer months. Dawson and Idyll (1915) observed that *P. argus* spawns from March to November in waters around Florida.

Attempts to estimate the apparent growth-rate of the fished population by following the successive progression of the monthly dominant mode met with only partial success. The number and complexity of the modes over a period of several months confuse the growth pattern and preclude the possibility of identifying the various size-groups and of tracing the growth-rate. In the case of males, an irregular shift in the dominant mode is apparent from June to October, showing an increase in length of 10 mm. from June till August. The trend is still more confusing in the case of females. It is therefore suspected that the monthly landings might not originate from one and the same population.

All body measurements carried out during and in between moultings in all cases, show a steady increase. But this increase progressively diminishes from moult to moult until it becomes almost insignificant or shows an apparent decrease after the fourth moult. A similar decrease in measurements after moulting has also been recorded for *P. argus* by Dawson and Idyll *(loc. cit.)* after four to five months of holding. One does not know how far such observations could be held to be true when applied to natural populations. Availability of sufficient calcium in the diet for forming a new exoskeleton might perhaps play an important role in determining the pattern of moulting. This might explain the failure to successfully complete moulting in some individuals kept in captivity. Sweat (1968) reported an increase in moulting frequency during the warmer summer months, which seems to indicate that temperature might also play a role in determining the moulting pattern. During the intermoult period, a negligible increase in total weight is observed both in males and females.

Rearing experiments and growth studies are being continued and expanded to cover both juveniles and adults. Attempts are also being made to rear in captivity other species of lobsters found in this area for comparative growth studies.

V. SUMMARY

1. Monthly landings of spiny lobster, *Panulirus polyphagus*, at Phuket fishing harbour on the west coast of Thailand were sampled and studied twice a week during the period February, 1971 to January, 1972.

2. The catches were analysed for their morphological relationships, size-composition and their monthly fluctuations, sex-ratio, sexual maturity, growth-rate, and observations on spawning season.

3. The animals are nocturnal in habit and live on a muddy bottom; they are caught in the net during bottom trawling operations for prawns.

4. The most predominant size-groups in the landings are 240-249 mm. for males and 250-259 mm. for females. The specimens landed are of the size-range 120-399 mm. and 130-399 mm. respectively. Males are slightly longer than females.

5. Of the total yearly landings 44.8 percent are males and 55.2 percent females, a more or less 1:1 sex-ratio. The sex-ratio of the individual size-groups fluctuated considerably.

6. Maximum landings occur during the monsoon months, June to September. Size-groups smaller than 220 mm. in total length are landed only during this period and those larger than 300 mm. predominate after the monsoon. Size-groups of 220 to 300 mm. make the maximum contribution to the yearly landings abounding in the monsoon catches and decreasing thereafter

7. Ovigerous females are recorded only in the 70-129 mm. size-range, the maximum abundance being from 80 to 99 mm. Egg-bearing females show a clear-cut abundance during the monsoon months indicating one single yearly spawning peak.

8. The number and complexity of dominant modes of monthly landings confuse the growth pattern considerably and preclude the possibility of identifying the various age-groups and of tracing the growth-rate.

9. Rearing experiments on juvenile specimens of *P. versicolor*, conducted in the laboratory, show a steady, but progressively diminishing increase in body measurements from moult to moult.

10. The process of moulting in captivity is described.

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APPENDIX : Calculations

For all calculations, X axis (carapace length measurements) is a constant, while Y axis is a variable such as total length, carapace width, first abdominal segment width and total weight. The observed values are given in the Table 10.

Constants

Males:

$\Sigma X = 3288.72$ cm.
$\bar{X} = 9.264$
$N = 355$

Females:

$\Sigma X = 3893$
$\bar{X} = 8.89$
$N = 438$

Correlation of carapace length (X) to carapace width (Y)

Males:

$\Sigma Y = 2448.23$
$\bar{Y} = 6.899$
b calculated from above $= 0.632$
Y intercept $= 1.047$
$Y = 1.047 + (0.632)\ X$

Females:

$\Sigma Y = 2929.25$
$\bar{Y} = 6.69$
b calculated from above $= 0.7276$
Y intercept $= 0.22$
$Y = 0.22 + (0.7276)\ X$

Correlation of carapace length (X) to total length (Y)

Males:

$\Sigma Y = 9548.0$
$\bar{Y} = 26.898$
b calculated from above $= 2.559$
Y intercept $= 3.193$
$Y = 3.193 + (2.559)\ X$

Females:

$\Sigma Y = 12023.56$
$\bar{Y} = 27.45$
b calculated from above $= 3.4396$
Y intercept $= -3.13$
$Y = -3.13 + (3.4396)\ X$

Correlation of carapace length (X) to fist abdominal segment width (Y)

Males:	ΣY	=	2001.14
	$\overline{Y}$	=	5.637
b calculated from above		=	1.1235
Y intercept		=	– 4.776
	Y	=	– 4.776 + (1.1235) X
Females:	ΣY	=	2556.43
	$\overline{Y}$	=	5.84
b calculated from above		=	0.6957
Y intercept		=	– 0.34
	Y	=	– 0.34 + (0.6957) X

Correlation of carapace length (X) to total weight (Y)

For this correlation, carapace lengths are grouped into 10 mm. size-groups and average total weight determined for each size-group. The ΣX value in this case is calculated by multiplying log W of the mean carapace length for each size - group by the frequency (f) for that size-group and expressed as ΣfX

Males:	ΣfX	=	694.6716
	$\overline{X}$	=	1.9623
	ΣfY	=	972.8402
	$\overline{Y}$	=	2.7481
b calculated from above		=	2.5249
Y intercept		=	– 2.2065
	W	=	$0.006216\ X^{2.5249}$
Females:	ΣfX	=	851.3996
	$\overline{X}$	=	1.9438
	ΣfY	=	1198.977
	$\overline{Y}$	=	2.7352
b calculated from above		=	2.6759
Y intercept		=	– 2.4752
	W	=	$0.003348\ X^{2.6759}$

Table 1. The sex-ratio within each size class in a one year sampling at Phuket fishing harbour.

Carapace length interval (mm.)	Numbers		Percentages	
	Males	Females	Males	Females
40 - 49	2	2	50	50
50 - 59	5	7	41.66	58.34
60 - 69	13	22	37.14	62.86
70 - 79	29	49	37.18	62.82
80 - 89	107	155	40.84	59.16
90 - 99	109	129	45.79	54.21
100 - 109	44	41	51.76	48.24
110 - 119	24	29	45.29	54.71
120 - 129	16	3	84.21	15.79
130 - 139	7	1	87.50	12.50
Total	356	438	44.8	55.2

Table 2. The montly sex-ratio in a one year sampling at Phuket fishing harbour.

Months	Numbers		Percentages	
	Males	Females	Males	Females
Feb.	13	25	34.21	65.79
Mar.	3	6	33.34	66.66
Apr.	7	1	87.50	12.50
May	no. sampling			
Jun.	104	137	43.16	56.84
Jul.	46	62	42.59	51.71
Aug.	67	112	37.43	62.57
Sep.	42	51	45.16	54.84
Oct.	25	20	55.55	44.45
Nov.	23	10	69.59	30.30
Dec.	12	5	70.59	29.41
Jan.	7	9	43.75	56.25

Table 3. Results of morphological relationships.

Sex	Correlation of carapace length (X) to—			
	Total length	Total weight	Carapace width	1st. Abd. segment width
Male.[1]	$3.193+(2.559)X$	$0.006X^{2.525}$	$1.047+(0.632)X$	$-4.776+(1.124)X$
Female.[2]	$-3.130+(3.440)X$	$0.003X^{2.676}$	$0.220+(0.728)X$	$-0.340+(0.696)X$

[1]Total of 355 observations over a carapace length range of 50 - 139 mm.
[2]Total of 438 observation over a carapace length range of 40 - 139 mm.

Table 4. Carapace length interval (mm.) and average weight (g.) in a one year sampling of the male spiny-lobsters.

Carapace length-int.	Mid. value (Lx)	Frequency (f)	Log Lx (X)	Average wt.	Log W (Y)
50 - 59	54.5	5	1.7364	134.0	2.1271
60 - 69	64.5	13	1.8096	240.8	2.3816
70 - 79	74.5	29	1.8722	321.6	2.5073
80 - 89	84.5	107	1.9269	456.1	2.6591
90 - 99	94.5	109	1.9754	614.3	2.7884
100 - 109	104.5	44	2.0191	773.5	2.8885
110 - 119	114.5	24	2.0588	990.0	2.9956
120 - 129	124.5	16	2.0951	1205.6	3.0794
130 - 139	134.5	7	2.1287	1307.1	3.1163
Total		354	17.6222		24.5433
			$\overline{Y}$= 1.9580		$\overline{X}$ = 2.7270

Table 5. Carapace length interval (mm.) and average weight (g.) in a one year sampling of female spiny lobsters.

Carapace length-int.	Mid. value (Lx)	Frequency (f)	Log Lx (X)	Average wt.	Log W (Y)
40 - 49	44.5	2	1.6484	82.5	1.9165
50 - 59	54.5	7	1.7364	137.9	2.1396
60 - 69	64.5	22	1.8096	299.8	2.3613
70 - 79	74.5	49	1.8722	357.9	2.5538
80 - 89	84.5	155	1.9269	496.8	2.6962
90 - 99	94.5	129	1.9754	657.0	2.8176
100 - 109	104.5	41	2.0191	846.3	2.9276
110 - 119	114.5	29	2.0588	1107.9	3.0448
120 - 129	124.5	3	2.0951	1240.0	3.0934
130 - 139	134.5	1	2.1287	1350.0	3.1303
Total		438	19.2706		26.6811

Table 6. Relationship of carapace length and carapace width in males.

Carapace length (X) (cm.)	Carapace width(Y) (cm.)	XY (cm.)	$X-\bar{X}$	X^2 (cm.)	N
6.80	5.18	35.2240	—2.464	6.073	1
7.52	5.59	42.0368	—1.744	3.042	2
8.09	5.68	45.9512	—1.174	1.378	3
8.55	6.29	53.7795	—0.714	0.510	4
9.99	7.46	74.5254	0.726	0.527	5
10.30	7.64	78.6920	1.036	1.073	6
12.25	8.99	110.1275	2.986	8.916	7
↓	↓	↓	↓	↓	↓
.. ..	.. ..	.. .. ..	.. ..	.. ..	..
.. ..	.. ..	.. .. ..	.. ..	.. ..	..
Total 3288.72	2448.23	23204.36		814.797	355

Table 7. Monthly record of the number of egg-bearing females in each size-class during 1971-1972 period.

Size-class	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Total
50-59	-	-	-	-	-	-	-	-	-	-	-	-	-
60-69	-	-	-	-	-	-	-	-	-	-	-	-	-
70-79	3	-	-	-	-	1	2	-	-	-	-	-	6
80-89	-	-	-	-	3	10	10	3	1	-	1	-	28
90-99	-	-	-	-	7	1	13	6	4	-	2	2	35
100-109	1	-	-	-	-	2	-	2	3	1	-	3	12
110-119	-	-	-	-	1	-	-	-	-	1	1	2	5
120-129	1	-	-	-	-	-	-	-	-	-	-	-	1
130	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	5	-	-	-	11	14	25	11	8	2	4	7	87

Table 8. Frequency distribution of male spiny lobsters (total length) in each size class.

Size-class (mm.)	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Total
120-129	-	-	-	-	-	1	-	-	-	-	-	-	-	1
130-139	-	-	-	-	2	-	-	-	-	-	-	-	-	2
140-149	-	-	-	-	-	-	-	-	-	-	-	-	-	-
150-159	-	-	-	-	1	-	-	-	-	-	-	-	-	1
160-169	-	-	-	-	1	-	1	-	-	-	-	-	-	2
170-179	-	-	1	-	1	-	-	-	-	-	-	-	-	2
180-189	-	-	-	-	3	1	1	-	-	-	-	-	-	5
190-199	-	-	-	-	2	1	2	1	-	-	-	-	-	6
200-209	-	-	-	-	3	2	2	-	-	-	-	-	-	7
210-219	-	-	-	-	6	-	1	1	-	-	-	-	-	8
220-229	1	-	-	-	7	4	3	-	-	-	-	-	-	15
230-239	1	-	-	-	13	7	8	2	-	1	-	-	-	32
240-249	2	-	-	-	14	5	11	3	2	-	-	-	-	37
250-259	1	-	-	-	11	7	12	5	1	-	-	-	-	37
260-269	2	-	2	-	11	3	7	6	2	5	2	-	-	40
270-279	1	-	-	-	7	7	3	3	6	4	3	-	1	35
280-289	-	1	-	-	7	2	4	6	2	6	2	1	-	31
290-299	3	1	1	-	4	1	5	1	1	5	1	3	1	27
300-309	1	-	-	-	3	2	4	2	2	-	1	1	-	16
310-319	1	-	-	-	1	2	1	-	4	1	-	-	1	11
320-329	-	1	1	-	1	1	-	4	-	1	1	-	-	10
330-339	-	-	1	-	2	-	1	3	-	-	-	-	1	8
340-349	-	-	-	-	2	-	-	-	2	-	-	-	1	5
350-359	-	-	1	-	1	-	-	4	2	-	2	1	1	12
360-369	-	-	-	-	1	-	-	-	-	-	-	-	-	1
370-379	-	-	-	-	-	-	-	1	-	-	-	1	-	2
380-389	-	-	-	-	-	-	-	-	-	-	-	-	-	-
390-399	-	-	-	-	-	-	1	-	1	-	-	-	-	2
Total	13	3	7	-	104	46	67	42	25	23	12	7	6	355

Table 9. Frequency distribution of female spiny lobster (total length) in each size class.

size-class (mm.)	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Total
120-129	-	-	-	-	-	-	-	-	-	-	-	-	-
130-139	-	-	-	-	-	1	1	-	-	-	-	-	2
140-149	-	-	-	-	-	-	-	-	-	-	-	-	-
150-159	-	-	-	-	2	-	-	-	-	-	-	-	2
160-169	-	-	-	-	1	-	2	-	-	-	-	-	3
170-179	-	-	-	-	-	-	4	-	-	-	-	-	4
180-189	-	-	-	-	4	-	2	-	-	-	-	-	6
190-199	-	-	-	-	3	-	2	-	-	-	-	-	5
200-209	-	-	-	-	2	1	3	-	-	-	-	-	6
210-219	-	-	-	-	3	1	3	-	-	-	-	-	7
220-229	2	-	-	-	8	-	6	1	-	-	-	-	15
230-239	-	-	-	-	7	4	5	2	-	-	-	-	18
240-249	1	-	-	-	12	8	6	3	-	-	-	-	29
250-259	1	1	-	-	27	10	11	2	1	1	-	-	52
260-269	2	-	-	-	15	9	16	5	2	-	-	-	49
270-279	2	1	-	-	13	12	16	5	-	-	-	-	49
280-289	2	-	-	-	21	4	12	5	-	-	1	-	45
290-299	3	1	-	-	12	3	12	8	2	1	-	1	43
300-309	-	-	-	-	2	1	4	2	2	2	1	2	16
310-319	1	1	1	-	6	4	2	7	4	1	-	2	29
320-329	3	-	-	-	1	1	3	4	3	1	-	-	16
330-339	-	1	-	-	1	3	-	4	1	-	-	-	10
340-349	4	-	-	-	-	-	-	2	4	3	1	1	15
350-359	2	-	-	-	1	-	-	-	1	-	-	-	4
360-369	2	-	-	-	-	-	2	1	-	-	2	1	8
370-379	-	1	-	-	-	-	-	-	-	1	-	2	4
380-389	-	-	-	-	-	-	-	-	-	-	-	-	-
390-399	-	-	-	-	1	-	-	-	-	-	-	-	1
Total	25	6	1	0	137	62	112	51	20	10	5	9	438

Table 10. Measurements of spiny lobster, *Panulirus versicolor*, in experimental rearing.

Date of measurement	Eyestalk length[1]		Carapace length[1]		Body length[1]		Telson length[1]		Total length[1]		Wt. of carapace[2]		Total wt.[2]		Remarks
	initial	increase	initial	increase	initial	increase	initial	increase	initial	increase	initial	increase	initial	increase	
15 Sep. 71	0.15	-	1.70	-	2.20	-	1.0	-	5.45	-	1.30	-	4.50	-	
2 Oct. 71	←													→	1st moult.
18 Oct. 71	0.15	0	1.95	0.25	2.40	0.20	1.3	0.3	6.40	0.95	1.50	0.20	7.60	3.10	
26 Oct. 71	0.25	0.10	1.95	0	2.50	0.10	1.3	0	6.50	0.10	1.50	0	-	-	2nd moult.
29 Nov. 71	0.25	0	2.20	0.25	2.70	0.20	1.5	0.2	6.90	0.40	1.70	0.20	9.60	2.00	
8 Dec. 71	0.25	0	2.20	0	2.70	0	1.4	—0.1	7.00	0.10	1.70	0	-	-	3rd moult.
10 Dec. 71	0.25	0	2.20	0	2.80	0.10	1.5	0.1	7.10	0.10	1.75	0.05	9.95	0.35	
10 Jan. 72	0.30	0.05	2.20	0	2.60	—0.20	1.5	0	7.10	0	1.80	0.10	10.20	0.25	
2 Feb. 72	←													→	4th moult.
4 Feb. 72	0.27	—0.03	2.26	0.06	2.52	—0.12	1.5	0	7.11	0.01	1.79	—0.01	10.10	—0.10	
14 Feb. 72	0.24	—0.03	2.27	0.01	2.54	0.02	1.52	0.02	7.13	0.02	1.78	—0.01	10.30	0.20	Died, Feb. 21, 1972

[1] Lengths in centimeter.
[2] Weights in gram.