THE LIFE HISTORY OF THE CRAYFISH, ORCONECTES VIRILIS (HAGEN)

by

Kenneth Vernon Weagle

Submitted in partial fulfillment of the requirements of
a Master of Science degree in Biology
at Lakehead University, Thunder Bay, Ontario, Canada

August 15, 1970

Section 1

ACKNOWLEDGEMENTS

I would like to express my appreciation to Dr. G. W. Ozburn, my supervisor, who during the course of this study always seemed to be able to cope with my different moods and put me back on the correct track; to Mr. W. P. Russel and my wife Janice, who often assisted me with my collections; to Mr. D. W. Barr, of the Royal Ontario Museum, for confirming my identification of the species *O. virilis*; to Dr. W. T. Momot and Dr. D. E. Aiken for supplying additional information and making helpful suggestions on the interpretation of my data; to Mr. G. Hachiguchi for helping with the developing and printing of the plates of the thesis, and to the rest of the technical staff of Lakehead University, Department of Biology, who have assisted me at one time or another.

The research has been supported by the National Research Council of Canada and by the President's special fund.

TABLE OF CONTENTS

TABLE OF CONTENTS

Section 3

LIST OF FIGURES

Section 4

LIST OF PLATES

Section 5

LIST OF TABLES

ABSTRACT

A one-year study was conducted to expand upon the life history of the crayfish Orconectes virilis (Hagen). In the course of the study, 852 adults and 692 young were examined.

The eggs were laid in the spring of the year, during the last week of May. The number of eggs carried per female was proportional to the carapace length and averaged 214. The eggs hatched during the second week of July. During their first summer, the young underwent five molts; the first occurred while the young were still attached to the pleopods of the mother and the other four occurred while the young were free living. It was before or during the second molt that the young became free living.

Year I individuals underwent three to four molts. If maturity was reached on the third Year I molt, no further molting activity occurred; if maturity was not reached at this time, another molt occurred. Fifty percent of the males and 65 percent of the females reached maturity during Year I. The remaining individuals reached maturity during Year II.

Year II and Year III males underwent two molts; the first was from Form I to Form II (mid-June), and the second was from Form II to Form I (late July and early August). The Year II and Year III females, however, underwent only one molt, which occurred towards the end of July.

The mating season occurred in August and September and the mating procedure was similar to that found in other species of crayfish.

Growth rates were highest in the young, with an increase in carapace length from 3.5 mm. to 13.1 mm. in their first year.

Mortality increased with age and a high mortality was noted during the peak molting periods.

CHAPTER II

INTRODUCTION

Crocker and Barr (1968: 92), in their book Handbook of the Crayfish of Ontario, suggested the necessity of a detailed study of the life history of the crayfish *Orconectes virilis* (Hagen) in Ontario. In personal communication with Dr. Walter Momot, of the Ohio State University, I was also encouraged to conduct such a study. Thus the present study, to gain a more accurate knowledge of the life history of the crayfish *Orconectes virilis* (Hagen), began.

Orconectes virilis is the most common crayfish in Northwestern Ontario. The only other crayfish found in the area are *Orconectes propinquus propinquus* (Girard), in the Rainy River area; and *Orconectes rusticus rusticus* (Girard), in the Kenora area; which most likely have been introduced by sport fishermen (Crocker and Barr, 1968: 71, 88). In the study area, only *O. virilis* was found.

This species originally was described by Hagen (1870: 63-75) as *Cambarus virilis*. After assorted descriptions (Bundy, 1876: 24; Streets, 1877: 803; Ortmann, 1905: 107), it reached its present taxonomic status via Hobbs (1942).

Orconectes virilis is very similar to two other species. These are *O. nais* (Faxon, 1885: 140-141), which is found in the Mississippi River drainage of the southern U.S.A. (Kansas, Arkansas, Oklahoma, Missouri, (Williams and Leonard, 1952); and *O. immunis* (Hagen, 1870: 71-73), which is found in southern Ontario and some of the eastern and central states of the U.S.A. (New York, New Hampshire, New Jersey, Massachusetts, Pennsylvania, West Virginia, Tennessee, Oklahoma, Kansas, Wisconsin, Michigan; Crocker and Barr, 1968: 106-107). Williams and Leonard (1952) and Aiken (1968) have commented on the difficulties in distinguishing between ~~the three species~~. O. nais and O. virilis.

O. virilis can be found in lakes, ponds or streams. However, it prefers areas with broken rock and rubble, affording good habitat protection, and tends to avoid open areas with silt and sand, where protection is at a minimum (Crocker and Barr, 1968: 92). O. virilis has been collected in burrows in California (Riegel, 1959), but is not considered to have a burrowing habit in its normal range (It was introduced into California between 1939 and 1941: Riegel, 1959).

It is necessary, before entering into a study of the life history of any crayfish, to review the two Forms found in the male. The Forms are distinguishable by a change in the size and shape of the first and second pleopods, which are modified to form copulatory stylets. As a juvenile, these copulatory stylets are thick and are not capable of transferring the sperm to the female (Plate I). With the last juvenile molt, the male changes to Form I. The chela of the Form I male (Plate II) is larger, relative to carapace length, and the copulatory stylets are more slender and more heavily sclerotized than in the juvenile male. This is the sexually competent Form and the only Form which has been observed to mate. After the mating season, the males molt to Form II (Plate III). The copulatory stylets in this Form are similar to those of the juvenile. The molting from Form I to Form II, and from Form II to Form I, is controlled by the amount of male hormone in the individual's system. When the amount of male hormone is high (mid-summer), the animal will molt from juvenile, or Form II to Form I, when the amount

PLATE I

Plate I: ~~Dorsal~~ Ventral view of a mature female crayfish from the species *Orconectes virilis* (carapace length 30.2 mm.)

PLATE II

Plate II, a: Ventral ~~Dorsal~~ view of a Form I male *Orconectes virilis* (carapace length 29.3 mm.).

Plate II, b: The right copulatory stylet from the above Form I male.

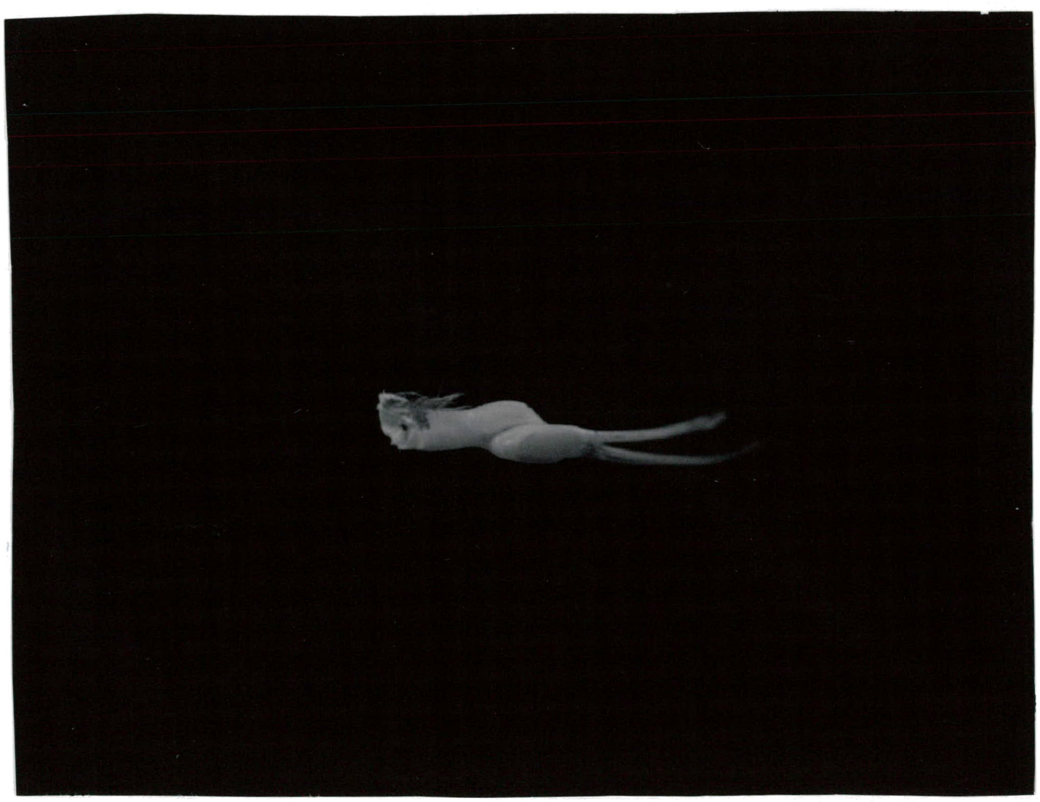


PLATE III

Plate III, a: Ventral ~~Dorsal~~ view of a Form II male *Orconectes virilis* (carapace length 26.7 mm.).

Plate III, b: The right copulatory stylet from the above Form II male.

is low, the animal will molt from Form I to Form II (Scudamore, 1948). The testes of Form II males are in a state of development. The sperm, therefore, is not ripe and mating is not possible. This change of Form in the male crayfish was first observed by Hagen (1870: 22) and first explained by Faxon (1884).

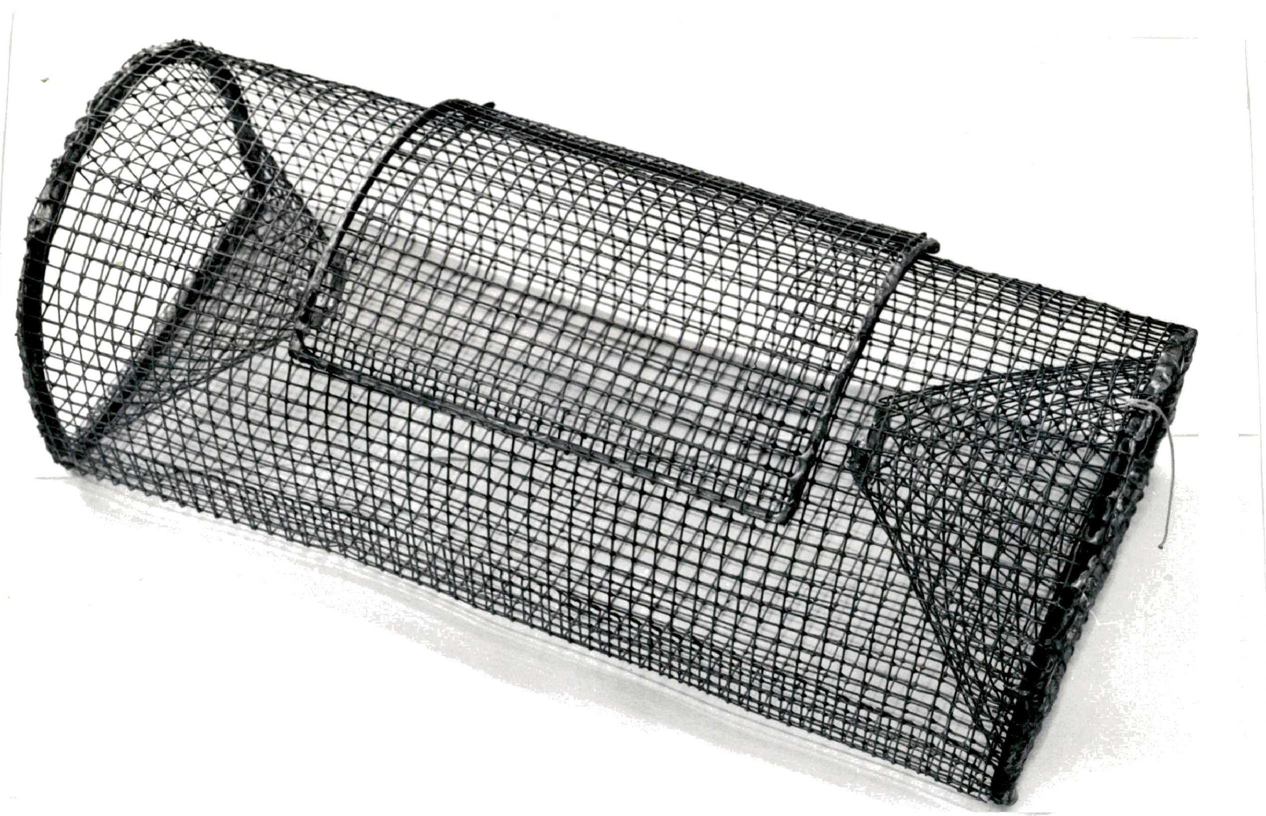
The term "adult" incorporates all the individuals in Year I, Year II and Year III. The term "juvenile" incorporates all the individuals that have not reached sexual maturity. These two terms sometimes overlap; "adult" is meant to give an indication of the size and age, and "juvenile" is meant to indicate a state of sexual development.

The methods of collecting used in the study were simple. It is hoped that they have yielded results as good or better than those yielded by other methods. The traps (Plate IV) were too selective as to size range sampled and a seine net could not be used successfully because of the rocky nature of the stream substrate. It is believed that samples collected in this manner were unbiased.

Although in some sections of this thesis statistical methods were applied to the data, the trend has been towards placing more emphasis on observations of the entire population. I believe that life history studies can benefit more from extended, subjective observations than from large statistically significant samples.

PLATE IV

Plate IV: The type of crayfish trap tried at one time during the study. Each was constructed of one-quarter inch hardware wire covering a metal frame. They were twelve inches long and the ends were semi-circular, with a five-inch radius. The cone extending inward from each end was four inches long.



CHAPTER III

LITERATURE SURVEY

The crayfish lends itself very well to physiological studies and many such studies have been carried out on the group (Fasten, 1914; Kyer, 1942; Roberts, 1944; Scudamore, 1947; Travis, 1960; Devilley, 1965; Aiken, 1967 and 1969; Wood, 1967; Jungreis and Hopper, 1968; to name a few). It seems strange, therefore, that such a limited number of studies have been conducted on the life histories of crayfish. Physiological data can be misleading without a full understanding of mating, oviposition, developmental stages, growth and mortality in the species under consideration.

In the literature, detailed life histories were found for only six of the estimated 206 species of crayfish. They were Orconectes causeyi (Dean, 1969), Orconectes (=Faxonella) clypeatus (Smith, 1953), Orconectes (=Cambarus) immunis (Tack, 1941), Orconectes (=Cambarus) propinquus (VanDeventer, 1937), Cambarus clarkii (Penn, 1943), Cambarus longulus longulus (Smart, 1962).

Life History Data for the Genus Orconectes:

Crocker and Barr (1968: 52) suggest there are 51 species in the genus Orconectes. Excluding virilis, life history data are ~~is~~ available for only seven of these species. Table I summarizes this information.

Literature Survey for the Species Orconectes virilis:

Orconectes virilis can be found over much of the eastern and central U.S.A. and central and western Canada (East of the Rockies). Table II gives an outline of the distribution. The species is widely distributed

TABLE I

SPECIES	AUTHORITY	MATING SEASON	OVIPOSITION	INCUBATION	LENGTH OF LIFE	LOCATION	TYPE	BURROWING
O. Causeyi	Dean, 1969	Aug. to Sept.	April to June	6-9 weeks	3 years	New Mexico	Stream	Yes
O. rusticus	Langlois, 1935	Sept. to Oct.	April to May	1 week (1)	?	Ohio	Pond	Yes
O. immunis	Tack, 1941	July to Oct.	Oct. to Nov.	3-4 weeks (2)	2-3 years	New York	Pond	Yes
O. propinquus	Vandeventer, 1937 Creaser, 1933-34	Spring & Fall	Spring	4-6 weeks	2-3 years	Illinois	?	Yes
O. nais	Momot, 1966	?	?	?	2 years	Oklahoma	Stream	Yes
O. clypeatus	Smith, 1953	Aug. to Sept.	September	2 weeks	2 years	Louisiana	Stream Pond	Yes
O. limosus	Andrews, 1904	Fall & Spring	March to April	6-8 weeks	?	Maryland	Pond	Yes

Table I: A comparison of life history data for seven crayfish species from the genus Orconectes.

(1) Crocker and Barr 1968: 86)

(2) Bovbjerg (1952)

PROVINCE or STATE		AUTHORITY
Ontario		Crocker and Barr, 1968 Huntsman, 1915
Manitoba		Huntsman, 1915
Saskatchewan		Rawson & Moore, 1944
Alberta		Aiken, 1968
Quebec		Suggested by Aiken, (1968) and Crocker and Barr, (1968)
Maine		Aiken, 1965
Massachusetts		Travis, 1960
New Hampshire		Aiken, 1965
New York		Crocker, 1958
Illinois		McWhinnie, 1962
Michigan		Langler & Langler, 1944
Wisconsin		Graenischer, 1913 Threinen, 1958 a,b
Minnesota		Jungreis, 1968
Missouri		Steel, 1902 Bovbjerg, 1953
Colorado		Engle, 1929
Nebraska		Engle, 1929
Montana		Holthius, 1962
Wyoming		Hobbs & Zinn, 1948
Maryland)	Introduced	(Meredith & Schwartz, 1962
California)		(Riegel, 1959

TABLE II: A summary of the distribution of Orconectes virilis, showing the location and the authority quoted.

over most of Ontario, but is most common in the northwestern part of the province. Around the City of Thunder Bay, it has been found in many lakes (including Lake Superior) and in almost all of the streams (data supplied by the Thunder Bay Regional Office of the Ontario Water Resources Commission).

Life history data on O. virilis is scarce, that available being summarized in Table III. The data shown is taken from studies on the physiology, productivity and distribution of the species. To my knowledge, no one has produced a complete life history study on the species.

Bovbjerg (1953) worked on the dominance order in the species and found the males to be dominant over the females and large individuals to be dominant over smaller individuals within the sex.

Riegel (1959) found that the species had been introduced into California in the late 1930's or early 1940's, where it can be found in burrows.

TABLE III

AUTHORITY	LOCATION	TYPE	SEX	AVERAGE SIZE (Carapace length mm) O	I	II	III	YOUNG MOLTS	SPRING	SUMMER	MATING SEASON	OVIPOSITION	LENGTH OF LIFE
Aiken (1965)	New Hampshire	Lake	M F						June 9 to July 7	July 24 to Sept. 7			
Aiken (1969)	Alberta	Stream	M F					4 4					
Crocker & Barr (1968)	Ontario	Stream Lake	M F							July	Aug. to Oct. & May to June	May to June	3 years
Fasten (1914)	Wisconsin										Sept. to Oct. & April to May (2)		
Momot (1967)	Michigan	Lake	M F	20.8 19.2	31.2 29.5	36.5 36.4	40.8 (1)		June 1 to July 16	July 5 to Aug. 9 & June 17 to July 8	Mid- August to to September	May	3 years
Threinen (1958, a)	Wisconsin	Lake									Late Summer to Fall & Spring (3)	April to June	3 years
Aiken (1967)	Alberta	Stream	M F		25.3 25.3								

Table III: A summary of the life history data for Orconectes virilis that was found in the literature.

(1) Readings taken in the month of November.

(2) Statement reads "In early spring a period of copulation may ensue..."

(3) Statement reads "Mating probably continues into early spring".

DESCRIPTION OF SITE

The study was conducted on the McIntyre River, where it runs through the campus of Lakehead University, Thunder Bay, Ontario, Canada, (Figure I). Site 'a' (Figure I 'a'; Plate V) was situated on a straight section of the stream, southwest of the Centennial Science Building. At the upstream end of this site was a small riffle leading into a pool. The pool varied in average depth from 130 cm. on April 30, 1970, to 71 cm. on June 23, 1970. The substrate consisted of large broken shale (144 cm.^{2} to 288 cm.^{2}) and gravel. The pool was 20 meters long and averaged 15 meters wide.

The pool led into a section of shallow water that had a consistent depth over its entire length. On April 30, 1970, the depth averaged 93 cm., and on June 23, 1970, it averaged 35 cm. The sides of this area had a substrate of broken shale and large rocks, while the ~~substrate on the bottom~~ was gravel, with few rocks of any size. Sampling efforts were concentrated along the banks because of the abundance of crayfish in this location. Few crayfish were found on the gravel in the middle of the stream. The width of this section of the stream averaged 16 meters and the length was 60 meters. Sampling was conducted over an area beginning at the upstream end of the pool and extending 80 meters downstream from this point.

In 1969, the maximum water depth occurred on May 1st; in 1970, the maximum depth occurred on April 30th.

Site 'b' was on a bend in the river, just upstream from the University foot bridge (Figure I 'b'). The substrate at this site was

FIGURE I

Figure I: A to-scale plan of the study area, showing the sampling sites and various buildings:

a - Sampling Site 'a'

b - Sampling Site 'b'

1 - Centennial Science Building

2 - University Centre Extension

3 - Old Men's Residence

4 - New Residence

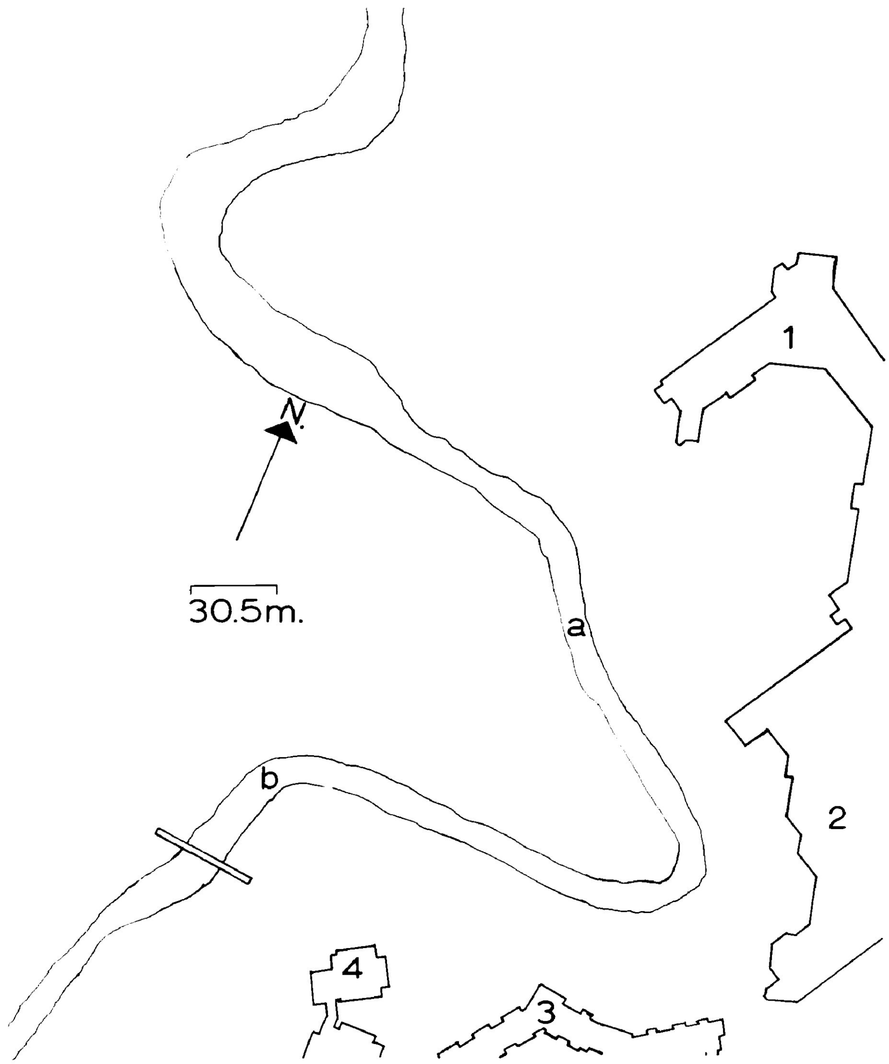

N.
30.5m.
a
b
1
2
3
4

PLATE V

Plate V: The study area as seen on June 23, 1970 (Site 'a').

solid shale in the middle of the stream, with broken shale along the banks. Sampling was conducted at this site until the middle of August, 1969. It was not sampled in 1970. Site 'b' was used as a control site, in the event that construction in the area of Site 'a' rendered it useless. No data on the individuals collected at Site 'b' ~~is~~ are contained in the text of this thesis.

During the study period, there were no aquatic vascular plants found at either site. During June, July and August, when the water levels were low and the water temperatures were high (20^{o}C to 22^{o}C), areas along the banks of the streams were covered with a thick mat of Spirogyra sp. The current in these areas was also much reduced and there was a build-up of organic matter.

The oxygen concentration in the water remained near saturation level, while the water temperature varied from 0^{o}C in April and November to 22^{o}C in July and August. The water in the stream was very clear, with the bottom of the stream visible from the time immediately after the spring high until the freeze-up in November.

METHODS

The larger crayfish (19.0 mm. carapace length) were collected with the aid of a hand net (Mesh #0, 38 holes/in. sq.) and a stick. The net was placed behind the crayfish and the animal was disturbed with the stick. As it left the substrate, the crayfish was collected in the net. At each station, all the crayfish seen on each sampling date were collected. All those collected were kept in a bucket until the sampling in that particular area was finished. Then the carapace length was measured to the nearest 1/10 mm. with a vernier caliper; and the sex, Form (in the case of the males) and texture of the exoskeleton were noted. The carapace length was taken as the distance from the tip of the rostrum to the posterior edge of the cephalothorax. After they were measured, they were released back into the stream at the middle of the sampling site.

Young-of-the-year were collected with a hand net (Mesh #34, 173 meshes/in. sq.) dragged behind the collector. As the young were disturbed by the collector's feet, they would leave the substrate and be collected in the net. Approximately 50 individuals were collected and preserved in alcohol at each station and on each sampling date. In the laboratory, the carapace length of the young was measured to the nearest 1/10 mm. by means of a dissecting microscope fitted with a measuring ocular lens~~e~~, and the sex and exoskeleton texture of the individuals were noted.

An attempt was made to make weekly collections from July 15, 1969, until July 15, 1970, but this was not always possible because of adverse weather conditions or high water level. Collecting was not carried out during the winter months (November through to March), since no successful method of collecting through the ice was found. While collecting, care was taken to disturb the bottom of the pool as little as possible.

In the present study, the age groups have been established as:

Young-of-the-year	- Leas than 10 months old
Year I	- 10-22 months old
Year II	- 22-34 months old
Year III	- More than 34 months old

To calculate the carapace length ranges for the adult age groups, two criteria were used. First, by using the growth increment per molt, the number of molts and the carapace length ranges for the young-of-the-year in the fall, the carapace length ranges for the adult groups were calculated. Secondly, a histograph was prepared for all the adult males and females examined in the study by grouping them according to carapace length. By examining the modes of this histograph, the age groups could be estimated. The results of both these methods were compared to give a more accurate estimate of the ranges.

The times of the molts in each age group were estimated by an examination of the percentage of crayfish with soft exoskeletons in each sample. After the molt, the exoskeleton remains in a soft condition for three to four days, during which time the crayfish stays in hiding. These soft crayfish were found by turning over rocks or forcing them from their hiding places with a stick. No extra effort was made during the sampling to find soft crayfish, with the result that the sampling remained random.

In male crayfish, a molt must take place before they can change from Form I to Form II or from Form II to Form I and females of other species do not molt while carrying young or eggs. This information was valuable also in determining the times of the molts. The foregoing methods were applied to the young as well as to the adults.

Growth rates were calculated as the average growth increment per molt (mm. per molt). Calculations were made by dividing the number of molts in a certain period into the increase in carapace length over the same period. Growth rates were calculated for the young-of-the-year as a group; and for the males and females of the Year I, Year II and Year III age groups.

In male crayfish, the attainment of sexual maturity can easily be detected by the first appearance of the Form I copulatory stylets. When this had taken place, on the next molt the male molted to Form II. Mature Form II individuals can readily be separated from the juvenile males by noting the size difference between the two groups (Form II males usually were over 27 mm. carapace length).

Female crayfish have no external indication of their maturity before eggs appear in the spring. To determine the minimum size of a mature female, twelve females, collected on September 4, 1969 (well into the mating season), were dissected and their ovaries examined to ascertain their state of maturity. The smallest individual found with mature ovaries was assumed to be the minimum size for mature females. This assumption was supplemented by the size of the smallest female carrying eggs in the spring. The spring data also gave an opportunity to estimate the error in percentage maturity calculations. The females over the minimum size that were not carrying eggs in the spring were collected and dissected and their ovaries examined to determine their state of maturity.

The mating season was assumed to have begun when the first couple were observed mating in the field and to have ended when no further mating activity was observed. When copulation was observed, notes were made as to the time of day, the area in the stream where it occurred and the size of the participating pairs.

During the spring of 1970, extended observations and collections were made of females to determine when the eggs were laid, when the eggs hatched and when the molts occurred in the young-of-the-year attached to the females. These observations were made during the normal sampling period. During the early weeks of May, several of the larger females were dissected and their ovaries examined. This was done in an attempt to determine exactly when the eggs were laid.

When the females with eggs were found in abundance (first week of June, 1970), seventeen were collected and their eggs counted. A regression line was then calculated for the number of eggs per female vs carapace length of the female.

Numberous notes were taken throughout the study on the habits of the individual crayfish. No definite procedure was used in watching for these habits. The notes accumulated have helped immensely in the interpretation of various stages within the life history.

Throughout the study period, bi-weekly oxygen concentration readings were taken with the HACH kit, Model DR-EL (supplied by the HACH Chemical Company, P. O. Box 907, Mames, Iowa, U.S.A.). Temperature~~s~~

readings were taken in degrees Centigrade on every sampling date.

CHAPTER VI

RESULTS AND DISCUSSIONS

(a) Age Groups:

The first active adults were found in the study area during the second week of May. These were mainly Year I individuals. Year II and Year III individuals were not common until the latter part of May. Young-of-the-year were found in the study area towards the end of July. The young had an average carapace length of 5.7 mm., when first collected on July 31, 1969, and 3.9 mm. when first found on July 21, 1970. (In 1969, sampling for the young-of-the year did not begin until the above date). The maximum average carapace length for the young was 14.3 mm. on October 23, 1969. Although the males, as a rule, were larger than the females, in the young there was no statistically significant difference between the two groups (X^2, a = 0.05). The young were distinguished easily from the Year I individuals throughout the study because of this size difference.

Table IV shows the estimated carapace length ranges for the three adult age groups. In calculating the male ranges, the values estimated from the growth data were similar to the values estimated from the histograph (Figure II) and it is believed, therefore, that these ranges were close to the actual values.

In estimating the female ranges, the histograph (Figure III) showed no indication of age groups and, as a result, more emphasis was put on the estimations made from the growth data.

Aiken (1967, b) and Momot (1964) have given carapace length

TABLE IV

	AGE GROUPS	CARAPACE LENGTH RANGES
Male	Year I	* to 28.0 mm.
	Year II	*28.0 mm. to 32.0 mm.
	Year III	32.0 mm. to **
Female	Year I	* to 27.0 mm.
	Year II	27.0 mm. to 31.0 mm.
	Year III	31.0 mm. to **

* The Year I individuals are easily distinguishable from the Young-of-the-year.

** It was assumed that all individuals over this length were in their third year. In one case only was there an individual found that could have been Year IV.

Table IV: The carapace length ranges (mm.) for the three adult age groups found in the study area.

FIGURE II

Figure II: A histograph showing the distribution of 180 individuals over the entire range of carapace lengths for the adult males of *Orconectes virilis*.

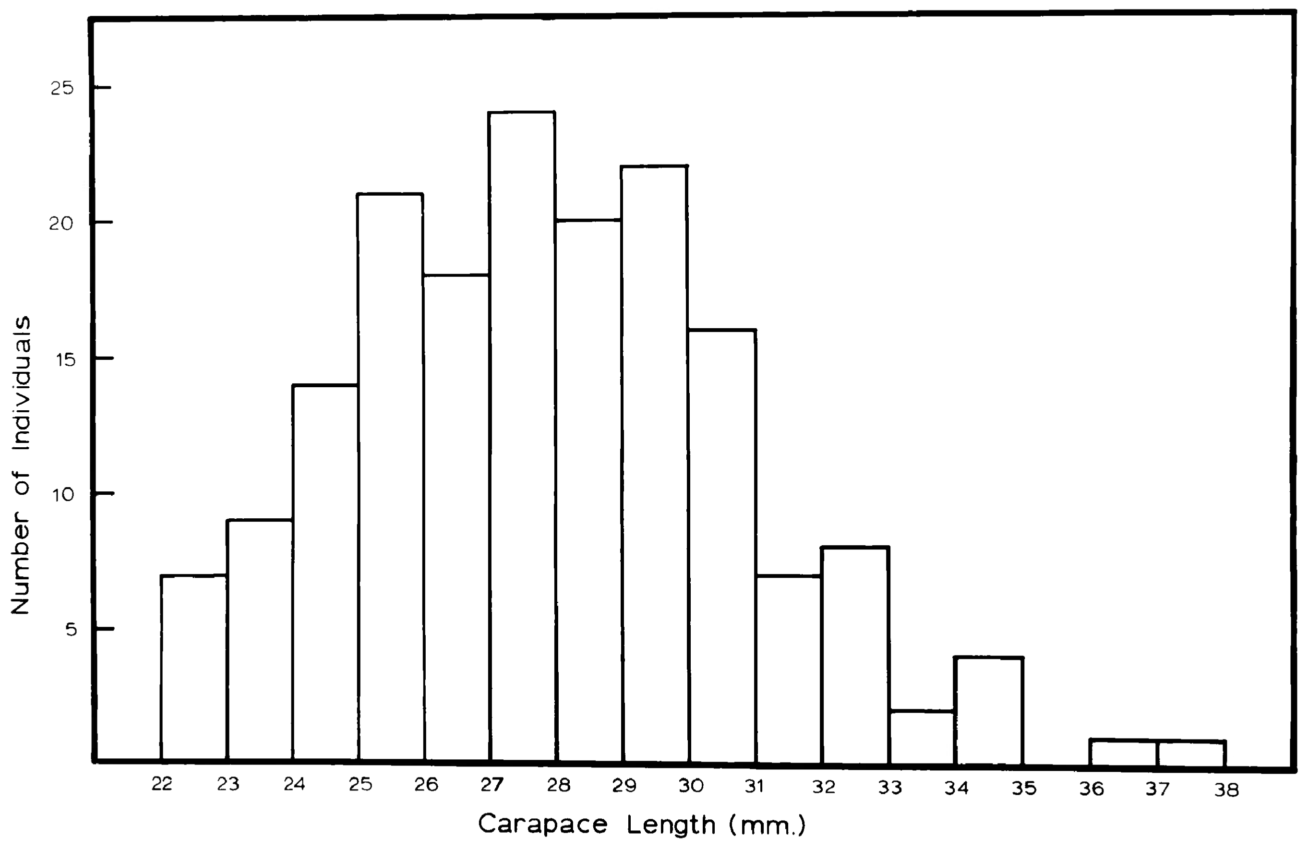
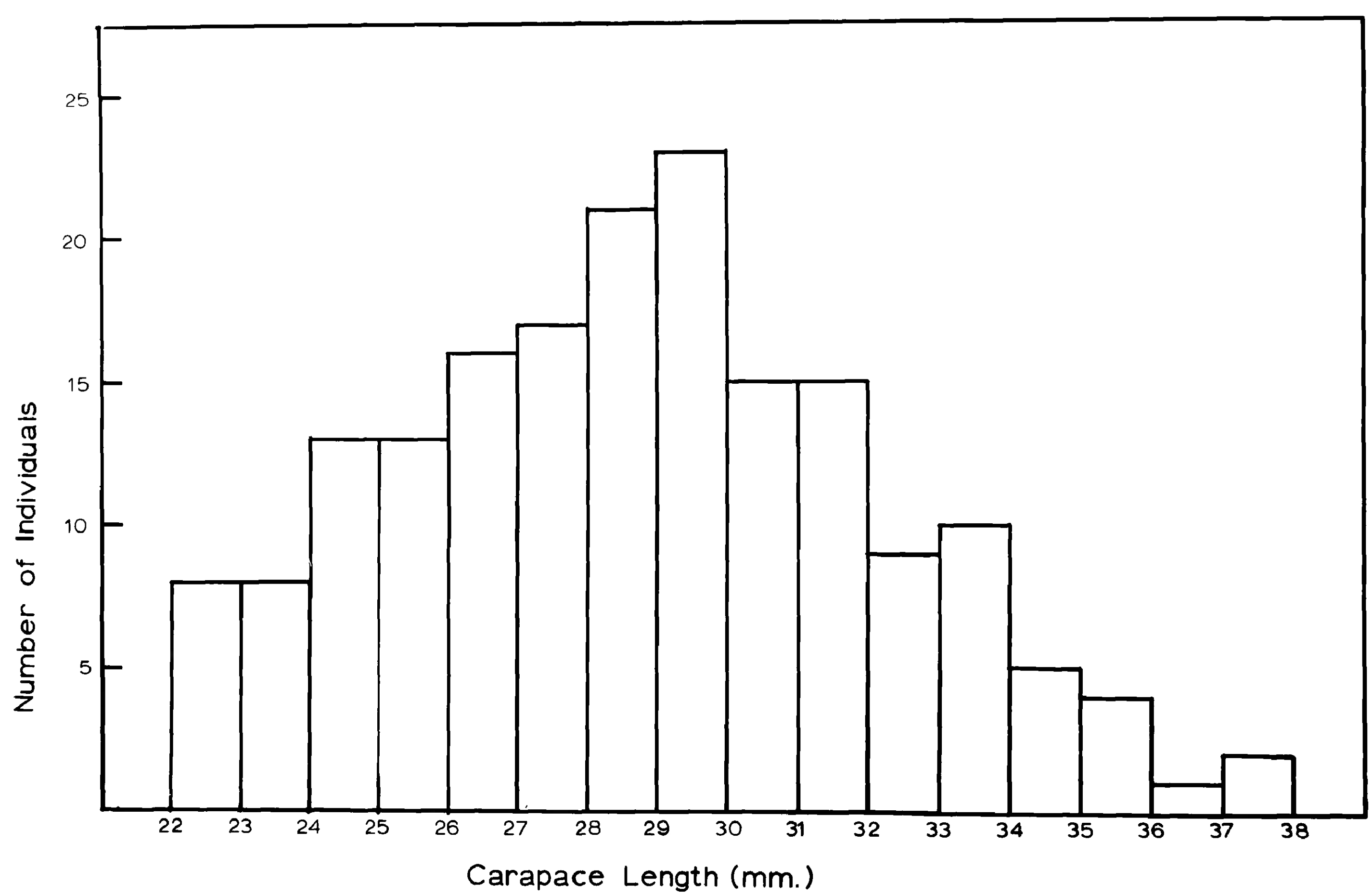

Number of Individuals
5
10
15
20
25
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
Carapace Length (mm.)

FIGURE III

Figure III: A histograph showing the distribution of 186 individuals over the entire range of carapace lengths for the adult females of *Orconectes virilis*.


Number of Individuals
5
10
15
20
25
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
Carapace Length (mm.)

ranges for Orconectes virilis (Table V). The age group ranges in my study are larger than those from Alberta, but smaller than those from Michigan. Momot (per. comm.) has suggested an increase in size within the species as one moves south within its range.

Errors caused by the overlapping of age groups could not be calculated, because at no time during the study did I know the exact ranges for any age group. Such errors were calculated by Momot (1967). He states that "about 20% were one year older or younger, depending on the interval assigned...". The methods used in both cases were very similar and it is hoped than an accuracy similar to Momot's was attained in the present study.

No attempt was made to estimate the number of individuals in the population. The method of collecting the adults, however, allowed me to calculate the percentage each adult group made up in the total population (Table VI). These calculations suggest that the mortality rate increased as the animals grew older. Momot (1967) had similar results. However, Momot extended his data and showed different mortality rates for different seasons of the year. During the study, the number of dead crayfish found in the stream increased during the times of high molting activity, with numerous females found dead after the summer molt, and dead males common after both the spring and summer molts. Momot's periods of high mortality could also be associated with the periods of high molting activity. This death rate during molting has been elaborated upon by Aiken (1967, a).

TABLE V

AUTHORITY	LOCATION	YOUNG	YEAR I	YEAR II	YEAR III
Aiken (1967, b)		8 mm.	17-24 mm.	30-35 mm.	36-42 mm.
Momot (1964)	Michigan	13-15 mm.	26-30 mm.	31-37 mm.	36-42 mm.
Weagle (Present Study)	N.W. Ont.	8.5-18 ~~5-16~~ mm.	18-28 ~~16-28~~ mm.	27-32 ~~28-32~~ mm.	31-45 ~~32-44~~ mm.

Table V: Comparative data from three areas of the carapace length ranges of the species Orconectes virilis.

TABLE VI

AGE GROUP	PERCENTAGE OF TOTAL ADULT POPULATION FOR EACH SEX	
	MALE	FEMALE
Year I	49%	52%
Year II	38%	37%
Year III	13%	11%
TOTAL NUMBER EXAMINED	288	287

Table VI: The age group breakdown in percentage of total adult population for each sex, for the three age groups found in the study area (collections taken in 1969).

(b) Molting:

The young-of-the year, from the time they hatched until late fall, underwent an average of five molts. The first molt occurred while the young were still attached to the pleopods of the female and will be described later. The remaining four molts occurred in the free-living young.

The first free-living molt in the young occurred towards the end of July. At this time, the young had a very soft exoskeleton and it was not possible to distinguish the newly-molted young from the rest of the sample. The evidence that led me to believe this molt occurred was the increase in carapace length from the time the young were still attached to the pleopods of the female until the end of July. This increase (1.8 mm.) indicated that a molt must have occurred.

The second molt occurred during the second week of August, the third during the last week of August and the fourth during the second and third weeks of September. No differences between the males and the females, with regard to the times of the molts, were noted in this age group. No information on molts in the young-of-the-year for this species was found in the literature.

The first molt in Year I males occurred during the second and third weeks of June, the second during the second week of July and the third during the fourth week of July. During the third molt, 40% of the Year I males changed from juvenile to Form I. These individuals did not molt again until the following spring. The other 60% underwent a fourth molt during the third week of August, during which time another 10% also molted to Form I.

The first Year I female molt occurred during the second and third weeks of June; the second occurred during the second week of July and the third during the first week of August. It was estimated that 65% of the Year I females reached maturity during their third molt. It is possible that there was a fourth molt in this group and, if so, it occurred during the first week of September and only those individuals that did not reach maturity during a previous molt participated.

Aiken (1967, b) recorded the molting periods for the yearlings of O. virilis as follows: First molt, late May; second molt, latter part of June; third molt, middle of July; fourth molt, first week of August. In my study area, the molts in this age group began about one week later and there was an average of two rather than three weeks between the molts. The June 1st to 15th male molt, from Form I to Form II in Aiken's group, was also approximately one week earlier than in my study area, as was his male molt from Form II to Form I. The adult female molt in Aiken's area, July 10th to 31st, was very close to the corresponding molt in my area. Aiken assumed 80% of his yearlings reached maturity (apparently he observed no differences between the males and the females).

Entering Year II, the males were either Form I or juvenile. In both cases, the first Year II molt occurred during the third week of June. During this time, the juveniles underwent another juvenile molt and the Form I males molted to Form II. The second Year II male molt occurred during the second and third weeks of

August. At this time, all the males molted to Form I.

Year II females that did not bear eggs in the spring underwent their first molt during the third week of June and their second molt during the second week of July. It was assumed that the latter molt brought these individuals to maturity. The females that bore eggs underwent a signle molt in their second summer, and it occurred after the young had left the mother, during the month of July. There was a close synchrony between the leaving of the young and this molt.

Year III males underwent two molts. The first occurred during the third week of June, when they molted from Form I to Form II; the second occurred during the first two weeks of August, when they molted from Form II back to Form I. One Year III male was found in July, 1970, that had apparently molted from Form I to Form I.

Year III females underwent only one molt, which occurred during the last two weeks of July. This molt, as the corresponding molt in Year II females, occurred only after the young had abandoned the mother.

Figures IV and V show the estimated molt periods for the four-year groups. These are the periods of highest molting activity and newly-molted individuals can be found at any time throughout the study.

In Michigan, Year II and Year III male molts from Form I to Form II occurred between June 5th and July 4th (90% had molted by June 14th) and the molt from Form II to Form I took place between

FIGURE IV

Figure IV: The periods of oviposition, hatch, and highest molting activity for the males of *Orconectes virilis*.

O - Oviposition.

H - Hatch

1, 2, 3, etc. - The number of the molt in the age group under consideration.

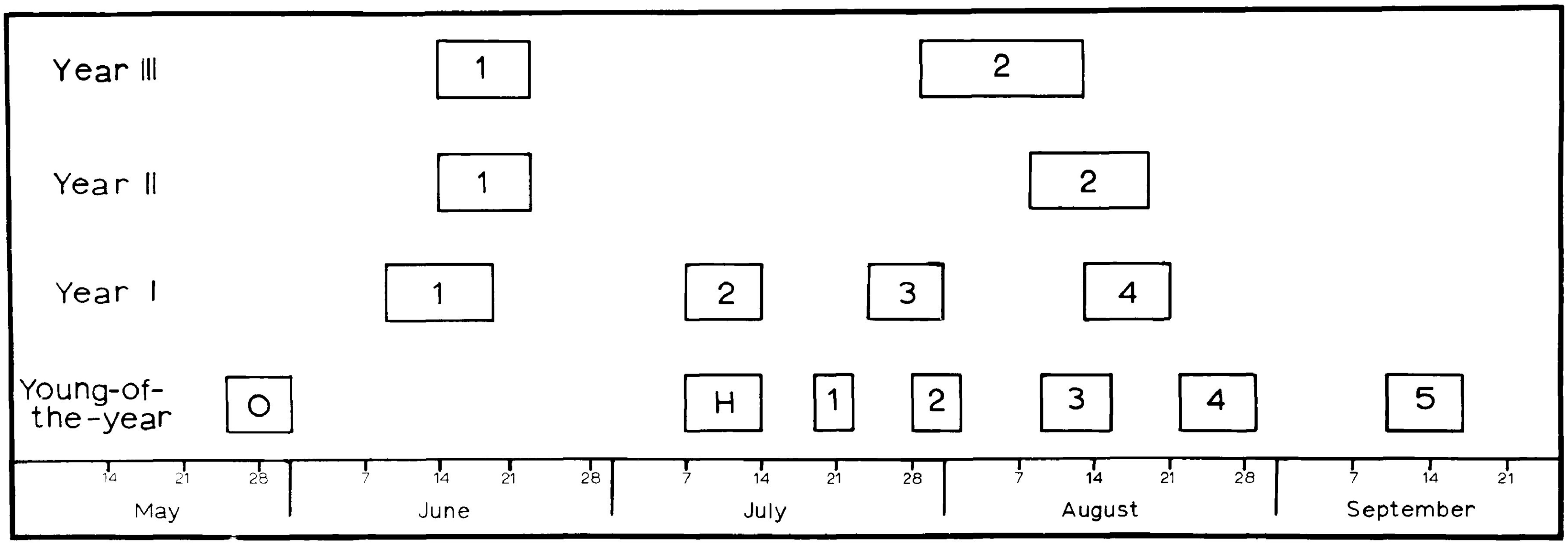
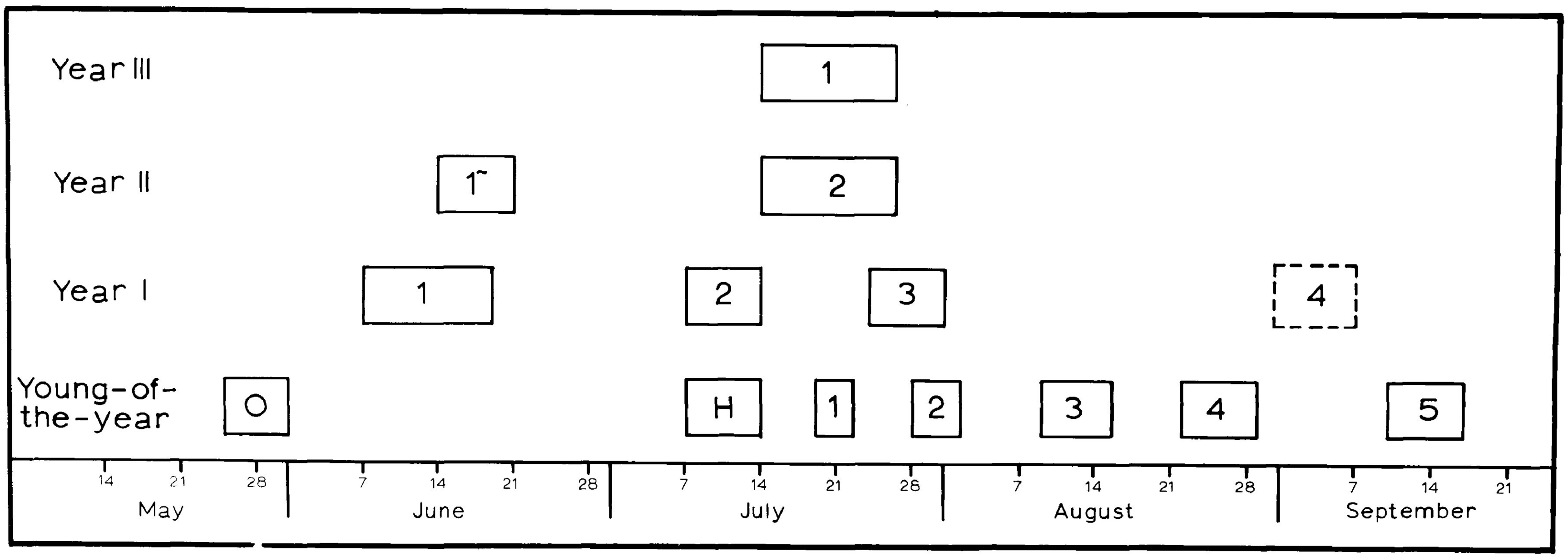

Year III
1
2
Year II
1
2
Year I
1
2
3
4
Young-of-the-year
O
H
1
2
3
4
5
14 21 28
May
7 14 21 28
June
7 14 21 28
July
7 14 21 28
August
7 14 21
September

FIGURE V

Figure V: The periods of oviposition, hatch and highest molting activity for the females of *Orconectes virilis*.

0	- Oviposition.
H	- Hatch
1, 2, 3, etc.	- The number of the molt in the age group under consideration.
1^*	- Only Year II females that did not bear eggs molted at this time.
Year I '4'	- This molt may have occurred in the females that did not reach maturity during that year.


Year III
Year II
Year I
Young-of-the-year
1
1˜
2
1
2
3
4
O
H
1
2
3
4
5
14
21
28
May
7
14
21
28
June
7
14
21
28
July
7
14
21
28
August
7
14
21
September

July 5th and August 9th (90% of Year II had molted within 20 days and 90% of Year III had molted within 17 days) (Momot, 1967). The yearling males in Michigan molted three to four times, similar to mine, but Momot suggested that the yearling females molted only once, whereas mine molted at least three times.

~~The phenomenon of molting from Form I to Form I in the males has been reported also in Alberta (Momot, 1967; per. comm. with Aiken).~~

(c) Growth:

The growth increments per molt are shown in Table VII. There were no statistical differences between the average carapace lenths of the young-of-the-year males and females (X^2, a = 0.05) and, therefore, these two groups were combined for average growth increments per molt calculations.

The growth increments for the females are larger than those for the males, but again these differences are not statistically significant (X^2, a = 0.05).

No average growth increments per molt were calculated for Year III individuals because there ~~was~~ were never enough individuals found in this age group to make a valid estimate.

The average growth increment per molt shows that the young-of-the year have a much higher growth rate than any of the other three age ~~year~~ groups. The average increase in carapace length, over the pre-molt carapace length (average growth increment per molt/average pre-molt carapace length) for the young-of-the-year was 0.24 and only 0.09 for Year I and 0.07 for Year II. When looking at the

TABLE VII

AGE GROUP	AVERAGE GROWTH INCREMENT PER MOLT	
	MALE	FEMALE
Young-of-the-year	2.5 mm./molt	2.5 mm./molt
Year I	2.1 mm./molt	2.3 mm./molt
Year II	2.3 mm./molt	2.6 mm./molt
*Year III	?	?

*Year III - sufficient data ~~was~~ were not available to make a valid estimation of the average growth increment per molt.

Table VII: The average growth increment per molt (mm./molt) calculated for the 1969 season.

calculated growth increments, one must remember that this is the "average" for all the molts in that age group. It does not mean to suggest that on the first young-of-the-year molt the increase in carapace length was 2.5 mm. - this figure is the average increase found over the four molts in this age group.

Momot (1967), using instantaneous growth rates also, showed a higher growth rate in the young than in the other three age groups.

(d) Maturity and Mating:

The smallest male found with Form I copulatory stylets was 24.9 mm. carapace length. In order that there would be no error in the calculations of the percentage of mature and immature males, only males with Form I copulatory stylets and large Form II males were considered to be mature. During Year I, 50% of the males reached maturity - 40% on the third Year I molt and 10% on the fourth Year I molt.

The smallest female found with mature ovaries in the fall was 23.9 mm. carapace length. The smallest female found carrying eggs in the spring was 24.5 mm. carapace length. It is believed that 65% of the Year I females reached maturity on their third molt; the remaining females reaching maturity on their second Year II molt. In view of the fact that some males had Form I copulatory stylets at 24.9 mm. carapace length and others had them for the first time at 28.0 mm. carapace length, there was very likely a similar variation in the attainment of maturity in the females of this species.

Momot (1967) reported the smallest females he found to be carrying eggs was 24.6 mm. carapace length.

In the spring of 1970, examinations of the ovaries of 26 females (17 with eggs and 9 without eggs), ranging in carapace length from 23.8 mm. to 35.3 mm., suggested that few Year I female crayfish mated during the fall mating season. Over the winter, the ova of those females that did not mate ~~was~~ were resorbed into the ovaries, leaving only small white oocytes in the spring. These oocytes were not found in the females which had laid eggs in the spring. Oocytes were absent also in some Year II females examined (Year I, during the mating season). It was assumed that these latter individuals had not reached maturity during Year I.

Stephens (1952) showed that in the females of O. virilis ovarian eggs were readily resorbed under experimental conditions. These experimental conditions were similar to those present in the field when the eggs in some of my Year I females were resorbed.

Mating was observed only between Form I males and mature females. The fall mating season began during the last week of July (1969). It was at this time that the first Form I males were collected. Mating was observed in the field on the following dates in 1969: July 18th, July 19th, August 12th, August 14th, August 25th, September 4th and September 10th. The foregoing observations were made during the day (from 10:00 a.m. to 3:00 p.m.) and mating seemed to be independent of the time of day. There also seemed to be no size preference between pairs; with Year I, Year II and Year III individuals mating randomly with each other. This observation, could, however, be misleading, in view of the fact that few of the mature Year II females bore eggs.

Mating was not observed in the spring of 1970. Attempts to induce mating between females without eggs and Form I males at this time met with failure. Such a spring mating season has been suggested by Crocker and Barr (1968: 94), Fasten (1914), and Threinen (1958). It should be noted that Crocker and Barr's statement was made in light of Fasten's statement, "In early spring a period of mating may ensue...". Threinen (1948), however, states that spring mating in this species has been observed in Wisconsin. Aiken (per. comm.) and Momot (per. comm.) suggested that there was no spring mating season in Orconectes virilis in either Alberta or Michigan. In view of the state of the ovaries in the spring, it is extremely unlikely that a spring mating would be fertile. Aiken (1967) found egg laying to be dependent on the raising of the water temperature to 11°C after winter conditions, which would also point to the failure of a spring mating.

Bovbjerg (1953) produced findings which may explain the small number of Year I females that produced eggs. Working with dominance order, Bovbjerg showed that the larger individuals within a sex were dominant over the smaller individuals and, thus, the higher rank the individual held in the dominance order, the more active it would be. Since mating seemed to be random, the possibility of mating would be proportional to the amount of contact ~~exhibited~~ experienced by the individual. A higher ranking female is more likely to encounter a mate than a lower ranking female because she would cover more territory and have a higher chance of contact with a male. Bovbjerg also states, "When established social groups of the two sexes were joined, there followed many instances of low ranking males fighting and copulating with dominant females".

The males were the aggressive members of the pairs and always initiated copulation. It was observed that males would stay concealed in the entrance to their hiding places and wait for an approaching individual. The male would then make the first contact, usually in an aggressive manner. There was a brief conflict and then the couples would either copulate or break apart. There seemed to be no formal seeking out of mates, with mating dependent on the random meeting of consenting individuals. On August 19, 1969, one male was observed trying to mate with four separate individuals. The first three encountered were males (two Form II and one Form I) and the fourth was a female. The encounters with the males ended with conflicts that lasted up to two minutes.

When a receptive female encountered a receptive male, there was little resistance on the part of the female and copulation began promptly. The male, using his chela, grasped the female and turned her onto her back. He then grasped her four walking legs with his, her chela with his chela, and held her down (as depicted in Plate VI). The female's telson and uropods were folded over her abdomen, while the male's telson and uropods were extended posteriorly. The female's telson may have helped to guide the male's copulatory stylets into the seminal receptable. Once the copulating pair was in position, no movement was observed in either their bodies or genitalia. Only one couple was observed approaching each

PLATE VI

Plate VI: A pair of crayfish (O. virilis) copulating in an aquarium. The picture was taken during the fall of 1969. The carapace lengths of the two individuals ~~was~~ were not noted. Note the position of the chela, uropods and copulatory stylets.

other, copulating and then releasing. The entire process lasted about thirty minutes. The other copulating pairs observed were found already in position.

The position assumed during copulation was very similar to that assumed by other crayfish species.

Mating was very common in the collecting bucket, where there was a high probability of contact between males and females.

Once the water temperature reached $10^{o}C$ (second week of September), the adults became sluggish and mating pairs became scarce.

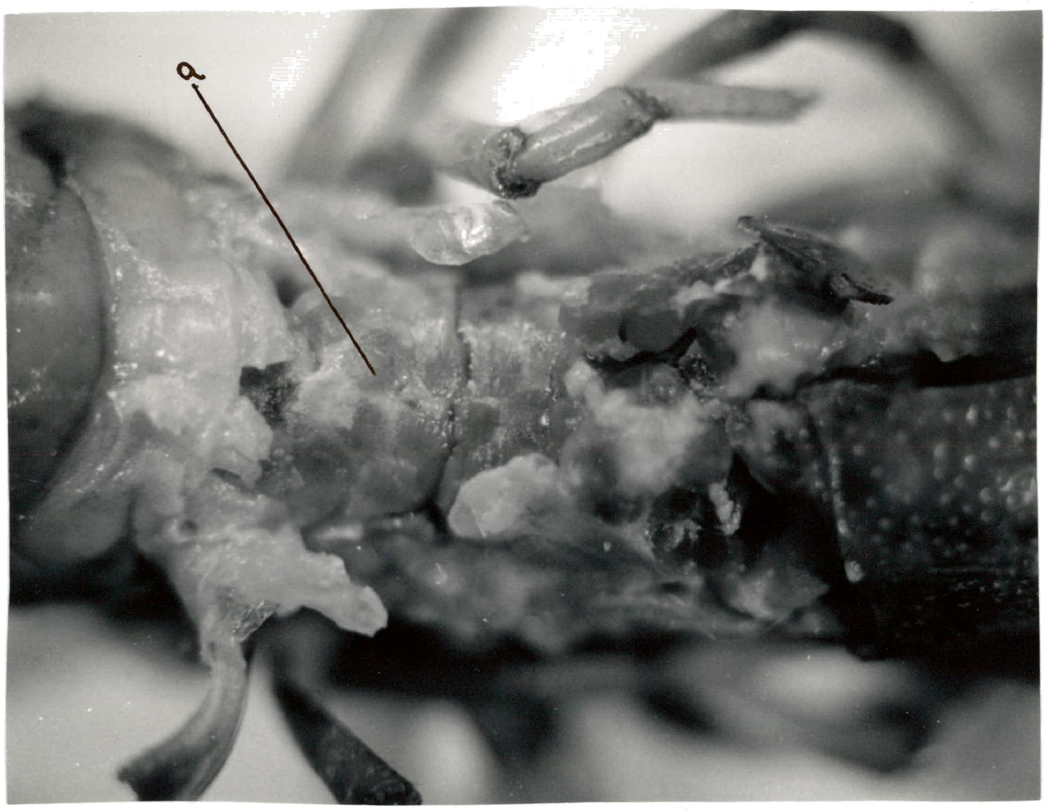
(e) Oviposition and Early Development:

The exact time of oviposition was not determined. The ovaries of the first mature female collected in the spring (May 19, 1970) contained fertilized eggs (Plate VII). At this time, no females were collected with eggs attached to their pleopods. Few females were collected before the first week of June, when the majority of females carried eggs. None of the mature females collected on June 3, 1970, and dissected, had mature eggs in their ovaries. Aiken (1967) suggested that the eggs were not laid until the water temperature had reached $11^{o}C$ in the spring. The water temperature in my study area on May 28, 1970, was $10^{o}C$, and on June 3, 1970, it was 15 C. On or before May 28, 1970, no females were found with eggs, and by June 3, 1970, no mature females were found without eggs (except in the case of Year II females as mentioned earlier), which would indicate the actual laying of eggs to be during the last week of May. Crocker and Barr (1968: 94) suggest May and

PLATE VII

Plate VII: Fertilized eggs within the ovary of the female. This female was collected on May 19, 1970, and was 26.9 mm. carapace length.

'a' - Fertilized eggs.


a

Threinen (1958) suggests April to June.

The average number of eggs carried per female was 214. Figure VI, however, shows that the number of eggs carried per female increases directly with carapace length. The largest number of eggs found on a single female was 320. The carapace length of that female was 34.0 mm. Several females were found with three to five eggs attached to their pleopods. The reason for this is unknown. Momot (1964) calculated the average number of pleopod eggs to be 83 for Year II females and 107 for Year III females. This is much lower than the average number of eggs for the same groups in my study area. With the number of eggs per female in Momot's study area being directly proportional to carapace length, and the females in his area being generally larger than those in my area, it seems strange that there would be such a difference in the number of eggs per female. The maximum number of eggs found per female by Momot (220) was also considerably lower than that found in my study area (320).

The first young were found attached to the mothers during the first week of July and by the end of the second week 90% of the mothers carried young. The first instar young remained attached to the mother's pleopods by an embryonic thread.

The first molt in the young-of-the-year occurred while they were still attached to the mothers and took place towards the end of the third week of July. After this molt, the young remained attached to the mothers by their chela. During the second instar, most of the young abandoned the mothers. The majority of the young had abandoned

FIGURE VI

Figure VI: The regression line represents the relationship between the number of eggs carried per female and the carapace length of the female.

Formula: $Y = 15.15\,x - 239$

r^2: 0.80

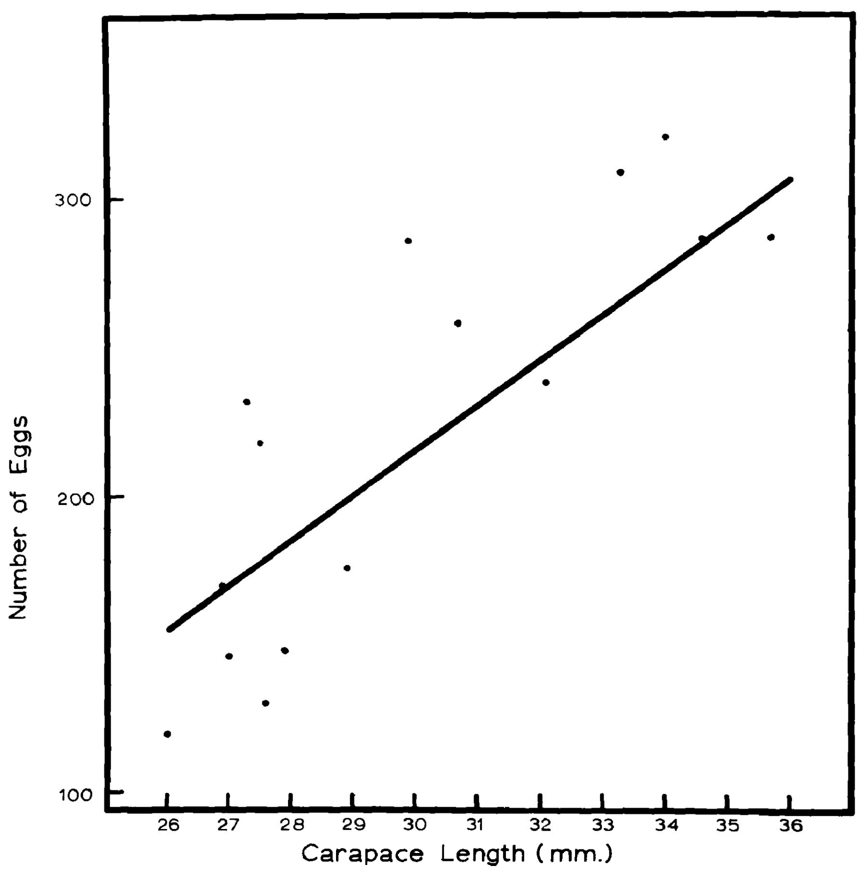

300
200
100
Number of Eggs
26
27
28
29
30
31
32
33
34
35
36
Carapace Length (mm.)

PLATE VIII

Plate VIII: Eggs attached to the pleopods of the female. This female, collected on June 15, 1970, was 29.5 mm. carapace length and was carrying 287 eggs.

the mothers by the time of the second molt (referred to earlier as the first free-living molt). The young still attached to the mothers ~~during~~ to the time of this molt abandoned their mothers immediately preceding it and from that time on were free living.

(f) Overwintering:

In mid-September, with the lowering of water temperature~~s~~, adults became very scarce in the samples. After October 3, 1969, at which time the water temperature was 9°C, no adults were found. Young, however, were present in numbers in the stream until the freeze-up in early November. Young were even found frozen in the ice in some of the shallows near shore. During the winter, the ice reached a depth of 35 cm. in the sampling area.

The first individuals observed in the spring (May 6, 1970), were Year I (young from the fall). At this time, the water temperature was 2°C. Since the water was very silty and high, no collections were attempted. Most of the first adults collected in the spring were taken from under rocks, where they were found to be in a dormant state. At these low water temperatures, they were very slow to respond and were captured easily. Even in low water temperatures, individuals under 18 mm. carapace length were active.

The high water during the spring prevented the actual counting of dead crayfish, but it was assumed that there was a heavy winter mortality. This mortality would be caused partially by natural deaths and partially from being frozen in the ice.

Aiken (1968, b) has done some investigation into the over-wintering of crayfish, but adequate research has not been carried out in this field to date.

(g) Orconectes virilis vs Other Crayfish Species:

In Table VIII, I have attempted to compare the life histories of eleven species of crayfish, eight from the genus Orconectes and three from the genus Cambarus.

The majority of North American crayfish have a life span of three years and reach maturity at the end of their second summer, or, as it is referred to in this study, Year I. O. virilis is no exception. O. nais, O. propinquus and O. clypeatus, however, have only a two-year life span. Crocker and Barr (1968: 70) suggest O. propinquus reaches maturity at about four months, which would give the female an opportunity to produce two broods in a life span, even though it lives only for two years. O. limosus also reaches maturity in approximately four months (Andrews, 1904).

Although complete carapace length ranges for the age groups of all the eleven species were not found, one can see that O. virilis is neither the smallest nor the largest species of crayfish. C. l. longulus is notably smaller than O. virilis and O. causeyi is notably larger. Several other species from the genera Astacus and Cambarus also are larger than O. virilis. As mentioned earlier, there is a tendency within the species to find larger individuals in the southern extensions of its range (Momot, per. comm.). The average carapace lengths for Year III individuals of O. virilis range from 30 mm. in Alberta to 47 mm. in Wisconsin (Momot, unpublished). The carapace lengths of the newly-hatched young in the eleven species have little variation, ranging from 2.5 mm. to

SPECIES	AUTHORITY	LOCATION	LENGTH OF LIFE	Sex	SIZE (Carapace Lengths in mm.) Young	Year I	Year II	Year III	MATURITY Age	Size	MATING SEASON	OVIPOSITION Date	Average No. of Eggs	Max. No. of Eggs	INCUBATION PERIOD	HABITAT	BURROWS
Orconectes virilis	Present Study	Northwestern Ontario	3 years	M F	3.5 - 18.0 mm. 3.5 - 18.0 mm.	18.0 - 28.0 mm. 18.0 - 27.0 mm.	28.0 - 32.0 mm. 27.0 - 31.0 mm	32.0 - 45.0 mm. 31.0 - 38.0 mm.	13 months 13 months	25.0 mm. 24.0 mm.	Aug. to September	Last of May	214	320	7 weeks	Stream	No
Orconectes causeyi	Dean (1969)	New Mexico	3 years	M F	3.5 - 22.0 mm. 21.0 mm.	44.0 mm. 41.0 mm.	52.0 mm. 47.0 mm.	61.0 mm. 63.0 mm	14-15 months 14-15 months	44.0 mm. 41.0 mm. C.l.	Aug. to September	March to May	415	1,051	6-9 weeks	Lake	Yes
Orconectes rusticus	Langlois (1935, 1936)	Ohio	?		6.0 - 43.0 mm. Total Length						Sept. to October	April to May		574	1 week	Pond	Yes
Orconectes immunis	Tack (1941)	New York	3 years	M F	3.0 - 29.0 mm. 3.0 - 29.0 mm.	29.0 mm. 23.0 mm.	35.0 mm. 40.0 mm.		13 months 13 months	22.0 mm. 22.0 mm.	July to October	Oct. to November	144	289	3-4 weeks	Pond	Yes
Orconectes propinquus	VanDeventer (1937) Creaser (1933, 1934) Vannote (1963)	Illinois	2 years		26.0 mm.	32.0 mm.	39.0 mm.		4 months	15.0 mm.	Spring & Fall	Spring			4-6 weeks	?	Yes
Orconectes nais	Momot (1966)	Oklahoma	2 years	M		20.4 mm. 21.3 mm.		36.5 mm. 35.4 mm.								Stream	Yes
Orconectes clypeatus	Smith (1953)	Louisiana	2 years						1 year		Aug. to September	September	142		2 weeks	Stream	Yes
Orconectes limosus	Andrews (1904)	Maryland	?	F					4½ months	50.0 mm. Total Length	Fall & Spring	March & April			6-8 weeks	Pond	Yes
Cambarus montanus acuminatus	Wood & Hobbs (1958)	Virginia	3 years	M					18 months	23.0 - 28.0 mm.	Fall to Spring					Stream	?
Cambarus longulus longulus	Smart (1962)	Virginia	3 years	M F	2.5 - 17.0 mm. 2.5 - 16.0 mm.	19.0 - 23.0 mm. 18.0 - 22.0 mm.	22.0 - 26.0 mm. 21.0 - 25.0 mm.	26.0 - 28.0 mm. 24.0 - 28.0 mm.	Year I or II Year I or II	19.0 - 23.0 mm. 18.0 - 22.0 mm.	March to April Sept. to October	April to June		45	3 weeks	Stream	Yes
Cambarus bartoni bartoni	Crocker & Barr (1968: 110-118) Chidester (1908, 1913)	New York									Possibly all Year	Sept. to Nov. & March to May					Yes

Table VIII: A comparison of the life history data for seven species from the genus Orconectes and three species from the genus Cambarus, with the data accumulated for Orconectes virilis in the present study.

3.5 mm.

There are basically three times for mating in crayfish. The first, and the one in which O. virilis is included, is the fall mating season, usually during the time of cooling water temperatures; the second, a spring and fall mating season; and the third a mating season which extends through most of the warmer months. From Table VIII, it would appear that the Orconectes species are most likely to have a fall mating season, with the Cambarus species having a spring and fall mating season. Crocker and Barr (1968: 112-113) suggest C. b. bartoni has a mating season which possibly extends over the entire summer, with oviposition in the spring and fall. In six of the species in Table VIII, oviposition occurs in the spring; in two of them it occurs in the fall and in one it takes place in both spring and fall. O. virilis again is in the majority group, with oviposition occurring in the spring.

O. clypeatus and C. l. longulus had the least number of eggs carried per female. O. causeyi had the most eggs carried per female and O. virilis was near the middle of the range again.

Incubation periods range from one week in O. rusticus to nine weeks in O. causeyi. O. virilis had a long incubation period, which may be explained by the colder water temperatures during the spring in this area.

O. virilis is selective as to the type of substrate it inhabits, but is not selective as to the type of water in which this substrate is located. Collection records for the species can be found for rivers, streams, ponds and lakes. In this way O. virilis is different from ~~to~~ many other crayfish species, which are very selective, both as to the type of substrate and the type of water they inhabit. C. l. longulus, for example, is found only in riffle areas and flowing water (Smart, 1962) and O. immunis is found solely on mud bottoms and in stagnant water (Tack, 1941).

O. virilis is the only species of the eleven which is not known to burrow in its normal range. Riegel (1959) reported finding this species in burrows in California. Riegel also states that it shared a common habitat with Procambarus clarkii, which does burrow. O. virilis, in this case, may have been occupying the burrow of the former species and not a burrow it constructed itself.

SUMMARY

In Northwestern Ontario, the females of *Orconectes virilis* laid their eggs during the last week of May. The average number of eggs per female was 214 and the maximum number of eggs found on a single female was 320. After approximately seven weeks the eggs hatched (second week of July). The young-of-the-year remained attached to the mother after they hatched and underwent their first molt during the third week of July, after which they remained attached to the mother until just prior to or during the second molt, which occurred during the last week of July. The free-living young-of-the-year underwent an additional three molts; the third during the second week of August, the fourth during the last week of August and the fifth during the second and third weeks of September. By this time, the young had grown from 3.5 mm. (just after their first molt) to an average carapace length of 13.1 mm.; and exhibited a growth rate of 2.5 mm./molt.

Year I males underwent three to four molts. The first occurred during the second and third weeks of June, the second during the second week of July, the third during the last week of July and the fourth during the second week of August. Fifty percent of the Year I males ranged in carapace length from 18 mm. to 28 mm. and exhibited a growth rate of 2.1 mm./molt.

Year I females underwent an average of three molts. The first occurred during the second and third weeks of June, the second during the second week of July and the third during the last week of July and the first week of August. At this time, 65% of the Year I females had

reached maturity. Year I females ranged in carapace length from 18 mm. to 27 mm. and exhibited a growth rate of 2.3 mm./molt.

The minimum size of a mature male was 24.9 mm. and the minimum size of a mature female was 23.9 mm.

Year II males underwent two molts. The first occurred during the third week of June, at which time mature males molted from Form I to Form II and juvenile males underwent another juvenile molt; the second occurred during the second and third weeks of August. With the second molt, all the males molted to Form I. Year II males ranged in carapace length from 28 mm. to 32 mm. and exhibited a growth rate of 2.3 mm./ molt.

Year II females that did not bear eggs underwent two molts; the first during the third week of June and the second during the second week of July. Year II females that carried eggs underwent one molt only and this occurred after the young had abandoned the mothers in July. Year II females ranged from 27 mm. to 31 mm. carapace length and exhibited a growth rate of 2.6 mm./molt.

Year III males underwent two molts, the first occurring during the third week of June, when they molted from Form I to Form II, and the second occurring during the first two weeks of August, when they molted from Form II to Form I. The carapace length ranges for Year III males were 32.0 mm. to 40.0 mm.

Year III females underwent only one molt, which took place after the young had become detached in July. The carapace length ranges for Year III females was 31 to 36 mm.

The mating season in <u>O. virilis</u> was during August and September.

Although 65% of the Year I females reached maturity, few of them mated during their first season.

Aiken, David E., 1965. Distribution and ecology of three species of crayfish from New Hampshire. Amer. Midl. Nat., 73 (1): 240-244.

_____, 1967, a. Subdivision of Stage E (ecdysis) in the crayfish, Orconectes virilis. Canad. J. Zool., 46: 153-155.

_____, 1967, b. Environmental regulations of molting and reproduction in the crayfish, Orconectes virilis (Hagen) in Alberta. Ph.D. Thesis. Univeristy of Alberta, Edmonton, 167 pg.

_____, 1968, a. Further extension of the known range of the crayfish, Orconectes virilis (Hagen). Nat. Mus. Canada Bull. No. 223, Contr. to Zool., IV (4): 43-48.

_____, 1968, b. The crayfish, Orconectes virilis: survival in a region of severe winter conditions. Canad. J. Zool., 46: 207-211.

_____, 1969. Photoperiod, endocrinology and the crustacean molt cycle. Science, 164: 149-155.

Andrews E. A., 1904. Breeding habits of the crayfish. Amer. Nat., 38: 164-206.

Bovbjerg, R. V., 1953, b. Dominance order in the crayfish, Orconectes virilis (Hagen). Physiol. Zool., 26: 173-178.

Bundy, W. F., 1876. Cambarus debilis n. sp. In S. A. Forbes "List of crustacea with descriptions of new species". Bull. Ill. Mus. Nat. Hist., 1: 3-25.

Chidester, F. E., 1908. Notes on the daily life and food of Cambarus b. bartoni. Amer. Nat., 42: 710-716.

Creaser, E. P., 1933. Seasonal changes in the male population of Faxionus propinquus (Girard). Occ. Paper Mus. Zool. (Univ. of Mich.), 253: 1-9.

_____, 1934. Age, growth and sex ratios in the crayfish, Faxonius propinquus. Paper Mich. Acad. Sci. Arts and Letters, 19: 581-585.

Crocker, D. W., 1957. The crayfishes of New York State (Decapoda: Asticadae). N. Y. St. Mus. Bull., 353 (1): 1-97.

_____, and D. W. Barr, 1968. Handbook of the Crayfishes of Ontario. University of Toronto Press, 158 pg.

Dean, J. L., 1969. Biology of the crayfish, Orconectes causeyi and its use for the control of aquatic weeds in trout lakes. Tech. Paper #24, Bur. of Sp. Fish. and Wildl., U. S. Dept. of Interior. 15 pg.

Devilley, E. J., 1965. Isolation of the proteolytic digestive enzyme from the gastric juices of the crayfish, Orconectes virilis (Hagen). Comp. Biochem. Physiol., 14: 577-586.

Engle, E. T., 1929. Crayfishes of the genus Cambarus in Nebraska and eastern Colorado. Bull. U. S. Bur. of Fish., 42 (Document 994): 87-104.

Fasten, Nathen, 1914. Spermatogensis of the American crayfish, Cambarus virilis and Cambarus immunis with special reference to synapsis and chromatoid bodies. Journ. Morph., 25: 587-649.

Faxon, Walter, 1884. On the so-called dimorphism of the genus Cambarus. Amer. J. Sci., 5 (3), 27 (157): 42-44.

_____, 1885, a. A revision of the Astacidae. Mem. Mus. Comp. Zool. at Harvard College, 10 (4): 1-186.

Graenischer, C. J., 1913. Some notes on the habitat and distribution of Wisconsin crayfish. Bull. Wisc. Nat. Hist. Soc., 10: 118-123.

Hagen, H. A., 1870. Monograph on the North American Astacidae. Illus. Cat. Mem. Mus. Comp. Zool., 3: 1-110.

Hobbs, H. H., Jr., 1942, a. A generic revision of the crayfish of the subfamily Cambarinae with a description of a new genus and species. Amer. Midl. Nat., 28 (2): 334-357.

_____, and D. J. Zinn, 1948. Crayfish of southern Nevada. Science. 107 (2780): 369.

~~Holthuism~~ Holthuis, L. B., 1962. The occurrence of the crayfish, Orconectes virilis (Hagen, 1870) in Montana, U.S.A. (Decapoda, Macrura, Astacidae). Crustaceana, 3 (3): 246-247.

Huntsman, A. G., 1915. The freshwater malacostraca of Ontario, Dominion of Canada, 5th Sess., 12th Parliament; Sess. Paper 36 b, Contr. Canada Biol. Fasc., 2 (6): 145-163.

Jungreis, A. M., 1968. The role of stored glycogen during long-term temperature acclimation in the freshwater crayfish, Orconectes virilis. Comp. Biochem. Physiol., 24 (1): 1-6.

_____, and A. B. Hopper, 1968. Physiological properties of cold resistance adaption in the freshwater crayfish, Orconectes virilis. Comp. Biochem. Physiol., 26 (1): 91-100.

Kyer, D. L., 1942. The influence of the sinus gland on gastrolity formation in the crayfish. Biol. Bull., 82: 68-78.

Lagler, K. F., and M. J. Lagler, 1944. Natural enemies of the crayfish in Michigan. Paper Mich. Acad. Arts, Sci. and Letters, 29: 293-303.

Langlois, T. H., 1935. Notes on the habits of crayfish, (*Cambarus rusticus*) (Girard) in fish ponds of Ohio. Trans. Amer. Fish. Soc., 65: 189-193.

______, 1936. Further observations on the habits of the crayfish, (*Cambarus rusticus*) (Girard). Trans. Amer. Fish. Soc., 66: 275-276.

McWhinnie, M. A., 1962. Gastrolith formation and calcium shift in the freshwater crayfish, *Orconectes virilis*. Comp. Biochem. Physiol., 7: 1-14.

Meredith, W. G., and F. J. Schwartz, 1962. The crayfishes of Maryland. Maryland Tidewater News, 15 (1): 1-2.

Momot, W. T., 1964. Population Dynamics of the Crayfish, *Orconectes virilis*, in relation to predation by the brook trout *Salvelinus fontinalis*. Ph.D. Thesis. Univ. of Michigan, Ann Arbor, 79 pg.

______, 1966. The upstream movement of crayfish in an intermittent Oklahoma stream. Amer. Midl. Nat., 75 (1): 150-159.

______, 1967, a. Population dynamics and productivity of the crayfish, *Orconectes virilis*, in a marl lake. Amer. Midl. Nat., 78 (1): 55-81.

Ortmann, A. E., 1905. *Procambarus*, a new subgenus of the genus *Cambarus*. Ann., Carneg. Mus., 3 (3): 435-442.

______, 1906. The crawfishes of the State of Pennsylvania. Mem. Carnegie Mus., 2: 343-524.

Penn, G. H., Jr., 1943. A study of the life history of the Louisiana Red crawfish, *Cambarus clarkii* (Girard). Ecology, 24 (1): 1-18.

Rawson, D. S., and E. L. Moore, 1944. The saline lakes of Saskatchewan. Canadian J. Res., D. 22: 141-201.

Riegel, J. A., 1959. The systamitics and distribution of crayfish in California. Calif. Fish and Game, 45 (1): 29-50.

Roberts, T. W., 1944. Light, eyestalk, chemical and certain other factors as regulators of ~~the~~ community activity for the crayfish, *Cambarus virilis* (Hagen). Ecol. Monogr., 14: 359-392.

Scudamore, H. H., 1947. The influence of the sinus gland upon molting and associated changes in the crayfish. Physiol. Zool., 20: 187-208.

Scudamore, 1948. Factors influencing the molting and sexual cycle in the crayfish. Biol. Bull., 95: 229-237.

Smart, G. C., Jr., 1962. The life history of the crayfish, Cambarus longulus, longulus. Amer. Midl. Nat., 68 (1): 83-94.

Smith, E. W., 1953. The life history of the crawfish, Orconectes (=Faxonella) clypeatus (Hay).

Steele, M., 1902. The crayfish of Missouri. Univ. Cincinnati Bull. 2 (Ser. 2): 1-54.

Stephens, G. J., 1952. Mechanisms regulating the reproductive cycle in the crayfish, Cambarus. I, The female cycle. Physiol. Zool., 25: 70-84.

Streets, T. H., 1877. Description of Cambarus couesi, a new species of crayfish from Dakota. Bull. U. S. Geol. Surv. Terr., 3 (4): 803-804.

Tack, P. I., 1941. The life history and ecology of the crayfish, Cambarus immunis (Hagen). Amer. Midl. Nat., 25: 420-446.

Threinen, C. W., 1958, a. A summary of observations on the commercial harvest of crayfish in northern Wisconsin, with notes on the life history of Orconectes virilis. Wisc. Cons. Dept., Fish Mang. Divis., Misc. Rept., 2: 1-14.

_____, 1958, b. Wisconsin crayfish. Wisc. Cons. Bull. 23: 13-15.

Travis, D. F., 1960. The deposition of skeletal structures in the crustacea. I, The histology of the gastrolith skeletal tissue samples and the gastrolith of the crayfish, Orconectes (Cambarus) virilis (Hagen). Decapoda. Biol. Bull. 118: 137-149.

VanDeventer, W. C., 1937. Studies on the biology of the crayfish, Cambarus propinquus (Girard). Ill. Biol. Monogr. 15 (3): 1-67.

Vannote, R. L., 1963. Community productivity and energy flow in an enriched warm water stream. Ph.D. Thesis, Michigan State Univ., 156 pg.

Williams, A. B., and A. B. Leonard, 1952. The crayfishes of Kansas. Univ. Kans. Bull. 34, Pt. II, No. 15: 961-1012.

Wood, P. J., 1967. Histological and histochemical observations of the haemolymph cells in the crayfish, Orconectes virilis. J. Morophol., 123 (4): 559-567.

Word, B. H., Jr., and H. H. Hobbs, Jr., 1958. Observations on the testis of the crayfish *Cambarus montanus* ~~*acunatus*~~ *acuminatus*. Faxon. Trans. Amer. Microscop. Soc., 77 (4): 435-450.

Collection Data for the Adults

Length:		Carapace Length in millimeters
Form:	I	Form I
	II	Form II
Texture:		Texture of Exoskeleton
	H	Hard
	S	Soft
	NM	Newly-molted
Eggs:	0	No eggs
	Yes	There were eggs
	Instar I	Developmental stage of young
	Instar II	Developmental stage of young
	Hatch	Newly-hatched eggs

July 14, 1969 - Water Temperature: 20°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
34	II	H	31	Instar I	H
32	II	S	32	Instar I	H
32	II	H	28	0	S
29	II	S	26	0	H
36	II	S	23	0	H
29	II	S	26	0	S
35	II	H	27	0	H
24	II	S	27	0	H
28	II	H	22	0	H
19	II	H	35	0	S
26	II	H	26	0	S
24	II	H	25	0	H
30	II	H	24	0	H
23	II	H	29	0	H
32	II	H	25	0	H
26	II	H	25	0	H
28	II	H	21	0	H
20	II	H	20	0	H
27	II	H	22	0	S
29	II	H	23	0	H
26	II	H	20	0	H
27	II	H	26	0	H
16	II	S	22	0	H
24	II	S			
23	II	H			
19	II	H			
27	II	H			

APPENDIX I

July 17, 1969 - Water Temperature: 21°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
33.8	II	H	29.2	0	H
32.5	II	H	31.0	Instar I	H
29.1	II	H	25.9	0	H
29.0	II	H	25.1	0	H
31.2	II	S	29.1	Instar I	H
26.4	II	S	24.4	0	H
27.5	II	H	26.9	Instar I	H
31.8	II	H	25.8	0	H
26.1	II	H	22.6	0	H
27.4	II	S	23.4	0	H
28.6	II	H	25.1	0	S
30.0	II	H	22.7	0	H
33.5	II	H	25.3	0	H
26.7	II	H	20.4	0	H
28.5	II	S	27.2	Instar I	H
28.8	II	S	23.1	0	H
30.2	II	H	30.9	Instar I	H
29.2	II	H	25.4	0	H
24.9	II	S	28.7	0	H
29.1	II	H	22.8	0	H
25.0	II	H	24.5	0	H
28.8	II	H	32.6	0	H
17.0	II	S	28.4	Instar I	H
26.3	II	H	23.7	0	H
28.6	II	H	26.3	0	S
26.3	II	H	28.2	0	H
24.1	II	H	29.4	Instar I	H
20.2	II	H	25.7	0	H
26.6	II	S	21.2	0	H
27.8	II	H	23.7	0	H
25.6	II	H	23.5	0	H
20.1	II	H	22.6	0	H
18.0	II	H	22.6	0	H
20.2	II	H	28.1	Instar I	H
22.3	II	H	24.9	0	H
23.7	II	H	26.5	0	H
26.4	II	H	20.9	0	H
23.6	II	H	25.4	0	H
38.9	II	S	31.4	Instar I	H
38.9	II	H	33.1	Instar I	H
26.0	II	H	35.6	0	H
21.1	II	H	27.2	0	H
22.7	II	H	33.9	0	H
23.0	II	H	28.0	0	S
			27.2	0	H

July 17, 1969 - Water Temperature: 21^{o}C (Cont.)

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
			24.2	0	H
			27.1	0	S
			24.4	0	H

July 29, 1969 - Water Temperature 22^{o}C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
34.4	I	H	27.1	0	H
37.2	I	H	28.8	Instar II	S
32.1	I	H	30.9	Instar II	H
29.6	I	S	23.4	0	S
35.7	I	H	26.9	0	H
32.8	I	H	22.5	0	H
28.0	II	S	24.8	0	H
24.4	II	S	25.5	0	H
28.5	I	H	26.7	0	H
24.9	II	S	27.7	0	H
22.0	II	H	20.0	0	H
24.4	II	H	28.3	Instar II	H
20.9	II	S	28.4	Instar II	H
26.4	I	H	36.0	0	H
23.2	II	H	27.4	Instar II	H
26.9	I	H	28.5	0	H
29.8	I	H	27.8	0	H
29.7	II	H	24.6	0	H
24.6	II	H	23.7	0	H
23.3	II	S	30.6	0	H
29.1	I	H	29.1	0	H
33.5	II	H	27.6	0	S
26.9	I	H	29.7	0	S
29.4	I	S	25.6	0	S
31.0	I	H	23.2	0	H
19.1	II	S	26.7	0	S
30.1	I	S	32.0	0	H
33.8	I	H	29.1	0	H
22.8	II	H	28.5	0	H
27.7	II	H	31.0	0	H
30.2	II	H	23.5	0	H
24.1	II	S	31.5	0	H
32.5	II	H	21.9	0	S
24.6	II	S	22.5	0	H
27.4	II	H	22.6	0	H
29.7	I	H	29.9	0	H
20.6	II	H	23.2	0	H
26.6	II	H	27.6	0	H
15.0	II	H	24.3	0	H
29.6	II	S	33.9	0	H
31.4	I	H	24.8	0	H
31.4	I	H	27.1	0	H
29.6	II	H	26.5	0	S
21.7	II	H	23.9	0	H
31.0	I	H	26.2	0	H

July 29, 1969 - Water Temperature 22^{o}C (Cont.)

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
32.7	I	H	17.0	0	S
26.7	II	H	18.7	0	H
22.5	II	H	23.5	0	H
28.7	I	S	19.1	0	H
28.8	II	H	22.0	0	H
24.7	II	H	22.8	0	H
24.1	II	H	26.6	0	H
29.6	II	H	18.2	0	H
27.2	II	H	24.4	0	H
25.5	II	H	21.1	0	H
26.0	II	H	21.1	0	H
25.9	II	H	19.5	0	H
18.6	II	H			

APPENDIX I

August 1, 1969 - Water Temperature 22°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
35.1	I	H	34.8	0	H
34.4	I	H	29.1	0	S
33.9	I	H	31.1	0	H
33.9	I	S	27.8	0	H
29.2	I	S	27.1	0	H
28.6	II	H	29.3	0	H
32.2	I	H	30.8	0	H
34.1	II	H	31.4	0	H
28.0	I	S	34.2	0	H
29.8	I	H	27.9	0	H
32.7	I	H	32.0	0	H
31.9	I	H	28.9	0	H
31.9	I	H	30.9	0	S
31.5	I	H	28.8	0	H
28.9	I	H	30.0	0	H
30.5	I	H	29.5	0	H
31.3	I	H	30.9	0	S

August 5, 1969 - Water Temperature 20°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
43.6	I	S	31.5	0	H
35.4	I	S	32.9	0	H
25.9	II	H	34.7	0	S
24.3	II	H	29.8	0	S
28.5	I	H	25.2	0	H
24.0	II	H	23.3	0	H
30.9	I	H	30.6	0	H
28.9	II	H	25.8	0	H
19.6	II	S	27.8	0	H
24.7	II	S	25.7	0	H
27.3	I	H	27.3	0	H
21.7	II	H	25.0	0	H
26.7	II	H	28.4	0	H
23.3	II	S	31.4	0	H
29.6	I	H	27.5	0	H
25.9	II	H	25.0	0	H
27.1	II	H	23.6	0	S
27.3	II	H	25.7	0	H
15.5	II	H	26.8	0	H
25.0	II	H	28.8	0	H
26.2	I	H	33.8	0	H
25.0	II	S	27.4	0	H
26.8	II	H	27.2	0	H
26.3	II	H	25.5	0	H
23.0	II	H	26.8	0	H
23.9	II	H	26.9	0	H
21.6	II	H	27.9	0	S
20.2	II	H	25.0	0	H
			28.0	0	H
			24.1	0	H
			24.0	0	H
			24.6	0	H
			19.1	0	S
			24.3	0	H
			21.9	0	H
			22.9	0	H
			18.9	0	H

APPENDIX I

August 14, 1969 - Water Temperature 20^{o}C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
34.3	I	H	29.1	0	H
29.2	I	H	27.4	0	H
29.8	II	S	29.9	0	S
35.3	I	H	32.0	0	H
32.8	I	H	28.0	0	H
25.7	I	H	25.8	0	H
33.9	I	H	27.9	0	H
37.8	I	H	21.6	0	H
27.5	II	H	25.7	0	H
30.8	II	H	26.0	0	H
26.7	II	S	28.7	0	H
26.4	I	H	26.6	0	H
33.8	I	H	26.9	0	H
28.8	II	H	32.5	0	H
22.4	II	H	28.5	0	H
29.2	I	H	29.8	0	H
28.7	I	H	25.6	0	H
29.2	II	H	26.4	0	H
24.3	II	H	29.5	0	H
25.9	I	H	26.2	0	H
29.4	I	H	26.4	0	H
25.0	I	H	24.3	0	H
26.1	II	H	25.0	0	H
30.8	I	H	26.6	0	H
28.4	II	H	24.8	0	H
27.0	I	H	24.7	0	H
24.8	II	H	21.1	0	H
26.2	II	H	22.0	0	H
23.9	II	H	21.5	0	H
26.8	I	H	22.0	0	H
24.0	II	H	20.0	0	H
20.0	II	S	21.4	0	H
23.8	II	H	22.8	0	H
23.0	II	H			
20.1	II	S			
21.0	II	S			
22.4	II	H			
23.4	II	H			

August 19, 1969 - Water Temperature 21°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
28.9	I	H	29.1	0	H
33.8	I	H	29.3	0	H
31.6	I	H	29.0	0	H
28.9	I	H	29.8	0	H
30.0	I	H	38.2	0	H
29.9	I	S	24.6	0	H
26.3	II	H	23.8	0	H
29.9	I	H	28.8	0	H
30.0	I	H	28.7	0	H
28.3	II	H	22.9	0	H
34.6	I	S	30.6	0	H
32.0	II	H	29.5	0	H
29.7	I	H	26.8	0	H
30.0	I	H	25.5	0	H
31.5	I	H	29.8	0	H
27.3	II	H	28.0	0	H
26.0	I	H	24.1	0	H
28.9	I	H	27.9	0	H
26.8	II	H	27.9	0	H
32.4	I	S	23.0	0	H
27.7	II	H	24.0	0	H
29.1	I	H	25.7	0	H
25.9	II	H	27.7	0	H
21.4	II	H	24.3	0	H
27.9	II	H	22.0	0	H
22.6	II	H	19.9	0	H
26.0	II	S	20.6	0	H
22.0	II	S			
25.8	II	H			
24.4	II	H			
22.4	II	H			

August 25, 1969 - Water Temperature 23^{o}C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
31.0	I	H	32.8	0	H
29.1	I	H	29.3	0	H
31.2	I	H	30.6	0	H
30.4	I	H	29.6	0	H
30.0	I	H	29.6	0	H
27.9	I	H	30.5	0	H
29.0	I	H	30.9	0	H
29.3	I	H	27.0	0	H
33.7	I	H	28.2	0	H
32.7	I	H	27.8	0	H
31.0	I	H	29.4	0	H
30.4	I	H	28.7	0	H
29.8	I	H	28.3	0	H
27.0	I	H	33.9	0	H
29.2	I	H	27.1	0	H
27.3	I	H	29.1	0	H
25.4	I	H	27.0	0	H
26.5	I	H	24.6	0	H
29.1	I	H	28.1	0	H
26.4	I	H	26.1	0	H
27.0	II	H	25.7	0	H
29.9	II	H	25.3	0	H
27.7	II	H	19.6	0	H
28.8	II	H	23.8	0	H
29.2	II	H	21.0	0	H
25.1	II	H	18.8	0	H
24.5	II	H	18.6	0	H
21.2	II	H			
21.3	II	H			
23.8	II	H			
23.7	II	S			
20.0	II	H			
20.0	II	H			
21.1	II	H			
20.5	II	H			

September 4, 1969 - Water Temperature $22^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
36.2	I	H	28.7	0	H
32.1	I	H	21.1	0	H
28.9	II	H	34.3	0	H
31.2	I	H	30.3	0	S
30.8	II	S	30.0	0	H
31.2	I	H	27.2	0	H
28.7	II	NM	30.4	0	H
30.1	I	H	26.5	0	H
27.8	I	H	24.0	0	H
29.0	I	H	25.9	0	H
30.2	I	H	23.2	0	H
31.9	I	H	24.7	0	H
32.5	II	H	23.3	0	H
28.9	I	H	27.6	0	H
30.4	I	H	20.3	0	H
28.6	I	H	23.0	0	H
25.1	II	H	22.5	0	H
24.1	II	H	20.4	0	H
27.0	II	H			
25.3	II	H			
28.6	I	H			
28.2	II	NM			
26.5	II	H			
24.9	II	H			
24.8	II	H			
25.0	II	H			
21.0	II	H			

September 10, 1969 - Water Temperature $13^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
31.8	I	H	30.7	0	H
32.0	I	H	33.4	0	H
28.1	II	H	28.8	0	H
26.0	I	H	29.1	0	H
24.4	II	H	28.7	0	H
22.6	II	H	29.0	0	H
			25.0	0	H
			24.5	0	H
			24.0	0	H
			23.1	0	H

September 17, 1969 - Water Temperature $12^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
31.2	I	H	33.2	0	H
33.0	I	H	30.0	0	H
35.9	I	H	30.8	0	H
28.6	I	H	24.5	0	H
25.5	I	H	26.0	0	H
24.1	II	H	26.9	0	H
22.7	II	H	23.0	0	H
24.2	II	H	26.1	0	H
39.2	I	H	27.6	0	H
			24.7	0	H
			23.4	0	H

APPENDIX I

October 3, 1969 - Water Temperature $9^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
32.6	I	H	28.8	0	H
25.3	II	H	30.9	0	H
			22.3	0	H
			23.5	0	H

May 19, 1970 - Water Temperature 8°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
20.1	II	H	20.0	0	H
25.4	II	H	25.3	0	H
23.0	II	H	26.1	0	H
27.0	I	H	22.7	0	H

May 28, 1969 - Water Temperature $10^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
29.1	I	H	27.0	0	H
30.9	I	H	22.3	0	H
			25.4	0	H

June 3, 1970 - Water Temperature $15^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
28.6	I	H	27.8	Yes	H
25.6	I	H	28.9	Yes	H
25.1	II	H	26.1	0	H
26.7	II	H			
30.1	I	H			
30.2	II	H			
27.5	II	H			
27.3	I	H			
32.0	I	H			
30.9	I	H			
26.0	II	H			
26.1	II	H			
24.8	II	H			

June 9, 1970 - Water Temperature $21^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
34.4	I	H	36.1	Yes	H
28.8	I	H	31.0	Yes	H
29.0	I	H	28.9	Yes	H
26.9	I	H	25.3	0	H
30.0	I	H	31.0	5	H
28.8	I	H	27.3	Yes	H
24.8	II	H	27.6	Yes	H
26.7	II	H	25.5	0	H
27.7	II	H	24.8	0	H
28.7	II	H	24.5	0	H
30.0	I	H	25.3	0	H
27.0	I	H	23.9	0	H
26.5	II	H	25.0	0	H
28.2	II	H			
32.3	I	H			
26.2	I	H			
26.2	II	H			
22.6	II	H			
25.1	I	H			

June 15, 1970 - Water Temperature $17^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
32.1	I	H	29.1	Yes	H
30.8	I	H	28.4	Yes	H
24.8	II	H	28.7	Yes	H
32.5	II	H	28.7	Yes	H
30.8	II	S	26.1	0	S
30.4	I	H	28.0	Yes	H
34.6	I	H	34.3	Yes	H
26.4	II	S	30.3	Yes	H
30.0	I	H	27.3	Yes	H
26.1	II	S	25.6	0	H
26.3	II	H	22.6	0	H
30.0	I	H	26.4	0	H
26.1	I	H	23.4	0	H
28.1	I	H	24.4	0	H
26.6	I	H			
27.3	I	H			
25.6	II	S			

June 15, 1970 - Water Temperature $16^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
30.6	II	NM	31.6	0	NM
34.9	I	H	31.9	0	H
30.1	I	H	31.9	0	NM
33.4	II	NM	29.0	0	NM
30.6	II	NM	27.7	0	NM
33.3	I	H	26.4	0	NM
32.5	II	S	25.4	0	NM
28.5	I	H	25.0	0	NM
30.3	II	NM	19.8	0	H
26.4	II	H	12.9	0	H
28.3	I	H	18.7	0	H
31.0	II	NM	19.5	0	NM
30.4	II	NM	17.0	0	NM
28.4	II	NM	19.5	0	NM
28.7	II	NM	16.9	0	NM
26.1	II	NM	14.6	0	H
28.1	II	NM	16.1	0	NM
28.5	II	NM	16.4	0	NM
20.0	II	NM	32.1	237	H
19.7	II	NM	27.9	148	H
18.4	II	NM	24.5	100	H
18.8	II	NM	33.3	308	H
18.9	II	NM	26.9	170	H
16.9	II	NM	26.0	119	H
14.3	II	H	27.0	146	H
17.7	II	NM	33.8	188	H
13.5	II	H	34.0	320	H
			29.9	287	H

June 30, 1970 - Water Temperature $19^{o}C$

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
28.4	II	H	28.5	Yes	H
32.3	II	NM	34.0	0	H
30.0	II	H	30.3	Yes	H
35.1	II	NM	30.6	Yes	H
30.6	I	H	30.6	Yes	H
29.5	II	NM	28.7	Yes	H
39.9	II	S	30.7	1	H
36.1	II	S	27.7	0	H
33.0	II	NM	26.6	Yes	H
30.6	II	H	27.3	0	NM
33.4	II	NM	30.2	Yes	H
26.0	II	NM	26.2	0	NM
37.5	II	S	25.4	0	NM
29.4	II	S			
30.1	II	NM			
24.7	II	NM			
23.3	II	NM			
24.8	II	NM			

July 14, 1970 - Water Temperature 21°C

MALE			FEMALE		
Length	Form	Texture	Length	Eggs	Texture
37.3	I	S	38.6	Hatch	H
28.9	II	S	25.6	0	H
25.0	II	H	23.4	0	H
25.4	II	S	22.1	0	NM
22.6	II	S	27.9	Hatch	H
25.2	II	NM	24.1	0	H
24.2	II	NM	25.2	Hatch	H
20.0	II	H	28.9	Yes	H
			27.6	Hatch	H
			29.3	Yes	H

Collection Data for Small
(less than 21 mm. C.l.)

Date	Average C.l.		Total Number	Percentage Soft
	Male	Female		
July 31, 1969	5.7 mm.	5.7 mm.	80	?
Aug. 5, 1969	7.2 mm.	7.2 mm.	52	8
Aug. 13, 1969	9.0 mm.	8.4 mm.	37	73
Aug. 19, 1969	10.4 mm.	9.9 mm.	34	14
Aug. 26, 1969	11.4 mm.	11.0 mm.	39	58
Sept. 4, 1969	12.5 mm	11.4 mm.	57	10
Sept. 10, 1969	12.6 mm.	12.9 mm.	33	75
Sept. 17, 1969	12.9 mm.	13.2 mm.	39	8
Oct. 3, 1969	13.8 mm.	14.1 mm.	24	0
Oct. 16, 1969	13.6 mm.	12.6 mm.	27	0
Oct. 23, 1969	14.4 mm.	13.9 mm.	26	0
May 28, 1970	14.3 mm.	14.4 mm.	15	0
June 3, 1970	15.3 mm.	15.2 mm.	29	0
June 9, 1970	16.4 mm.	14.3 mm.	23	0
June 15, 1970	17.8 mm.	18.1 mm.	38	87
June 23, 1970	17.5 mm.	17.1 mm.	22	83
June 30, 1970	18.0 mm.	17.9 mm.	37	5
July 7, 1970	18.8 mm.	18.1 mm.	33	10
July 14, 1970	20.2 mm.	19.8 mm.	47	68

APPENDIX III

Following is a paper submitted and accepted for publication in the Canadian Journal of Zoology.

The paper was a result of work carried out in connection with the thesis.

SEXUAL DIMORPHISM IN THE CHELA

OF

ORCONECTES VIRILIS (HAGEN)

K. V. Weagle and G. W. Ozburn

Department of Biology

Lakehead University

Thunder Bay, Ontario.

ABSTRACT

The length and width of the left and right chela and the carapace length of 67 mature crayfish were measured to 1/10 mm. The regression lines for the carapace length vs chela length showed a measurable difference in chela length for the three adult groups. Form I male chela were found to be 19% longer and 12% wider than the Form II male chela, and 24% longer and 16% wider than the female chela. The Form II male chela were 8% longer and 5% wider than the female chela. The ratio of chela length to chela width showed that the chela of all the three groups had slightly different shapes.

INTRODUCTION

The ability to tell the sex and Form of the crayfish *Orconectes virilis* (Hagen) by looking at the chela led to a study of the sexual dimorphism of the chela in this species. Williams and Leonard (1952), Williams (1954) and Crocker and Barr (1968: 103) have all made general comments ("lighter and smaller", "shorter and less powerful" and "smaller and weaker") regarding the chela of the Form II males. However, to date no evidence to support these general statements has been presented. The following data substantiate~~s~~ the general comments of the above authors.

METHODS

The crayfish used were collected from the McIntyre River as it flows through the campus of Lakehead University, Thunder Bay, Ontario, Canada; between the dates of August 5 and September 1, 1969. Sixty-seven mature individuals were measured to 1/10 mm. by means of vernier caliper to obtain carapace length, left and right chela length and left and right chela width. The chela length was taken from the tip of the propodus to the hinge between the propodus and the carpus; the width was taken across the widest part of the propodus just below the dactyl hinge. The carapace length was taken from the tip of the rostrum to the posterior edge of the cephalothorax. The animals were measured while still alive.

The data was analyzed by means of regression lines for the carapace length vs chela length for the Form I and Form II males and for the females. Data was also analyzed by comparing the ratios of carapace length/chela length, carapace length/chela width and chela length/chela width for the Form I and Form II males and the females, with a student 't' test.

RESULTS AND DISCUSSION

It was found that the left and right chela were statistically similar (student 't', a = 0.5) and, therefore, only the data for the left chela was used in the rest of the comparisons.

The regression lines (Figure I) illustrate the relationship of carapace length vs chela length for the left claw of the collected individuals. In Form I males, the chela, over the entire range of carapace lengths, are longer than chela from either Form II males or the females. The chela of the Form II males are also longer than those of the females over the entire range of carapace lengths. The slopes of the regression lines for Form I and Form II males are almost identical (slope Form I = 1.32, slope Form II = 1.30), while the slope for the female regression line is much less (slope = 0.90).

Table I gives the formulae, regression coefficients and variances for these three graphs. The analysis by means of an ANOVA table (Ehrenfeld and Littauer, 1964: 395) showed that all three graphs had 'F' values that were highly significant (Form I males, F = 240.9; Form II males, F = 40.34; females, F = 51.62), which indicated that the regression lines showed a direct relationship between carapace length and chela length.

Table II gives various ratios of claw proportions among the three groups. The Form I chela are longer and wider than either Form II or the female chela. The Form II chela are longer than female chela, but there is no significant difference between the Form II male and female chela widths (a = 0.5). The ratios for chela length to chela width show that the chela of all three groups have slightly different shapes. The Form I male chela are 19% longer and 12% wider than the Form II males', and 24% longer and 16% wider than the females' chela.

The above information indicates that there is a definite sexual dimorphism in the claws of the crayfish Orconectes virilis (Hagen) with the Form I males having the largest chela, the Form II males the next largest and the females the smallest chela.

ACKNOWLEDGEMENTS

This study was supported in part by a grant from the National Research Council of Canada to G. W. Ozburn.

LITERATURE CITED

Crocker, Denton W., and David W. Barr. 1968. Handbook of the Crayfishes of Ontario. Univ. of Toronto Press.

Erenfeld, S., and S. B. Littauer. 1964. Introduction to Statistical Methods. MacGraw-Hill Book Company.

Williams, B. A. 1954. Speciation and Distribution of the Crayfishes of the Ozark Plateaus and Ouachita Provinces. Univ. of Kans. Sci. Bull. 36, Pt. II, No. 12: 803-918

Williams, A. B., and A. B. Leonard. 1952. The Crayfishes of Kansas. Univ. of Kans. Sci. Bull. 34, Pt. II, No. 15: 961-1012.

	FORMULA	r^2	VARIANCE
FORM I	$Y = 1.32 X - 17.9$	0.912	2.10
FORM II	$Y = 1.30 X - 18.5$	0.728	1.17
FEMALE	$Y = 0.90 X - 9.7$	0.691	2.44

TABLE I: The formula and statistics for the three graphs appearing in Figure I.

Leaf 95 omitted in page numbering.

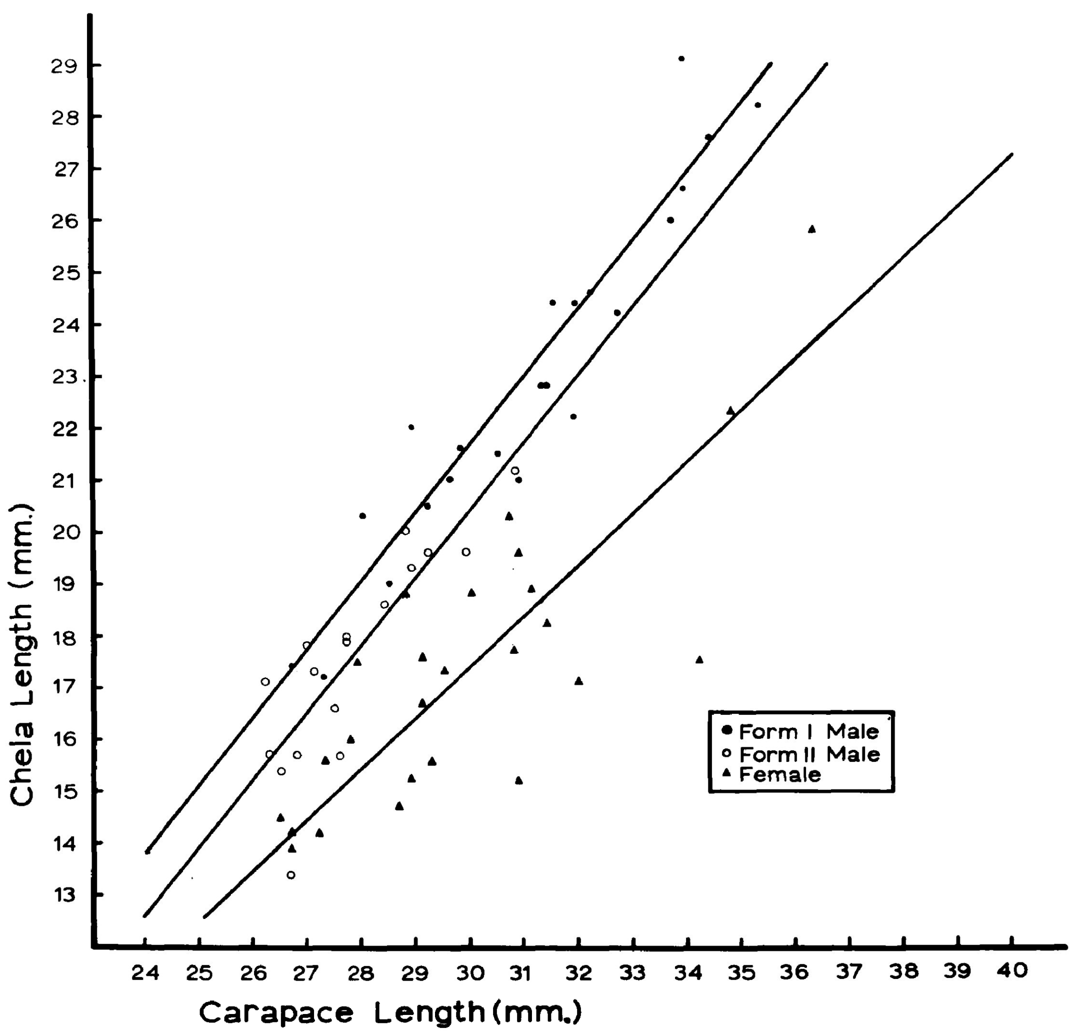
		AVERAGE RATIO	VARIANCE
	FORM I	1.34	0.015
CARAPACE LENGTH/	FORM II	1.59	0.020
CLAW LENGTH	FEMALE	1.76	0.025
	FORM I	3.49	0.064
CARAPACE LENGTH/	FORM II	3.98	0.208
CLAW WIDTH	FEMALE	4.17	0.203
	FORM I	2.61	0.024
CLAW LENGTH/	FORM II	2.51	0.019
CLAW WIDTH	FEMALE	2.38	0.028

TABLE II: The various ratios used to show the sexual dimorphism in the claws of Orconectes virilis.

FIGURE I

The regression lines for carapace length (mm.) vs chela length (mm.) for Form I males, Form II males and adult females of *Orconectes virilis*. The formulae for the graphs are:

Form I males	$Y = 1.32\,x - 17.9$;
Form II males	$Y = 1.30\,x - 18.5$; and
Females	$Y = 0.90\,x - 9.7$


29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
Chela Length (mm.)
24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Carapace Length (mm.)
Form I Male
Form II Male
Female