1957S—SMART—CRAYFISH LIFE HISTORY

A CONTRIBUTION TOWARD A KNOWLEDGE OF THE

LIFE HISTORY OF THE CRAYFISH *CAMBARUS LONGULUS LONGULUS*

GIRARD

BY

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[illegible]

[illegible]

A Thesis Presented to the
Graduate Faculty of
the University of Virginia
in Candidacy for the
Degree of
Master of Arts

[illegible]

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ACKNOWLEDGMENTS

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The author is also grateful to the Virginia Academy of Science for a grant which financed the collecting trips.

His thanks are extended to the Department of Statistics of The Virginia Polytechnic Institute, Blacksburg, Va., and especially to Dr. Clyde Y. Kramer of that department for his most able and willing assistance with the statistical data contained in this work.

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INTRODUCTION

Of the six genera of crayfishes which occur in North America, detailed life history studies of only four members of three of them have been made. Although crayfishes of the genus Cambarus are relatively wide spread, only fragmentary data relative to their life histories are available.

The present study of Cambarus longulus longulus Girard, has been undertaken in order to determine to what extent the life history of this member of the genus Cambarus is similar to those of the members of other genera of the Subfamily Cambarinae. The need for such a study was realized at an earlier time by Dr. Horton H. Hobbs, Jr. of the University of Virginia. When he discovered on a collecting trip in 1946 that C. l. longulus could be obtained in large numbers from Swift Run, which is near the University of Virginia, he immediately contemplated doing a life history study but was unable to do so until 1950. In April 1950 he began a series of bimonthly collections which lasted until September 1951 at which time the project was interrupted. No further work was done until September 1956 when the present investigator resumed the study. Collections were made from the same stream from September 1956 until July 2, 1957. Data from the collections by the author and those recorded by Dr. Hobbs have been combined in the analysis of the life history of this crayfish.

Summary of Previous Work

The life histories of three species of the genus Orconectes have been studied in detail: O. propinquus propinquus (Girard) by Creaser (1933a) in Michigan, by van Deventer (1937) and by Bovbjerg (1952) in Illinois;

O. *immunis* (Hagen) by Tack (1941) in New York; and O. *clypeatus* (Hay) by Smith (1953) in Louisiana. The life history of *Procambarus clarkii* (Girard) has been studied by Penn (1943) in Louisiana.

For P. *clarkii* in Louisiana, Penn found that in the majority of the population mating occurs during July, August, September, and October, and that eggs are laid in August, September, and October. The eggs hatch from late August through November, and during the period from early May to late July of the following year, the young males of this group reach sexual maturity, molting to form I. This group of males, after spawning, migrate *en masse* from the swamps and marshes and die either as prey or from "old age." Thus the majority of the males have a life span of only one year. Those males which do not reach sexual maturity at the end of one year over-winter a second time and live for two years spawning, however, only once.

The females follow the same pattern as the males; they hatch in the fall and become sexually mature in the following year from early May to late July. Several females join in the "death-migration" with the males at the end of the first spawning season, but a number of them over-winter. Those that survive the winter undergo a spring molt which seems to reinvigorate them, and they spawn a second time.

Van Deventer found O. p. *propinquus* copulating or in copulatory attitudes in September, October, November, and March. Van Deventer and Bovbjerg noted that laying occurs from early April to early May with young appearing as "free swimmers" from the last of May to the first of June. This group of juveniles becomes sexually mature in August and September after which mating occurs. The males remain in the first form throughout the winter; then from April to May these form I males molt to form II,

and shortly thereafter, molt again to form I. After this second adult molt all these males die. The life span is thus only 12 to 14 months. A few of the males which did not reach sexual maturity the first fall after hatching, do not do so until the second fall when they breed, over-winter a second time, undergo two successive molts in the spring, and die at an age of two years.

The juvenile females become sexually mature in August and September at the same time as the males. They participate in the fall breeding season and lay their eggs from April to May. Soon after the young become independent, approximately June, these females molt and die at an age of about 14 months. If the animals did not reach sexual maturity by the first fall after hatching, they do not produce a brood until their second spring after which they molt and then die as two year olds. A few of these females live for a third year, but it is not certain that more than a single brood is produced by any one individual.

For juvenile and mature crayfish of both sexes no growth occurs from October until April. Then growth is resumed with the immature yearling group (those failing to reach sexual maturity by their first fall) molting twice concurrently with the adult males from April to June, and two subsequent molts probably occur during the summer. At the second spring molt the immature yearlings attain sexual maturity.

Tack found that O. immunis mate from the middle of June to the middle of October with oviposition occuring from late October to early November. These eggs are retained by the females over winter and hatch about the middle of May. Growth for the males occurs until the first of September.

and shortly thereafter, molt again to form 5. After this second adult molt all these males die. The life span is thus only 17 or 18 months. A few of the males which did not reach sexual maturity the first fall after hatching, do not do so until the second fall when they breed, over-winter a second time, undergo two successive molts in the spring, and die at an age of two years.

The juvenile females become sexually mature in August and September at the same time as the males. They participate in the fall breeding season and lay their eggs from April to May. Soon after the young become independent, approximately [illegible], these females molt and die at an age of about 14 months. If the animals do not reach sexual maturity by the first fall after hatching, they do not produce a brood until their second spring after which they molt and then die as two year olds. A few of these females live for several years but it is not certain that more than a single brood is produced by any one individual.

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It then ceases until April at which time they molt, and at the next molt in July they attain the first form when they enter their first breeding season. Following the breeding season the majority of these males die, but a few live through the winter and in April molt to the second form. It is not known whether any of these males live to breed for a second time.

The females hatch along with the males in mid-May and grow until September. In April growth resumes with the immature female molt. These animals become sexually mature in the late summer or fall and participate in the breeding season. Their young become independent in May and by late May the former molt then die at an age of approximately two years. A few females live for three years producing young a second time.

In her study of O. clypeatus, Smith showed that females lay their eggs from September through December. The young hatch and appear in the population from October through January. In the following September most of these juveniles reach sexual maturity and participate in the September-December spawning. The majority of the males die after the first mating season at an age of one year, and most of the females die after their spring molt at one and a half years of age. A few males and females live to be about two years old, but none spawn more than once.

Except for the contributions of Bovbjerg (1952), only scattered notes on the life histories of the genus Cambarus are available. Bovbjerg gives a brief outline of the life history of Cambarus fodiens, but does not present any details. His main contribution is the correlation of the burrowing habit of C. fodiens with the winter freeze and the summer drying in them season until April at which time they molt, and at the next molt in July they attain the first form when they enter their first breeding season. Following the breeding season the majority of these males die, but a few live through the winter and in April molt to the second form. It is not known whether any of these males live to breed for a second time.

The females molt along with the males in mid-May and grow until September. In April growth resumes with the immature female molt. These animals become sexually mature in the late summer or fall and participate in the breeding season. Their young become independent in May and by late May the females then die at an age of approximately two years. A few females live for three years producing young a second time.

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Except for the contributions of Bovbjerg (1952), only scattered notes on the life histories of the genus Cambarus are available. Bovbjerg gives a brief outline of the life history of Cambarus fodiens, but does not present any details. His main contribution is the correlation of the burrowing habit of C. fodiens with the winter freeze and the summer drying of the pond under study. He also noted that ovigerous females and some young appear in March, and that there is a high adult mortality throughout the spring.

The Study Area

The life history of C. l. longulus was studied from September 1956 through July 1957 from collections by the author. Much data was furnished for 1950-51, and for scattered months of 1946, 1947, and 1949 by Dr. Horton H. Hobbs, Jr. All collections were made from a stream in Greene County, Virginia, located near U. S. Highway 33 about six miles west of Stanardsville, Virginia. The stream, a tributary of the James River, originates in the Blue Ridge Mountains near Swift Run Gap and is known as Swift Run. It averages about five feet across varying from approximately three to ten feet. The average depth is about a foot with pools up to three feet deep, and shallow areas only a few inches. The bottom of the stream is sandy with some silt and littered with rocks of various sizes. The rocks form riffle areas which alternate with quiet pools. The usual flow of the stream is about 1.5 ft./sec.

Along parts of the shore there are dense growths of Alnus rugosa and Vitis sp. Other plants found are Liriodendron tulipifera, Robinia pseudoacacia, Platanus occidentalis, Pinus virginiana, Juglans nigra, and Acer rubrum. Along much of the stream the shores have been cleared for pasturage, and cattle are permitted free access to the water at all times. In most of the area from which collections were made very little shade is afforded by the shore vegetation, and there is little vegetation hanging into the waters.

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Along banks of the stream there are dense growths of Typha latifolia and Salix sp. Other plants found are Liriodendron tulipifera, Robinia pseudo-acacia, Platanus occidentalis, Pinus virginiana, Juglans nigra, and Acer rubrum. Along much of the stream the shores have been cleared for pasturage, and cattle are permitted free access to the water at all times. In most of the area from which collections were made very little shade is afforded by the shore vegetation, and there is little vegetation hanging into the water.

Methods of Study

Collections were made periodically with an eighth inch mesh minnow seine, a dip net, and a square-foot bottom sampler. For most of the year the seine was found adequate for a uniform sampling of all groups in the population, but during the months when smaller animals were present, the dip net and square-foot bottom sampler were used in addition to the seine in order to sample more adequately.

All collections were taken to the laboratory and the following data were recorded for each individual; weight, lengths of cephalothorax, areola, and chela, and length and width of the palm of the chela. In addition, ovarian studies were made of a representative portion of the females. Other data such as recent molts and the presence of cement glands were noted. After all data had been recorded, the remaining animals were returned to the stream except for the last collections (July, 1957) which was preserved in 70% alcohol.

The crayfish collected in November and December of 1956 were marked by cutting a deep "V" notch in the lateral ramus of the left uropod and then returned to a particular place in the stream. This was done in order to determine whether or not molting occurs during the winter months and to what extent the animals remain in a restricted portion of the stream.

In order to determine if a correlation exists between the length of the carapace and the weight of the animal, and between certain other anatomical features, a regression line was calculated for each set of characters.

Distribution of the Subspecies

The range of *Cambarus longulus longulus* extends from the southern headwaters of the Rappahanock River in Greene County, Virginia, southward

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The range of *Cambarus longulus longulus* extends from the southern headwaters of the Rappahannock River in Greene County, Virginia, southward to the upper Yadkin River in North Carolina. Within these limits it lies between the Allegheny Mountains and the middle piedmont province.

Habitat

Cambarus l. longulus is found only in flowing water, and usually only in rather swift portions of the stream. In Swift Run this subspecies is found almost entirely in the riffle areas or immediately above and below them in the shallower swift waters under or among the rocks. Only occasionally are the adults found in the deeper pools or the slow moving waters close to the shore. Although adults for the most part stay in the swifter waters, the young inhabit the quieter waters of the shore.

Also occuring in Swift Run is *Cambarus bartonii bartonii* (Fabricius) and *Cambarus montanus acuminatus* Faxon. These animals are found mainly along the quiet shallow shores and in the pools.

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Also occurring in Swift Run is Cambarus bartonii bartonii (Fabricius) and Cambarus [illegible] Faxon. These animals are found mainly along the quiet shallow shores and in the pools.

THE LIFE CYCLE

Period of Ovulation and Embryonic Development

In Swift Run the females lay their eggs from late April to the middle of July. Females with eggs were found in the April 24, April 29, May 4, May 10, and May 29 collections of 1957, and in the June 22, July 2, and July 19 collections of 1950. Parish (1948) found ovigerous females in April, May, and July of 1948 in Virginia but does not specify the localities. Five females with eggs were observed in Maple Creek at Steele's Tavern, Virginia, on March 24, 1950. This locality, however, is at a lower altitude than Swift Run.

From the available data it is impossible to determine with certainty the length of the egg carrying period and the length of dependency of the young. Considering the 1957 data alone, it was noted that the first females found with eggs was on April 24, and the last was on May 29. Also, in the May 10 collection the only females of mature size collected were carrying eggs. Then on May 29, several mature sized females not carrying eggs were collected all of which showed definite signs of having recently molted, and no cement glands were visible. Upon dissection, the ovaries were found to be small and contained small white eggs. From this information, a period of at least thirty-five to forty days would have been required for the eggs to have been laid and hatched, the young to have become independent, and the mothers to have molted. It may be postulated that allowing two weeks for the young to become independent and another for the mothers to molt, the period of development of the embryos would be approximately three weeks.

THE LIFE CYCLE

Period of Ovulation and Embryonic Development

In Smith Run the females lay their eggs from late April to the middle of July. Females with eggs were found in the April 24, April 29, May 4, May 10, and May 25 collections of 1951, and in the June 22, July 7, and July 20 collections of 1950. Jordan (1940) found ovigerous females in April, May, and July of 1938 in Virginia but does not specify the localities. Five females with eggs were observed in [illegible] Creek at [illegible] Tavern, Virginia, on March 25, 1950. This locality, however, is at a lower altitude than Smith Run.

From the available data it is impossible to determine with certainty the length of the egg carrying period and the length of dependency of the young. Considering the 1951 data alone, it was noted that the first females found with eggs was on April 24, and the last was on May 25. Also, in the May 10 collection the only females of mature size collected were carrying eggs. Then on May 25 several mature sized females not carrying eggs were collected all of which showed definite signs of having recently molted, and no cement glands were visible. Upon dissection, the ovaries were found to be small and contained small white eggs. From this information, a period of at least thirty-five to forty days would have been required for the eggs to have been laid and hatched, the young to have become independent, and the mothers to have molted. It may be postulated that allowing two weeks for the young to become independent and another for the mothers to molt, the period of development of the embryos would be approximately three weeks.

Males

The young hatch from April through July and according to Osborne (1951) newly hatched crayfish are between 2.5 and 3.2 mm. carapace length. They are attached to the pleopods of the mother by the "telson thread" as explained for Orconectes limosus (= Cambarus affinis) by Andrews (1895). Soon after hatching they molt, and attain a carapace length of 3.5 to 4.2 mm. and remain with the mother (Osborne, loc. cit.). At the second molt, after which they become independent, their carapace length is 5.0 to 5.9 mm. (ibid.). These young should first appear in the population in May but no specimens of this size have been observed in May or June, but were observed, for the first time, in the July collections and are found also in the August, September, October, and November collections. This is believed to be a result of inadequate sampling rather than their absence from the population since newly-molted mature females are found in May. Their young, assuming that they produced a brood, obviously have become independent before this molt.

The young undergo an undetermined number of molts (estimated by Osborne (1951) to be six to eight) and by mid-July have a carapace length of 10 to 15 mm. (Figures 1 and 3). They remain this length until September at which time they attain a length of 13 to 17 mm. No more growth occurs through the winter. In late April or May an apparent single molt results in a carapace length of 16 to 19 mm. In August or September an additional molt occurs whereupon the carapace length reaches 18 to 21 mm. and the animals become sexually mature, changing from the second form to the first form. Thus sexual maturity is reached when the males are 16 to 17 months of age. With this "maturity" molt, growth ceases until the

Males

The young hatch from April through July and according to Osborne (1951) newly hatched crayfish are between 1.[illegible] and 3.[illegible] mm. carapace length. They are attached to the pleopods of the mother by the fashion [illegible] as explained for Cambarus affinis (= Orconectes limosus) by Andrews (1895). Soon after hatching they molt, after which carapace length of 3.5 to 4.[illegible] mm. and remain [illegible] (Osborne, loc. cit.). At the second molt, after which they become independent, their carapace length is 5.0 to 5.[illegible] mm. (Table 1). When young crayfish first appear in the population in May but no specimens of this size have been collected in May or June, [illegible] were observed, [illegible] the first time, in the July collections and are found also in the August, September, October, and November collections. This is believed to be a result of the [illegible] sampling rather than their absence from the population since newly-molted [illegible] females are found in May. Their young, assuming that they produced a brood, certainly have become independent before this date.

The young males [illegible] (confirmed by Osborne (1951) [illegible] and [illegible]) have a carapace length of 10 to 15 mm. (Figures 1 and 2). They [illegible] this length until September at which time they attain a length of 13 to 17 mm. No more growth occurs through the winter. In late April or May a [illegible] molt results in a carapace length of 15 to 18 mm. In August or September an additional molt occurs [illegible] with carapace lengths between 18 to 22 mm. and the animals become sexually mature, changing from the second form to the first form. This sexual maturity is reached when the males are 15 to 17 months of age. After this [illegible] molt, growth ceases until the following June or early July. At this time the form I males molt to form II with a carapace length of 19 to 22 mm. In late August or early September these second form males molt back to form I in preparation for their second breeding season. At this molt they attain a carapace length of about 22 to 25 mm., some perhaps reaching a length up to 28.2 mm. which is the maximum length recorded for the subspecies at this locality. After their second breeding season most of the males die during the late spring or early summer of their 25th to 28th month. It is possible that some few undergo an additional early summer and late summer molt and participate in a third breeding season. There is, however, little evidence to support this possibility; on the contrary, there is good evidence that only two breeding seasons exist for any one individual as discussed under "Testicular Development."

It is believed that this group of large crayfish (25 to 28.2 mm. carapace length) represent that segment of the young which were hatched late in the summer and hence did not attain a carapace length of 13 to 17 mm. by September. The majority of these animals probably form the upper parts of the 10 to 15 mm. group of the following July and the 13 to 17 mm. group of September and do not reach sexual maturity at the end of their second fall but in the next fall at 24 to 26 months of age. These males would be expected to be in the upper part of the 19 to 22 mm. group at that time. The spring molt would increase their length to 22 to 25 mm., and at the fall molt they should be in the 25 to 28.2 mm. group hence accounting for these larger specimens which occur sparingly in the population. Some of the group that hatched in the late summer probably become sexually mature at the end of their second fall at an age of 14 months.

following made in early July, but this time the form I [illegible] made to form II with a [illegible] length of 13 to 17 cm. In late August or early autumn [illegible] these second form [illegible] [illegible] the form I in [illegible] [illegible] for their second breeding season. At that time they attain a [illegible] length of about 22 to 25 cm., with [illegible] [illegible] length to be [illegible] cm. which is the maximum length recorded for [illegible] at this locality. After their second breeding [illegible] [illegible] the [illegible] die during the late spring or early summer of their fifth [illegible]. It is possible that some few continue to [illegible] [illegible] [illegible] and [illegible] in a third breeding season. There is, however, little evidence to support this possibility [illegible] [illegible] [illegible] that only the breeding [illegible] [illegible] [illegible] [illegible] individual [illegible] [illegible] under [illegible] development.

It is believed that both groups of [illegible] measuring [illegible] to [illegible] cm. [illegible] lengths [illegible] the [illegible] of the group which were hatched late in the [illegible] [illegible] [illegible] [illegible] lengths of 13 to 17 cm. in September. The majority of these animals probably form the upper part of the 13 to 15 cm. group at the following July and the 15 to 17 cm. group of [illegible] and do not [illegible] maturity at the end of their second fall [illegible] in the same fall as [illegible] [illegible] [illegible]. These [illegible] would be expected to be [illegible] [illegible] of the 15 to 17 cm. group at that time. [illegible] [illegible] [illegible] [illegible] length [illegible] to 22 to 25 cm., and at the fall [illegible] [illegible] [illegible] the 25 to 28 [illegible] group [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] probably become sexually mature at the end of their [illegible] [illegible] at an age of 15 months.

This assumption would account for the small (16.8 to 19 mm. carapace length) first form males that are found in September and May.

It is seen that the majority of the males live for 36 to 37 months and probably breed twice (once during their second year and again in their third), and die the following spring. The larger first form males that appear in the population in September were probably hatched late in the summer. They reach sexual maturity at the end of their second year, breed then, and again at the end of their third year, and die the following spring at an age of three and one-half years.

Females

With few exceptions the life cycle of the female is similar to that of the male. The females, along with the males, are hatched from late April to mid-July. In July the major group has attained a carapace length of 10 to 15 mm. (Figure 2), and by September this length has increased to 12 to 16 mm. No growth occurs during the winter. In May the females molt, attaining a carapace length of 15 to 19 mm., and in July and August another molt increases the length to 18 to 22 mm., at which time sexual maturity is reached (16 to 17 months). This length is maintained through the winter and until after their first brood of young have become independent in the spring. At the spring molt the length increases to 21 to 25 mm. No other molts occur during the summer or fall. The females breed again, produce their second brood the following spring, and may or may not undergo the spring molt before the majority die at an approximate age of three years. The young that were hatched in late summer do not appear to reach sexual maturity until their third fall at an age of about 26 months. At

This assumption would account for the small (12.5 to 15 mm. carapace length) first form males that are found in September and May.

It is seen that the majority of the males live for 36 to 37 months and probably breed twice (once during their second year and again in their third), and die the following spring. The larger first form males that appear in the population in September were probably hatched late in the summer. They reach sexual maturity at the end of their second year, breed then, and again at the end of their third year, and die the following spring at an age of three and one-half years.

Females

With few exceptions the life cycle of the female is similar to that of the male. The females, along with the males, are hatched from late April to mid-July. In July the major group has attained a carapace length of 10 to 15 mm. (Figure 9), and by September this length has increased to 12 to 18 mm. No growth occurs during the winter. In May the females molt, attaining a carapace length of 15 to 18 mm., and in July and August another molt increases the length to 18 to 22 mm., at which time sexual maturity is reached (15 to 17 months). This length is maintained through the winter and until after their first brood of young have become independent in the spring. At the spring molt the length increases to 21 to 25 mm. No other molts occur during the summer or fall. The females breed again, produce their second brood the following spring, and may or may not undergo the spring molt before the majority die at an approximate age of three years. The young that were hatched in late summer do not appear to reach sexual maturity until their third fall at an age of about 28 months. At this time they should occur in the upper segment of the 18 to 22 mm. group. At this carapace length they produce their second brood and at the spring molt should attain a carapace length of 25 to 28 mm. and die by September. Only a few females with a carapace length above 26 mm. have been found and these in June and August. This could account for the large size of a few females without assuming a third breeding season for some of them although this possibility should not be excluded.

Of the one hundred and three crayfish which were marked and returned to the stream in November and December, one was recovered in January and seven in March, a total return of 7.8%. None of these animals had molted during this period of time, and all were caught from the same area in which they had been released. Since, however, the returns were so small, one could not predict the extent to which an animal moves from one place to another in the stream. From this evidence of lack of molts in winter, and from the fact that the distribution of size groups in the population appear to be the same in March as in the preceding October (Figures 1, 2, and 3), it is strongly believed that no molting for any group occurs during the winter months.

Figure 1. The monthly size distribution of male *Cambarus longulus longulus* utilized in this study.

Circles represent the specimens collected in 1950.

Triangles represent the specimens collected in 1951.

Squares represent the specimens collected in 1956-57.

Solid figures represent second form males.

Open figures represent first form males.

The radii represent the length of the carapace in mm.

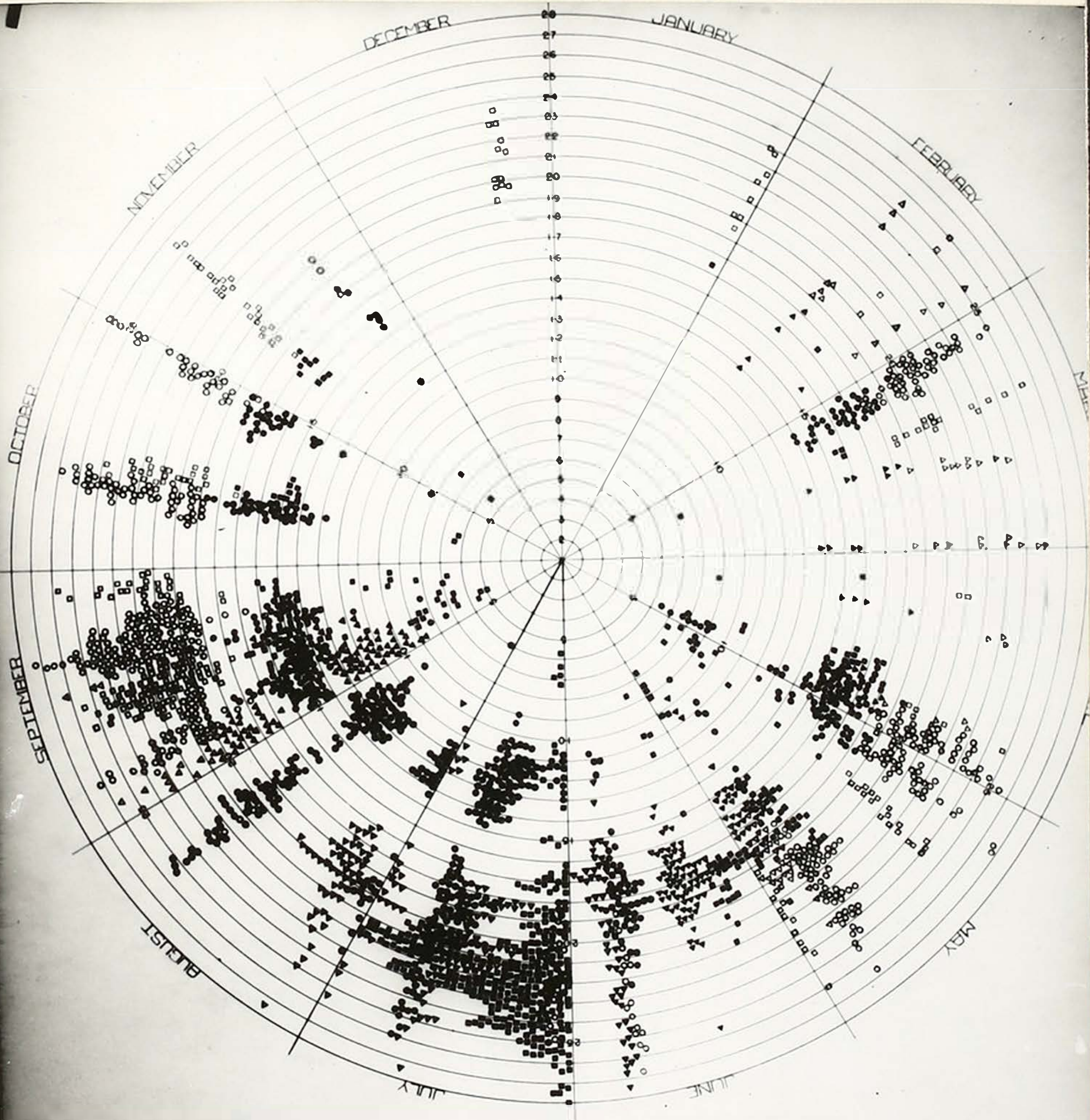

JANUARY
FEBRUARY
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE 1

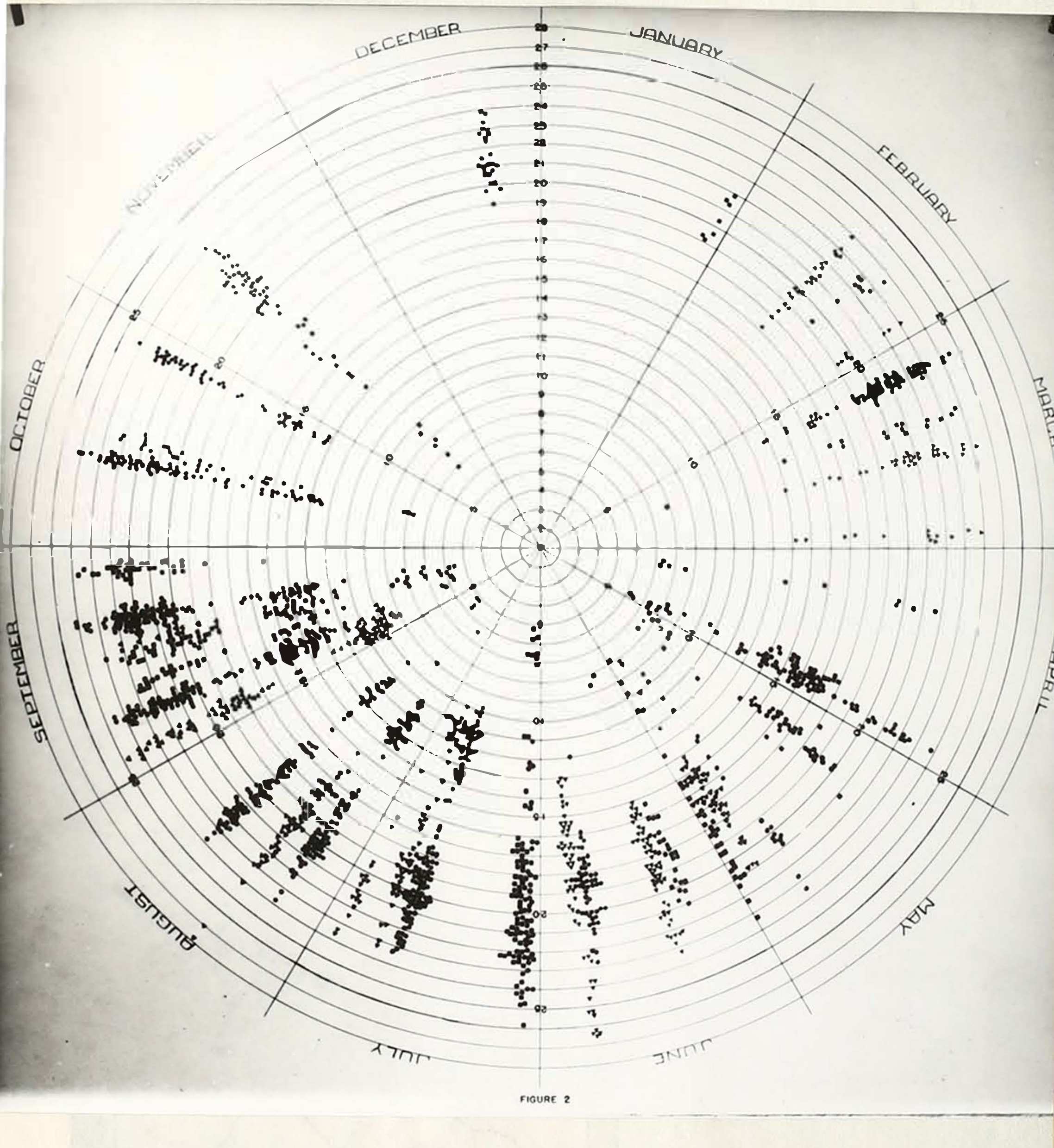
Figure 2. The monthly size distribution of female *Cambarus longulus longulus* utilized in this study.

Circles represent the specimens collected in 1950.

Triangles represent the specimens in 1951.

Squares represent the specimens collected in 1956-57.

The radii represent the length of the carapace in mm.



JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

FIGURE 2

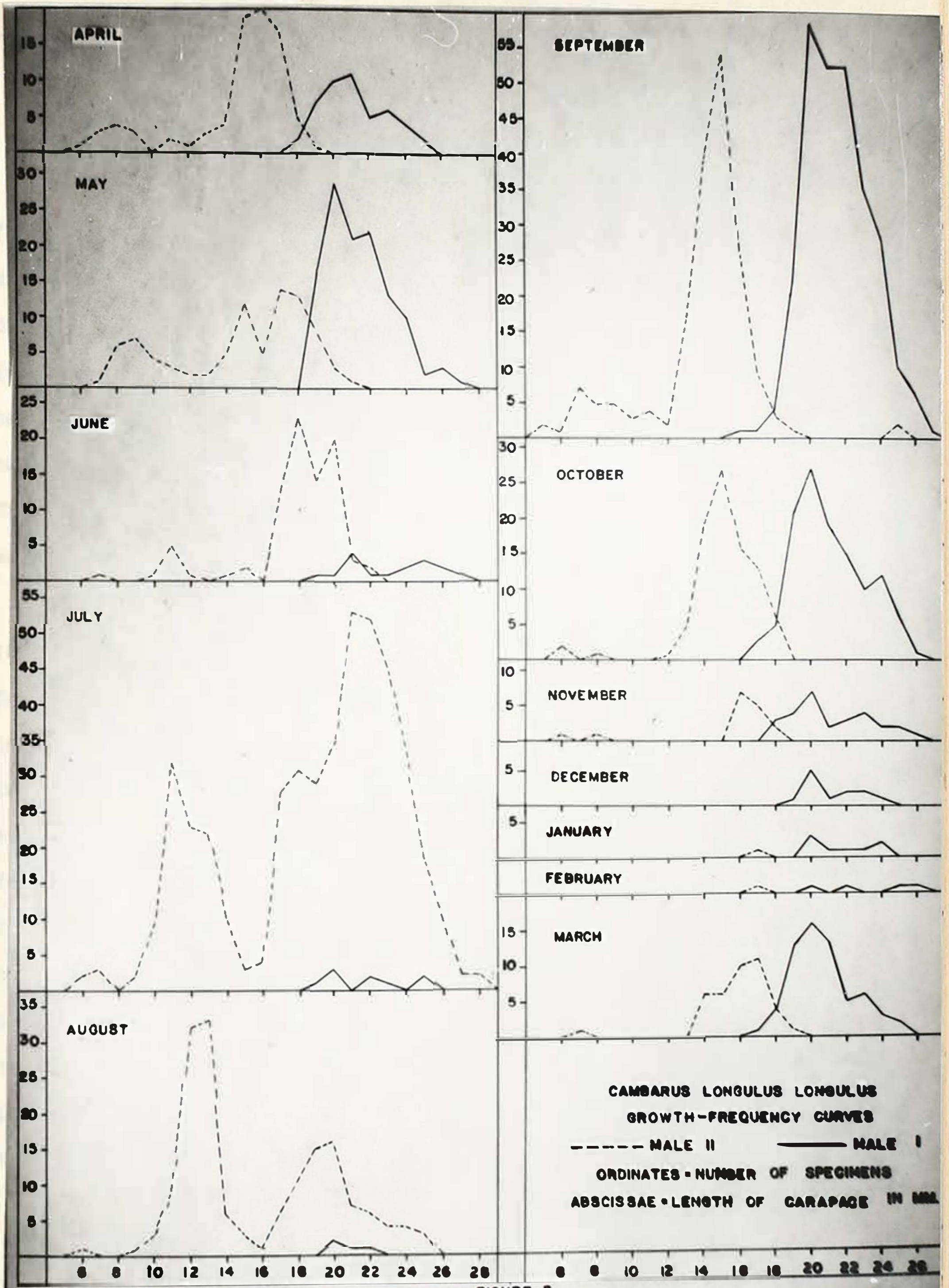

APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
CAMBARUS LONGULUS LONGULUS
GROWTH-FREQUENCY CURVES
----- MALE II
MALE I
ORDINATES = NUMBER OF SPECIMENS
ABSCISSAE = LENGTH OF CARAPACE IN MM.

FIGURE 3

OVARIAN EGG DEVELOPMENT

At the beginning of the ovarian studies on September 15, the color (Ridgway, 1886) of the eggs was raw umber and they averaged 1.38 mm. in diameter. The eggs of juvenile females were all white and had an average diameter of 0.37 mm. The largest female found with eggs characteristic (white and averaging 0.37 mm. in diameter) of the juvenile females had a carapace length of 17.6 mm., and the smallest female found with eggs characteristic of the mature females had a carapace length of 18.2 mm. Thus 18 mm. carapace length is used to separate, arbitrarily, the mature and juvenile females.

On September 26 the color of the ovarian eggs of the mature crayfish ranged from raw umber to olive, and the diameter had increased to 1.63 mm. Eggs of the juvenile females were white and averaged 0.40 mm. in diameter. In the October 13 collection the color range of the eggs of the adult females was the same, but there was a somewhat greater shift toward the olive; the diameter had increased to 1.81 mm. The eggs of the juvenile females were white but had increased to 0.47 mm. in diameter. By December 21 all eggs of the adult group had become darker in color ranging from olive to black. The majority of the eggs were black. The diameter had increased to 2.36 mm. which seemed to be about the size maintained until the eggs are laid. For January 29, February 18, March 13, and April 7, it can be seen from Table 1 that little change occurs in the diameter of the eggs.

[illegible] AND DEVELOPMENT

At the beginning of the ovarian studies on September 15, the eggs (Table 7, 1951) of the eggs that were taken and they averaged 1.28 mm. in diameter. The eggs of juvenile females were all white and had an average diameter of 0.57 mm. The largest female found with eggs characteristic (white and very pale, 0.37 mm. in diameter) of the juvenile females had a carapace length of 17.4 mm., and the smallest female found with eggs characteristic of the mature females had a carapace length of 19.5 mm. Thus 18 mm. carapace length is used to separate, arbitrarily, the mature and juvenile females.

On September 28 the color of the ovarian eggs of the mature crayfish changed from red-amber to olive, and the diameter had increased to 1.43 mm. Eggs of the juvenile females were white and averaged 0.60 mm. in diameter. By the October 12 collection the color range of the eggs of the adult females was the same, but there was a somewhat greater shift toward the olive; the diameter had increased to 1.81 mm. The eggs of the juvenile females were white and had increased to 0.67 mm. in diameter. By December 12 all eggs of the adult group had changed in color ranging from olive to black. The majority of the eggs were black. The diameter had increased to 2.29 mm. which seemed to be about the size maintained until the eggs were laid. For January 20, February 15, March 15, and April 1, it can be seen from Table 7 that little change occurs in the diameter of the eggs.

Table 1

Average Diameter of Ovarian Eggs

Date	Adult	Juvenile
September 15, 1956	1.38	0.37
September 26, 1956	1.61	0.40
October 13, 1956	1.81	0.47
December 21, 1956	2.36	
January 29, 1957	2.30	
February 18, 1957	2.42	
March 13, 1957	2.29	
April 7, 1957	2.30	
July 2, 1957	0.69	0.45

In the collections of May 10, May 29, and June 7, all non-ovigerous females of a mature size had very small ovaries containing only small white eggs very similar to those of juvenile females. On July 2, 1957, the eggs averaged 0.69 mm. in diameter and were cream color to Naples yellow in color. One female with a carapace length of 24.2 mm. obviously had not molted, but had small gastroliths (evidence of an approaching ecdysis). No cement glands were present, no egg membranes were attached to the pleopods, and the ovary contained eggs of a gallstone yellow that were only 0.85 mm. in diameter. This suggests an abortive attempt on the part of an aging female to produce an additional clutch of eggs, particularly in view of the fact that there was no evidence of resorption of the developing eggs. Whatever the explanation, the usual physiological activities associated with the reproductive cycle were out of phase.

In the July collection it was noted that the ovaries of females with a carapace length of 18 mm. or greater contained eggs that were distinctly larger than those of the females with a carapace length less than 17 mm. Hence deutoplasmic deposition in the oocytes of the juvenile females which will molt to maturity in the fall, as well as those females that have already

produced one brood, seems to begin in June or July.

NUMBER OF OVARIAN EGGS

There is considerable variation in the number of eggs found in the ovaries of different specimens, but the scatter diagram represented in Figure 4 indicates that a relationship exists between the size of the female and the number of eggs produced. The smallest number of ovarian eggs was 30 from a female measuring 18.2 mm. carapace length, and the largest number was 129 from a female with a carapace length of 26.5 mm.

Egg counts from only four ovigerous females are available, and from these limited data there appears to be a marked reduction in the number of eggs affixed to the pleopods from the number observed in the ovaries of females of comparable sizes prior to ovulation. Forty-five is the largest number of eggs found attached to the pleopods and this on a female the carapace length of which was 20.5 mm. This number agrees very well with the ovarian complement, but in the other three cases the number in each clutch was about half that of the ovarian number in specimens of similar sizes. The factor, or factors, responsible for this observed reduction in number is not known. Upon examination of the ovaries of females that had ovulated recently, however, no indication of retention of eggs was evident. Penn reported that four females of P. clarkii that ovulated in captivity failed to extrude all the ovarian eggs, and Smith noted that large eggs were found in some females of O. clypeatus after the main laying season was over. She concluded that these eggs were resorbed. The only indication of resorption of eggs in C. l. longulus was in the fall, several months prior to the period of ovulation.

NUMBER OF OVARIAN EGGS

There is considerable variation in the number of eggs found in the ovaries of different specimens, but the scatter diagram represented in Figure 4 indicates that a relationship exists between the size of the female and the number of eggs produced. The smallest number of ovarian eggs was 50 from a female measuring 13.9 mm. carapace length, and the largest number was 125 from a female with a carapace length of 25.5 mm.

Egg counts from only four ovigerous females are available, but from these limited data there appears to be a marked reduction in the number of eggs attached to the pleopods from the number observed in the ovaries of females of comparable sizes prior to ovulation. Forty-five is the largest number of eggs found attached to the pleopods and this on a female the carapace length of which was 20.5 mm. This number agrees very well with the ovarian complement, but in the other three cases the number in each clutch was about half that of the ovarian number in specimens of similar sizes. The factor, or factors, responsible for this observed reduction in number is not known. Upon examination of the ovaries of females that had ovulated recently, however, no indication of retention of eggs was evident. Penn reported that some females of P. clarkii that ovulated in captivity failed to extrude all the ovarian eggs, and Smith noted that large eggs were found in some females of O. virilis after the main laying season was over. She concluded that these eggs were resorbed. The only indication of resorption of eggs in P. l. longulus was in the fall, several months prior to the period of ovulation.

NUMBER OF EGGS
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
4
6
8
10
12
14
16
18
20
22
24
26
28
LENGTH OF CARAPACE

FIGURE 4

Figure 4. A scatter diagram indicating the numbers of ovarian eggs in sexually mature females of different sizes.

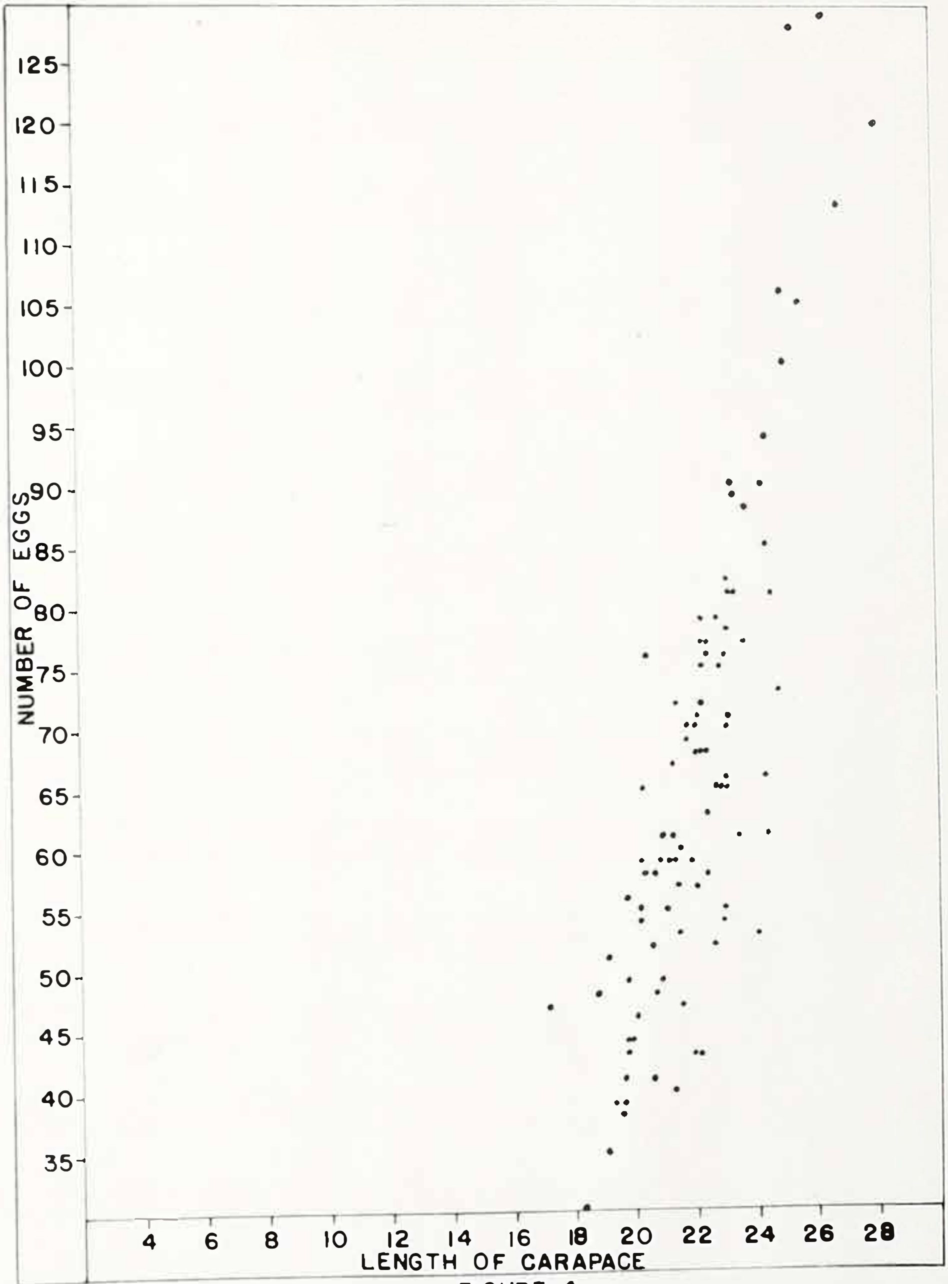

NUMBER OF EGGS
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
4
6
8
10
12
14
16
18
20
22
24
26
28
LENGTH OF CARAPACE

FIGURE 4

TESTICULAR DEVELOPMENT

In males with a carapace length between 11.4 and 15.4 mm., the testis is not separated into distinct lobes but is heart-shaped (Figure 5). As the animal increases in size, with a carapace length up to 19.2 mm., the testis becomes distinctly trilobed as seen in Figure 6, and opaque spots are present at the junction of the three lobes. These spots are concentrations of acini in which spermatids or spermatozoa are present; no sperm, however, are present in the vasa deferentia. After the spermatozoa are transferred to the vasa deferentia, in preparation for the first breeding season, that portion of each lobe of the testis which produced them degenerates to form a slender stalk as seen in Figure 7 (Word, 1954). With the approach of the second breeding season the stalk is lengthened by additional degeneration. Therefore, within limits, the length of the stalk may be indicative of the number of times sperm have been produced and hence of the number of breeding seasons.

In Figure 7 the stalks are seen to be about half as long as those in Figure 8 and the testis from which the latter figure was drawn must have produced spermatozoa a second time. Since no testis has been found with stalks three times the length of those in Figure 7, it is believed that sperm are produced no more than twice and thus no individual has more than two breeding seasons.

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Figures 5-8. Outline drawings of the testes of crayfish with carapace lengths of 13.4 mm., 19.2 mm., 20.2 mm., 28.1 mm., respectively.

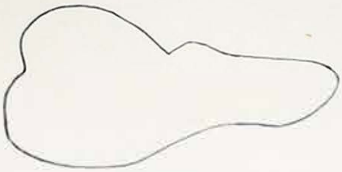

FIGURE 5

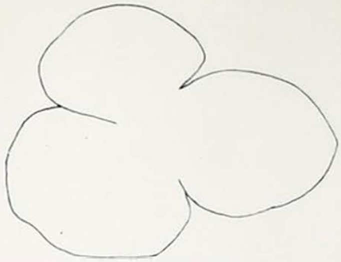

FIGURE 6

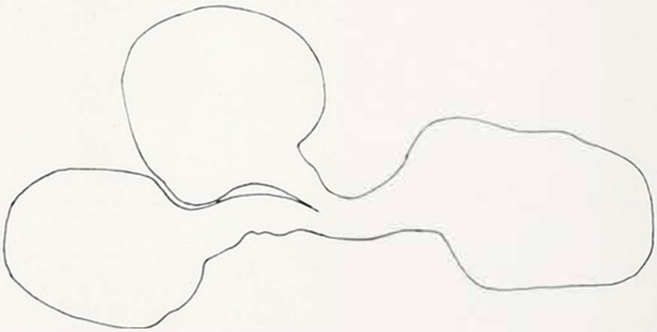

FIGURE 7

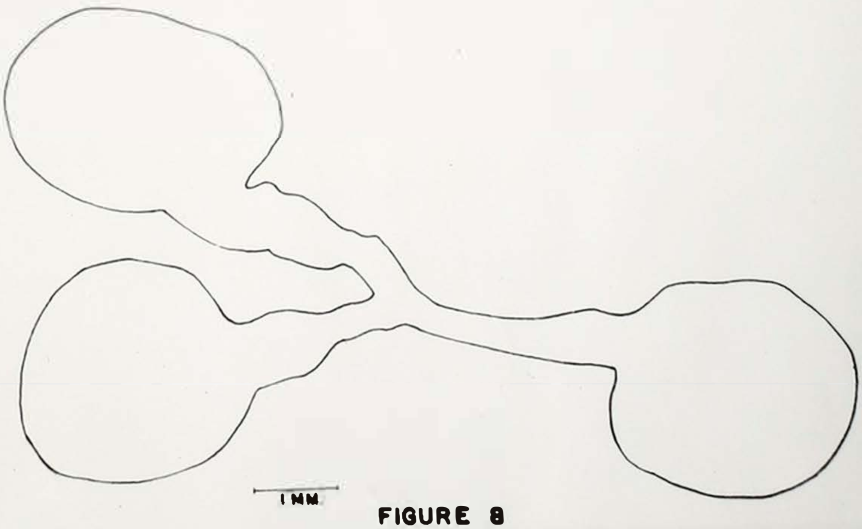

FIGURE 8

COPULATION

Van Deventer (1937) found O. p. propinquus copulating or in copulatory attitudes in September, October, November, and March. Tack (1941) found that O. immunis copulate from mid-June to mid-October, and Penn (1943) noted that for P. clarkii mating occurs most frequently in July, August, September, and October, but ". . . may occur whenever mature males (form I) and females come together in shallow warm water." C. l. longulus has not been found copulating in nature but observations of copulation in the laboratory have been made in March and April. (Parish 1948, and Hobbs, personal communication).

Parish (1948) gives the following description of copulation in this subspecies. "The male had moved forward over the supine female and held her first two pairs of pereipods firmly with his large chelae. The female appeared completely passive showing no signs of life and having the abdomen tightly bent so that her telson approached the last thoracic somite. On the other hand the abdomen of the male curved forward enclosing that of the female posteriorly. Throughout the process of copulation the male's excitement was manifested by the water currents around the cephalic portion of his body as a result of rapid movements of the maxillipeds. Immediately following the abrupt termination of the process in which the male suddenly moved backward releasing the female . . ."

COPULATION

Van Deventer (1937) found O. p. pennsylvanicus copulating or in copulatory attitudes in September, October, November, and March. Tack (1941) found that O. lancifer copulate from mid-June to mid-October, and Penn (1943) noted that for P. clarkii mating occurs most frequently in July, August, September, and October, but ". . . may occur whenever mature males (Form I) and females come together in shallow warm water." O. l. lancifer has not been found copulating in nature but observations of copulation in the laboratory have been made in March and April. (Parish 1945, and Hobbs, personal communication).

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BURROWING HABIT AND SEX RATIO

With the onset of cold weather, usually in October in this locality, C. l. longulus burrows for the winter, during which time only a very few specimens can be obtained. Attempts were made to open the burrows, but due to the extreme rocky condition of the stream, these resulted in failure. In view of the fact that during the several years that C. l. longulus has been observed at relatively regular intervals at Swift Run, and that no one has observed them in copulation, except in the laboratory, it is suggested that this is accomplished during the period (October to March) when the animals are in their burrows. Among other species of crayfishes, Hobbs (personal communication) has observed that frequently a male and a female occupy the same burrow. That C. l. longulus may also over-winter in pairs seems possible in view of the fact that copulation in their native habitats has never been observed.

It may be inferred from Table 2 that more individuals are present in the "free" population from April through July than during the winter months. Also it may be seen that a higher percentage of males than females occurs in the water during this period. The females almost certainly stay in the burrows from the time of ovulation until after they have molted. Evidence to support this contention is found in the sex ratios for April, May, and July. A predominance of males is found in May with the numbers tapering for April, June, and July as seen in Table 2. It will be noted that during the middle of May there is an overwhelming ratio of males to females, 380 males to 100 females; a ratio of 555 males to 100 females using sexually mature animals only.

HIBERNATING HABIT AND SEX RATIO

With the onset of cold weather, usually in October in this locality, C. l. longulus burrows for the winter, during which time only a very few specimens can be obtained. Attempts were made to open the burrows, but due to the extreme rocky condition of the streams, these resulted in failure. In view of the fact that during the several years that C. l. longulus has been observed at relatively regular intervals at [illegible], and that no one has observed them in copulation, except in the laboratory, it is suggested that this is accomplished during the period (October to March) when the animals are in their burrows. Among other species of crayfishes, [illegible] (Cambarus [illegible]) has observed that frequently a male and a female occupy the same burrow. That C. l. longulus may also over-winter in pairs seems possible in view of the fact that copulation in their native habitats has never been observed.

It may be inferred from Table 2 that more individuals are present in the "free" population from April through July than during the other months. Also it may be noted that a higher percentage of males than females occurs in the water during this period. The females almost certainly stay in the burrows from the time of ovulation until after they have molted. Evidence to support this contention is found in the sex ratios for April, May, and July. A preponderance of males is found in May with the numbers tapering for April, June, and July as seen in Table 2. It will be noted that during the middle of May there is an overwhelming ratio of males to females, 280 males to 100 females; a ratio of 335 males to 100 females using sexually mature animals only.

Further evidence to support the belief that females remain in their burrows until after the young have been liberated is that of the 2055 females which have been collected in Swift Run, only 26 were carrying eggs and 7 were carrying young, and these were found with considerable difficulty. In the April 24, May 4, and May 10 collections of 1957 the only mature females collected were carrying eggs, and in the May 29 collection of the same year, the mature females not carrying eggs showed definite signs of recent molts. Also in the June 7 collection all females of mature size had molted. It is of interest to note that in the July 2, 1957, collection there were a few adult females which had not yet molted although none were found with eggs or young. Those females which had not molted had small to medium sized gastroliths in the stomachs indicating a molt in the near future. It is probable that this group of females had ovulated later than the majority of animals and their young had recently become independent.

The overall sex ratio based on 4525 specimens is 120 males to 100 females, and using mature animals the sex ratio is 109 males to 100 females. Excluding the months of May, June, and July, when the females are obviously in their burrows, the sex ratio is 99 males to 100 females. This ratio seems more accurate.

Further evidence to support the belief that females remain in their burrows until after the young have been liberated is that of the [illegible] females which have been collected in Salt Run, only 26 were carrying eggs and 7 were carrying young, and these were found with considerable difficulty. In the April 26, May 4, and May 10 collections of 1957 the only mature females collected were carrying eggs, and in the May 29 collection of the same year, the mature females not carrying eggs showed definite signs of recent molts. Also in the June 7 collection all females of mature size had molted. It is of interest to note that in the July 8, 1957, collection there were a few adult females which had not yet molted although none were found with eggs or young. These females which had not molted had small to medium sized gastroliths in the stomach indicating a molt in the near future. It is probable that this group of females had ovulated later than the majority of animals and their young had recently become independent.

The overall sex ratio based on [illegible] specimens is 127 males to 100 females, and using mature animals the sex ratio is 109 males to 100 females. Excluding the months of May, June, and July, when the females are obviously in their burrows, the sex ratio is 98 males to 100 females. This ratio seems more accurate.

Table 2

Analysis of Swift Run Population of
Cambarus longulus longulus with Sex Ratios

Date	Females Below 18 mm.*	Females Above 18 mm.	Total Females	Males II or Below 19 mm.	Male I or Above 19 mm.	Total Males	Total Sex Ratio	Sex Ratio of Mature Males/Females	Total Number Specimens
1/29/57	0	7	7	1	8	9	1.28	1.14	16
2/14/51	0	24	24	5	8	13	0.54	0.33	37
2/18/57	0	9	9	1	4	5	0.55	0.44	14
2/27/51	0	8	8	1	6	7	0.87	0.75	15
Feb. Totals	0	41	41	7	18	25	0.61	0.44	66
3/4/50	20	91	111	34	47	81	0.73	0.52	192
3/13/57	5	12	17	5	16	21	1.23	1.33	38
3/17/51	4	27	31	6	10	16	0.51	0.37	47
3/31/51	4	9	13	4	10	14	1.08	1.11	27
Mar. Totals	33	139	172	49	83	132	0.77	0.60	304
4/7/57	6	4	10	2	2	4	0.40	0.50	14
4/11/51	-	-	-	4	3	7	-	-	7
4/24/57	17	0	17	14	5	19	1.12	-	36
4/29/51	-	-	-	6	5	11	-	-	11
4/29/50	50	19	69	57	44	101	1.48	2.31	170
4/30/50	7	0	7	10	-	10	1.43	-	17
Apr. Totals	80	23	103	93	59	152	1.48	2.57	255
5/4/57	5	1	6	4	3	7	1.16	3.00	13
5/7/50	26	10	36	34	37	71	1.97	3.70	107
5/10/57	4	2	6	5	19	24	4.00	9.50	30
5/21/50	9	11	20	15	61	76	3.80	5.55	96
5/27/51	40	8	48	34	24	58	1.21	3.00	106
5/29/57	14	18	32	30	20	50	1.56	1.11	82
May Totals	98	50	148	122	164	286	1.93	3.28	434

Table 2 - Continued

6/7/57	10	16	26	19	11	30	1.15	0.69	56
6/11/51	24	33	57	57	21	78	1.37	0.64	135
6/22/50	12	41	53	37	32	69	1.30	0.78	122
6/23/51	31	23	54	23	27	50	0.93	1.17	104
Jun. Totals	77	113	190	136	91	227	0.93	0.81	417
7/2/50	8	23	31	16	30	46	1.48	1.30	77
7/2/57	29	53	82	37	187	224	2.62	3.55	307
7/19/50	51	82	133	112	65	177	1.33	0.79	310
7/19/51	24	26	50	10	38	48	0.96	1.46	98
7/29/51	3	16	19	10	12	22	1.16	0.75	41
7/30/49	5	16	21	5	13	18	0.86	0.81	39
Jul. Totals	120	216	336	190	345	535	1.59	1.60	872
8/5/50	43	52	95	27	14	41	0.43	0.27	136
8/9/51	12	47	59	15	41	56	0.95	0.87	115
8/19/50	39	62	101	80	44	124	1.23	0.71	225
Aug. Totals	94	161	255	122	99	221	0.87	0.61	476
9/3/51	47	40	87	52	36	88	1.01	0.90	175
9/6/50	65	69	134	80	54	134	1.00	0.78	268
9/8/46	2	12	14	5	10	15	1.07	0.83	29
9/12/56	13	20	33	12	36	48	1.45	1.80	81
9/16/51	3	13	16	6	8	14	0.88	0.62	30
9/18/56	32	39	71	36	58	94	1.32	1.49	165
9/20/50	24	87	111	42	117	159	1.43	1.34	270
9/26/56	1	37	38	10	24	34	0.90	0.65	72
Sep. Totals	187	317	504	243	343	586	1.16	1.08	1090
10/11/50	20	50	70	35	56	91	1.30	1.12	161
10/13/56	11	19	30	12	23	35	1.17	1.21	65
10/14/49	8	48	56	17	34	51	0.91	0.71	107
10/29/50	20	33	53	26	29	55	1.04	0.88	108
Oct. Totals	59	150	209	90	142	232	1.11	0.95	441
11/8/49	1	6	7	-	6	6	0.86	1.00	13
11/12/56	15	32	47	11	24	35	0.74	0.75	82

Table 2 - Continued

11/21/50	3	8	11	6	4	10	0.91	0.50	21
Nov. Totals	19	46	65	17	34	51	0.78	0.74	116
12/21/56	-	25	25	-	12	12	0.48	0.48	37
GRAND TOTALS	767	1288	2055	1070	1398	2468	1.20	1.09	4524

* In this table measurements in mm. = length of carapace.

GROWTH CORRELATION

The regression lines in Figures 9 through 18 were obtained by Least Squares in order to determine if a relationship exists between the length of the carapace and the following: the length of the areola, the length of the chela, the length of the inner palm of the chela, the width of the chela at the palm, and the weight.

Figures 9 through 13 are regression lines based upon females and Figures 14 through 18 upon males. Females do not exhibit dimorphism and hence no distinction was made between juveniles and adults in the construction of these graphs. The males, however, do show dimorphism and they were separated into second form males, which included both juveniles and adults, and first form males.

Since no first form males found in Swift Run have a carapace length less than 16.8 mm., broken lines are utilized for form I males below this length. These broken lines would be the hypothetical growth correlations if such first form males existed. A solid line is used above 16.8 mm. carapace length. In July and August, form I males molt to second form and are in these two months as large as first form males. Thus a solid line is utilized throughout to represent second form males. The differences in the slopes of the regression lines for the first form and the second form males is indicative of allometric growth as the animals reach sexual maturity.

For each graph, the regression line was constructed from the ordinate intercept ($\bar{y}$) and the slope (x) which are given below. In addition, the correlation coefficient (r) is also given for each. The data for first

GROWTH CORRELATION

The regression lines in Figures 9 through 17 were obtained by least squares in order to determine if a relationship exists between the length of the carapace and the following: the length of the areola, the length of the chela, the length of the inner edge of the chela, the width of the chela at the palm, and the weight.

Figures 9 through 13 are regression lines based upon females and Figures 14 through 17 upon males. Females do not exhibit dimorphism and hence no distinction was made between juveniles and adults in the construction of these graphs. The males, however, do show dimorphism and they were separated into second form males, which included both juveniles and adults, and first form males.

Since no first form males found in Swift Run have a carapace length less than 16.5 mm., broken lines are utilized for form I males below this length. These broken lines would be the hypothetical growth correlations if such first form males existed. A solid line is used above 16.5 mm. carapace length. In July and August, form I males molt to second form and are in these two months as large as first form males. Thus a solid line is utilized throughout to represent second form males. The differences in the slopes of the regression lines for the first form and the second form males is indicative of allometric growth as the animals reach sexual maturity.

For each graph, the regression line was constructed from the ordinate intercept (a) and the slope (b) which are given below. In addition, the correlation coefficient (r) is also given for each. The data for first and second form males were combined and values were calculated. Graphs were not constructed for the combined data for all males; however, the data are presented here in the text, because they indicate that even though allometric growth begins as the animals approach sexual maturity, there is still a high degree of correlation for all characteristics when the data for both forms are combined.

Figure 9. Correlation between the length of the carapace and the length of the areola for the females.

Number of specimens - 329
$\hat{y} = -.4578 + .3823x$
$r = .9953$

Figure 10. Correlation between the length of the carapace and the width of the chela measured at the palm.

Number of specimens - 329
$\hat{y} = -1.7175 + .3894x$
$r = .6240$

When a scatter diagram is made, the line in Figure 10, instead of being straight, curves upward at approximately a carapace length of 18 mm. Since this is about the size of the females when sexual maturity is reached, this graph seems to indicate a difference in growth rates, at least in the width of the chela, for immature and mature females. This, however, is the only graph that so obviously indicates the growth differential. Also this is the only graph in which the correlation coefficient is relatively low.

Figure 11. The regression line in this figure indicates the correlation between the length of the carapace and the length of the palm, measured along the inner margin, for the females.

and second form males were combined the values were calculated. Graphs were not constructed for the combined data for all males; however, the data are presented here in the text, because they indicate that even though allometric growth begins as the animals approach sexual maturity, there is still a high degree of correlation for all characteristics when the data for both forms are combined.

Figure 9. Correlation between the length of the carapace and the length of the areola for the females.

Number of specimens - 328
$\hat{Y} = -.1275 + .3698x$
$r = .9953$

Figure 10. Correlation between the length of the carapace and the width of the chela measured at the palm.

Number of specimens - 329
$\hat{Y} = -1.7175 + .1991x$
$r = .8560$

When a scatter diagram is made, the line in Figure 10, instead of being straight, curves upward at approximately a carapace length of 18 mm. Since this is about the size of the females when sexual maturity is reached, this graph seems to indicate a difference in growth rates, at least in the width of the chela, for immature and mature females. This, however, is the only graph that so obviously indicates the growth differential. Also this is the only graph in which the correlation coefficient is relatively low.

Figure 11. The regression line in this figure indicates the correlation between the length of the carapace and the length of the palm measured along the inner margin, for the females.

Number of specimens - 329
$\hat{y} = -.7760 + .2903x$
$r = .9627$

Figure 12. The correlation between the length of the carapace and the length of the chela of the females.

Number of specimens - 329
$\hat{y} = -1.6651 + .7750x$
$r = .9814$

Figure 13. The correlation between the length of the carapace and the weight of the females.

Number of specimens - 181
$\hat{y} = -4.1171 + .3343x$
$r = .9525$

Figure 14. The correlation between the length of the carapace and the weight for the first form and second form males. Data for the total males are also given.

Male I:
Number of specimens - 123
$\hat{y} = -8.0132 + .5412x$
$r = .9659$

Male II:
Number of specimens - 93
$\hat{y} = -2.9135 + .2584x$
$r = .9328$

Total males:
Number of specimens - 216
$\hat{y} = -5.9701 + .4419x$
$r = .9552$

Figure 15. The correlation between the length of the carapace and the length of the areola for first form and second form males. The data for the total males are also given.

Number of specimens - 359
Ŷ = -.1750 + .2803x
r = .9667

Figure 11. The correlation between the length of the carapace and the length of the chela of the females.

Number of specimens - 329
Ŷ = -1.0051 + .1750x
r = .9814

Figure 13. The correlation between the length of the carapace and the weight of the females.

Number of specimens - 361
Ŷ = -4.3379 + .9161x
r = .9585

Figure 14. The correlation between the length of the carapace and the weight for the first form and second form males. Data for the total males are also given.

Male I:
Number of specimens - 223
Ŷ = -3.1252 + .9140x
r = .9459

Male II:
Number of specimens - 91
Ŷ = -2.7135 + .8584x
r = .9815

Total males:
Number of specimens - 306
Ŷ = -4.0901 + .1117x
r = .9552

Figure 15. The correlation between the length of the carapace and the length of the chela for first form and second form males. The data for the total males are also given.

Male I:
Number of specimens - 202
$\hat{y} = -1.0592 + .4126x$
$r = .9778$

Male II:
Number of specimens - 159
$\hat{y} = -.2789 + .3705x$
$r = .9917$

Total males:
Number of specimens - 361
$\hat{y} = -.4643 + .3841x$
$r = .9941$

Figure 16. The correlation between the length of the carapace and the width of the chela for first and second form males. The data for the total males are also given.

Male I:
Number of specimens - 202
$\hat{y} = -4.4843 + .6017x$
$r = .9112$

Male II:
Number of specimens - 159
$\hat{y} = -1.6556 + .3993x$
$r = .9796$

Total males:
Number of specimens - 361
$\hat{y} = -3.4212 + .5404x$
$r = .9655$

Figure 17. The correlation between the length of the carapace and the length of the palm, measured along the inner margin, for the first form and second form males. Data for the total males are also given.

Male I:
Number of specimens - 202
$\hat{y} = -3.8306 + .4963x$
$r = .9018$

Male II:
Number of specimens - 159
$\hat{y} = -.6255 + .2920x$
$r = .9755$

Total males:
Number of specimens - 361
$\hat{y} = -2.0462 + .4053x$
$r = .9585$

Figure 18. The correlation between the length of the carapace and the length of the chela for first form and second form males. Data for the total males are also given.

Male I:
Number of specimens - 202
$\hat{y} = -9.6479 + 1.3174x$
$r = .9599$

Male II:
Number of specimens - 159
$\hat{y} = -1.5333 + .7944x$
$r = .9839$

Total males:
Number of specimens - 361
$\hat{y} = -5.3018 + 1.0916x$
$r = .9703$

Figures 9-18. Regression lines showing correlations between the data indicated. See pp. 22-26 for explanations.

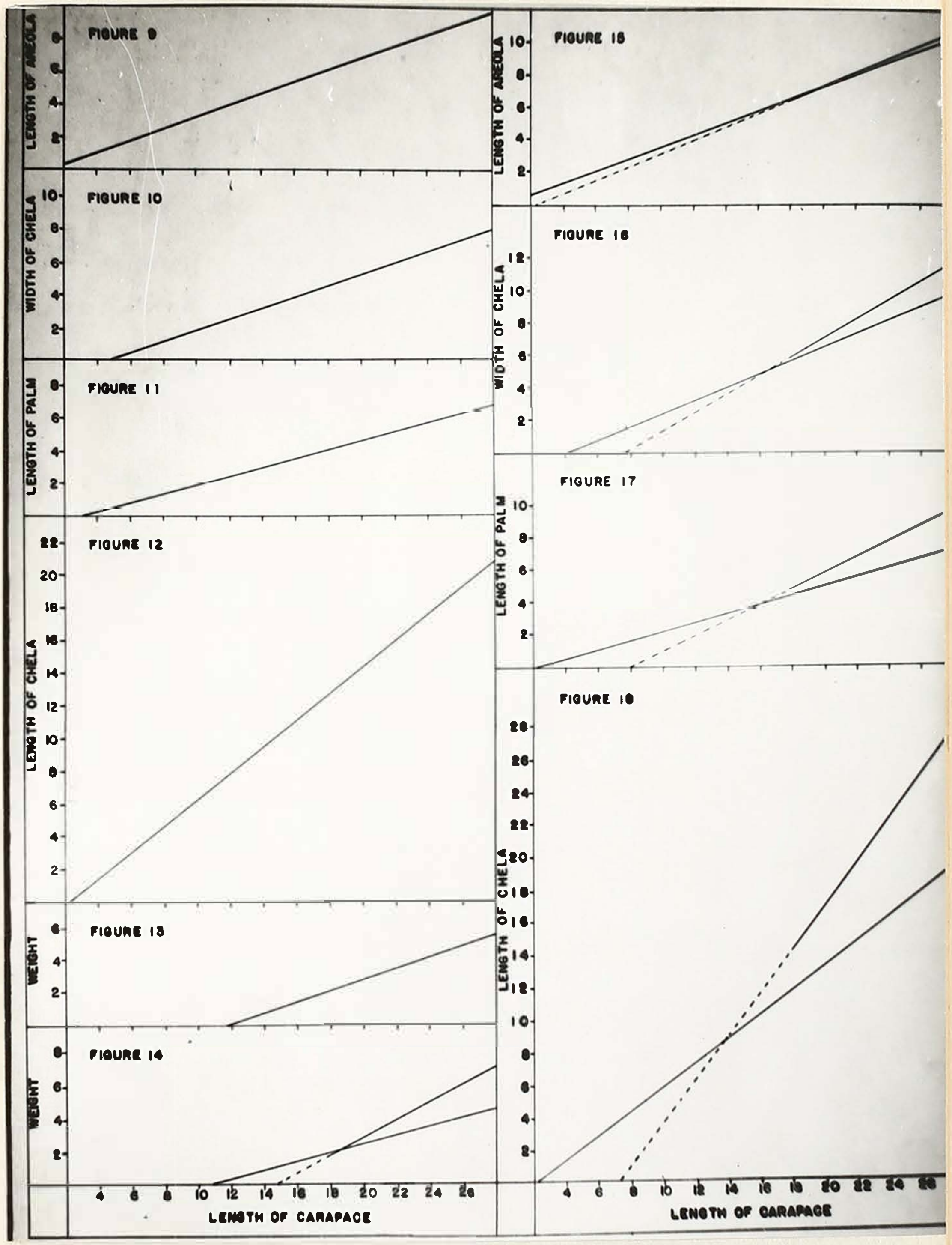
FIGURE 9
LENGTH OF AREOLA
FIGURE 10
WIDTH OF CHELA
FIGURE 11
LENGTH OF PALM
FIGURE 12
LENGTH OF CHELA
FIGURE 13
WEIGHT
FIGURE 14
WEIGHT
4 6 8 10 12 14 16 18 20 22 24 26
LENGTH OF CARAPACE
FIGURE 15
LENGTH OF AREOLA
FIGURE 16
WIDTH OF CHELA
FIGURE 17
LENGTH OF PALM
FIGURE 18
LENGTH OF CHELA
4 6 8 10 12 14 16 18 20 22 24 26
LENGTH OF CARAPACE

SUMMARY

Cambarus longulus longulus is found only in flowing water and usually in the swifter reaches of a stream.

The females lay their eggs from late April to mid-July. The eggs hatch in approximately three weeks with the young appearing from May through July. Newly hatched crayfish are between 2.5 and 3.2 mm. carapace length. They are attached to the pleopods of the mother by the "telson thread". At their first molt they remain with the mother, but become independent after the second molt.

By September the majority of the young males attain a carapace length of 13 to 17 mm. Growth then ceases until April or May when a carapace length of 16 to 19 mm. is reached by an apparent single molt. In August or September an additional molt occurs at which time a carapace length of 18 to 21 mm. is attained, and the animals become sexually mature at an age of 16 to 17 months. They then enter their first breeding season. In the following June or early July the form I males molt to form II with a carapace length of 19 to 22 mm. These form II males molt back to the first form in August or early September in preparation for their second breeding season. At this molt they attain a carapace length of 22 to 25 mm., with some presumably reaching the maximum length of 28.2 mm. After their second breeding season, the majority of the males die during the late spring or early summer at an age of 25 to 28 months. It is possible that a few males may participate in a third breeding season.

The females, which hatch from late April to mid-July, attain sexual maturity in September of the following year at an age of 16 to 17 months;

the carapace length is approximately 18 to 22 mm. This length is maintained until their first brood of young have become independent in the spring. At the spring molt the carapace length increases to 21 to 25 mm. At this length they produce their second brood in the following spring, and may or may not undergo the spring molt before the majority die at an approximate age of three years. A few females may live to produce a third brood.

Development of the ovarian eggs of females which have produced one brood, and of those females which will become sexually mature at the late August or early September molt, begins in June or July. In July the diameter of the eggs of these two groups averages 0.69 mm. and their color is cream color to Naples yellow. By December most of the eggs have become black and the diameter averages 2.36 mm. Both this color and diameter of the eggs seem to be maintained until they are laid.

Copulation probably occurs in March and April.

About October in this locality all of the crayfish burrow for the winter.

The sex ratio based on 4525 specimens is 120 males to 100 females. However, excluding the months of May, June, and July when the females are obviously in their burrows, the sex ratio is 99 males to 100 females.

The correlations between the length of the carapace and the length and width of the chela, the length of the inner palm of the chela, and the weight of the animal are found to be high.

the carapace length is approximately 18 to 22 mm. This length is maintained until their first brood of young have become independent in the spring. At the spring molt the carapace length increases to 21 to 25 mm. At this length they produce their second brood in the following spring, and may or may not undergo the spring molt before the majority die at an approximate age of three years. A few females may live to produce a third brood.

Development of the ovarian eggs of females which have produced two broods, and of those females which will become sexually mature at the late August or early September molt, begins in June or July. In July the diameter of the eggs of these two groups averages 0.89 mm. and their color is cream color to Naples yellow. By December most of the eggs have become black and the diameter averages 2.30 mm. Both this color and diameter of the eggs seem to be maintained until they are laid.

Copulation probably occurs in March and April.

About October in this locality all of the crayfish burrow for the winter.

The sex ratio based on 2555 specimens is 120 males to 100 females. However, excluding the months of May, June, and July when the females are obviously in their burrows, the sex ratio is 99 males to 100 females.

The correlations between the length of the carapace and the length and width of the chela, the length of the inner palm of the chela, and the weight of the animal are found to be high.

BIBLIOGRAPHY

Baron, Vera Frances. 1951. A Study of the Cyclic Behavior of Cambarus longulus longulus, Girard with Notes on the Juvenile Males. University of Virginia Masters Thesis, pp. 1-38.

Bovbjerg, Richard V. 1952. Comparative Ecology and Physiology of the Crayfish Orconectes propinquus and Cambarus fodiens. Phys. Zool. 25(1):34-56.

Clawson, A. B. Some Results of a Study of Correlation in the Crayfish. Mich. Acad. Sci., 7th Ann. Rep., pp. 103-108.

Creaser, Edwin P. 1933a. Seasonal Changes in the Male Population of Faxonius propinquus. Occ. Pap. Mus. Zool. Univ. Mich. (253):1-9.

_______ 1934a. Age, Growth and Sex Ratios in the Crayfish, Faxonius propinquus. Pap. Mich. Acad. Sci., Arts, and Letters, 19:581-585.

Hart, C. W., Jr. 1951. On the First Pleopod of the Male Crayfish Cambarus longulus longulus Girard. University of Virginia Masters Thesis, pp. 1-54.

Hobbs, Horton H., Jr. 1942. A Generic Revision of the Crayfishes of the Subfamily Cambarinae (Decapoda, Astacidae) with the Description of a New Genus and Species, Amer. Midl. Nat., 28(2):334-357.

Osborne, Paul J. 1951. The Post-Embryonic Development of the Cephalic and Gnathothoracic Appendages of the Crayfish, Cambarus longulus longulus Girard. University of Virginia Masters Thesis, pp. 1-55.

Parish, Claude E. 1948. A Contribution toward a Knowledge of the Crayfish, Cambarus longulus dasydactulus, with Special Reference to the Annulus Ventralis. University of Virginia Masters Thesis, pp. 1-75.

Penn, George H., Jr. 1943. A Study of the Life History of the Louisiana Red Crawfish, Cambarus clarkii Girard. Rep. Ec., 24(1):1-18.

Ridgway, Robert. 1886. Nomenclature of Colors for Naturalists. Little, Brown, and Company.

Smith, Elsie Wayne. 1953. The Life History of the Crayfish Orconectes (Faxonella) clypeatus (Hay). Tulane Stud. Zool., 1(7):79-96.

Tack, Peter Isaac. 1941. The Life History and Ecology of the Crayfish Cambarus immunis Hagen. Amer. Midl. Nat., 25(2):420-446.

Van Deventer, William Carl. 1937. Studies on the Biology of the Crayfish Cambarus propinquus Girard. Illinois Biological Monographs, 15(3):1-67.

Word, Benjamin H. 1954. Observations on the Testis of the Crayfish *Cambarus montanus acuminatus* Faxon. University of Virginia Masters Thesis, pp. 1-37.