A Study of the Marine Spiny Crayfish *Jasus lalandii* (Milne-Edwards)*

Including Accounts of Autotomy and Autospasy

SUMMARY

In 1947 and 1948, 2,126 specimens of *Jasus lalandii,* caught in Wellington waters, were examined. The data from these show that males range from 17.9 cm. to 48 cm. (total length) and females from 17 cm. to 40 cm. Males and females in Wellington waters reach a greater size than in Tasmania, and males reach a greater size than females in both countries. The size-range of the female population is fairly stable throughout the year, but the size-range of the male population increases temporarily in September.

Females predominate in the December, January, February, and March catches, probably because of moulting in males at that time. In April, few crayfish can be caught, probably because of moulting and egg-extrusion in females and copulation. In May, males predominate, probably because of moulting and egg-extrusion in females. Equal numbers of both sexes are caught in June, July, and August. In September, males predominate, largely as the result of an increase in the number of very large males, and it is at this time that the heaviest catches are taken. After September, the number of females increases, and this sex predominates in December.

The present minimum legal size is reasonable, as it protects most of the immature females, prevents the meat wastage involved in using small crayfish, and affects the fishermen only to the extent of 8% by weight of his catch.

Females become mature between 7 cm. and 9.7 cm. in carapace length. There is no evidence of loss of fertility in old females. Egg-extrusion begins late in April, and all mature females are "in berry" in May. Large females extrude eggs before small ones. Most females release larvae in October, and all females are free of eggs by the end of December. Larval release may be correlated with increasing temperature from August onwards. The number of eggs produced increases approximately as the cube of body length. Females between 8.3 cm. and 13.5 cm. (carapace length) produce 86,000 to 549,000 eggs.

Of 168 specimens tagged and released, nine were recaptured. Two methods of tagging were used, both of which were satisfactory, since the tags were retained in moulting and had little effect on the tissues. A female 24.8 cm. in total length and a male 21.5 cm. in total length

grew 1.9 cm. and 2.1 cm. in total length respectively in one year, during which time two moults would be expected to have occurred. The nine returns indicate no definite migration, merely a random wandering movement.

The amount of usable meat ranges from 47 gm. to 1,449 gm. over the carapace size range 6.7 cm. to 19.6 cm. The weight of usable meat per unit carapace length ranges from 6.7 gm. to 74 gm. over the same size-range. The leg meat in specimens above 9 cm. in carapace length comprises one-third of the total meat. One-half of the crayfish caught are between 9 cm. and 13 cm. in carapace length, and provide one-half of the usable meat in the catch.

A slight shrinkage in the carapace length occurs in cooking, and the total length may undergo a slight increase or decrease. There is a considerable loss in weight, and this increases with size.

Jasus lalandii exhibits autotomy of the legs and autospasy of the antennal flagella. The legs may also exhibit autospasy. The autotomy point in the legs is in the junction of the basipodite and ischiopodite. The autospasy point in the antenna is close to the base of the flagellum. Points for autotomy or autospasy may also exist in the junction of the first and second, and the second and third, segments of the antennal peduncle. Damage to a leg does not always lead to autotomy. Amputation is more common in females than in males, and the total number of legs amputated is also greater in females. In males, all the legs have equal tendencies to be lost, although there is some indication that the fifth leg may be more frequently lost. In females, the tendencies to loss of the first two legs are equal. The third leg is lost three times more often than the first two, the fourth is lost four times as often, and the fifth five times. The frequencies of absence of the first two legs are not significantly different in the two sexes. The frequencies of absence of the third, fourth, and fifth are greater in females than in males. Of the males with leg amputations, 16.2% have more than one leg missing. For females, the corresponding number is 19%. Females in the size-group 28.1 cm. to 30 cm. have the greatest number of amputations. This point is the peak of a normal curve. In males, the curve is not a normal one; the number of amputations increases with size. One or both flagella are sometimes lost in nature and can be regenerated. The loss of a part of a flagellum is thought to be a case where the damage inflicted has not been associated with enough pulling to evoke autospasy. A flagellum may be almost completely regenerated in one year.

INTRODUCTION

Jasus lalandii occurs in South Africa, the southern coasts of Australia, Tasmania, New Zealand, Chile, Juan Fernandez, Tristan da Cunha, and Saint Paul (Indian Ocean).

In South Africa, Australia, and New Zealand, it is of considerable economic importance. In South Africa, a valuable canning industry has existed since 1902. In 1938–39, this produced £129,862 worth of canned "crawfish." The value of the exports of frozen tails and canned meat was £243,010 in 1939. In Australia and New Zealand, large numbers are cooked and sold on the local market. In New Zealand, in 1946, 16,766 hundredweight (£30,801) of crayfish was marketed. The value of canned and frozen crayfish exported was £11,704. The landings at Wellington were greater than at any other port (£7,685), but Dunedin exported overseas a greater amount of canned and frozen crayfish (£5,314) than Wellington (£4,938).

Jasus lalandii has been studied extensively in South Africa, chiefly by Gilchrist (1913–1920), Gilchrist and C. Von Bonde (1922), C. Von Bonde (1928), W. Von Bonde (1930), C. Von Bonde and Marchand (1935), and C. Von Bonde (1936).

Some work has been done in Australia by Challenger (1943) and Sheard (1947), and in Tasmania by Hickman (1945). In New Zealand, Parker (1884) described the skeleton, and Young (1926) studied the growth of a crayfish in captivity. Apart from this, no work appears to have been done in New Zealand.

Whenever natural resources are tapped, it is essential that a sound method of utilization be adopted. Before a proper method of utilization can be evolved, it is necessary to have a thorough knowledge of the natural history of the species concerned. This is moderately well known in South Africa, but little is known of the species in New Zealand.

The work covered in this paper has been restricted to the Wellington area from Oteronga Bay to the Orongorongo River (see Fig. 2). The fishing is carried out mainly in shallow water around the rocky parts of the coast. Observations were made during 1947 and 1948 on board the fishing boats operating from Island Bay. These boats supply most of the crayfish consumed on the Wellington market, and some of the catch is sent to inland towns in the Wellington province. Random samples of the catch have been examined as often as has been possible. These observations provide data on the population composition and its variation throughout the year, the onset and duration of the spawning season, segregation of the sexes and migration, the onset of maturity in females, and the effect of minimum-size regulations on the fishermen's income. Weather and temperature conditions were noted on each fishing occasion; salinity estimations were begun but were soon terminated, as the variations were considered too small to be of biological significance (see Fig. 3). In 1948, fishing was carried out at Moa Point using a dinghy and standard pots. This work has provided additional data and specimens for tagging, for the estimation of egg production, estimation of the amount of usable meat in specimens of various sizes, and shrinkage in cooking. Of 168 specimens tagged, nine were recaptured, giving limited information on the growth rate and movements.

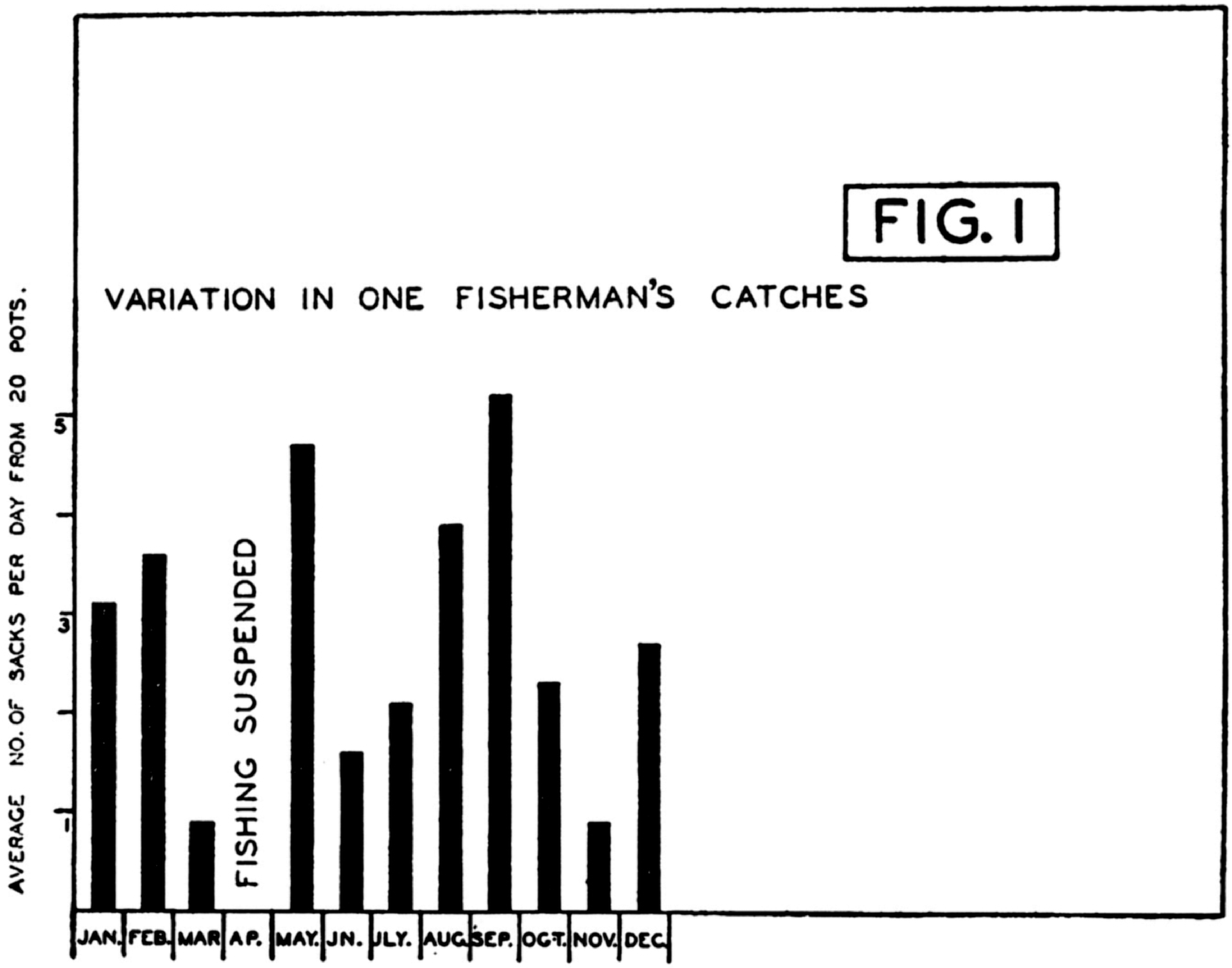
A total of 2,126 specimens was examined over the period of two years. Weather conditions greatly influence fishing. Accordingly, there are some months for which only limited data have been obtained. As samples from the 1947 catches are not significantly different from those of 1948, the data for the two years have been combined and the conclusions presented concern this period as a whole. The conclusions must be taken as representing the Wellington area from Oteronga Bay to the Orongorongo River as a whole. Statements made about the population in this area as a whole at some particular time may not be true of a small division of it.

I wish to express my sincere thanks to the Marine Department for financial assistance, to Professor Richardson, of Victoria University College for his guidance and assistance during the course of this study, to Mr. Kaberry, of the Marine Department, for his helpful suggestions, and to Mr. Alberino, of Island Bay, for allowing me to accompany him on many fishing trips.

FISHING METHODS AND LOCALITY OF FISHING

The specimens examined on the commercial boats were trapped in the common type of pot—namely, a beehive-shaped basket made of supplejack vines with a tapered opening at the top. The height of the pot is about 14 inches, the breadth about 27 inches, and the distance between the horizontal rings of the basket one inch to two inches. The diameter of the external mouth of the funnel is 12 inches, and of the internal mouth seven inches. The length of the funnel is six inches. These measurements are approximate, as no two pots are identical. The pot is weighted and a hauling rope is attached near the base so that it is hauled up on its side. The other end of the rope is attached to a series of cork floats which marks the position of the set pot.

FIG. 1



The most common bait used is fish heads, since they are effective and are easily obtained from other fishing boats. Paua *(Haliotis iris)* is considered to give better results, but is harder to obtain and is therefore not used extensively.

The number of pots used depends on the size of the boat, and varies, as pots are lost from time to time. This variation has been noted in order to find the variation in the catch per pot per day. The commonest boats carry two men and employ 18–20 pots. Fig. 1 shows the average number of sacks taken by 20 pots on an "average" day each month. (A sack contains approximately 100 lb.)

All of the specimens examined on the commercial boats were caught along the rocky coastline from Oteronga Bay to the mouth of the Orongorongo River between 50 and 800 yards off shore in depths varying between 2.7 and 14.2 fathoms. The areas fished each month are given below (see Fig. 2).

January	Oteronga Bay to Sinclair Head
February	Oteronga Bay to Sinclair Head
March	Sinclair Head
April	No fishing due to off-season
May	Ohiro Bay
June	Sinclair Head to Dorset Point
July	Ohiro Bay to Pencarrow Head
August	Moa Point to Fitzroy Bay
September	Karori Rock to Island Bay
October	Near Island Bay
November	Moa Point to Dorset Point
December	Breaker Bay to Fitzroy Bay

The pots were cleared and rebaited every morning (weather permitting) and, at about weekly intervals, were moved to different parts of these areas.

In June, July, and August, 1948, experimental fishing was carried out at Moa Point, mainly to supply specimens for tagging and laboratory work. A ten-foot dinghy and four spot-welded No. 6 gauge wire pots of one-inch mesh were used. Fish-heads were used for bait, and a total of 171 crayfish were caught. The pots were set around Moa Point within 100 yards off shore. They were lifted on each occasion twenty-four hours after they were set.

WEATHER

Wind, sea, and sky conditions and the temperature of the air, surface and bottom waters were noted on each occasion with a view to detecting a possible connection between weather conditions and the size and composition of the catches.

The temperature of the surface and bottom waters was taken with a hydrographic bottle (Dwyer, 1932) and a standard laboratory thermometer (see Fig. 3). It has been possible to correlate the temperature only with the release of larvae (see page 16).

POPULATION COMPOSITION

Good weather and continuous fishing activities allowed the examination of large samples in January, February, July, August, and September. In April, fishing is suspended, since only very small catches are obtained. This is probably due to moulting, copulation, and egg-extrusion at this time. In late March and early May, no fishing is done for the same reason. Consequently, in the two years of this study, few specimens were examined in March, none in April, and few in May. A total of 2,126 crayfish were measured and sexed, and size-frequency graphs were constructed each month (see Fig. 4).

Since the samples are taken at random, these analyses must approximate the true composition of the population each month. The size-groupings are in 2 cm. of total length as measured from the tip of the rostral spine to the end of the telson. Fig. 5 is the analysis of the whole sample for the two years.

Examination of Figs. 4 and 5 shows:—

(*a*) *Size ranges*: The samples are distributed over different size-ranges at different times. The ranges in the smaller samples will only roughly approximate the true size-range of the population in those months. For the months in which larger samples have been obtained, the size-range given must be fairly close to the true size-range of the population. It is apparent that the population in the fishing area is composed of males up to about 48 cm. and females up to about 40 cm. The maximum size in the males may be greater than this, because the entrance aperture in the fishing baskets may be too small to allow the entry of crayfish larger than about 48 cm. This cannot be so with the females, since 40 cm. must be near the maximum size, for, if males of 48 cm. can enter the pots, it would also be possible for females larger than 40 cm. to do so.

The conclusion is that few, if any, females larger than 40 cm. are found in this area and that males larger than 48 cm. may occur, but, if they do, they are rarely caught. Trawler fishermen operating in deep water report that their catches consist entirely of "outsize males," and no females are ever caught. It may be said, then, that males grow to a greater size than females.

Hickman (1945) examined 1,058 crayfish in Tasmania over a period of five years. Of these, 485 were males and 572 were females. The largest male was 15.9 cm. in carapace length (about 40 cm. total length), and the largest female was 12.4 cm. in carapace length (about 32 cm. total length). This indicates that in Tasmania also males reach a greater size than females.

It appears that the largest males taken off Wellington are caught between July and September. This suggests the possibility of an in-shore movement of large males at this time. This is further discussed on pages 7 and 9. The smallest crayfish caught was 17 cm. The mesh of the pots ranged from 2.5 cm. to 5 cm. As it is most unlikely that specimens even considerably smaller than 17 cm. could escape from as small a mesh as this, it appears that small crayfish are either absent from the fishing grounds or are not attracted by the bait used. It is interesting to note that the smallest specimen reported by Hickman (1945) from the examination of 1,058 specimens in Tasmania was 6.3 cm. in carapace length—i.e., about 17 cm. total length. He does not state the size of the mesh used.

(*b*) *Size-range of greatest frequency*: Different months see different size-groups taking prominence in the catches. In males, the size most often caught is larger in September than at any other time. The increase from August to September and the decrease from September to October is very sudden and striking. This suggests a September movement of large males towards the fishing grounds. The return of the mode back to 20.1 cm. to 22 cm. in October would indicate that the large males have moved away again. Consequently, their stay is very temporary. It may be connected with some food becoming temporarily available, possibly as a result of the warming of the water which begins in late August (see Fig. 3).

The size of greatest frequency in the catches of females does not differ significantly from month to month. This indicates a stable female population.

(*c*) *Proportion of males to females*: The ratio of the sexes in the catches varies from month to month. Table 1 gives the percentage of females in each month's sample.

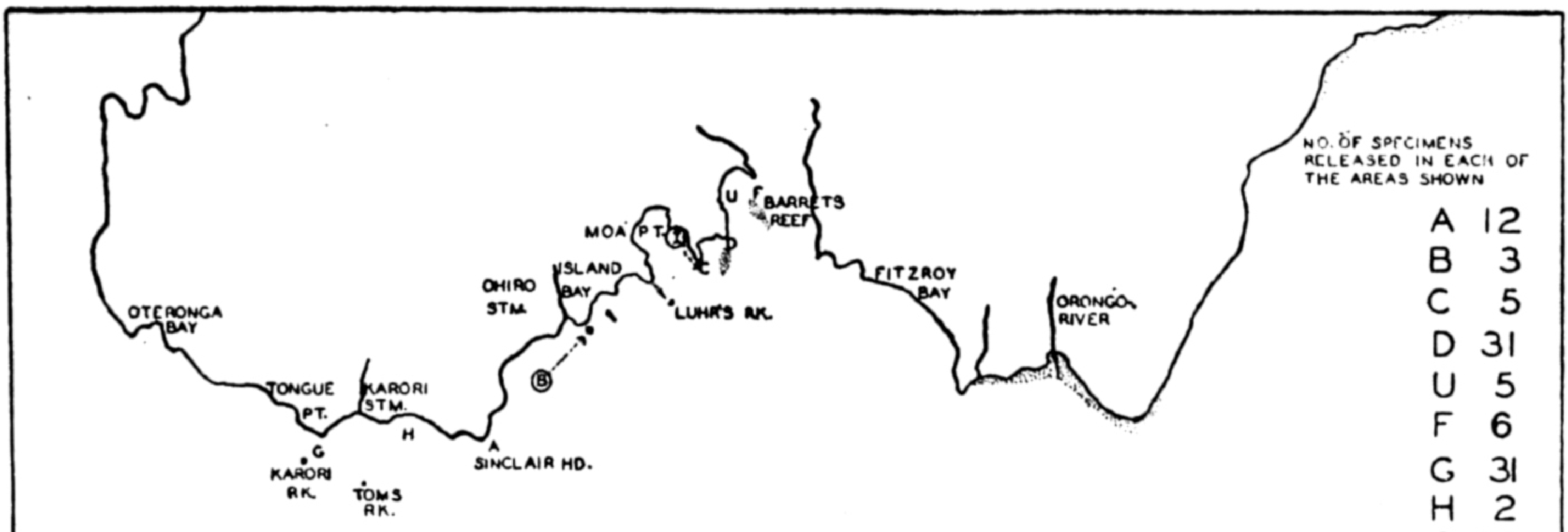


FIG. 2

POINTS OF RELEASE AND RECAPTURE OF TAGGED SPECIMENS

TABLE 1

Month	*Size of Sample*	*Percentage of Females*
January	256	79.7
February	375	79.2
March	49	65.3
May	29	27.6
June	124	52.4
July	421	49.2
August	266	51.5
September	270	24.8
October	83	39.8
November	83	45.8
December	170	65.3

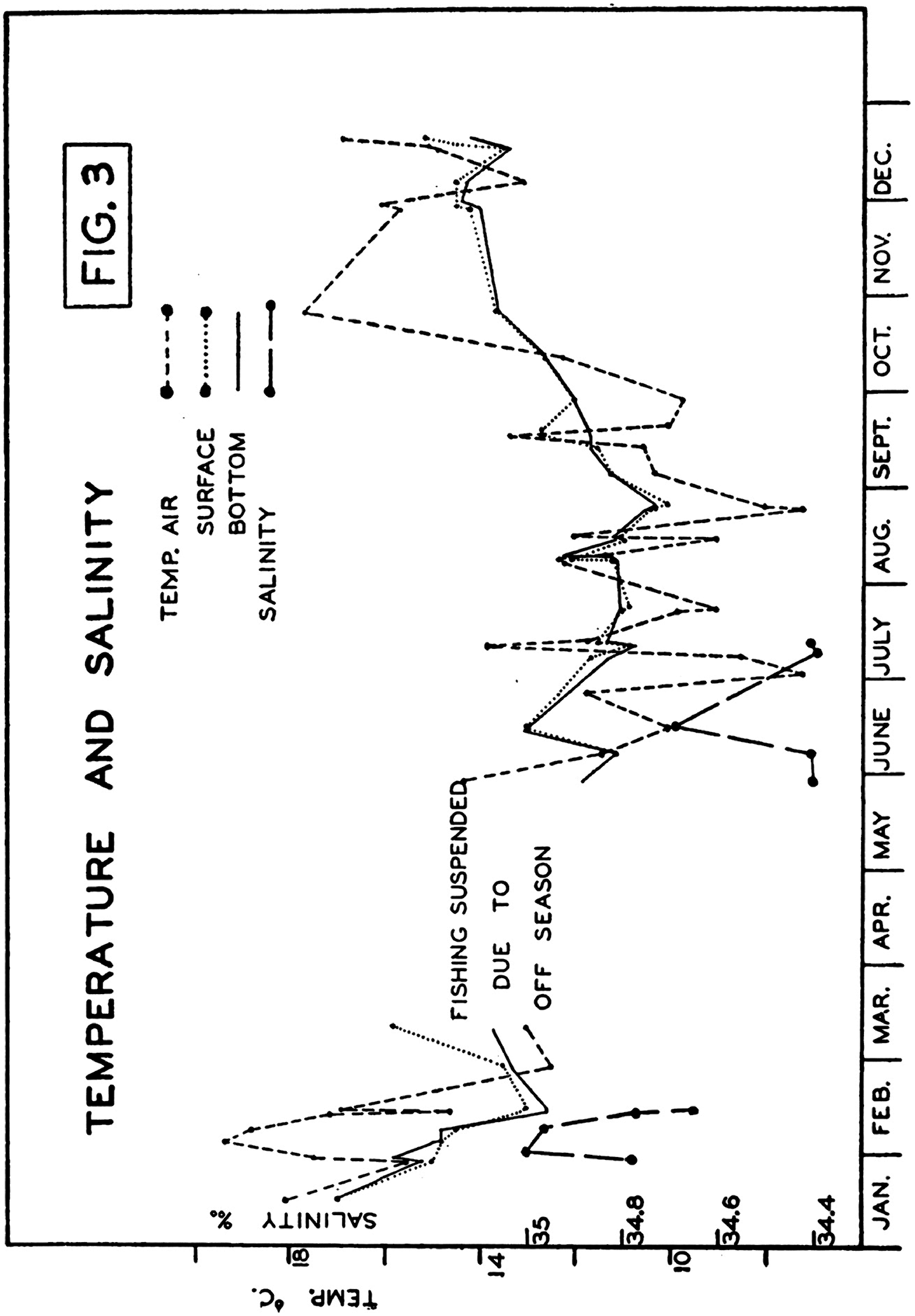


FIG. 3
TEMPERATURE AND SALINITY
TEMP. AIR
SURFACE
BOTTOM
SALINITY
FISHING SUSPENDED
DUE TO
OFF SEASON
SALINITY %
TEMP. °C.
18
14
10
35
34.8
34.6
34.4
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.

Males and females often segregate temporarily in small, distinct, and adjacent areas. Since the pots are usually distributed over a considerable area each day, there is just as much chance of trapping crayfish from the male areas as from the female. Accordingly, this segregation would not greatly affect the ratio of the sexes in the catch; some other phenomena must account for the different sex ratios shown in Table 1. The high percentage of females in January and February is probably due to the moulting of the males, which, according to Von Bonde and Marchand (1935, p. 23), "does not correspond completely with the female season in any particular area, and therefore during the male ecdysis the crawfish population consists of a majority of females." Predator pressure during the soft-shelled stage sends the crayfish into hiding. Consequently, they do not enter the pots at this time. Wellington fishermen report having caught an occasional soft-shelled crayfish in December and January. Unfortunately, the sex of these is unknown, but, since males are known to moult before females (Von Bonde, 1936, p. 9), which moult in or about April, it is probable that they were males.

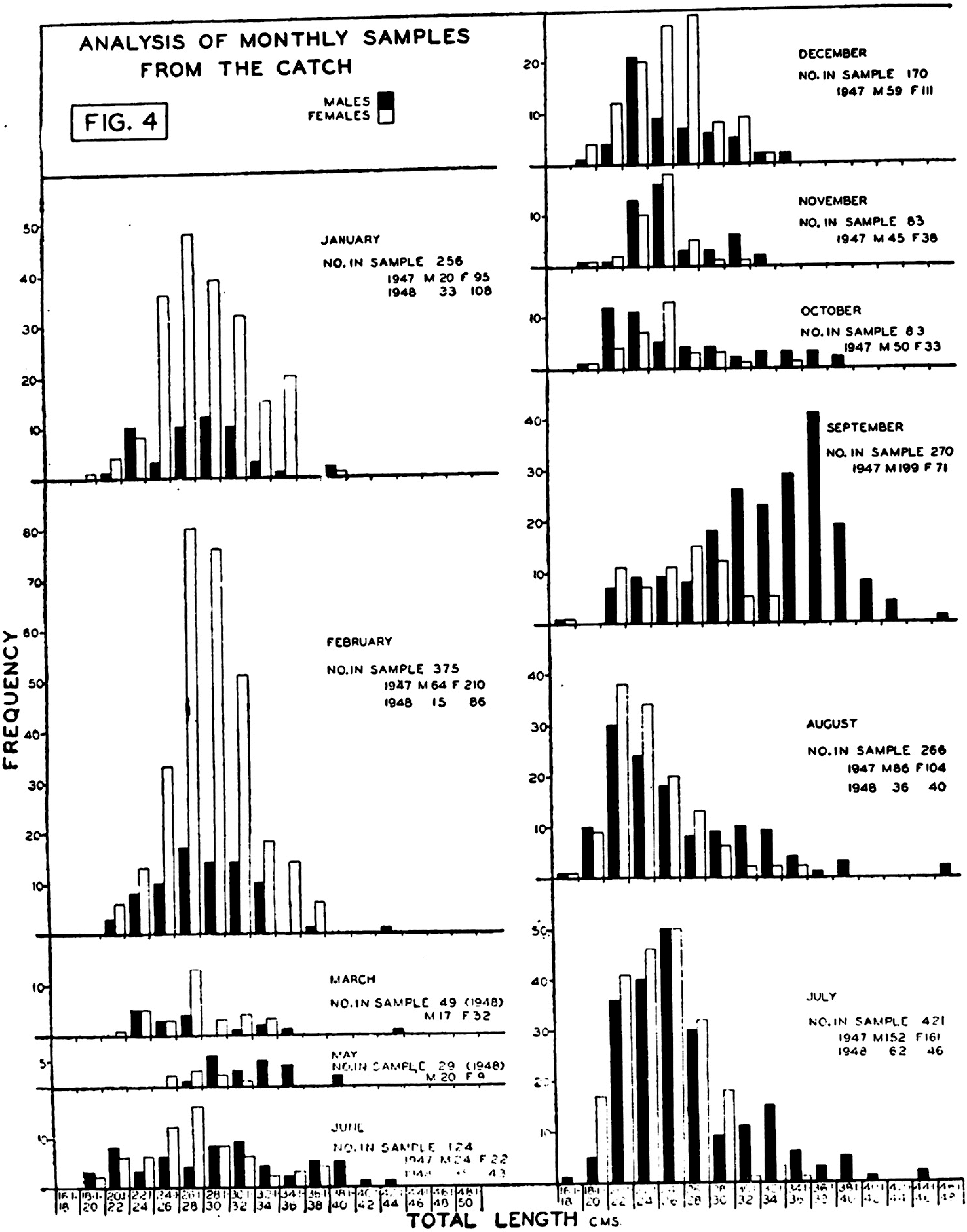
Although the small size of the May sample cannot give a very true picture of the population in this month, there is an indication of an increase in the percentage of males. This is probably due to the moulting and egg-extrusion occurring in the female population. Hickman (1945, p. 29) says: "In April the catches consist largely of males. This is no doubt due to the fact that the females are preparing to lay their eggs, and therefore do not enter the pots." Since moulting in females immediately precedes egg-extrusion (Von Bonde, 1936, p. 10), moulting must also play a part in reducing the number of females caught in or about April.

September sees a sudden increase in the proportion of males, the result of the appearance of large numbers of large males indicating a possible movement of larger males towards the fishing grounds at this time (see pages 6 and 7). Moulting in males is known to occur in December and January (see above), and may begin before this. This would account for the decreasing percentage of males from October onwards shown in Table 1.

Effect of Minimum-size Regulations on the Legal Catches

The minimum size of crayfish which may be taken from the Wellington area has recently been raised from eight inches (20.3 cm.) to nine inches (22.9 cm.) in total length. These limits have apparently been fixed in an arbitrary manner, since no research appears to have been carried out to determine the best legal limit.

The purpose of setting a size-limit is to conserve stocks. Accordingly, it is a matter of principle that small individuals should not be taken until they have had a chance to reproduce. The smallest berried female found was 7.5 in. in total length and the smallest found by Hickman (loc. sit.) was 7.7 in. in total length. It is apparent, then, that most of the females will reach maturity within the protected range. It must be noted also that small crayfish yield a relatively small amount


ANALYSIS OF MONTHLY SAMPLES FROM THE CATCH
FIG. 4
MALES
FEMALES
JANUARY
NO. IN SAMPLE 256
1947 M 20 F 95
1948 33 108
FEBRUARY
NO. IN SAMPLE 375
1947 M 64 F 210
1948 15 86
MARCH
NO. IN SAMPLE 49 (1948)
M 17 F 32
MAY
NO. IN SAMPLE 29 (1948)
M 20 F 9
JUNE
NO. IN SAMPLE 124
DECEMBER
NO. IN SAMPLE 170
1947 M 59 F 111
NOVEMBER
NO. IN SAMPLE 83
1947 M 45 F 38
OCTOBER
NO. IN SAMPLE 83
1947 M 50 F 33
SEPTEMBER
NO. IN SAMPLE 270
1947 M 199 F 71
AUGUST
NO. IN SAMPLE 266
1947 M 86 F 104
1948 36 40
JULY
NO. IN SAMPLE 421
1947 M 152 F 161
1948 62 46
FREQUENCY
TOTAL LENGTH CMS

of meat. Leg meat, rarely extracted from crayfish smaller than 9 in. because of its difficulty of removal, comprises approximately one-third of the total meat obtainable from specimens only slightly larger than 9 in. (see page 24). Protection of small specimens on the basis of their immaturity and waste of meat must, however, be reconciled with the effect on the fisherman's income. The whole random sample examined in this study included 20% below the legal size-limit. On a weight basis, this is 8% of the catch. This is the important percentage to be considered and it shows that the present size restrictions do not have a very great effect on the fishermen except in the work involved in selecting and rejecting the undersized individuals.

For the above reasons it may be said that, although the 9 in. size-limit seems to have been imposed without much preliminary research, it appears to have been a fairly good choice.

MIGRATION

The results of tagging operations in South Africa (Gilchrist, 1918) indicate that considerable movements take place, but in a haphazard manner, probably due to slow wandering in search of food. In the present investigation, of 168 tagged crayfish, nine were returned. One female moved from the middle of Ohiro Bay (point B in Fig. 2) to a point 200 yards off the fish-oil factory at Island Bay, a distance of about 2,000 yards in four and a half months. Two males moved from Moa Point to the extremity of the headland to the east of Moa Point (point C in Fig. 2), a distance of 1,300 yards in five weeks. A female covered the same area in 55 weeks. A male and a female released at point I moved 300 yards in three months, and a male moved the same distance in two and a half months. These are, of course, the minimum distances covered, since the crayfish could have taken any route. No data could be obtained on the movements of the other two specimens.

These limited returns do not point to any definite migration. They indicate that movement is more of a random, wandering nature. The female which was liberated for 55 weeks, and another which was liberated at the same time and returned after 55½ weeks, point to a possible off-shore movement of females. The fact that they eluded capture for over a year and were then retaken in September within a few days of each other suggests that, some time after tagging, they moved to some area not fished (possibly deep water) and then returned to the fishing area (in-shore) in preparation for the release of larvae which begins in September. This is, however, only a tentative suggestion based on two returns, and must await further tagging operations for confirmation.

MATURITY OF FEMALES

Two methods were used in an attempt to find the size at which a female becomes mature. These are:

(i) *Detection of the smallest female "in berry."*

Von Bonde (1936, p. 8), working in South Africa, observed females "in berry" when only $1\frac{3}{4}$ in. (4.4 cm.) in carapace length. He states that this size is reached at the age of approximately two and a half years. Challenger (1943, p. 52) says: "Very small female fish have been found in Tasmanian waters ($1\frac{1}{2}$ in.) with berry attached, which proved, however, to be unfertilized." The measurement of $1\frac{1}{2}$ in. (3.8 cm.) is presumably carapace length. Hickman (1945, p. 31) says: "Of the 572 females examined, the smallest one which, by the presence of empty egg-capsules on the pleopods, gave evidence of having carried eggs, measured 7.2 cm. in carapace length. The smallest specimen actually "in berry" had a carapace length of 7.4 cm. The eggs of this specimen contained embryos at the late nauplius stage of development and therefore had been fertilized."

Of the 1,219 females examined in the present investigation, the smallest one "in berry" was 7 cm. in carapace length (about 19 cm. total length). Of the 12 females smaller than 7.2 cm., none had either eggs or the setae to which eggs are normally attached. These, and a number of others up to 9.7 cm. which had no setae or only a few fine ones, were apparently immature, since the pleopods were not ready for oviposition. The endopodite of the smaller ones was merely a small rod-like projection. In the larger ones (up to 9.7 cm.), it was fully developed, with a few fine setae. It appears that, as the animal grows, the endopodite develops, then setae begin to appear. When these are present in sufficient numbers to form a thick fringe, it is considered that the crayfish is ready, externally at least, for oviposition.

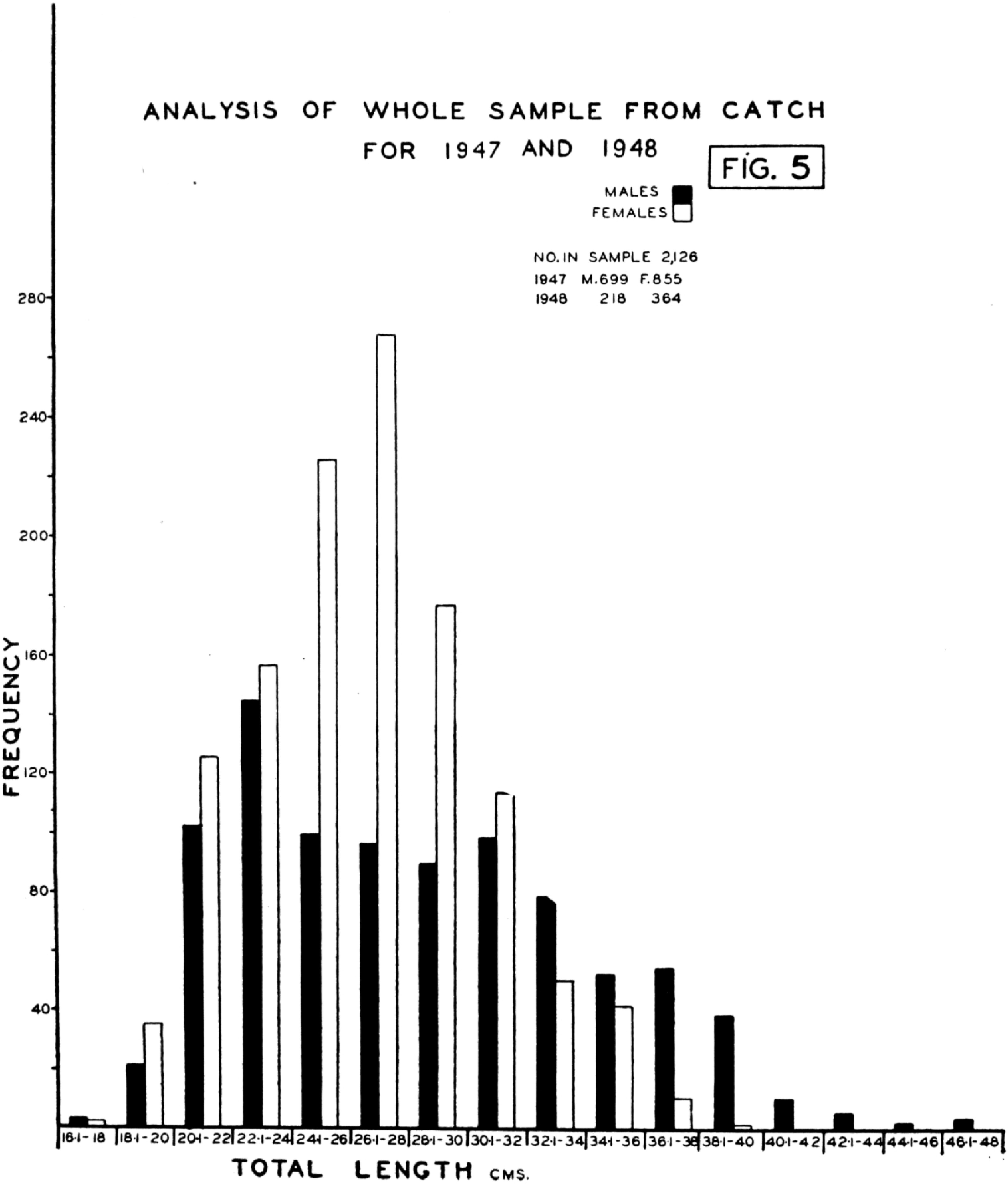
Accordingly, it appears that some crayfish in the Wellington area become mature when a carapace length of 7 cm. is reached, but many do not become mature until they are considerably larger. All appear to be mature by the time they are about 9.7 cm. in carapace length.

The agreement of Hickman's figure and mine for the smallest mature female is to be expected, since the waters of Tasmania and New Zealand have similar temperatures. Challenger's figure suggests the attainment of sexual maturity at a much smaller size. Von Bonde's figure indicates that, in South Africa, where the water is warmer, maturity is reached at a smaller size. This is understandable, since Templeman (1936) found that in the Canadian lobster (*Homarus americanus*) maturity was attained at a smaller size in warm waters than in cold.

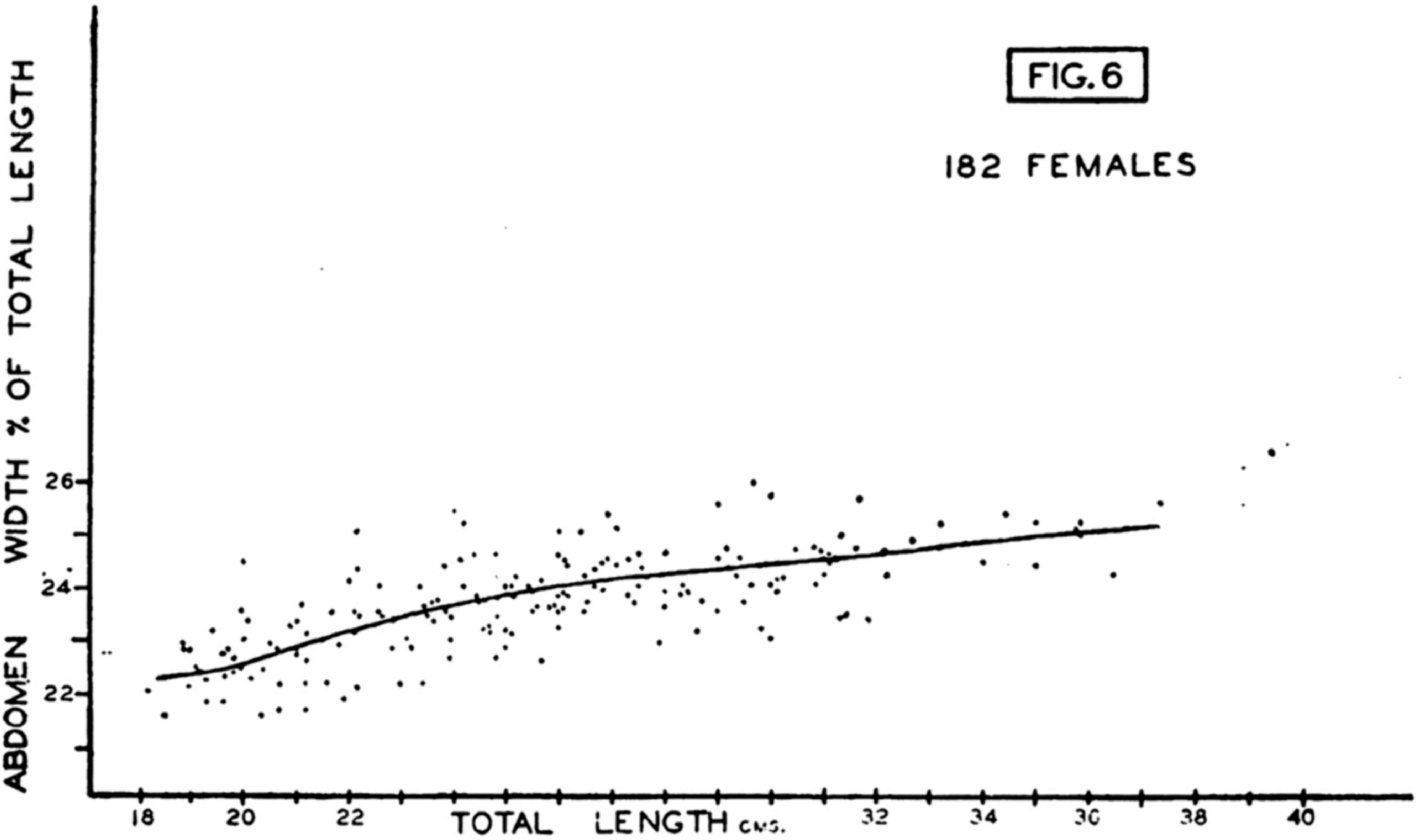
The largest female carrying eggs was 14 cm. in carapace length. The largest female was caught in January, and had setae but no eggs. It was 14.4 cm. in carapace length. This indicates that the largest females caught are still fertile.

(ii) *Detection of change in the growth rate of the abdomen.*

Huxley (1932) noted a relationship between sexual maturity and the width of the abdomen in the female Brachyura: "In the female Brachyura the abdomen is always heterogonic in some part of its development, since it is always relatively narrow in the immature stages and relatively broad in the adult." Templeman (1935 and 1944), working on the North American lobster (*Homarus americanus*), found that the rate of growth of the abdomen began to increase on the attainment


ANALYSIS OF WHOLE SAMPLE FROM CATCH
FOR 1947 AND 1948
FIG. 5
MALES
FEMALES
NO. IN SAMPLE 2,126
1947 M.699 F.855
1948 218 364
FREQUENCY
40
80
120
160
200
240
280
16·1-18
18·1-20
20·1-22
22·1-24
24·1-26
26·1-28
28·1-30
30·1-32
32·1-34
34·1-36
36·1-38
38·1-40
40·1-42
42·1-44
44·1-46
46·1-48
TOTAL LENGTH CMS.

of sexual maturity. A graph of the total length (tip of the rostrum to the end of the telson) against the width of the second segment of the abdomen, expressed as the percentage of the total length, climbed slowly through the sizes up to sexual maturity, when it began to rise more rapidly.



The same method was used in the present investigation to obtain the size at which the female of *Jasus lalandii* becomes mature. Fig. 6 is a graph of the total length against the abdomen width expressed as the percentage of the total length. The width of the abdomen was taken across the tip of the pleural spines of the first abdominal segment. The curve was fitted by eye. Since there is only a small amount of data on small specimens, it is difficult to get the best fit for the curve in the smaller sizes. There does, however, appear to be a relatively flat region in the graph between 18 cm. and about 19.5 cm. total length. This suggests that sexual maturity is achieved in some females at about 19.5 cm. total length (about 7.2 cm. carapace length), which agrees with the conclusions from the detection of the smallest female "in berry," as described in the previous section.

FIRST APPEARANCE OF EGGS AND DURATION OF THE "BERRIED" SEASON

Females may be conveniently divided into three classes:

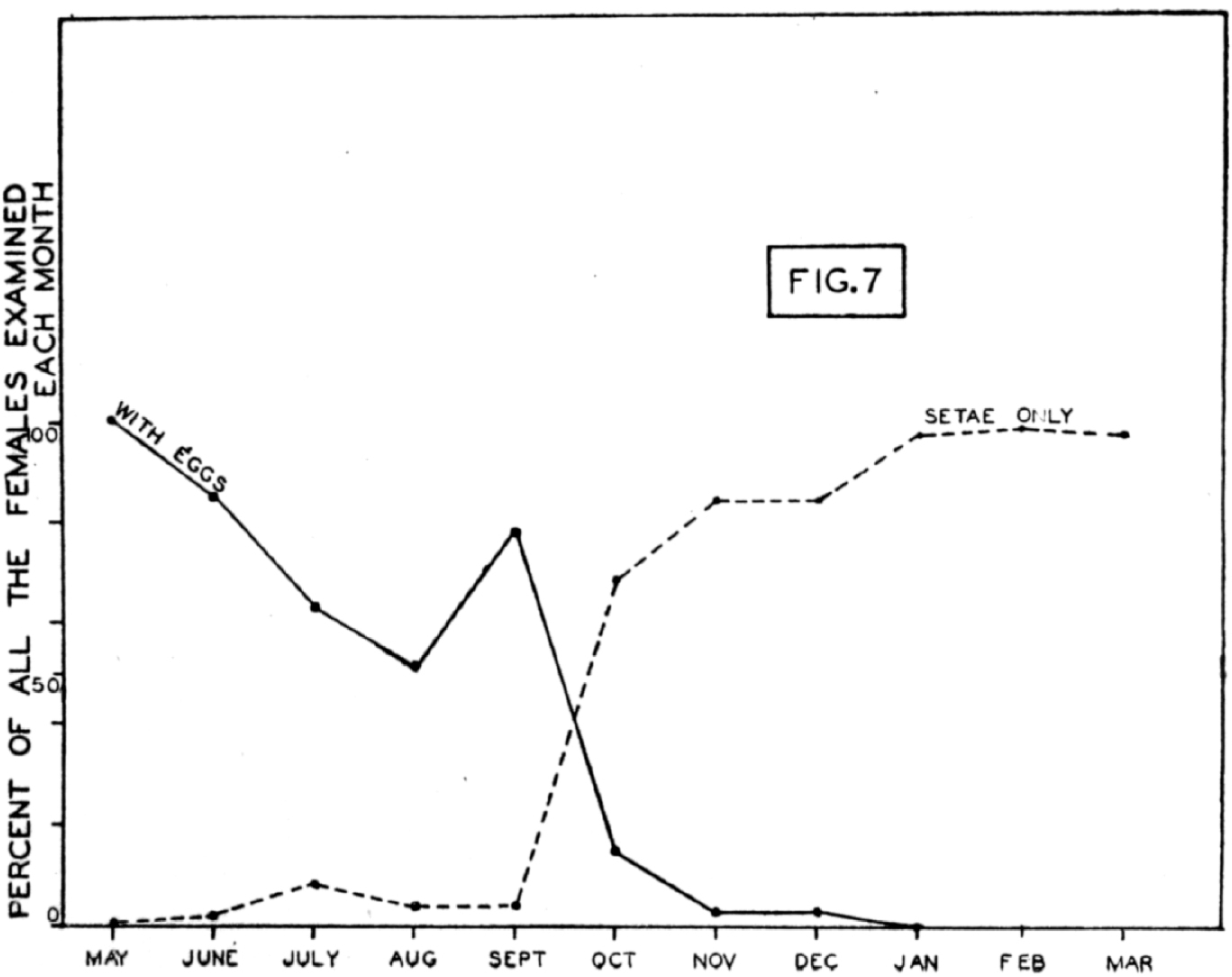
(i) Those with eggs attached to setae on the pleopods. Von Bonde (1936, p. 12) says: "There are a few plumose setae on the pleopods, but in no single instance have any eggs been noticed attached to them." In contradistinction to this, I have found that the eggs of the Wellington crayfish are always attached to these setae. Indeed, it is hard to conceive of any other manner of attachment. The setae are also present to the extent of more than a "few" on the pleopods. They form a rather thick fringe to the endopodite. Herrick (1909) states: "In the lobster the ova adhere principally to certain setae of the appendages of the five anterior segments of the abdomen."

(ii) Those with no eggs but with setae present. This is the normal state for a mature female except in the "berry" season.

(iii) Those with neither eggs nor setae. These are caught in small numbers all the year round, and are considered to be immature (see page 12).

Females carrying eggs make their first appearance in the catches in May. Nearly 100% of the females caught in May are in this condition. It is probable that egg-extrusion begins in April because of the large number "in berry" by May. Hickman (1945, p. 33) found the first berried female, over a period of five years, on 26th April. Unfortunately, in the present investigation, data for April was unobtainable owing to the suspension of fishing operations.

It is unlikely that any commence egg-extrusion earlier than April; certainly none have been observed "in berry" earlier than this. The eggs on the specimen reported by Hickman as having been caught on 26th April were at the morula stage. Von Bonde (1936, p. 13) has shown that this stage is reached three days after laying. Accordingly, the eggs were probably laid about 23rd April.



The percentage of females with eggs and the percentage with setae only are graphed in Fig. 7. The percentage with eggs is high from May to September. In October a significant decrease occurs. This agrees with Hickman, who says: "After September there is a rapid falling-off in the number of the 'berried' females caught." In November and December, the percentage is very small, and in January no females are carrying eggs. Hickman says "only three females in berry were taken in October, none in November, and one in December"—this from observations over a period of five years, involving the examination of 572 females. It may be said, then, that release of larvae from most of the females occurs in October, leaving only a few to hatch in November and December. This is supported by the fact that a tagged specimen released in the "berried" condition on 6th June, 1947, and another released on 12th July, 1948 were free of eggs when recaptured on 24th October, 1947, and 16th October, 1948, respectively.

Hickman says: "At Wedge Bay, laying takes place mainly during April, May, and June, and hatching during July, August, and September." He found that three out of 66 females taken in July carried eggs which were ready to hatch. Since oviposition seems to begin about the same time in Tasmania and Wellington, it seems probable that hatching in Wellington may also begin in a few specimens as early as July. This means that the eggs are carried for about three months, which agrees with Von Bonde and Marchand (1935, p. 14), who state: "In the aquarium experiments the female carried her eggs for about three to four months, under artificial conditions. It may be taken that, on a general average, the berried season last for two to three months."

From May to September, only a small number of females were without eggs but with the setae present to which eggs are normally attached (see Fig. 7). In October, there is a significant increase in the number of females in this condition, and the increase continues through to December. The number in this condition between May and September is small, because almost all of the females are carrying eggs. The increase from October onwards is the result of extensive hatching leaving the pleopods free from eggs but with the setae present. Reference to Fig. 7 will show that this is the time when the percentage of "berried" females shows a sharp decline.

Failure of the sum of "berried" and "setae only" females to reach 100% each month is due to the presence of a number of small specimens which have neither setae nor eggs. These are all between 17 cm. and 26.1 cm. in total length, with most of them between 17 cm. and 23 cm. These are considered to be immature, since there are no setae to which eggs could be attached, and this is supported by the fact that no female crayfish larger than 26.1 cm. lacked the setae. The presence of a thick fringe of setae on the endopodites of the pleopods is considered to be an index of maturity. This is further discussed on page 12.

It is interesting to correlate the hatching period with the temperature curve (Fig. 3). The bottom and surface temperatures begin to increase in August, and this increase continues through to January. That is, hatching occurs during a period of increasing temperature.

Table 2 gives the smallest and largest berried females in each month's sample.

TABLE 2

Month	*Number of berried females examined*	*Smallest berried female*	*Largest berried female*
May	9	24.5	30.4
June	55	21	37.3
July	127	19.1	36
August	70	21.4	35.2
September	53	22.7	33.8
October	5	22.2	25.8
November	1	24.7	24.7
December	3	20	26.6

It appears that, from October on, none of the largest females are "in berry." This suggests that large crayfish may "come into berry" before small ones, and consequently be free of eggs earlier. This has been recognized by local fishermen.

NUMBER OF EGGS CARRIED BY FEMALES OF VARIOUS SIZES

Hickman (1945) counted the number of eggs in 2-gram samples from six specimens, and obtained an average of 8,520 (standard error 93). He used this average to obtain the total number of eggs on specimens of various sizes by multiplying this number by the total weight of eggs on a specimen and dividing by 2.

This work has been repeated in the following manner: The whole egg-mass was stripped from the pleopods and weighed. Two grams of the mass was weighed out. The eggs, which are attached to one another by tough fibres so that the mass consists of a series of connected compact bunches, were separated from one another by hand, using a scalpel and forceps. After separation, the eggs were counted in an apparatus described by Bradstock (1948). Ten two-gram samples were counted, giving a mean of 7,630, with standard error 275. This mean is comparable with Hickman's, although the variation is greater. Using this mean, it was found that the number of eggs carried by 28 crayfish between 8.3 cm. and 13.5 cm. in carapace length ranged from 86,000 to 549,000. Hickman found that, for a range in carapace length from 7.4 cm. to 12.4 cm., the number of eggs ranged from 65,170 to 413,220. Von Bonde and Marchand (1935, p. 11) state that the number of eggs carried "may vary, according to the female's size, from about 3,000 to nearly 200,000." In a later publication, Von Bonde (1936, p. 9) says that this number varies from "about 3,000 in the smallest to about 20,000 in the largest.

Hickman quotes these figures without comment, but, since Von Bonde gives no explanation of why he changed the upper limit from 200,000 to 20,000, it seems that the 20,000 may be a misprint. Challenger (1943, p. 52) reports that an "average specimen carried 850,000 eggs." This so-called "average specimen" was 5 in. (12.7 cm.) in carapace length. This is actually a very large female. His figure is 547,000 higher than mine for a specimen only 0.2 cm. smaller and 450,410 higher than the figure obtained by Hickman for a specimen 0.3 cm. smaller. The difference between Challenger's figure and those of other workers, combined with the fact that he does not describe his method in any detail, leaves the accuracy of his method in doubt.

Herrick (1895, p. 52), discussing the American lobster (*Homarus americanus*), gives the general law of fecundity. "The number of eggs produced by female lobsters at each reproductive period vary in geometrical series, while the lengths of the lobsters producing these eggs vary in an arithmetical series." The figures given above indicate that this applies also to *Jasus lalandii*. Hickman found that his data obeyed this law with considerably less variation than the data presented here. Lateste (1896) observed that the number of eggs carried by a female lobster should be proportional to the volume of the body or cube of the length—i.e,

if E is the number of eggs laid, and
L is the length of the female, and
K is a constant, then
$E = KL^3$.

This is another way of expressing Herrick's law, whence

$$K = \frac{E}{L^3}$$

Von Bonde (1936) found that, for 50 specimens of *Jasus lalandii* in South Africa, the value of K varied between 263 and 265, so that this law is obeyed. For 28 specimens in the Wellington area ranging from 8.3 cm. to 13.5 cm. in carapace length, the value of K ranged from 135 to 261, with the mean value 194 (standard error 7.2). This indicates considerable variation, but there is, however, a tendency to constancy, so that the law is, at least approximately, obeyed. It is to be noted that the value of K is lower in Wellington than it is in South Africa. This means that the number of eggs produced increases with length more quickly in South Africa than in Wellington.

TAGGING

To obtain data on the growth rate and migration, tagging experiments were begun in June, 1947, and in the following three months 95 specimens were tagged and released. In 1948, an additional 73 were released in June, July, and August near Moa Point (see Fig. 2). The numbers of specimens released at various points around the coast are indicated in Fig. 2.

Since tags which are attached to the exoskeleton are lost in moulting, special types of tags were used which penetrate the exoskeleton and are embedded in the deeper tissues, and therefore are not so likely to be cast off. These were of two types, 50 of the specimens released in 1947 and all those released in 1948 being tagged with a small arrow-shaped piece of xylonite which was pushed under one of the abdominal terga so that the arrow-head gripped in the dorsal muscle mass, care being taken not to damage the dorsal artery. The shaft, which had a number stamped on it, projected about three-quarters of an inch, and, being white, would be easily seen on recapture. The remaining 45, released in 1947, were tagged with a numbered aluminium disc attached to a short wire whose other end was bent into a hook. The hook end was pushed through a small cut in the ventral aspect

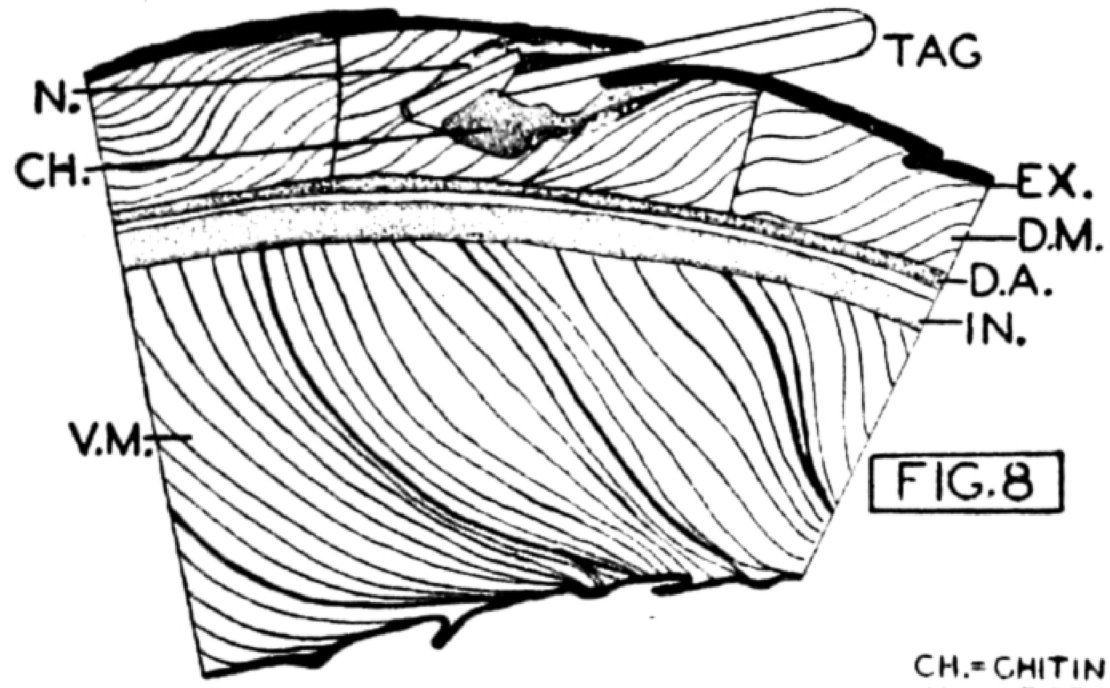


FIG. 8

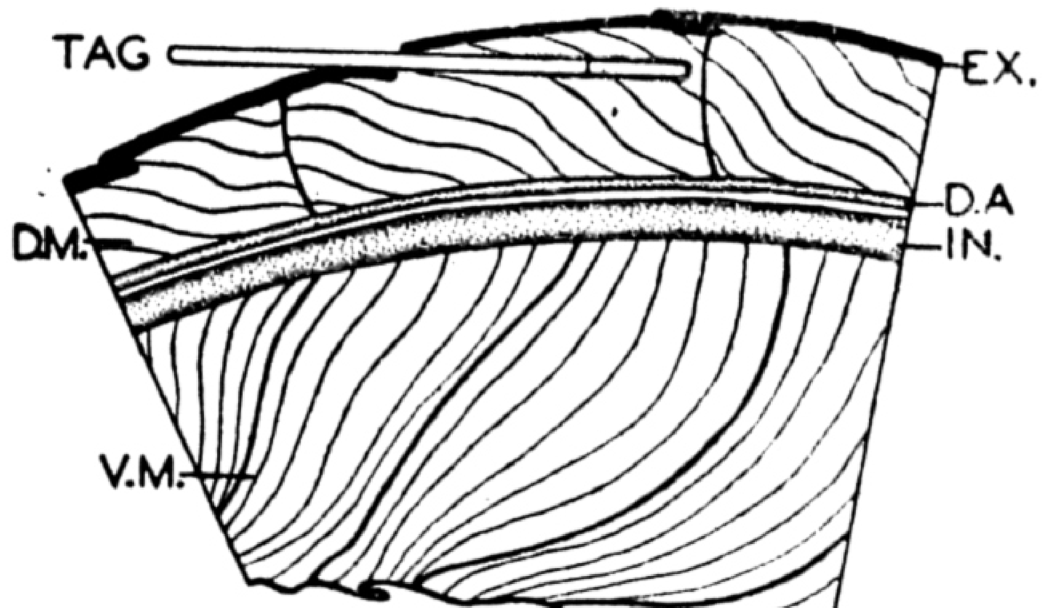
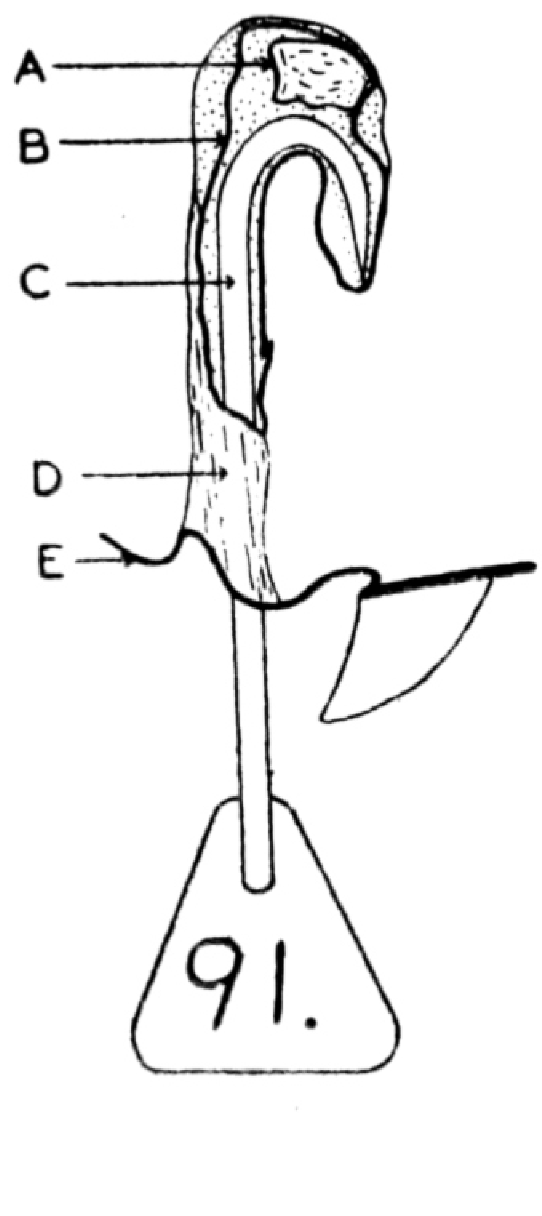


FIG. 9

CH. = CHITIN
N. = NECROTIC TISSUE
EX. = EXOSKELETON
D.A. = DORSAL ARTERY
IN. = INTESTINE
D.M. = DORSAL MUSCLE MASS
V.M. = VENTRAL " "

FIG. 10



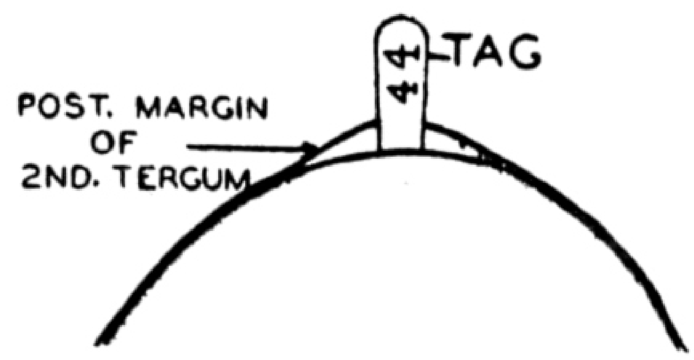


FIG. 11

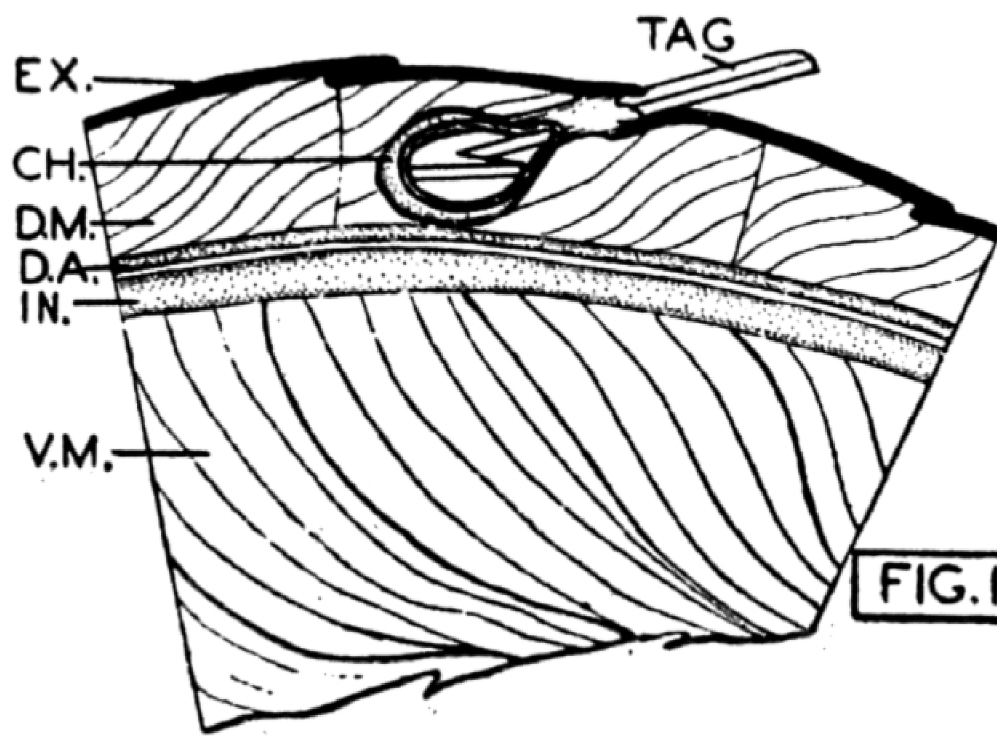


FIG. 12

of the abdomen, turned slightly, and pulled back so that it engaged in the tissues. This latter method has met with success in South Africa, where it has been retained during moulting (Von Bonde, 1928). Von Bonde used aluminium wire, but, as that was unobtainable here, stainless steel was substituted.

One female was recaptured in 1947 (tag No. 3, carapace length 11.5 cm.). This was released on 6th June, 1947, and recaptured on 24th October, and was handed in, in good condition, by the fisherman who caught it. This had been tagged with a xylonite arrow, and the wound contained only a small amount of necrotic tissue. The tag was encased in a chitinous sheath in which a considerable amount of foreign matter was embedded, and this held it firmly (see Fig. 8). Where the tag was in contact with the posterior edge of the tergum, the setae which usually fringe this border were absent, probably as a result of the rubbing action of the tag each time the tail was moved. No change in size had occurred. The crayfish was carrying eggs when released, but these were absent when recaptured, which indicates that hatching occurs between June and October (see page 16), and it had travelled from Ohiro Bay (point B on Fig. 2) to 200 yards off-shore from the fish-oil factory to the west of Island Bay, a distance of about 2,000 yards in four and a half months.

Eight specimens were recaptured in 1948. Two of these were liberated near Moa Point (point I in Fig. 2), the first on 10th July, 1948 (tag No. 125, carapace length 12.9 cm.) and the second on 30th July, 1948 (tag No. 121, carapace length 10.8 cm.). These two had the xylonite tag. Number 125 was recaptured on 15th August, 1948, and No. 121 on 7th September, 1948. Both were males and had travelled from Moa Point to the extremity of the headland to the east of Moa Point, commonly referred to as "the Island" (point C on Fig. 2)—a distance of about 1,300 yards in five weeks.

Fig. 9 is a longitudinal section of the tail of No. 125. There was no sign of necrosis of the tissue surrounding the tag. The tag was surrounded by a small amount of dark-coloured foreign matter. No chitinization could be detected. No change in size or other characters had occurred in either specimen. Number 121 was returned to the water at the same place as soon as it had been examined.

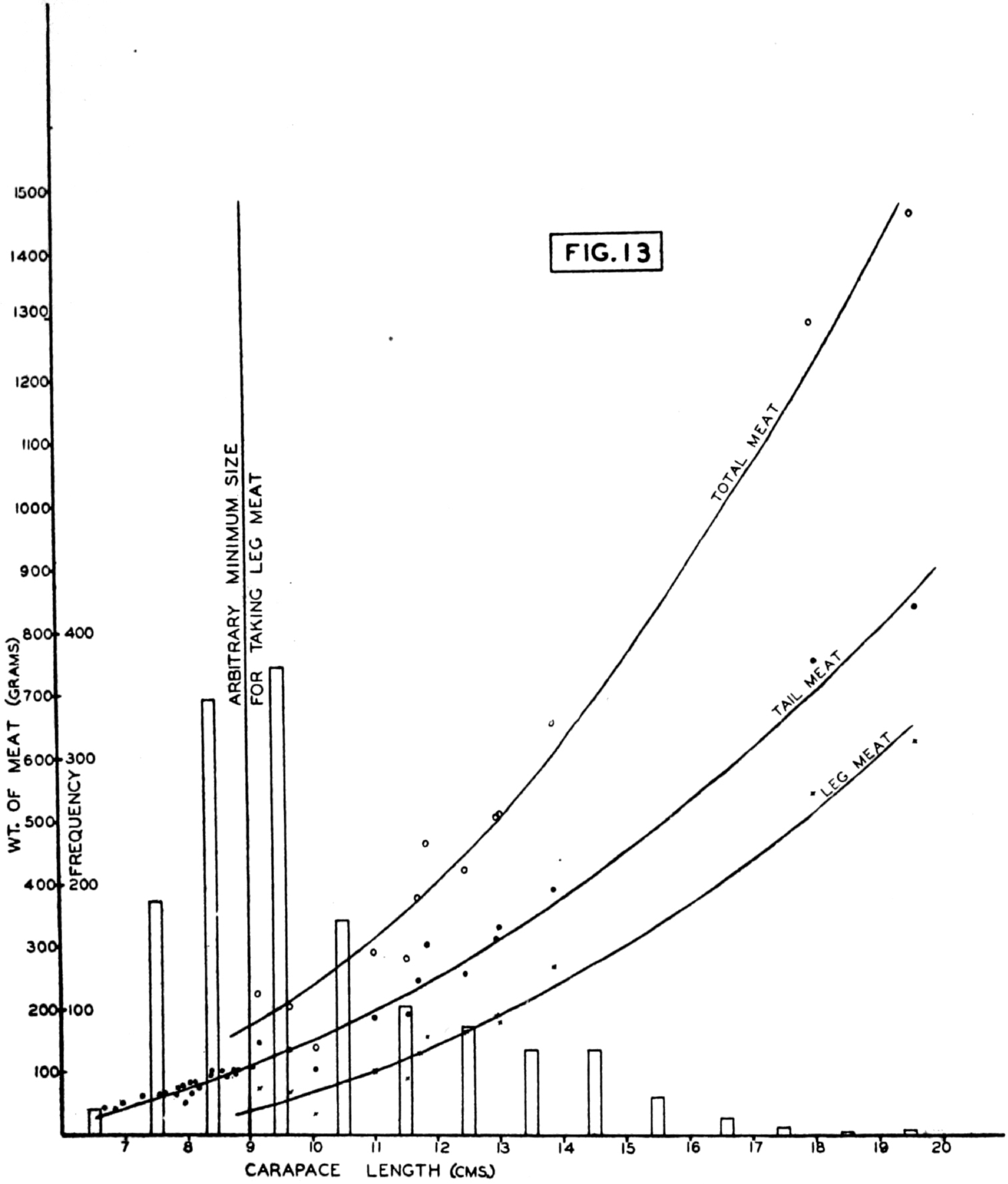
The third specimen (tag No. 91) had been marked with the stainless steel wire tag. It was a male, and was released on 24th August, 1947 and retaken fifty-five weeks later. It was handed in by a Wellington retailer. Unfortunately it had been cooked. The measurements are given below:

Date	*Total length*	*Breadth*	*Carapace length*	*Weight*
24/8/47	21.5 cm.	5.1 cm.	8.2 cm.	255 gm.
15/9/48	23.8 cm.	5.7 cm.	9.1 cm.	319 gm.

The breadth was taken across the carapace in line with the cervical groove. The second set of measurements given above will have been affected by the cooking.

The changes on cooking several specimens of this size have been observed (see page 25), and the measurements given below would be the approximate dimensions of this crayfish before it was cooked:

Length, 23.6 cm.; breadth, 5.7 cm.; carapace length, 9.2 cm.; weight, 370 gm.



The weight of the specimen when it was liberated was taken with a spring balance, but weighing on board a small boat is very inaccurate. Consequently the increase in weight is very approximate. The changes are given below:

Length, 2.1 cm.; breadth, 0.6 cm.; carapace length, 1.0 cm.; weight, 115 gm.

It is obvious that the specimen had moulted. Von Bonde (1935, p. 15) found that a specimen, 9.0 cm. in carapace length, kept in an aquarium, moulted twice in one year, whereas one of 10.4 cm. carapace length moulted only once. The tagged specimen was liberated for 55 weeks, so that it is probable that it had moulted twice. This indicates an average increase in size of 0.5 cm. carapace length at each moult.

Since the tag was not observed until the specimen reached the retailer, it is impossible to find the exact locality at which it was caught. Investigations revealed that it was taken by one of two fishermen. One of these was fishing off the Orongorongo River and the other off Island Bay and Palmer Head. The Orongorongo River is about 11,000 yards from the point of release (Palmer Head). Island Bay is about 4,000 yards away. Since another female travelled only 2,700 yards in the same time, it is unlikely that this specimen was retaken at the Orongorongo River. For the same reason, Island Bay is too far away. Accordingly, it is most probable that it was recaptured at Palmer Head, in which case it had either remained there for the whole period of liberation (55 weeks) or had returned to Palmer Head after moving to some other area. This type of tag does not appear to have a very harmful effect on the tissues. A sketch of the tag is given in Fig. 10. The tag lies in a pocket of chitinized tissue. A is an area of partly chitinized tissue surrounded by a denser chitin envelope. B is the main chitinous pocket surrounding the tag. C is the shaft of the tag. D is the part of the pocket, which has not been sectioned. E is the thin exoskeleton of the ventral aspect of the abdomen. Apart from a thin film of necrotic tissue surrounding the pocket, the muscle surrounding the tag seems to be unaffected.

A fourth specimen was recaptured on or about 10th August, 1948, at the same place as Nos. 121 and 125 (point C on Fig. 2). The fisherman who caught it had only recently taken charge of the boat and was unaware of the tagging operations. He returned it to the water without noting the number, so that no data are available from it. The tag was of the xylonite type.

The fifth specimen (tag 44) was tagged with a xylonite arrow and released on 24th August, 1947. It was recaptured 55½ weeks later. The measurements when released and when recaptured are given below:

Date	*Total length*	*Breadth*	*Carapace length*	*Weight*
24/8/47	24.8 cm.	5.8 cm.	9.1 cm.	425 gm.
18/9/48	26.7 cm.	6.0 cm.	9.2 cm.	483 gm.

It was "in berry" when released. When recaptured it had eggs which were near to hatching. These, however, could not be the same eggs. The weight, when released, is not very accurate, for the reasons described in the discussion of tag No. 91. The changes in dimensions over the period of liberation (55½ weeks) are:

Length, 1.9 cm.; breadth, 0.2 cm.; carapace length, 0.1 cm.; weight, 58 gm.

It has obviously moulted. Von Bonde (1935, p. 15) found that a crayfish, 9 cm. in carapace length, moulted twice in one year. Since the tagged specimen was about the same size and was liberated for a year, it is probable that it had moulted twice. The carapace increase is smaller than would be expected from consideration of No. 91 and from comparing it with the increase in total length. This is thought to be due to incorrect measurement of the carapace length when the specimen was liberated. It was released off Palmer Head and recaptured at Moa Point. Consequently, it had travelled 2,700 yards in 55½ weeks.

Fig. 11 shows the tag in position viewed from the posterior aspect to show that the posterior edge of the tergum under which the tag is inserted is bulged outwards, probably as a result of the moulding action of the tag on the soft shell during the hardening process after the moult. The setae which fringe this area are absent, probably as a result of the tag's rubbing action every time the tail is moved, and this is thought to account for the slight erosion of the shell in this area. Fig. 12 shows the tag *in situ* in a longitudinal section of the tail. The tag lies loosely in a cavity whose walls are lined with a thick and rather tough chitinous secretion. This pocket narrows behind the head of the tag and is closely applied to the shaft in this region. This constriction prevents the tag from being pulled out and at the same time allows considerable movement of the tag inside the pocket. There was only a thin layer of necrotic tissue surrounding this pocket.

Three specimens were retaken at Moa Point on 16th October, 1948. Two of these, a male (tag 146) and a female (tag 105), after three months' liberty, had moved 300 yards; a male (tag 143), after two and a half months, had moved the same distance. All three were marked with the xylonite tag. None had moulted. The female, "in berry" when released (12th July, 1948), was free of eggs when recaptured. This female and one male (tag 143) were returned to the water again at Moa Point. These nine returns comprise 5.4 per cent. of those released, which is a return of the order usually obtained in tagging work on Crustacea.

It appears that the xylonite tag is not very harmful. It has been retained at the moult in one specimen, and hence may prove to be a satisfactory type for future use. The chitinous sheath probably protects the surrounding tissues from necrosis. The other type of tag is also retained at the moult, and has little effect on the tissues, again probably because of the protection afforded by the secretion of chitin.

Although these two tags have been retained at the moult, it is possible that the chitin secreted around them would be thrown off at a later moult, in which case the tag would be lost.

Variation in the Amount of Usable Meat

The only parts of a crayfish which are eaten are the tail muscle, which extends into the cephalothorax, and the muscle from the legs and the antennal peduncle.

The legs of small crayfish (up to about 9 cm. in carapace length) are so small that few people would attempt to extract the meat they contain. Accordingly, only the tail meat of these is used. The legs of crayfish larger than about 9 cm. carapace length contain enough meat to make its extraction worthwhile. Consequently, both the leg meat and the tail meat of crayfish larger than 9 cm. is used. For the purpose of this investigation, 9 cm. carapace length was set as an arbitrary minimum for using leg meat. This represents a total length of about 23.5 cm., which is only 0.6 cm. above the legal size-limit.

A number of specimens were measured, "drowned" in tap water to prevent autotomy, brought to the boil in salted water, and boiled for 20 minutes. They were then removed from the water and allowed to cool in the air. This is the procedure followed in the commercial process. When they had cooled, the leg, antennal peduncle, and tail meat was removed and weighed. The meat from the legs and antennal peduncle is hereafter referred to as "leg meat."

The results are graphed in Fig. 13. For specimens larger than 9 cm., the tail, leg, and total meat are plotted, so that three graphs are given. In each case the curve is fitted by eye. There is only a gradual slope in the tail meat graph up to 9 cm. carapace length. In this size-range, this represents the total meat. The amount of available meat per unit carapace length increases rapidly with size. The figures are:

6– 7 cm.	......	6.4 gm.	11–12 cm.	......	31.8 gm.
7– 8 cm.	......	8.8 gm.	12–13 cm.	......	37.2 gm.
8– 9 cm.	......	10.9 gm.	13–14 cm.	......	47.2 gm.
9–10 cm.	......	20.2 gm.	18 cm.	......	71.3 gm.
10–11 cm.	......	26.2 gm.	20 cm.	......	74.0 gm.

It is obvious that the taking of small crayfish involves considerable wastage of potential meat. A specimen of 7 cm. carapace length provides 6.6 gm. per unit carapace length. If crayfish were protected until they had grown to about 9 cm., they would provide 11.7 gm. of usable meat per unit carapace length. At 20 cm., they provide 74 gm. The larger the crayfish, the smaller the waste. This should be taken into consideration in setting a legal size-limit. This should be high enough to prevent the wastage of potential meat. The present size-limit (9 in. total length, i.e., about 9 cm. carapace length) is reasonable in this respect. See page 9.

In Fig. 13 the frequency distribution over the carapace size-range for the whole random sample of the catch for 1947 and 1948 is superimposed on the graph of available meat against carapace length. Since the sample was taken at random, the analysis must approximate the true composition of the whole catch.

Thirty-eight per cent. of the sample falls below the 9 cm. line. The total meat from these crayfish is about 43,000 gm., and is hardly worth taking when compared with the 332,000 gm. available from larger specimens. Under the existing protection, the small, low meat-producing crayfish are able to grow to a more economic size, and, in addition, are able to reach maturity. The size-group 9 cm. to 13 cm. comprises 50 per cent. of the crayfish caught and provides 52 per cent. of the usable meat.

CHANGES IN SIZE AND WEIGHT IN COOKING

In the event of legal action being taken under the minimum-size regulations, on the basis of measurement of a catch after cooking, it would be of importance to know the approximate sizes of the crayfish before they were cooked. If the cooked crayfish were only slightly below the limit, it could be argued that they were above the minimum size when caught and had shrunk in cooking.

With this in mind, a number of crayfish were measured, then cooked by the usual commercial process described on page 24. The measurements were then retaken and any change in size recorded. The carapace shrinks no more than 1 mm. The change in total length is very variable because the muscles connecting the abdomen with the cephalothorax are in different stages of relaxation when death occurs. Accordingly, in some cases, an increase in size occurs. The abdomen breadth decreases no more than 1 mm.

Accordingly, it appears that the exoskeleton does undergo a slight shrinkage, but this is too small to be considered in a legal action. There is a considerable loss in weight, and this increases with the size of the crayfish.

DISCUSSION

Before this study was carried out, the only published information available on *Jasus lalandii* in New Zealand waters was that of Parker (1889), on the skeleton, and Young (1926), on the growth rate of a small crayfish in captivity. It is considered that, although the results presented here are based on limited data and are likely to be considerably modified by future work, an increase in the knowledge of several aspects of the crayfish population has been achieved.

Most of the crayfish caught in Wellington waters were taken in supplejack pots baited with fish-heads. In Australia, pots and bait of a similar kind are used. Iron hoops with netting bags suspended from them are used in South Africa. The bait is placed in the centre of the ring, and when the hoop settles on the bottom it lies on the top of the net and in the middle of the ring. Crayfish crawl over the bait, and when the net is raised they are held in the netting bag.

In the Wellington area, crayfish are caught mainly in-shore on the rocky parts of the coast, but trawlers occasionally take large catches in the trawl nets in deeper water. The in-shore fishery is centred mainly at Island Bay. Motor-launches carrying two or three men are used, and about twenty pots are employed by each boat. There is considerable variation in the size of the catches throughout the year, the heaviest catches being taken in September, when large males appear in considerable numbers in the catch. There appears to be some correlation between the increasing water temperature from August on and the release of larvae which begins about the end of September.

The sex and size composition of the catches in 1948 was approximately the same as in 1947. The catches consist of males from 17.9 cm. to 48 cm. (total length) and of females from 17 cm. to 40 cm. As the mesh of the basket seems to be small enough to hold crayfish smaller than 17 cm., it appears that specimens of this size are either absent from the fishing grounds or are not attracted to the bait used. Since females do not become mature until at least 19 cm. in total length, individuals between 17 cm. and 19 cm. must be protected by law to ensure the conservation of stocks. The smallest crayfish found by Hickman (1945) in a study of 1,058 specimens in Tasmania over a period of five years were a male and a female 17 cm. in total length, which agrees with the above. The largest female was 32 cm. and the largest male was 40 cm. It is to be concluded that both males and females in Wellington waters reach a greater size than they do in Tasmania, and that, in this species, males reach a greater size than females.

The size of males most often caught varies from month to month. This is probably due in part to the different localities fished, but the large number of very large males taken in September leads to the conclusion that large males, absent from the fishing grounds at any other time, move into the fishing areas in September. Few large males are taken in October, which indicates that their stay is very temporary. This habit may be related to some food becoming temporarily available, possibly as a result of the warming of the water which begins in late August. It cannot be due to movement for moulting, since, for males, this occurs in December, January, and February. In any case, if males were moulting, they would not enter the pots very readily, since in the soft-shelled condition they remain in seclusion to avoid predators. The size-range of the females most often caught does not vary greatly throughout the year, which indicates a fairly stable population.

The ratio of the sexes in the catches varies considerably from month to month. Females predominate in the December, January, and February catches. This is probably due to the moulting of males which occurs at this time, for, in a soft-shelled condition, crayfish are inactive. Von Bonde and Marchand (1935) found that moulting in males occurs mainly between November and February, and they consider that this is the reason for the high proportion of females at this time. The percentage of females in May is small. Since "berried" females first appear in May and since moulting precedes egg-extrusion by a few days (Von Bonde, 1936), it is considered that these two phenomena are responsible for the low percentage of females in the May catches. In April, so few crayfish may be obtained that fishing is not worth while. This also is probably a consequence of moulting, copulation, and egg-extrusion in females and copulation in males. In June, July, and August, there are approximately equal numbers of males and females caught. In September, the proportion of males increases, probably as a result of an in-shore movement of large males, as suggested above. Another possible contributing factor is an inactive condition of females just before and during the larval release. In October, when larval release is complete in many specimens, females appear in large numbers, and in November, when larval release is complete in almost all of the females and when males are beginning to moult, females are present in even larger numbers. In December, when all females have finished larval release and when many males are moulting, females predominate in the catches.

Although the present legal size-limit of 9 in. in total length appears to have been based on little research, it appears to have been a reasonable choice. Firstly, some females become mature when about 7½ in. in total length, and all are mature when they reach 10 in., so that the present restriction, although not protecting all the immature specimens, does protect most. This will tend to conserve stocks. The amount of usable meat in specimens below the limit is very small compared with the amount in larger specimens. One of the main reasons for this is that leg meat is too difficult to remove from small crayfish and consequently is used by few people. The leg meat of crayfish slightly larger than 9 in. can readily be extracted and comprises one-third of the usable meat. Small crayfish have relatively less tail meat than larger ones. For these two reasons it is wasteful to take crayfish smaller than about 9 in. in total length. It is far more economical to leave them to grow to a size where they will provide a reasonable amount of meat. At the same time this must not be carried to an extreme, for small crayfish make the best use of the available food as far as converting it to meat is concerned. The other important factor to be taken into consideration is the effect that size restrictions have on the fisherman's income. Under the 9 in. limit, the fisherman has to reject 8 per cent. by weight of his catch, which is not a very great hardship. It must be noted, however, that raising the limit another inch would necessitate the rejection of 15 per cent. of the catch.

Tagging operations in South Africa have not pointed to any purposive migration. Considerable movement occurs, but of the haphazard type to be expected from random wandering in search of food. The limited results of the present investigation (nine specimens returned) indicate a similar type of movement, and it is probable that no definite migration occurs. At the same time, the fact that two females, tagged and released on the same date, eluded recapture for a year and then were caught in September within a few days of each other suggests that they moved initially to some area not fished (possibly deep water) and then returned to the fishing area (in-shore) in preparation for the larval release which begins in September. This is, however, based on only two returns, and may not be confirmed by future work.

Some females become mature when 7 cm. in carapace length; others remain immature until 9.7 cm. in carapace length. The smallest mature female reported by Hickman (1945) was 7.2 cm. in carapace length. The agreement of these two sizes is to be expected, since Tasmanian and Wellington waters have similar temperatures. The smallest mature female reported by Von Bonde (1936) was 4.4 cm. in carapace length. This indicates that in South Africa, where the water is warmer, maturity is reached at a smaller size. This agrees with Templeman's finding (1936) that maturity in the North American lobster is attained at a smaller size in warm waters than in cold. The largest females caught appear to be still mature, and there is no evidence of loss of fertility in old females.

No females carrying eggs are found in March, but in May nearly 100 per cent. of the females are "in berry." No fishing is done in April, so that no data for this month are available, but since nearly all the females are "in berry" in May, it is probable that egg-extrusion begins in April. It occurs in Tasmania at the same time. Most of the females release larvae in October, but a few are still found "in berry" in December. All are free of eggs by the end of December. Hickman (1945) found that most of the females became free of eggs by the end of September and that all were free by the end of December, which is in agreement with my results. Larval release may be correlated with the period of increasing water temperature which begins in late August. There is evidence to indicate that large females extrude their eggs before small ones, since they are the first ones found "in berry."

The number of eggs produced increases approximately as the cube of the length. Von Bonde reached this conclusion, but the number of eggs increases more rapidly with length in South Africa than in New Zealand. For the size-range 8.3 cm. to 13.5 cm. carapace length, the number of eggs ranges from 86,000 to 549,000. This is in agreement with Hickman's figures (1945) of 65,170 to 413,220 for the carapace size-range of 7.4 cm. to 12.4 cm., but is considerably different from Von Bondes' results of 3,000 in the smallest to 200,000 in the largest (no sizes given). The conclusions of all three workers are at a variance with Challenger, who states that an average specimen carried 850,000 eggs. This "average" specimen was actually very large (12.7 cm. in carapace length), yet it is 1.2 cm. smaller than the largest examined in this investigation and which carried only 549,000 eggs. It is only 0.3 cm. larger than the largest examined by Hickman and which carried only 413,220. Challenger does not describe his method of counting in any detail, and his figure is much higher than those of other workers, so that the accuracy of his method may be in doubt.

One hundred and sixty-eight crayfish were tagged and released at various points around the coast. Since tags attached to the exoskeleton are lost during moulting, tags which were inserted through the exoskeleton and embedded in the deeper tissues were used; 5.4 per cent. have been returned. Eight of these were tagged with the xylonite tag described in the text, and one of these had passed through a moult. In all those that had been liberated for more than about six weeks, a chitinous pocket had formed around the tag. This appears to protect the surrounding tissues. Accordingly, this type of tag seems to be satisfactory. Only one of the specimens tagged with the wire type of tag has been returned. This had moulted, and the tag was embedded in chitin so that, judging from this single return, this type of tag is also satisfactory. At the same time, it is inferior to the xylonite type because its position on the ventral aspect makes it difficult to see. Von Bonde found that this tag was retained in moulting in aquaria. In both types of tag, the presence of the chitinous sheath indicates that the tag may be cast off with this chitin at a later moult. These tags seem to be efficient, but proof that they are retained for more than a few moults is wanting.

The tagging results have given data on migration, which is discussed above, and on growth rate. A male, 21.5 cm. in total length when released, grew 2.1 cm. in total length in one year. A female, 24.8 cm. in total length when released, grew 1.9 cm. in the same time. Von Bonde has shown that specimens of about this size moult twice a year, so that the average growth per moult for specimens of this size is about 1 cm. in total length. Templeman has found that, in the North American lobster, males and females grow at about the same rate until the female becomes mature, when the rate of growth of females becomes less than males. The female mentioned above was mature, so that it is not surprising to find that it did not grow as much as the male. Young observed that a specimen 4.2 cm. in total length moulted eight times in three years and two months in an aquarium. The size achieved at the end of this time was 14 cm. The average growth a year was about 3 cm. The fact that the yearly growth of this specimen was greater than that of the tagged specimens described above is to be expected, since small animals grow rapidly, but as they grow older the rate of growth decreases.

The amount of usable meat in Wellington crayfish increases from about 47 gm. in the smallest (6.7 cm. carapace length) to 1,449 gm. in the largest (19.6 cm. carapace length). The weight of usable meat per unit carapace length ranges from 6.7 gm. to 74 gm. over the same size-range. Leg meat is so difficult to extract from specimens smaller than about 9 cm. in carapace length that few, if any, people would take the trouble to extract it. In specimens slightly larger than this (9.1 cm. carapace length), 78 gm. can be extracted quite easily, which represents one-third of the total meat available. Accordingly, it is wasteful to take specimens smaller than about 9 cm. carapace length. This is about the same as the legal limit, so that one effect of the size restrictions is to prevent the wastage of potential leg meat.

One half of the crayfish caught are between 9 cm. and 13 cm. in carapace length, and these provide one-half of the usable meat in the catch. This is the most important size-group in an economic fishery, and the fact that specimens in this size-range comprise 50 per cent. of the catch indicates that the fishery is an economic one.

In the event of legal action being taken under the minimum-size regulations on the basis of measurements of a catch after cooking, it could be argued that the crayfish were above the minimum size when caught and had shrunk in cooking. Accordingly, it is of value to know whether any appreciable shrinkage does occur. A slight shrinkage was found, but it is too small to be considered. The total length may either increase slightly or decrease slightly, depending on the state of relaxation at death of the muscles connecting the abdomen with the cephalothorax. The loss of weight is considerable, and increases with size.

Some of the information essential for the proper exploitation of the crayfish population has been presented for the first time. Being based on limited data, it is only a start, and it is hoped that further work will be done in the near future so that the New Zealand crayfish industry may be placed on a sound basis.

AUTOTOMY AND AUTOSPASY

It is well known that autotomy (Fredericq, 1883), autospasy (Pieron, 1907), and autotilly (Wood, 1932) occur widely in Crustacea. Wood (1932) gives the following definitions after the above-mentioned workers: autotomy is the reflex severance of a part from the body by the animal itself; autospasy, the separation of an appendage from the body at a predetermined locus of weakness when pulled by an outside agent; autotilly, the rending of an appendage from the body at a predetermined locus of weakness by the mouth-parts, claws, or other legs of the animal itself.

Wood (1932) discovered that *Palinurus vulgaris* exhibits autotomy in all of the legs, and the antennae exhibit autospasy. *Jasus lalandii*, belonging in the same family (Palinuridae), would be expected to show similar phenomena. That it does so is shown by the following:—

(i) Crayfish are sometimes found with one or more legs missing. These have separated from a constant point which is the suture between the basipodite and ischiopodite. Freshly caught crayfish, struggling on the decks of the fishing boats, often throw off their legs without any traction on their own part or on the part of an outside agent. This is autotomy.

If a crayfish is lifted by a leg, the leg will sometimes be released. This indicates that the legs may exhibit autospasy also.

Some specimens are found with only a part of a leg missing or with some part of a leg crushed. Since such legs are not autotomized, damage to a leg does not invariably lead to autotomy.

(ii) Crayfish are sometimes found with one or both of the antennal flagella missing. In each case, the flagellum has been separated from a constant point near the base. If a crayfish is held by an antennal flagellum, traction is produced by flipping the tail, and the flagellum breaks off from the constant point near the base. Some specimens have been found with only a part of the flagellum missing. In these cases, the flagellum, although damaged, has not been thrown off. These two observations indicate that the antennal flagella are lost by autospasy.

(iii) No autotilly is reported in *Palinurus vulgaris* and no opportunity has presented itself for the study of autotilly in *Jasus lalandii*. It does, however, seem improbable that the mouth-parts are capable of removing legs because the legs and mouth-parts are too far separated and the mouth-parts seem hardly strong enough. It is possible that a leg may be torn off by the action of other legs, especially of the stronger anterior ones, but the absence of any chelation would make such a process rather difficult.

Much work has been carried out and many theories proposed to account for the mechanism of autotomy. This account discusses an aspect which appears to be untouched—namely, the relative tendencies of the various legs to be lost.

The data presented were obtained from a study of 1,937 crayfish caught near Wellington during 1947 and 1948. Of these, 889 were males and 1,048 were females. Only "total" amputations are considered. A "total" amputation is defined as the absence of all that part of a leg which is distal to the autotomy point. The presence of a regenerated leg is not considered as an amputation. Consequently, all of the amputations considered must have been received since the last, or certainly a recent, moult. Amputations received during capture are considered to be "unnatural," and are not included in the data. These are indicated by clean, flesh-coloured scars on the stumps, whereas older (and considered to be "natural") amputations are indicated by dark-coloured scars with thick, chitinous membranes over them.

Inclusion of regenerating legs as representing old amputations led to unreasonable results, such as a difference between opposite sides of the body, which is unacceptable in a bilaterally symmetrical animal. The difficulty of establishing criteria for the difference between a completely or almost completely regenerated leg and a leg which has never been amputated is thought to be the cause of this skewing effect.

Of the 1,937 specimens examined, 191 had one or more legs missing. Of these, 65 were males and 126 females. Since multiple amputations are common, the 191 specimens had a total of 250 legs absent. The males had 91 of these and the females had 159. Table 1 gives the figures.

TABLE 1

Sex	*Number examined*	*Number with amputations*	*Total number of amputations*
Male	889	65	91
Female	1,048	126	159
Both	1,937	191	250

More females than males have amputations (P = probability factor, is less than 0.01)—that is, the tendency to leg amputations is greater in females than in males. The total number of legs missing is greater in females than in males (P less than 0.01)—that is, a female tends to lose more legs than a male.

As is to be expected in a bilaterally symmetrical animal, there is no difference in the frequencies of autotomy on either side of the body in either sex.

Since there is no difference between opposite sides of the body, the frequencies of amputations on both sides have been totalled and the number of positions where amputation can occur is considered to be five. Table 2 gives the frequency of absence of each leg.

TABLE 2

Leg No.	Males	Females
1	18	11
2	17	11
3	19	38
4	13	42
5	24	57

See Fig. 14. The frequencies are plotted as percentages of all the amputations found in that sex. In females, leg five is not lost more often than leg four (P less than 0.2). Leg four is not lost more often than leg three (P less than 0.7), but legs three, four, and five are lost more often than legs one and two (P much less than 0.01). Hence there is a grouping of legs in the female—the last three legs are lost more often than the first two.

In males, all five legs show approximately equal tendencies to loss. Application of the chi-squared test to legs four and five gives a value of P only slightly greater than 0.05. Accordingly, it is possible that leg five is lost more often than the others.

Leg five is lost more often in females than in males (P less than 0.01). Leg four is lost more often in females than in males (P less than 0.01). Leg three is not lost more often in one sex, but, since P is only slightly greater than 0.05, a larger sample might show that this leg is lost more often in females. Leg two is not lost more often in one sex (P is less than 0.2). Leg one is not lost more often in one sex (P is less than 0.2).

Crayfish are sometimes found with more than one leg missing. Table 3 gives the frequencies of specimens which lack the various numbers of legs. The frequencies are expressed as the percentages of all the specimens of that sex which have amputations.

TABLE 3

Number of legs missing	Males %	Females %
1	81.6	79.4
2	4.6	13.5
3	6.2	4.8
4	3.1	0.8
5	1.6	—
6	—	—
7	—	—
8	—	—
9	1.6	—
10	—	—

Of all the males which have amputations, 16.2 per cent. have more than one amputation; 19 per cent. of the females which have amputations have more than one. Absence of more than four legs is uncommon.

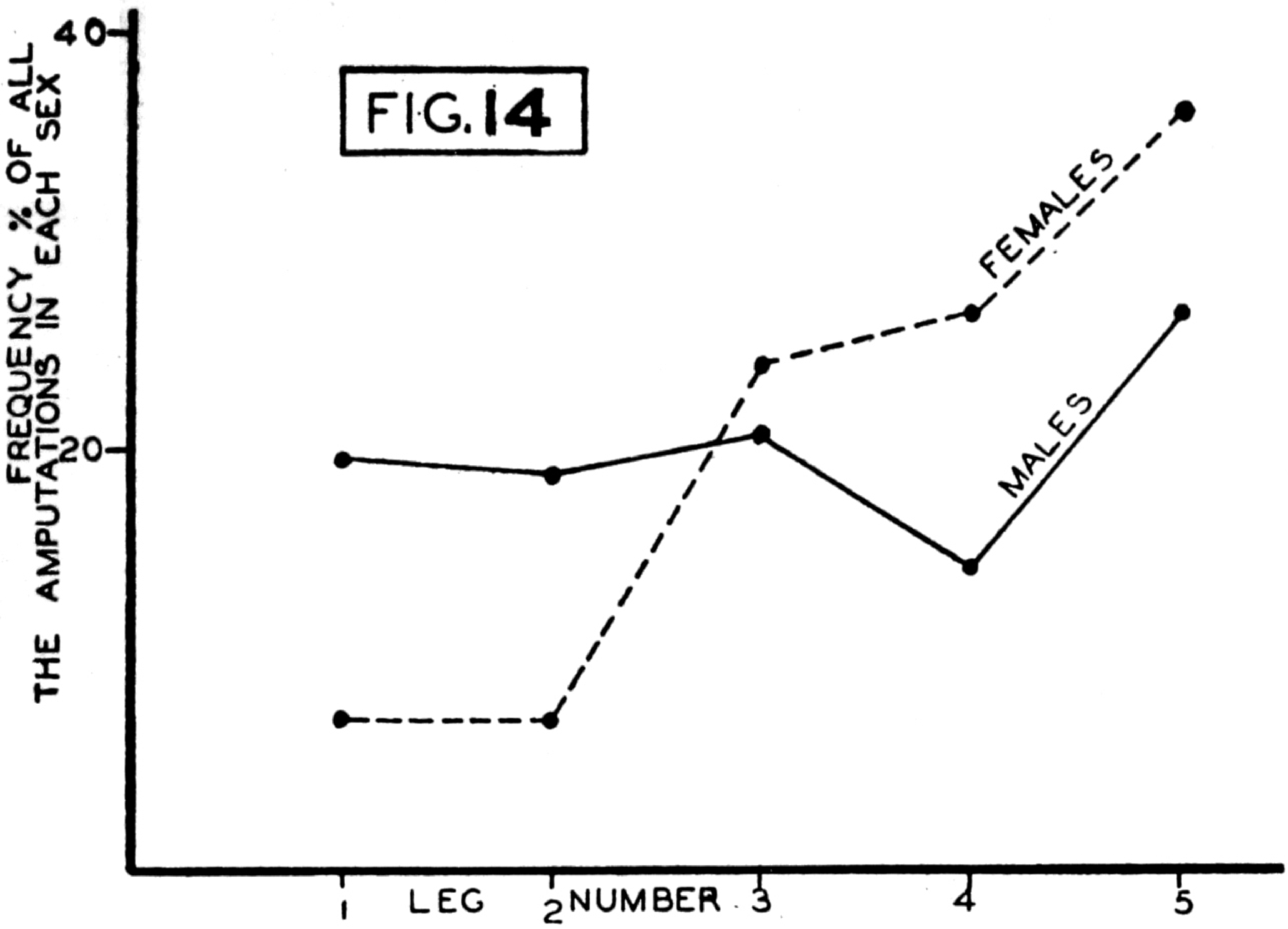


FIG. 14
FREQUENCY % OF ALL THE AMPUTATIONS IN EACH SEX
40
20
FEMALES
MALES
1 LEG 2 NUMBER 3 4 5

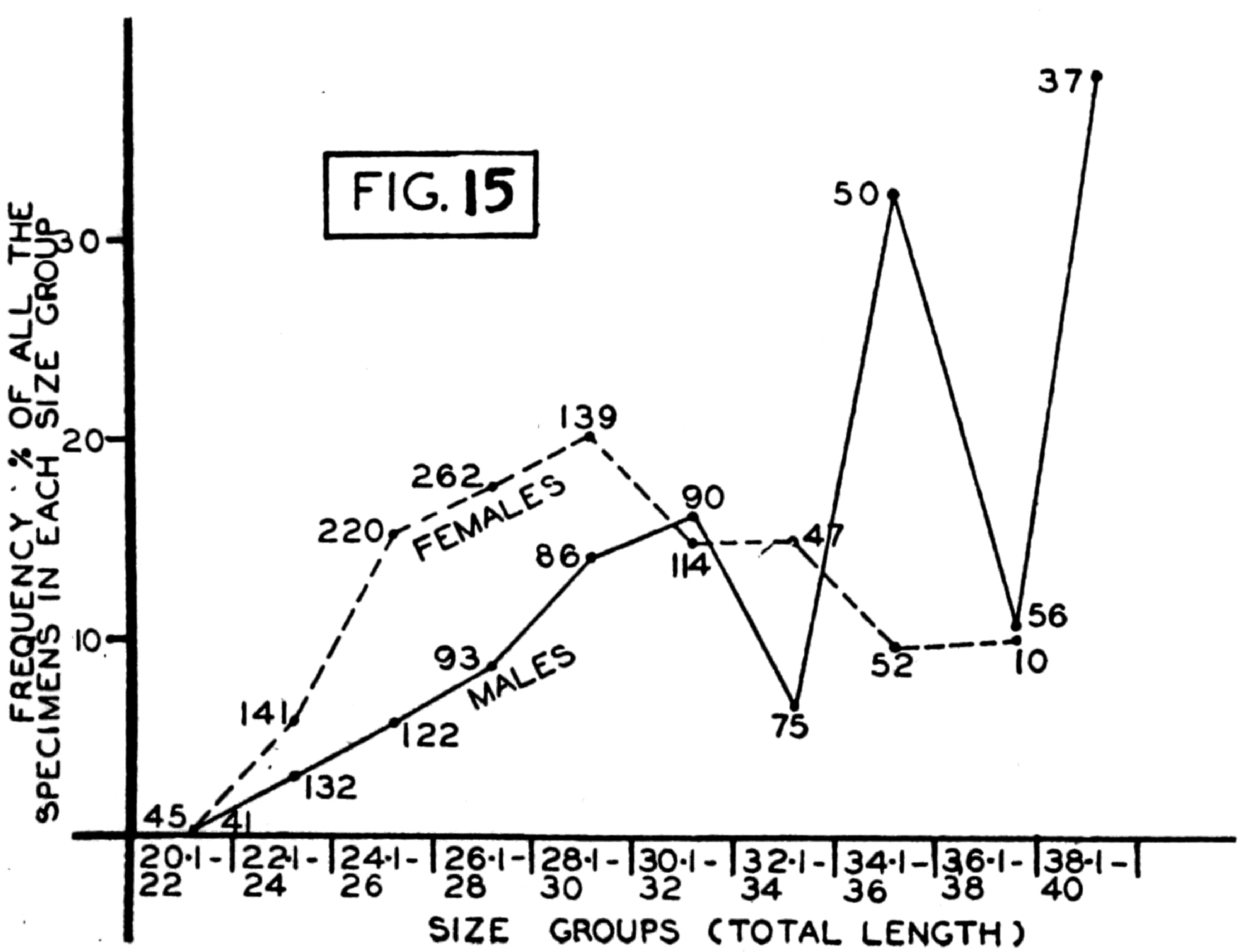


FIG. 15
FREQUENCY % OF ALL THE SPECIMENS IN EACH SIZE GROUP
30
20
10
37
50
139
262
220
FEMALES
90
86
114
47
56
93
MALES
52
10
141
122
75
132
45
41
20·1- 22
22·1- 24
24·1- 26
26·1- 28
28·1- 30
30·1- 32
32·1- 34
34·1- 36
36·1- 38
38·1- 40
SIZE GROUPS (TOTAL LENGTH)

Females in the size-group 28.1 cm. to 30 cm. have the greatest number of amputations. The frequency of amputation falls off to either side of this group (see Fig. 15). The number of amputations in males increases with size. In the graph, each plot is the number of amputations in the size-group as the percentage of all the specimens examined in that size-group. The numbers marked on each plot are the numbers of specimens examined in each size-group.

ANTENNAL AMPUTATIONS

Two crayfish were found with both antennal flagella missing. Eight were found with one flagellum absent and twenty-three with a part only of a flagellum absent. Six specimens were found with a small and apparently regenerated flagellum. The amputation of a part only of a flagellum must be a case where the flagellum, in being broken off at a point distal to the autospasy point, has not been held long enough or strongly enough to cause autospasy. This suggests the existence of a minimum pulling stimulus necessary to cause autospasy.

The third segment of the peduncle and the flagellum of the antenna of one female were absent, while in another female these parts were regenerated. That regeneration of these parts occurs indicates that a point for autotomy or autospasy may exist in the junction of the second and third segments of the antennal peduncle.

A male was found with the second and third segments of the peduncle and the flagellum of one antenna missing, while a female had these parts regenerated. This indicates that a point for autotomy or autospasy may exist in the junction of the first and second segments of the antennal peduncle.

A tagged specimen, released without the flagellum of the left antenna, was found to have this almost completely regenerated after a period of 55 weeks, during which time it would have undergone two moults (Von Bonde and Marchand, 1935, p. 15).

DISCUSSION

The data presented indicate that legs are lost by autotomy, which is regarded as a reflex response to injury. Lifting a crayfish by a leg will sometimes invoke the separation of that leg, so that autospasy may be exhibited also. Several cases of the absence of, or damage to, a part of a leg without its being autotomized indicate that, in *Jasus lalandii*, an injury does not always invoke autotomy. In these cases, sufficient damage must have been sustained to bring about autotomy if it is to occur. The explanation of the failure here may be that there is some fault in the reflex action such as might be expected from general shock, but, whatever the explanation, there must be a means of stopping excessive bleeding. It may be that when an injury is received the blood vessels are closed off at the point of autotomy, even if the leg is not autotomized. If this is so, necrosis would set in and the leg would be thrown off at the next moult.

In females the tendency for a leg to be lost increases from front to rear. This must be an indication of the hazards presented to the various legs during the animal's normal behaviour. The possibilities for loss are: escape from enemies, defence, feeding, or reproduction.

In escaping from an enemy, a crayfish flips its tail and darts rapidly backwards. The legs are directed anteriorly and lie close along the lower edge of the carapace. Each leg overlies, and to some extent protects, the leg in front of it. The fifth leg is the most exposed, to a lesser extent the fourth and third, so that when an enemy attacks, especially from the side, the fifth leg will be in the greatest danger. In defence, the slender nature of the fifth leg compared with the others would mean its more frequent loss. In moving over a bed of shellfish, it is possible that a leg may sometimes be trapped in a closing shell. The fifth, projecting from the body more than the others, would be most frequently lost in this way. Some hazard may be presented in reproduction, either in cleaning the abdomen prior to oviposition or in copulation. Copulation occurs when the females are soft-shelled, a time when legs would be most easily lost. This may help to account for the more frequent loss of legs in females. In cleaning the abdomen for oviposition, the female uses the chelate fifth leg. This represents a significant behaviour difference between the sexes. Since males do not carry out this abdomen-cleaning process, it appears that this behaviour in females may be an important contributing factor to the more frequent loss of the fifth leg in females than in males.

Whenever the legs are in danger, the long, slender nature of the fifth would mean its more frequent loss. Less force would be required to damage this leg. Consequently autotomy would be more readily produced in this leg than in the stouter anterior limbs. The increasing intrinsic strength of the legs from the fifth to the first and the increasing protection from the other legs are probably the greatest contributing factors to the gradient shown in the text.

In the backward escape from enemies, the crayfish cannot see obstacles behind. It must sometimes strike rocks, possibly with sufficient force to damage the fifth leg. The other legs, being cushioned by the fifth and being stronger, would not be damaged as often or as severely. Hence autotomy in these would be less frequent.

All of the above behaviour, except the cleaning of the abdomen for oviposition, would be exhibited by the male as well as by the female. Accordingly, it is difficult to see why the third, fourth, and fifth legs of a male are not lost more often than the others.

The frequency distribution of the number of amputations over the size-range, for females, is a normal curve, whereas, for males, it increases with size. No explanation can be suggested for this.

One or both antennal flagella are sometimes lost in nature and can be regenerated. A tagged specimen, released with a flagellum freshly broken off from the autospasy point, had almost completely regenerated the flagellum after one year, during which time it is considered to have undergone two moults.

LITERATURE CITED

ARCHEY, G., 1916.—*Notes on the Marine Crayfish of New Zealand*. Trans.N.Z. Inst., 48, 396–406.

BRADSTOCK, C. A., 1948.—*An Apparatus for Counting Large Numbers of Small Eggs*. N.Z. Science Review, July, 1948.

CHALLENGER, T., 1943.—*The Story of the Crayfish*. Tasmanian Jour. of Agriculture, 14 (2), 51–55.

DWYER, J. N., 1932.—*Hydrographic Water-bottle for Fisheries Survey*. Trans. American Fisheries Society, 62, 342–343.

ELMHIRST, R., 1930.—*An Interim Report of the Interdepartmental Committee on Crabs and Lobsters*; pp. 1–12. (London: H.M. Stationery Office.)

FREDERICQ, L., 1883.—*Sur l'autotomie, ou mutilation par voie reflexe comme moyen de defense chez les animaux*. Arch.Zool.exp.gen. (2), T.1, 413–426.

GILCHRIST, J. D., 1913.—(a) *The Cape Crawfish and Crawfish Industry*. Union of South Africa, Province of Cape of Good Hope, Marine Biological Report, No. 1.

————, 1913.—(b) *A Free-swimming Nauplioid Stage in* Palinurus. Jour.Linn. Soc.Zool., 32, 225–231.

————, 1914.—*The Cape Crawfish and Crawfish Industry* (continued). Union of South Africa, Province of Cape of Good Hope, Marine Biological Report, No. 2.

————, 1916.—(a) *Observations on Some South African Marine Invertebrates*. Union of South Africa, Province of Cape of Good Hope, Marine Biological Report, 1916, p. 39.

————, 1916.—(b) *Observations on South African Marine Invertebrates*. Union of South Africa, Province of Cape of Good Hope, Marine Biological Report, No. 3.

————, 1916.—(c) *Larval and Post-larval Stages of* Jasus lalandii. Jour.Linn. Soc.Zool., 33, 101–125.

————, 1918.—(a) *Crawfish Investigations, Including Experimental Hauls, Artificial Rearing, and Migratory Movements of the Cape Crawfish* (Jasus lalandii). Union of South Africa, Marine Biological Report, No. 4, 1–43.

————, 1918.—(b) *The Cape Lobster and the Cape Crawfish or Spiny Lobster*. Union of South Africa, Marine Biological Report, No. 4.

————, 1920.—*A Post-puerulus Stage of* Jasus lalandii. Journ.Linn.Soc.Zool., 34, 189–200.

GILCHRIST, J. D., and VON BONDE, C., 1922.—*Practical Zoology for Medical and Junior Students*. Edinburgh: E. & S. Livingstone.

[redacted] F. H., 1895.—*The American Lobster: A Study of its Habits and Development.* Bull. U.S. Fisheries Commission, 15, 1–252.

———, 1909.—*The Natural History of the American Lobster.* Bull. Bureau of Fisheries, 24, Document 747.

Hickman, V. V., 1945.—*Notes on the Tasmanian Marine Crayfish* Jasus lalandii (Milne-Edwards). Papers and Proc.Roy.Soc. Tasmania, 1945, 27–38.

Lateste, F., 1896.—*Fécondité de la famelle du Homard Americain en Fonction de sa Taille.* Actes de la Société des Science du Chile, t.6, 106–109. Santiago.

Parker, T. J., 1884.—*On the Structure of the Head in* Palinurus, *with Especial Reference to the Classification of the Genus.* Trans.N.Z. Inst., 16, 297–307.

Pieron, H., 1907.—*Autotomie et "Autospasie."* Compt.rend.Soc.Biol., T.63, 425–427.

Sheard, K., 1947.—*Notes on the Marine Crayfishes (Spiny Lobsters), Family Palinuridae of Western Australia.* MS.

Templeman, W., 1935.—*Local Differences in the Body Proportions of the Lobster* (Homarus americanus). Journ.Biol.Bd. Canada, 1 (3), 213–226.

———, 1936.—*Local Differences in the Life-history of the Lobster* (Homarus americanus) *on the Coast of the Maritime Provinces of Canada.* Journ.Biol.Bd. Canada, 2 (1), 41–87.

———, 1944.—*Abdominal Width and Sexual Maturity of Female Lobsters on Canadian Atlantic Coast.* Journ.Fish. Research Bd. Canada, 6 (3), 281–290.

Von Bonde, C., 1928.—*Preliminary Report on a Method of Tagging Crustacea, with Special Reference to the Problem of the Migration of Cape Crawfish* (Jasus lalandii). Union of South Africa Fish. and Marine Biol. Survey, Report No. 6, Special Report No. 3, 1–4.

———, 1936.—*The Reproduction, Embryology, and Metamorphosis of the Cape Crawfish* (Jasus lalandii) (Milne-Edwards). Ortmann. Union of South Africa, Fisheries and Marine Biol. Survey Division, Investigational Report, No. 6, 1–25.

Von Bonde, C., and Marchand, J. M., 1935.—(a) *Natural History and Utilization of the Cape Crawfish, Kreef or Spiny Lobster,* Jasus (Palinurus) lalandii (Milne-Edwards) Ortmann. Union of South Africa, Dept. of Commerce and Indust., Fish. and Marine Biol. Survey Division, Fishery Bulletin, No. 1, 1–54.

———, 1935.—(b) *Studies in the Canning of the Cape Crawfish, Kreef or Spiny Lobster,* Jasus lalandii. Union of South Africa, Dept. of Commerce and Indust., Fish. and Marine Biol. Survey Division, Investigational Report, No. 5.

VON BONDE, W., 1930.—*Post-brephalus Development of Some South African Macrura.* Union of South Africa, Fish. and Marine Biol. Survey Report, No. 8 (1).

WOOD, F. D., and WOOD, H. E., 1932.—*Autotomy in Decapod Crustacea.* Jour. Exp.Zool., 62 (1), 1–55.

YOUNG, M. W., 1926.—*Marine Biological Notes, No. 2.* New Zealand Journ. Science and Technology, 8 (5), 282–286.