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THE DISTRIBUTION OF THE CRAYFISHES OF MICHIGAN WITH ASPECTS OF THEIR LIFE CYCLE AND PHYSIOLOGY

By

Robert Lloyd Lippson

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ABSTRACT

THE DISTRIBUTION OF THE CRAYFISHES
OF MICHIGAN WITH ASPECTS
OF THEIR LIFE CYCLE AND PHYSIOLOGY

By

Robert Lloyd Lippson

The distribution of the crayfish of Michigan was investigated in order to document the number of crayfish species present, their habitat preferences, crayfish associations, and to present aspects of their life histories.

Collections of crayfish were made from all 83 Michigan counties. Records for species are recorded by county, lake or stream, township, tier, range and section. The entire crayfish collection has been reposited in the Entomology Museum of Michigan State University.

Seven species of crayfish were determined to be extent in Michigan; *Orconectes propinquus, O. virilis, O. rusticus, O. immunis, Cambarus robustus, C. diogenes,* and *Fallicambarus fodiens.*

O. propinquus was found to be the most abundant and widely distributed species in Michigan. *O. virilis* has a similar distribution but is not as ubiquitous or abundant as *O. propinquus*. *O. rusticus,* a species previously considered

to be distributed only in extreme southern Michigan, was found throughout the southern and northern regions of the Lower Peninsula of Michigan and also in the Upper Peninsula.

O. immunis and *Cambarus robustus* are not widely distributed in Michigan and are confined to Michigan's Lower Peninsula. Fewer data were collected on *C. diogenes* and *Fallicambarus fodiens* due to their secretive burrowing habits, *C. diogenes* was distributed throughout Michigan, while *F. fodiens* was confined to the Lower Peninsula of Michigan. A key to the species found in Michigan is provided. Their distribution is plotted on maps and also presented in detailed locality records.

The laboratory phase of this study was designed to elucidate specific physiological responses of selected species.

Thermal tolerance experiments demonstrated the median tolerance level (TLm) of *O. propinquus* acclimated at 25 C was 34.5 C, and 35.7 C when acclimated at 32 C. The TLm of *O. virilis*, acclimated at 32 C, was also 35.7 C. The TLm of *O. rusticus*, acclimated at 33 C, was 36.2 C. *O. immunis* was acclimated at 7 C and 30 C, a TLm of 34.3 C and 36.2 C was obtained respectively.

Oxygen consumption rates were determined for *O. propinquus*, *O. rusticus*, *O. virilis* and *C. robustus* over a temperature range of 10 C to 35 C. The rate of oxygen consumption of *O. propinquus* and *C. robustus* was higher than that of *O. rusticus* and *O. virilis* up to 20 C. *O. propinquus* and

C. robustus showed a decrease in oxygen consumption beyond 20 C, while *O. rusticus* and *O. virilis* showed an increase in oxygen consumption above 20 C.

ACKNOWLEDGMENTS

I deeply appreciate the encouragement, warmth, and enthusiasm that my professor and friend, Dr. T. Wayne Porter, provided me during our long association. I am just now beginning to realize the value of the many hours we spent together in the field.

My mother and father, and my wife Alice Jane have been supportive in so many ways that I shall happily be forever in their debt. Besides her supportive encouragement and enduring patience, my wife A.J. rendered many of the original illustrations and figures for this paper.

My sons, Skip, Kevin and Jamie often helped me collect in the field; we all gained from those experiences.

Dr. Aaron Rosenfield encouraged me to complete what I had started. I profoundly appreciate his concern in my behalf.

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INTRODUCTION

Representatives of the crayfish family Astacidae occur throughout North America and Europe and have been introduced into Japan and Hawaii (Penn, 1954). Crayfish, as a group, occupy a wide range of habitats. They are characteristic and common inhabitants of a variety of environments, including most types of running water, lakes, ponds, sloughs, swamps, underground waters, and even wet meadows (Pennak, 1953). Miller (1965) reported that some species of the genus *Pacifastacus* are found in the brackish waters of the lower Columbia River. Riegel (1959) similarly reported that *Pacifastacus leniusculus* has been collected in diluted brackish water.

Extensive surveys relating to the distribution of crayfish (Hay, 1895; Harris, 1903; Ortmann, 1905, 1906, 1931; Pearse, 1910; Turner, 1926; Newcombe, 1929; Creaser, 1931, 1932; Creaser and Ortenburger, 1933; Hobbs, 1942b; Williams, 1954; Crocker, 1957; Penn and Hobbs, 1958; Penn, 1959; Meredith and Schwartz, 1960; Crocker and Barr, 1968) have demonstrated that some species are confined to discrete habitats. *Cambarus diogenes* Girard and *Cambarus fodiens* (Cottle) usually secrete themselves in burrows, betrayed only by the telltale chimney of pelletized mud capping their excavations. They are seldom seen in open waters except during the spawning season in spring (Creaser, 1931). *Orconectes immunis* (Hagen) is primarily an inhabitant of ponds and ditches and has a decided preference for mud bottoms and stagnant or very slow moving water (Forbes, 1876; Tack, 1941). *Cambarus robustus* (Girard) is a common brook species found in habitats similar to *Cambarus bartoni* (Newcombe, 1929). *Troglocambarus maclanei* Hobbs is largely confined to cavern ceilings, of caves, that dip below the water level (Hobbs, 1942).

Although early studies were largely of a systematic and geographic nature, natural history and ecological notes were often included.

Helff (1927, 1928) and Hiestand (1931) were among the early investigators interested in respiratory regulation in crayfish. In 1940, Park,Gregg and Lutherman reported on an ecology class exercise in which crayfish were utilized to demonstrate the physiological factors which limit some species to ponds and others to streams. Although their paper was a result of class experiments and not put forward as a critical research program, it did stimulate many workers to investigate the causal factors that control crayfish distribution. Park (1945) reported on additional physiological-ecology studies utilizing crayfish species which also occur in Michigan. Bovbjerg (1952) furthered this line of research with his study of *Orconectes propinquus* and *Cambarus fodiens*. Since Helff's report a large series of papers have been published dealing with oxygen consumption, temperature tolerance, and endogenous rhythms in crayfish (Fingerman, 1955; Spoor, 1955; Fingerman and Lago, 1957; Presson, 1957; Valen, 1958; Wiens and Armitage, 1961; Aiken 1967; Bovbjerg, 1970).

Several ecological studies of crayfish in Michigan have been done in recent years. Creaser (1931) described the distribution of crayfish in Michigan and provided general ecological remarks. Creaser (1934a) reported on seasonal changes in male crayfish and growth and sex ratios of *Faxonius (= Orconectes) propinquus*. Momot (1967a) studied the population dynamics of *Orconectes virilis* to define the role of crayfish as a consumer in a marl lake ecosystem. In a second paper Momot (1967b) provided information on the effects of brook trout predation on the productivity of a population of *Orconectes virilis*. Momot and Gall (1971) presented data on growth, population density and mortality for blue color phase variants of *Orconectes virilis*. Lagler and Hubbs (1940), Lagler and Lagler (1943), and Ball (1948) documented the presence of significant numbers of crayfish in bowfin *(Amia calva)* and largemouth bass *(Micropterus salmoides)* stomachs from southern Michigan waters.

In this paper the present day distribution of Michigan crayfish species is discussed. With the succint statement of Hobbs (1942b), *"the differences and likenesses between situations that are most apparent to the student are by no means always the distinction most important to the crayfish,"* firmly in mind, an attempt has been made to document habitat preferences, crayfish associations, and aspects of their life histories. Data are presented on seven species based, mainly, on field observations, and augmented by laboratory experiments designed to evaluate certain environmental and physiological factors considered necessary to further the understanding of crayfish ecology.

MATERIALS AND METHODS

Description of the Area

Michigan is comprised of two tracts of land, the Upper and Lower Peninsulas, separated by the Straits of Mackinac.

Most of the state was covered repeatedly by glaciers moving downward from the north, grinding and mixing rock materials in their paths. Great local soil variations resulted from the varied mineralogical compositions of the materials left by the glaciers and their melting waters. Thick deposits of unconsolidated rock material, some over 600 feet, are found throughout most of the state (Whiteside, Schneider, and Cook, 1963).

Two distinct bedrock provinces occur in Michigan. The Michigan Basin containing Cambrian to Pennsylvanian shales, sandstones, carbonate rocks, and evaporites occupies all the Lower Peninsula and the eastern half of the Upper Peninsula. The Precambrian shield, which occupies the western half of the Upper Peninsula contains chiefly metamorphosed lava flows, iron formations, granite, conglomerates and sandstones (Wayne and Zumberge, 1965).

Michigan is richly endowed with water resources. Almost entirely surrounded by four of the Great Lakes - Superior, Michigan, Huron and Erie - the state has 3,121 miles of shoreline. In addition there are over 11,000 lakes and 43 river systems within its boundaries (Chandler, 1963).

The inland waters are widely distributed throughout the state corresponding, generally, with glacial geological features. Lakes are numerous in the outwash plains, morainic formations and bedrock outcrops, but are relatively few in glacial lake plains. Barry, Livingston and Oakland Counties, in the southern part of the Lower Peninsula, and Gogebic, Iron, Marquette, and Luce Counties, in the Upper Peninsula, have 0.4-0.6 lakes per square mile. All of the above counties are in areas containing outwash plains, moraines, or bedrock close to the surface. Except for a few small streams in the extreme southern part of the state and in the western part of the Upper Peninsula, all waters drain directly into the Great Lakes system (Chandler, 1963).

According to Brown (1944), Michigan has 43 principle river systems comprising about 36,000 miles. The Saginaw River system is the largest in Michigan with a drainage area of approximately 6,500 mi^2.

Gently rolling topography typifies the eastern regions of the Upper Peninsula and southern Lower Peninsula with hilly and rough terrain in the western Upper Peninsula and north-central Lower Peninsula.

The southern half of the Lower Peninsula lies within the deciduous forest belt while the Upper Peninsula lies entirely within the northeast conifer forest. Mixtures of both forest types occur in both the northern and southern parts of the state. The northern half of the Lower Peninsula is a transitional area where climax deciduous forest species intermix with evergreen formations (Darlington, 1945).

Field Methods

Collections of crayfishes were made from all 83 Michigan counties (Fig. 1). Records for species are listed under locality records and are recorded by county, lake or stream, township, tier, range and section as indicated on Michigan Department of Conservation county maps.

Crayfish occupy three generalized habitats; lakes and ponds, streams, and in burrows along the edges of lakes, ponds and streams.

An attempt was made to collect as widely as possible, throughout Michigan, so as to include all habitats. It soon became apparent, however, that lake and burrowing habitats were extremely difficult to sample, while stream or lotic environments yielded valuable data with relative ease. Consequently, records for the burrowing species, *Fallicambarus fodiens* and *Cambarus diogenes,* do not reflect the full extent of their state-wide distribution and relative abundance as compared to the stream and to some extent the lake species. Sufficient collections made in lakes and augmented by a search of the literature, allows the generalization that those forms which are found in streams are often found in lakes and that there are no species in Michigan which are confined solely to lakes.

Figure 1. Distribution of the crayfishes of Michigan.

Animals were collected with dip nets, seines, modified minnow traps and hand screens.

A twig was often utilized to prod or herd specimens into the dip net. Crayfish usually did not evince alarm when confronted by such a probe, probably because twigs abound and are a natural component in most streams.

The seine is a useful collecting tool when the area to be sampled is clear of snags and an additional person is available for help.

The common double-funneled wire minnow trap, baited with liver, is an excellent device for collecting in lakes and deep river pools. The funnels should be enlarged somewhat to allow the entrance of crayfish.

The handscreen or kickscreen is the most efficient type of equipment for collecting crayfish, particularly in streams. Ease of handling and the fact that only one individual is required for its use make it the gear of choice. The screen is a simple device, inexpensive and easily constructed in a few minutes. It consists of two five ft. poles with a length of window-screen, four ft. high and five ft. wide, tacked to the poles.

The screen is placed on the stream bottom, if only one individual is present, the tops of the poles are grasped in one hand. The screen then assumes an "A" shape with the apex formed by the poles. This method stretches the screen along the bottom and also forms a bag in the center of the screen. The collector stands upstream from the handscreen and kicks the rubble bottom or disturbs aquatic weed beds sufficiently to dislodge the crayfish and allow them to be swept into the screen by the current. This technique is more effectual for sampling stream bottoms than any of the above-mentioned methods.

The collections sites were described as to bottom type, depth, width of stream, estimation of flow and presence of aquatic plants.

The crayfish were killed and preserved in a solution of 75 percent ethanol, 20 percent distilled water and 5 percent glycerine. The glycerine retains the flexibility of the appendages and also prevents total loss of the specimen in the event of evaporation of the ethanol.

The entire collection of crayfish resulting from this study has been reposited in the Entomology Museum of Michigan State University where they are available for further study.

LABORATORY METHODS

The laboratory phase of this study has been designed to augment field observations and to elucidate specific physiological responses of selected species.

Specimens collected in the field for physiological experiments were transported to the laboratory and immediately transferred to aquaria. The crayfish were maintained in non-chlorinated aerated tapwater at temperatures usually within 10 degrees Celsius of the stream temperature. Only those specimens which appeared to be in good condition were retained. They were maintained on a diet of moistened dry dog food. The crayfish fed well, mortality was low, and the specimens used in the tests were healthy and vigorous.

Thermal Tolerance Experiments

A series of experiments designed to test the abilities of several crayfish species to withstand elevated temperatures were performed. The median tolerance level (TLm), or the temperature which will kill 50 percent of a test population for a given exposure period, was utilized. Median tolerance values for a species will increase or decrease as the acclimation temperature increases or decreases, thus allowing the organisms to tolerate higher temperatures in the summer compared with winter.

The TLm may be employed as a taxonomic tool, as it may be of value in indicating the presence or absence of genetic similarities between species that are phenotypically different (Fry, 1957).

The basic technique for TLm determinations is patterned after the classic bioassay. Constant-temperature water baths of non-chlorinated tapwater were established and held to ±0.5 C. The water was vigorously aerated during the entire duration of the experiments. Standard Winkler determinations for dissolved oxygen levels indicated that the oxygen content remained at 85 percent saturation even after animals were held in the water for 24 hours or more.

Animals were acclimated to a constant temperature before being utilized in an experiment. Acclimation temperatures were generally 15, 20, 25, 30, and 35 C. All animals were held in the acclimation baths for a minimum of 24 hours, and usually not over 72 hours. Spoor (1955) found that the increase in heat-resistance of *Orconectes rusticus* was quite rapid -- one day or less when the environmental temperature was raised from 4 C to 24 C.

Acclimated animals were introduced directly into a 60-liter constant temperature bath. During the course of this study the animals were exposed to a range of temperatures from a level not expected to cause mortality to one which would kill all the organisms in a 24-hour period of observation.

In all experiments a specimen was presumed to be dead based on the following criteria:

(a) animal placed on dorsum makes no response to right itself.

(b) no movement of eyes or other appendages elicited.

(c) animal turgid, first abdominal segment pulled away from carapace, no movement elicited.

Upon termination of the 24-hour experiment all animals were removed from the water bath, carapace length and sex determined, and viable specimens placed in a recovery tank for five days at a temperature of 22-25 C. Dead animals were removed from the recovery tank during the 5-day period and so noted.

Oxygen Consumption Experiments

A study of individual species' rate of oxygen consumption was undertaken to furnish information for a clearer understanding of habitat selection and distribution of crayfish. The difficulty encountered in controlling dissolved oxygen in test water may be one reason for the scarcity of data on the effects of various oxygen concentrations on fishes (Mount, 1961). The above statement applies equally to other stream forms, such as aquatic insects and crustacea. The test water should be renewed continuously in order to maintain uniform oxygen concentration and to facilitate removal of metabolic waste products.

Many workers (Fry, 1951; Whitemore, Warren, and Doudoroff, 1960) have devised systems utilizing the principle of nitrogen stripping, or the removal of oxygen by nitrogen displacement. Mount (1961) states that such systems are relatively expensive, require considerable attention, and the volume of water which can be degassed is limited by the cost of nitrogen.

A system using a partial vacuum to degas water is the method of choice. A compressor tank is used as the degassing chamber. A continuously running vacuum connected with a vacuum regulator (Manostat) will adjust and control the required dissolved oxygen concentrations to close tolerances. This method of degassing water is simple and economical and it can be applied to a wide variety of uses.

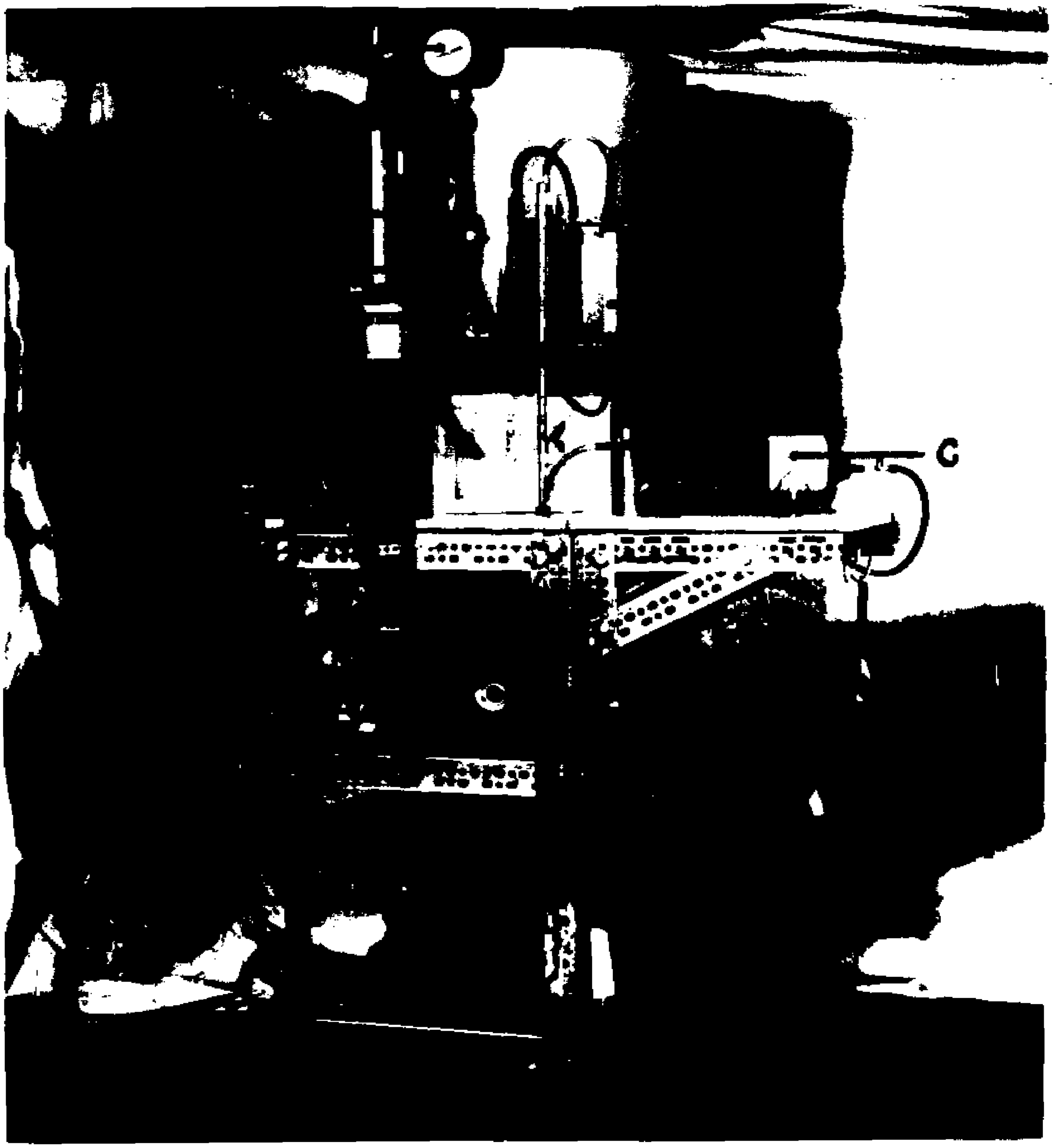
A modified Mount degasser (Mount, 1961, 1964) was designed and constructed for use in crayfish respirometry (Figs. 2-3). The respirometer is equipped with refrigeration and heating coils and is capable of bringing 144 liters of water to the desired test temperature (±0.5 C) within 2 hours. In addition, the respirometer incorporates a vacuum pump, vacuum regulator, aerator, and flow meter. Oxygen concentrations are adjusted by utilizing the vacuum pump in concert with the vacuum regulator or by introducing oxygen by aeration. This system can maintain the dissolved oxygen concentration level at a variation of less than 0.1 ppm without daily adjustments. Water flow is determined by a flow meter capable of measuring flow rate from 0 - 850 ml/min.

To determine oxygen consumption at different concentrations, a single crayfish is placed in an acrylic chamber 30.5 cm long with an inner diameter of 10 cm. The chamber is connected to the system with plastic tubing which allows water to enter and exit in a closed circuit (Fig. 4).

Static and flow-through assays can be run with this system. Generally the static test was chosen because of the very small amounts of oxygen utilized by one specimen.

The test animal, having been starved for 24-hours, is placed in the chamber and water allowed to flow through at the desired temperature and dissolved oxygen concentration for two hours. Upon termination of the acclimation period the oxygen concentration is obtained by the modified (azide)

FIGURE 2. MODIFIED MOUNT DEGASSER SHOWING A, CIRCULATION PUMP; B, VACUUM PUMP; C, RESPIRATION CHAMBER; D, FLOW METER; E, WATER TANK; F, VACUUM GAUGE; G, THERMOREGULATOR; H, MANOSTAT.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G

FIGURE 3. MODIFIED MOUNT DEGASSER SHOWING A, CIRCULATION PUMP; B, HEAT EXCHANGER.

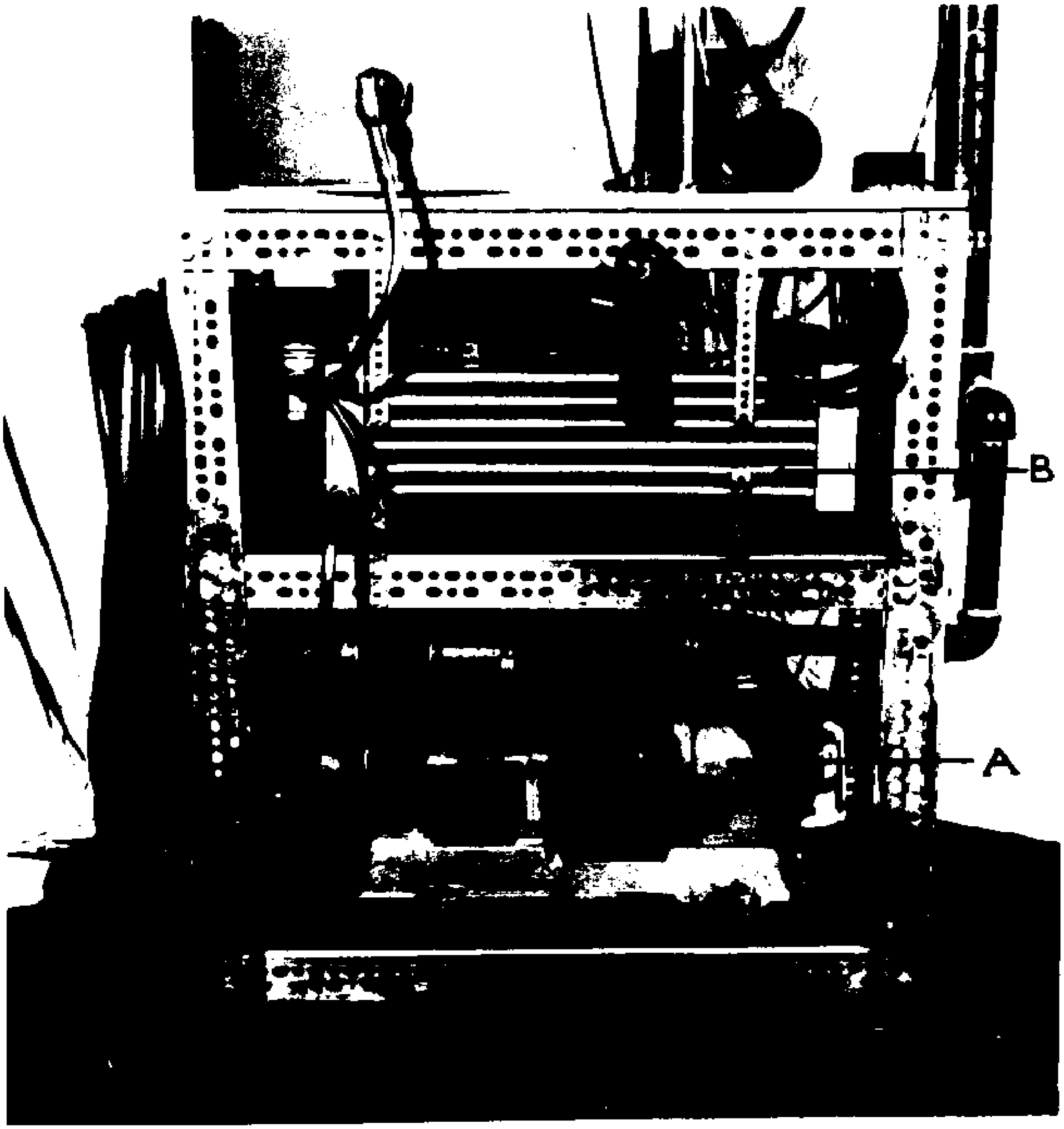
B
A

FIGURE 4. RESPIROMETER CHAMBER UTILIZED WITH MODIFIED MOUNT DEGASSER.

Winkler test, the flow is then cut off to the chamber and shunted through the system for 30 minutes. Water is then evacuated from the chamber into a glass stoppered bottle and the sample assayed for dissolved oxygen concentration. The chamber is again refilled with system water and allowed to recirculate at a constant flow for 15 minutes and the entire process is repeated. A series of four readings per animal are taken in this manner.

The specimens are placed in a drying oven for 24 hours at a temperature of 95 C. They are then weighed on a balance to 0.1 mg accuracy. The dry weight divided into the consumption per hour yields $mgO_2/l/gm/hr$.

Twenty-four hour tests were performed in the same manner with 32 readings taken during the period. All tests were run under a twelve hour light - twelve hour dark regime.

Sterilized stones were placed in the chamber as a substrate to approximate natural field conditions.

Systematic List of Michigan Crayfishes

Family Astacidae

Subfamily Cambarinae Hobbs, 1942

Genus *Orconectes* Cope, 1872

Section *propinquus* Ortmann, 1905

Group *propinquus* Ortmann, 1905

Orconectes propinquus (Girard) 1852

Group *rusticus* (Girard) 1852

Orconectes rusticus (Girard) 1852

Section *virilis* Ortmann, 1905

Group *virilis* Ortmann, 1905

Orconectes virilis (Hagen) 1870

Orconectes immunis (Hagen) 1870

Genus *Cambarus* Erichson, 1846

Section *bartonii* Ortmann, 1905

Cambarus (Puncticambarus) robustus Girard, 1852

Section *diogenes* Ortmann, 1905

Cambarus (Lacunicambarus) diogenes diogenes Girard, 1852

Fallicambarus fodiens (Cottle) 1863

In 1969, Hobbs erected a new genus, *Fallicambarus,* in which he placed *Cambarus (=Fallicambarus) fodiens*. *F. fodiens* along with seven other species were withdrawn from the genus *Cambarus,* primarily based on the curvature of the terminal elements of the male first pleopod at an angle greater than 95 degrees to the main shaft. Fallo (L. = deceive) was combined with *Cambarus* to indicate the close resemblance to the species within the genus *Cambarus*.

Hobbs (1969) also erected a new subgenus, *Lacunicambarus*, and placed *Cambarus diogenes diogenes* within it.

Cambarus (Puncticambarus) robustus is yet another species which has been placed into a new subgenus *(Puncticambarus)* by Hobbs (1969).

RESULTS

KEY TO THE CRAYFISHES OF MICHIGAN

It is generally recognized (Hobbs, 1942a; Crocker, 1957) that the copulatory stylets, the first pleopods, or gonopods, all of which are synonymous terms for the male copulatory organs, are the most reliable diagnostic feature of a species. The gonopods, however, should be from a male in breeding condition, usually referred to as a form I male. Adult form II males, the non-breeding condition, have gonopods which are not well-defined and are not of primary importance in the identification of a species.

The key herein presented is designed to identify Michigan crayfishes by utilizing several morphological characteristics and is not entirely dependent on reference to form I male gonopods. Terms which appear in the key are defined in the glossary below:

GLOSSARY OF TERMS USED IN KEY

ACUMEN:	tip of rostrum
AREOLA:	usually an hourglass-shaped area delimited by shallow grooves on mid-dorsal surface of thorax
CARAPACE:	exoskeletal covering of cephalothorax
CARINA:	longitudinal ridge located in trough of rostrum
CENTRAL PROCESS:	the more distal process of the gonopod
CHELA:	pincer of claw
DACTYL:	the moveable finger of the claw
GONOPOD:	the modified first and second abdominal swimmerets of male, the pleopod
MESIAL PROCESS:	the more proximal process of the gonopod
ROSTRUM:	anterior projection of the carapace extending forward between the eyes
TERMINAL PROCESS:	the two processes, central and mesial, distal to the main shaft of the gonopod

Key To The Species of Michigan Crayfish

(Decapoda: Astacidae)

1a Terminal processes of gonopods short, heavy and directed at approximately a 90-degree angle from the axis (Fig. 5): rostrum without lateral spines at base of acumen (Fig. 6).

\- -2

1b Terminal processes of gonopods straight or curved at less than a 90 degree angle from the axis (Fig. 10); distinct shoulder formed on rostrum at base of acumen; lateral spines or tubercles generally produced at base of acumen (Fig. 11).
- - -- - - - - - - - - - - - - - - *Orconectes* - -5

2a (1) Areola obliterated (Fig. 16); carapace higher than wide - 3

2b Areola wide or narrow, but never obliterated (Fig. 6); carapace wider than high - - - - - - -4

3a (2) Dactyl of chela with narrow to deep notch at base of opposable margin (Fig. 22); teeth of chela well-developed and of various sizes; a burrower inhabiting temporary woodland ponds and ditches.
- - - - - - - - - -*Fallicambarus fodiens* (Cottle)

3b Dactyl of chela without notch at base of opposable margin (Fig. 17); teeth of chela less well-developed and more uniform in size; a burrower along lake and stream margins.
- - - - - - - - - - - - - - - *Cambarus diogenes* Girard

4a (2) Outer margin of chela with depression on both dorsal and ventral aspects (Fig. 7); inner margin of palm with two rows of low tubercles; found in swift, stony streams, occasionally burrows.
- - - - - - - - - - - - - - - *Cambarus robustus* Girard

4b Outer margin of chela may have slight depression on dorsal aspect, but never ventral; inner margin of palm with one row of low tubercles; inhabits swift, stony streams and rivers, may burrow, distribution in Michigan not confirmed.

- - - - - - - - - - - - - *Cambarus bartoni* (Fabricius)

5a (1) Terminal processes of gonopods short, straight, and stout (Fig. 25); carina present on rostrum (Fig. 26); chela wide and heavy (Fig. 27); the most ubiquitous species in Michigan found in streams, rivers and lakes.

- - - - - - - - - - - *Orconectes propinquus* (Girard)

5b Terminal processes of gonopods straight or curved, but not short and stout (Fig. 30); carina not present on rostrum (Fig. 31).

- 6

6a (5) Terminal processes of gonopods straight, or very slightly curved, slender shafts with a distinct shoulder at base of central process (Fig. 30); dactyl usually sinuous (Fig. 32); typically with a reddish maculation on lateral aspect of carapace; in habits streams and rivers, often found below dam sites.

- - - - - - - - - - - - *Orconectes rusticus* (Girard)

6b Terminal processes of gonopods curved and without a shoulder (Fig. 35).
- 7

7a (6) Terminal processes of gonopods slender and gently curving caudad, mesial process spatulate distally (Fig. 10); opposable margin of dactyl straight or slightly sinuous, without notch at base (Fig. 12); prevalent throughout Michigan in streams, rivers and lakes.
- - - - - - - - - - - - - *Orconectes virilis* (Hagen)

7b Terminal processes of gonopods abruptly curved caudad at 45 degree angle, mesial process not spatulate distally (Fig. 35); chela weak and tends to be elongate with a shallow notch at base of opposable margin (Fig. 37); a pond or stagnant water species; may burrow horizontally into bank when water is low.
- - - - - - - - - - - - - *Orconectes immunis* (Hagen)

FIGURES 5-9 DIAGNOSTIC FEATURES OF *CAMBARUS ROBUSTUS* (GIRARD). FIG. 5, FORM I GONOPOD; FIG. 6, DORSAL VIEW OF MALE CARAPACE; FIG. 7, CHELA; FIG. 8, FORM II GONOPOD; FIG. 9, ANNULUS VENTRALIS

Figure 5

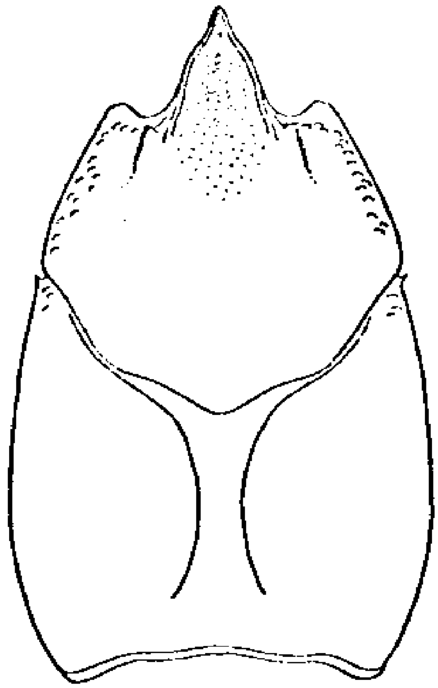

Figure 6

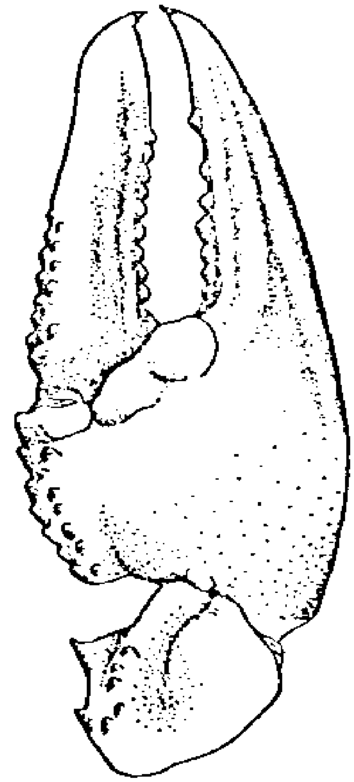

Figure 7

Figure 8

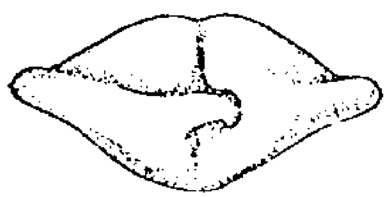

Figure 9

FIGURES 10-14 DIAGNOSTIC FEATURES OF *ORCONECTES VIRILIS* (HAGEN). FIG. 10, FORM I GONOPOD; FIG. 11, DORSAL VIEW OF MALE CARAPACE; FIG. 12, CHELA; FIG. 13, FORM II GONOPOD; FIG. 14, ANNULUS VENTRALIS.

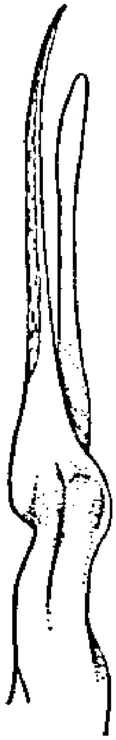

Figure 10

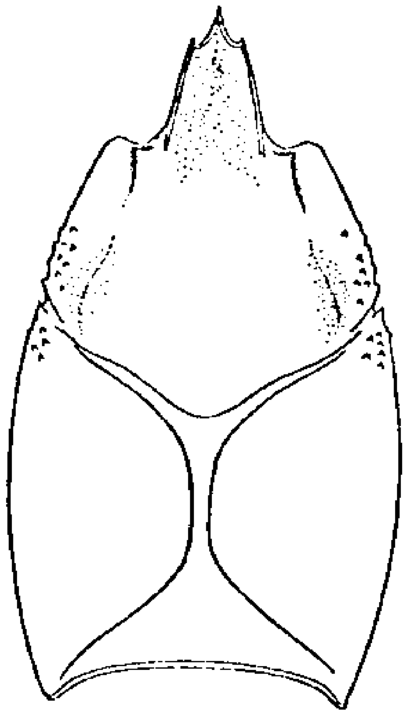

Figure 11

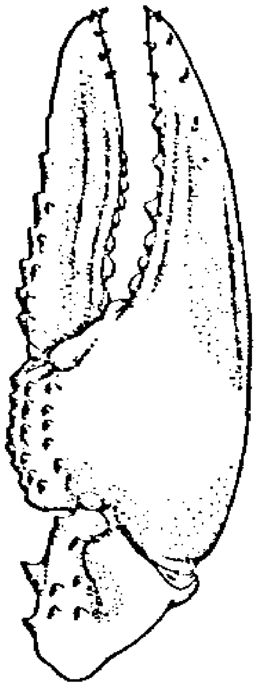

Figure 12

Figure 13

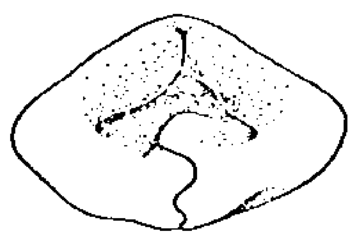

Figure 14

FIGURES 15-19 DIAGNOSTIC FEATURES OF *CAMBARUS DIOGENES* (GIRARD). FIG. 15, FORM I GONOPOD; FIG. 16, DORSAL VIEW OF MALE CARAPACE; FIG. 17, CHELA; FIG. 18, FORM II GONOPOD; FIG. 19, ANNULUS VENTRALIS.

Figure 15

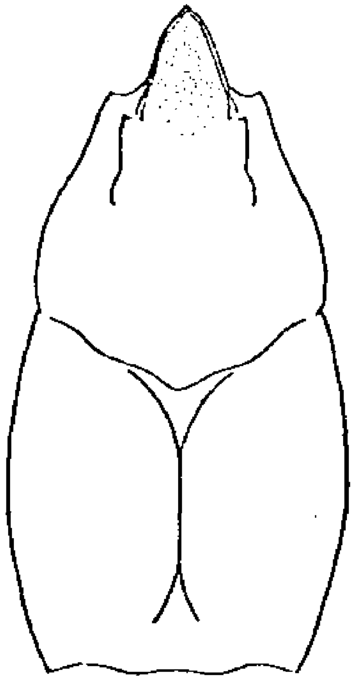

Figure 16

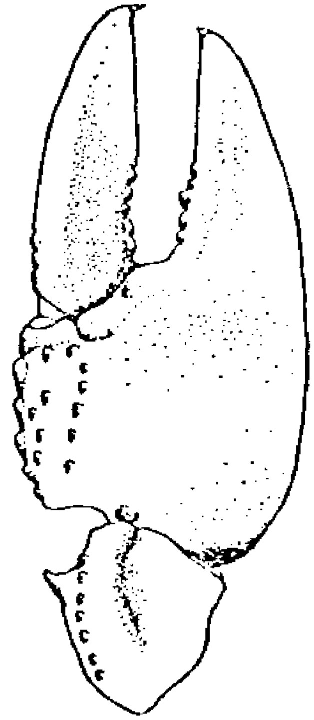

Figure 17

Figure 18

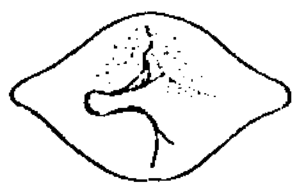

Figure 19

FIGURES 20-24 DIAGNOSTIC FEATURES OF *FALLICAMBARUS FODIENS* (COTTLE). FIG. 20, FORM I GONOPOD; FIG. 21, DORSAL VIEW OF MALE CARAPACE; FIG. 22, CHELA; FIG. 23, FORM II GONOPOD; FIG. 24, ANNULUS VENTRALIS.

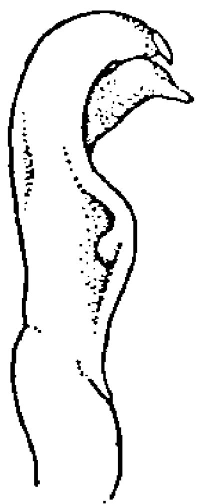

Figure 20

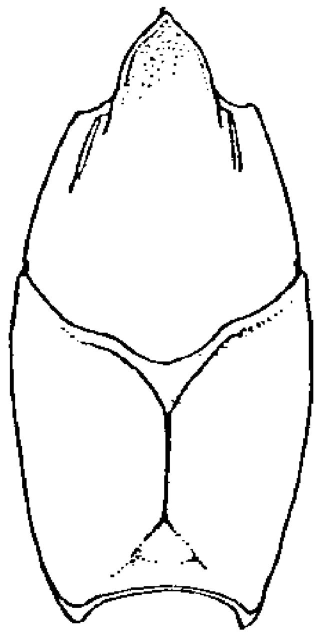

Figure 21

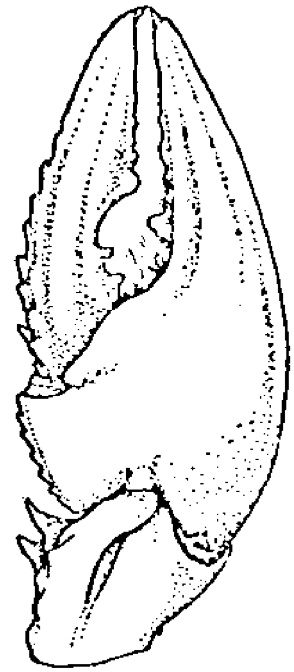

Figure 22

Figure 23

Figure 24

FIGURES 25-29 DIAGNOSTIC FEATURES OF *ORCONECTES PROPINQUUS* (GIRARD). FIG. 25, FORM I GONOPOD; FIG. 26, DORSAL VIEW OF MALE CARAPACE; FIG. 27, CHELA; FIG. 28, FORM II GONOPOD; FIG. 29, ANNULUS VENTRALIS.

Figure 25

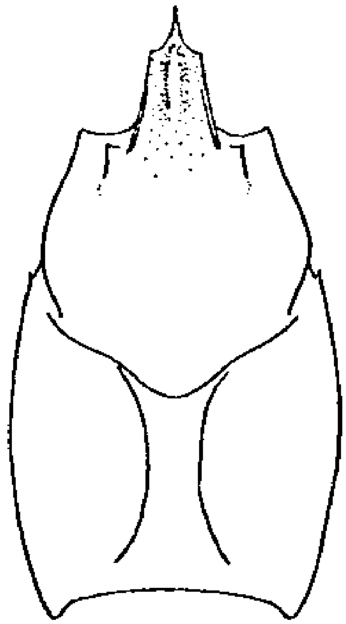

Figure 26

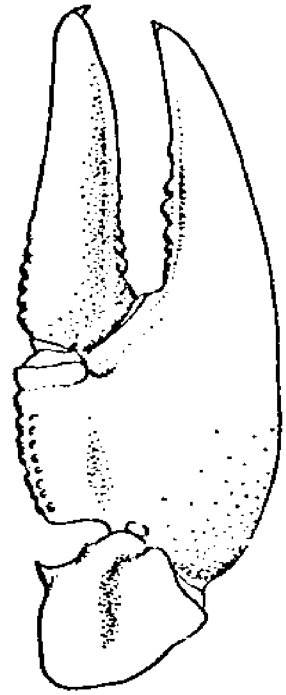

Figure 27

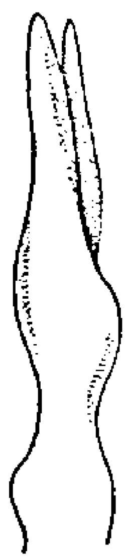

Figure 28

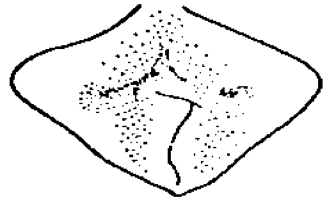

Figure 29

FIGURES 30-34 DIAGNOSTIC FEATURES OF *ORCONECTES RUSTICUS* (GIRARD). FIG. 30, FORM I GONOPOD; FIG. 31, DORSAL VIEW OF MALE CARAPACE; FIG. 32, CHELA; FIG. 33, FORM II GONOPOD; FIG. 34, ANNULUS VENTRALIS.

Figure 30

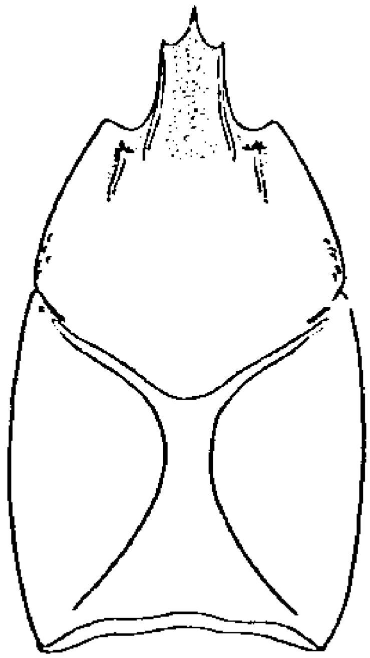

Figure 31

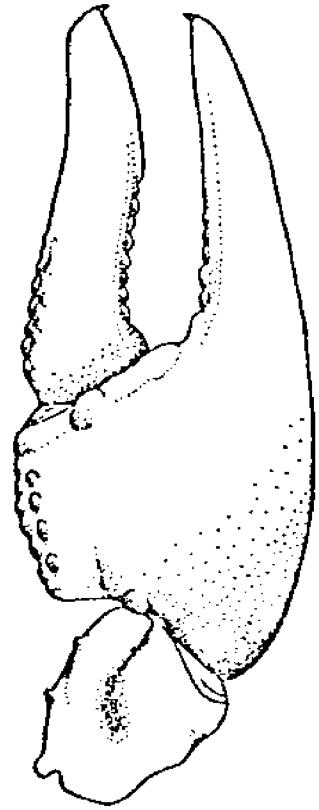

Figure 32

Figure 33

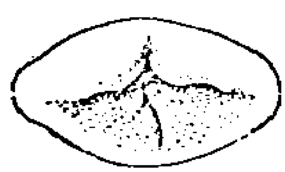

Figure 34

FIGURES 35-39 DIAGNOSTIC FEATURES OF *ORCONECTES IMMUNIS* (HAGEN). FIG. 35, FORM I GONOPOD; FIG. 36, DORSAL VIEW OF MALE CARAPACE; FIG. 37, CHELA; FIG. 38, FORM II GONOPOD; FIG. 39, ANNULUS VENTRALIS.

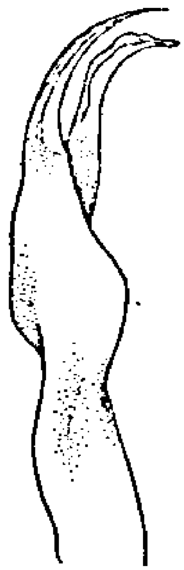

Figure 35

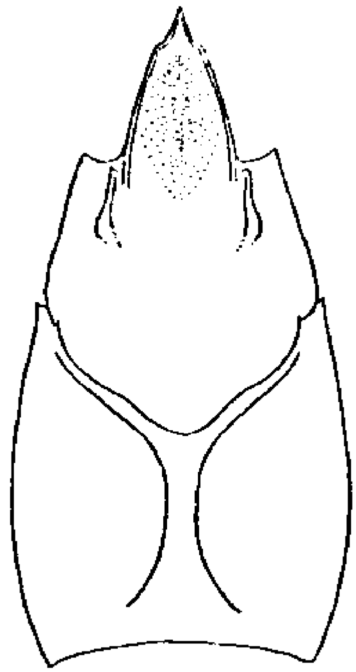

Figure 36

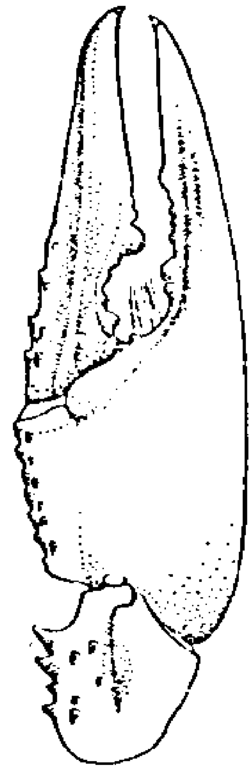

Figure 37

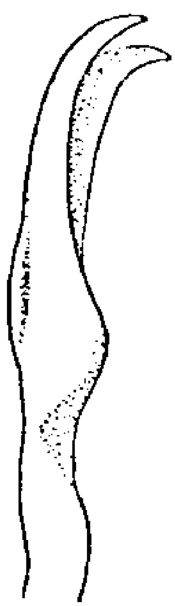

Figure 38

Figure 39

TABLE I

COUNTY DISTRIBUTION OF CRAYFISH SPECIES IN MICHIGAN

County	Species						
	O.propinquus	*O.virilis*	*O.rusticus*	*O.immunis*	*C.robustus*	*C.diogenes*	*F.fodiens*
Alcona	x				x		
Alger	x	x					
Allegan	x	x					x
Alpena	x	x					
Antrim	x	x	x				
Arenac	x				x		
Baraga		x					
Barry	x	x		x		x	
Bay		x					
Benzie	x	x					
Berrien	x	x				x	
Branch	x	x	x				
Calhoun	x		x				
Cass	x						

TABLE I cont'd

County	Species						
	O.propinquus	*O.virilis*	*O.rusticus*	*O.immunis*	*C.robustus*	*C.diogenes*	*F.fodiens*
Charlevoix	x	x	x				
Cheboygan	x		x				
Chippewa	x	x					
Clare	x	x	x		x		
Clinton	x	x		x		x	x
Crawford	x		x				
Delta	x	x					
Dickinson		x					
Eaton	x	x		x			x
Emmet	x	x	x				
Genesee	x	x					
Gladwin	x	x			x		
Gogebic		x					
Grand Traverse	x	x	x				

TABLE I cont'd

County	Species						
	O.propinquus	*O.virilis*	*O.rusticus*	*O.immunis*	*C.robustus*	*C.diogenes*	*F.fodiens*
Gratiot	x						
Hillsdale	x		x				
Houghton							
Huron	x	x					
Ingham	x	x				x	x
Ionia	x				x		
Iosco	x	x			x		
Iron	x	x	x				
Isabella	x						
Jackson	x						
Kalamazoo	x	x				x	
Kalkaska	x						
Kent	x						
Keweenaw							

TABLE I cont'd

County	Species						
	O.propinquus	*O.virilis*	*O.rusticus*	*O.immunis*	*C.robustus*	*C.diogenes*	*F.fodiens*
Lake	x						
Lapeer	x				x		
Leelanau	x	x					
Lenawee	x		x	x	x	x	
Livingston	x	x					
Luce	x						
Mackinac	x	x				x	
Macomb	x	x					x
Manistee	x	x					
Marquette	x	x					
Mason	x						
Mecosta	x		x				
Menominee	x	x					
Midland	x						

TABLE I cont'd

County	Species						
	O.propinquus	*O.virilis*	*O.rusticus*	*O.immunis*	*C.robustus*	*C.diogenes*	*F.fodiens*
Missaukee	x	x					
Monroe	x			x		x	
Montcalm	x	x	x				
Montmorency	x		x		x		
Muskegon	x						
Newaygo	x						
Oakland	x				x	x	
Oceana	x						
Ogemaw	x						
Ontonagon	x						
Osceola	x	x					
Oscoda			x				
Otsego	x		x				
Ottawa	x					x	

TABLE I cont'd

County	*O.propinquus*	*O.virilis*	*O.rusticus*	*O.immunis*	*C.robustus*	*C.diogenes*	*F.fodiens*
Presque Isle	x	x			x		
Roscommon	x	x					
Saginaw	x	x		x			
St. Clair	x	x		x	x		
St. Joseph	x	x	x				
Sanilac	x	x		x			
Schoolcraft	x						
Shiawassee	x	x		x			
Tuscola	x						
Van Buren	x	x		x			
Washtenaw	x	x					
Wayne				x			
Wexford		x	x				

LIFE HISTORY AND ECOLOGY

Fallicambarus fodiens (Cottle, 1863)

This species is one of the most poorly understood in Michigan. Creaser (1931) wrote that its habitat preference is for vernal woodland ponds, drainage ditches and marshes where it constructs burrows in sandy-clay soil. Few additional distributional records have resulted from this study because of the burrowing nature of *F. fodiens* and its propensity for inhabiting areas which are not necessarily near streams or permanent bodies of water.

F. fodiens is usually found in open water soon after the snow melts and forms temporary ponds. Crocker and Barr (1968) indicate that *F. fodiens* copulate in the fall or early spring. In Michigan, adults are found in the open water as early as mid-February. Pearse (1910) found females carrying eggs in early April and Hay (1895), Pearse (1910), and Crocker and Barr (1968) all report collecting young from early April through May. Collections made during the current investigations agree with earlier findings pertaining to the time of adults and young found in open water. It was noted that, subsequent to hatching of the young, a spatial distribution occurred between the newly-hatched crayfish and the adults. In most cases, particularly after the young were approximately two weeks or more old, the adults returned to their secretive burrows, while the young remained in open water until later in the spring. They emerged from the water as the ponds began to dry in May and early June and burrowed along the moist margins.

F. fodiens is a solitary species and is not generally found in association with other crayfish species. *Orconectes immunis*, the only species collected in association with *F. fodiens*, occurred in 17 percent of the collections.

Although the distributional knowledge of *F. fodiens* is far from complete, it appears from this study and that of Creaser's (1931) that *F. fodiens* is confined to central and southern lower Michigan which coincides with the occurrence of *F. fodiens* peripheral to Michigan. Hobbs (1972b) indicates that this species occurs in Illinois, Michigan and Ohio and additional southern states. Crocker and Barr (1968) report this species only in southwest and mid-Ontario, Canada.

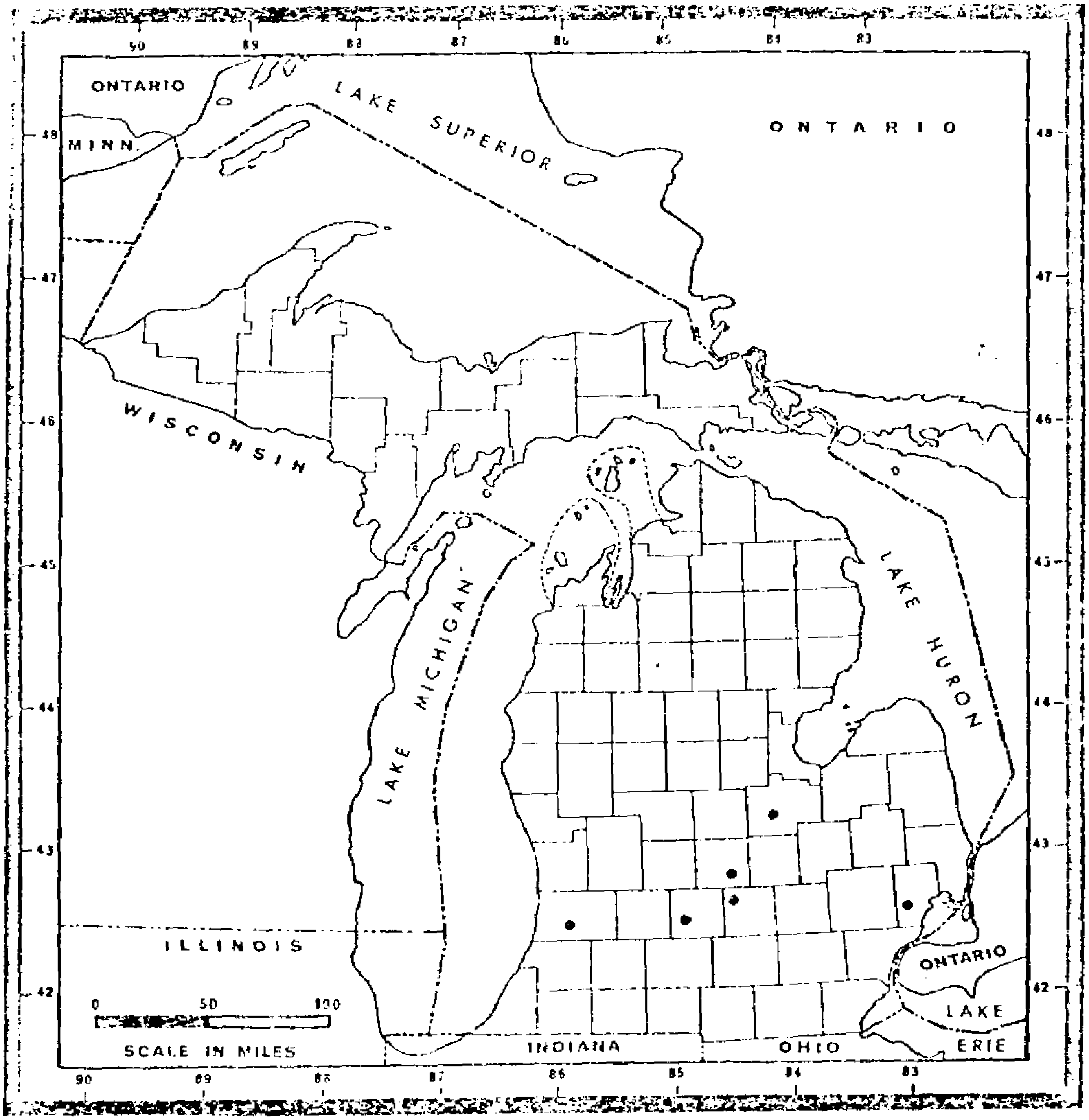

Figure 41. Distribution of *Fallicambarus fodiens* in Michigan.

Fallicambarus fodiens (Cottle)

Locality Records in Michigan

ALLEGAN: Kalamazoo R., L. Allegan, Allegan Twp., T.2N: R.13W: S.19, 18 September 1965, 1♀.

CLINTON: Looking Glass R. trib., Bath Twp., T.5N: R.1W: S.5, 16 May 1965, 1♂ I, 1♀.

EATON: Battle Creek R. trib., Bellevue Twp., T.1N: R. 6W: S.23, 17 May 1965, 1♂ II, 2♀♀.

INGHAM: Baker Woodlot, Mich. State Univ., Meridian Twp., T.4N: R.1W: S.19, 6 May 1965, 1♂ II, 3♀♀.

MACOMB: Roadside ditch, Harrison Twp., 25 April 1965, 4♂♂.

SAGINAW: Saginaw R., Spaulding Twp., T.11N: R.4E: S.8, 15 May 1965, 1♀.

Cambarus (Lacunicambarus) diogenes diogenes Girard, 1852

C. diogenes, like *F. fodiens,* is primarily a burrowing species which often constructs extensive burrows in poorly drained soils. Some of the burrows are quite complex in construction with lateral tunnels branching from the main vertical burrow and terminating in a cul-de-sac chamber. They may also join secondary vertical shafts or continue as a lateral extension to the waters edge. The diameter of the burrow and its attendant chimney is a function of the size of the individual and, to some extent, on the depth of the water table and the type of soil. *C. diogenes,* collected during this study inhabited areas where the soils ranged from marly-clay to peat. This species does occur in marshy areas which may be some distance from a permanent standing body of water or a stream. They are, however, found more frequently in and around permanent bodies of water.

The life cycle of *C. diogenes* is not completely known due to its secretive habits and inaccessibility. Marlow (1960) indicates that copulation takes place from late March through May. A pair in copula was observed by the author on March 21, 1968 in Sash-Abow Creek, Oakland County, Michigan. Girard (1852), Hay (1895), and Ortmann (1931) report gravid *C. diogenes* from March through May. Williams and Leonard (1952) note a single record of a female with young in June. A female with young was collected by the writer in Gull Creek, Kalamazoo County, Michigan, June 8, 1967.

Figure 42 shows the frequency of occurrence of form I (sexually mature) and form II (reproductively inactive) males on an annual basis. Although the data suffers from insufficient numbers of specimens (N=15) and a lack of monthly sequential collections, form I males do comprise the majority from February through mid-May. These data substantially agree with Marlow's (1960) observations that copulation occurs from late March through May.

C. diogenes, although generally a solitary burrowing species, does frequent lakes and streams from March through June. *O. propinquus* and *O. virilis* were found in association with *C. diogenes* in 26 percent and 20 percent of the collections, respectively.

Creaser (1931) states that the distribution of *C. diogenes* is not as well-known in Michigan as that of some other species, however it is found throughout the Upper and Lower Peninsulas. The distributional map (Fig. 43) and Table I indicate the counties in which *C. diogenes* were collected during the current study. The paucity of county records should not indicate to the reader that *C. diogenes* does not occur more widely in Michigan, but only that burrowing forms are difficult to collect and, therefore, are not generally reported upon with the same thoroughness as stream and lake forms.

C. diogenes is reported by Hobbs (1972b) to be widely-distributed throughout large portions of the United States and ranges from the southern states to New Jersey and west

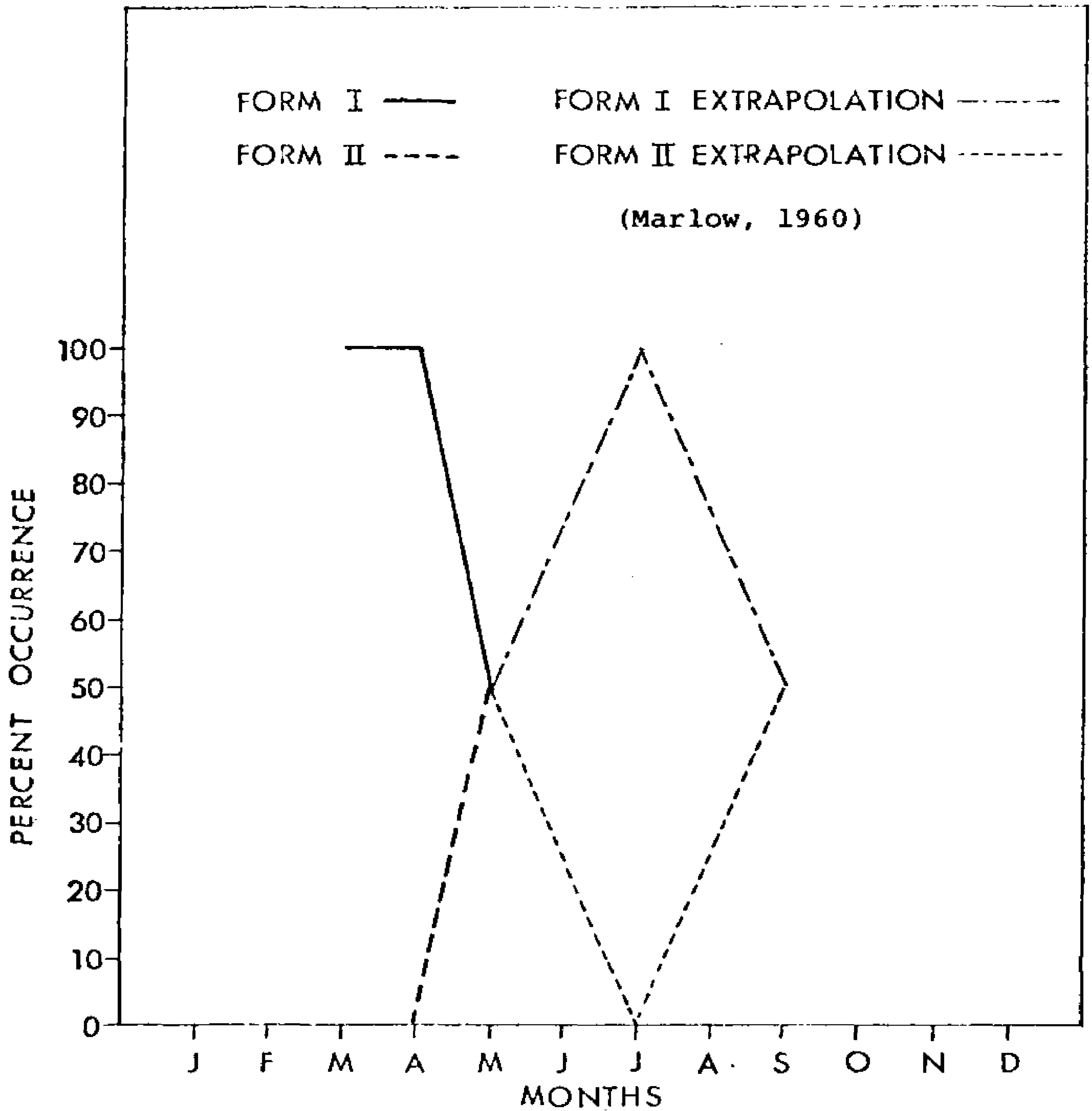

Figure 42. Frenquency of occurrence of form I and form II *Cambarus diogenes*.

Figure 43. Distribution of *Cambarus diogenes* in Michigan.

to Wyoming. Crocker and Barr (1968) report that *C. diogenes* is the rarest Ontario crayfish, occurring only in scattered colonies along the north shore of Lake Erie.

Cambarus diogenes Girard

Locality Records in Michigan

BARRY: Lawrence L., Barry Twp., T.1N: R.9W: S.27, 23 July 1964, 3 ♂♂ I, 1 ♀' Lawrence L., Barry Twp., T.1N: R.9W: S.27, 8 April 1965, 2 ♂♂ I; Lawrence L., Barry Twp., T.1N: R.9W: S.27, 10 March 1966, 1 ♀.

BERRIEN: Wolf Cr., Bainbridge Twp., T.4S: R.17W: S.27, 17 September 1964, 1 ♂ II.

CLINTON: Vermillion Cr., Bath Twp., T.5N: R.1W: S.24, 2 May 1965, 1 ♂ I.

INGHAM: Red Cedar R., Williamston Twp., T.4N: R.1E: S.35, 25 April 1965, 1 ♂ I.

KALAMAZOO: Howlandsburg Mill Pond, Ross Twp., T.1S: R. 9W: S.31, 23 July 1964, 3 ♀♀; Portage Cr., Kalamazoo Twp., T.2S: R.11W: S.33, 15 April 1966, 1 ♂ I.

LENAWEE: River Raisin, Raisin Twp., T.6S: R.4E: S.29, 19 April 1966, 1 ♂ I.

MACKINAC: Moran R., Moran Twp., T.40N: R.4W: S.10, 22 May 1968, 1 ♂ II.

MONROE: Woodlot near Petersburg, Summerfield Twp., 15 September 1965, 1 ♂ I.

OAKLAND: Sash-abow Cr., Independence Twp., T.4N: R.9E: S.26, 21 March 1968, 1 ♂ I.

OTTAWA: Tenhaden Cr., Port Sheldon Twp., T.6N: R.16W: S.27, 23 December 1967, 1 ♂ II.

SHAIWASSEE: Shiawassee R. trib., New Haven Twp., T.8N: R.3E: S.18, 3 April 1968, 1 ♂ I.

Cambarus (Puncticambarus) robustus Girard, 1852

C. robustus is a large species found in stony-bottomed swift-running rivers and streams. This species does not construct the characteristic cambarid burrow, but is often found in shallow excavations under flat stones.

A typical habitat of *C. robustus* is a fast-flowing, highly oxgenated, rubble-strewn river not exceeding four to five feet in depth. The streams are often stained a tea or coffee color and support little or no rooted aquatic vegetation. *C. robustus* is not an abundant or widely distributed species in Michigan streams. It appears for the most part to be confined to the eastern Lower Peninsula of Michigan (Fig. 44: Table I).

The limited data collected on *C. robustus* relative to frequency of occurrence of form I (sexually mature) and form II males (reproductively inactive) suggest that the breeding season is extended and not restricted to discrete periods in the fall or spring as in many other crayfish species (Fig. 45).

C. robustus, a stream dweller in Michigan, was collected in association with three other species commonly encountered in streams. *O. propinquus* was found in association with *C. robustus* in 62 percent of the collections, *O. virilis* and *O. rusticus* were each associated with *C. robustus* in 12 percent of the collections.

Figure 44. Distribution of *Cambarus robustus* in Michigan.

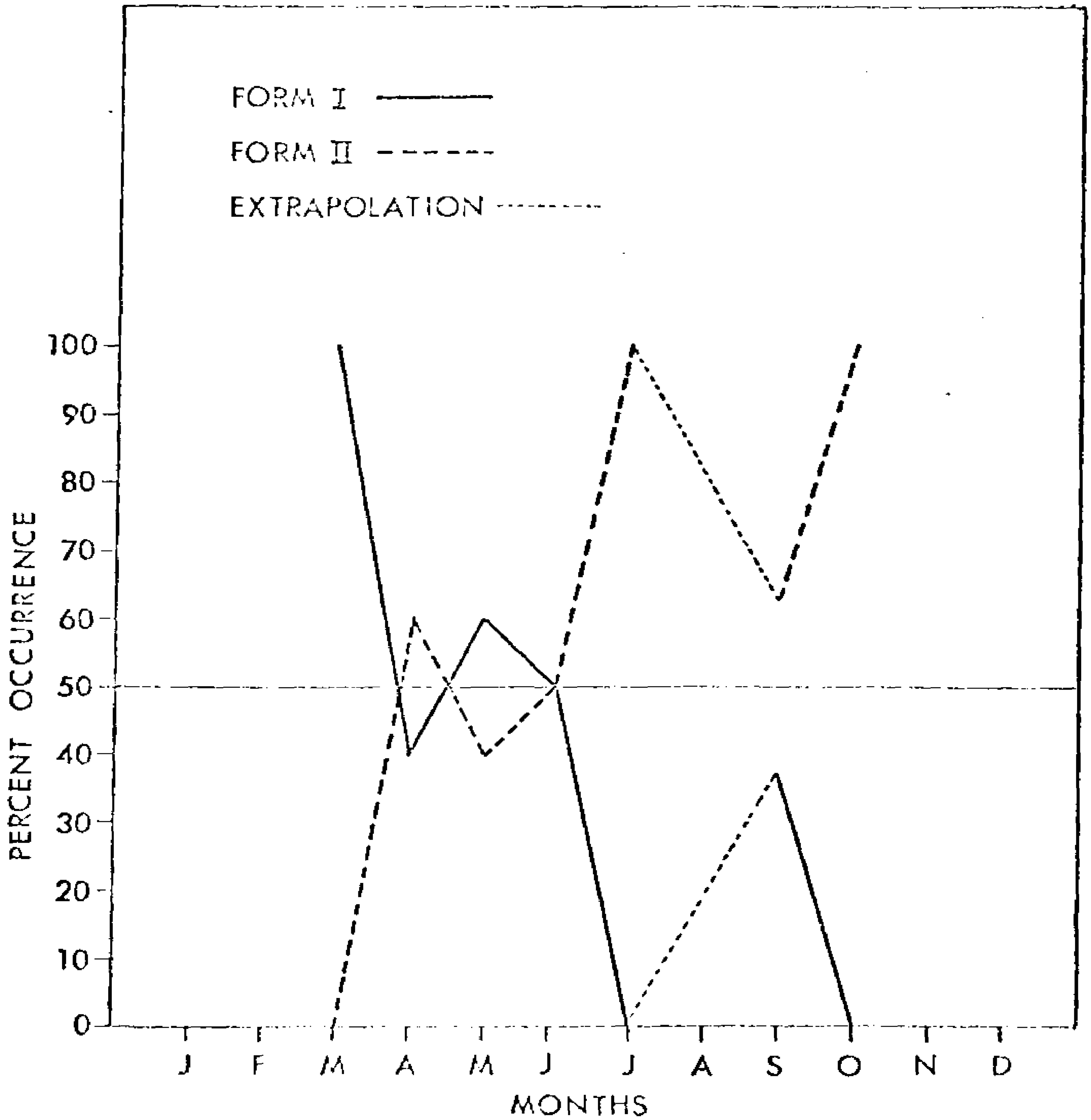

Figure 45. Frequency occurrence of form I and form II *Cambarus robustus*.

C. robustus is found in Ontario, Canada; Illinois, Indiana, Kentucky, Michigan, New York, North Carolina, Ohio, Pennsylvania, and West Virginia.

Cambarus robustus (Girard)

Locality Records in Michigan

ALCONA: Black R., Alcona Twp., T.28N: R.9E: S.34, 6 June 1968, 1 ♂ I, 1 ♂ II; E. Br. Pine R., Mikado Twp., T.25N: R.8E: S.3, 6 June 1968, 1 ♀.

ARENAC: Rifle R., Clayton Twp., T.20N: R.4E: S.18, 6 May 1968, 1 ♀; Cedar Cr., Mason Twp., T.20N: R.5E: S.12, 6 May 1968, 1 ♂ I, 1 ♂ II.

CLARE: McCuran Cr., Grant Twp., T.17N: R.4W: S.13, 16 April 1968, 2 ♂♂ II; Middle Br. Cedar R., Hamilton Twp., T.19N: R.3W: S.11, 16 April 1968, 1 ♀.

GLADWIN: Molasses R., Grim Twp., T.18N: R.2E: S.7, 19 April 1968, 2 ♀♀; Sugar R., Butman Twp., T.20N: R.1W: S.22, 19 April 1968, 1 ♂ I.

HILLSDALE: St. Joseph R., Amboy Twp., T.9S: R.3W: S.8, 12 July 1968, 1 ♂ II, 1 ♀.

IONIA: Prairie Cr., Ionia Twp., T.7N: R.6W: S.9, 13 May 1967, 1 ♂ I.

IOSCO: Porterfield Cr., Burleigh Twp., T.21N: R.5E: S.3, 7 May 1968, 1 ♀; Au Gres R., Reno Twp., T. 22N: R.5E: S.27, 7 May 1968, 1 ♂ II, 1 ♀; South Branch R., Plainfield Twp., T.24N: R.5E: S.11, 7 May 1968, 1 ♀.

LAPEER: S. Br. Flint R., Lapeer Twp., T.7N: R.10E: S.23, 24 April 1968, 1 ♂ II.

LENAWEE: Wolf Cr., Adrian Twp., T.6S: R.3E: S.28, 8 May 1965, 2 ♂♂ I, 2 ♀♀; Fitts Cr., Rollin Twp., T.6S: R.1E: S.20, 12 July 1968, 2 ♂♂ II.

MONTMORENCY: E. Br. Black R., Montmorency Twp., T.32N: R.1E: S.22, 6 June 1968, 1 ♀; Gilcrhrist Cr., Loud Twp., T.29N: R.3E: S.15, 6 June 1968, 1 ♀.

OAKLAND: Paint Cr., Avcn Twp., T.3N: R.11E: S.11, 15 September 1965, 2 ♂♂ I, 3 ♂♂ II, 4 ♀♀; Paint Cr., Avon Twp., T.3N: R.11E: S.4, 21 March 1968, 1 ♂ I, 3 ♀♀.

PRESQUE ISLE: N. Br. Thunder Bay R., Posen Twp., T.33N: R.6E: S.30, 5 June 1968, 2 ♀♀.

ST. CLAIR: Jeddo Cr., Burtchville Twp., T.8N: R.17E: S.12, 23 April 1968, 1 ♂ I.

Orconectes propinquus (Girard, 1852)

O. propinquus is a small to medium-sized species with a maximum cephalothorax length of approximately 35-40 mm. It can be easily distinguished from other species in Michigan by the presence of a distinct rostral medial carina.

O. propinquus is the most ubiquitous species in Michigan and occurs throughout the state from the most southerly tier of counties in the Lower Peninsula to the most northerly counties of the Upper Peninsula (Fig. 46; Table I). This species is an open water form most abundant on rock substrata, in riffle areas of streams and along the stony shores of lakes. However, it is often found in pools, below riffles, along the shoreline where it clings to vegetation, and occasionally on the silty bottoms of streams and lakes. It is not known to build distinct burrows, but often they shelter themselves under flat rocks, particularly during the winter months.

The seasonal life history of this species in Michigan generally follows the description given by Van Deventer (1937). However, on the basis of the presence of 50 percent, or greater, of form I males, which are considered to be sexually mature, there appears to be a minor mating period in the spring and a major mating period from July through September (Fig. 47). This pattern differs somewhat from that reported by Van Deventer for *O. propinquus* in Illinois, who indicated that there is a single mating period in the fall and a spring or summer period during which the males

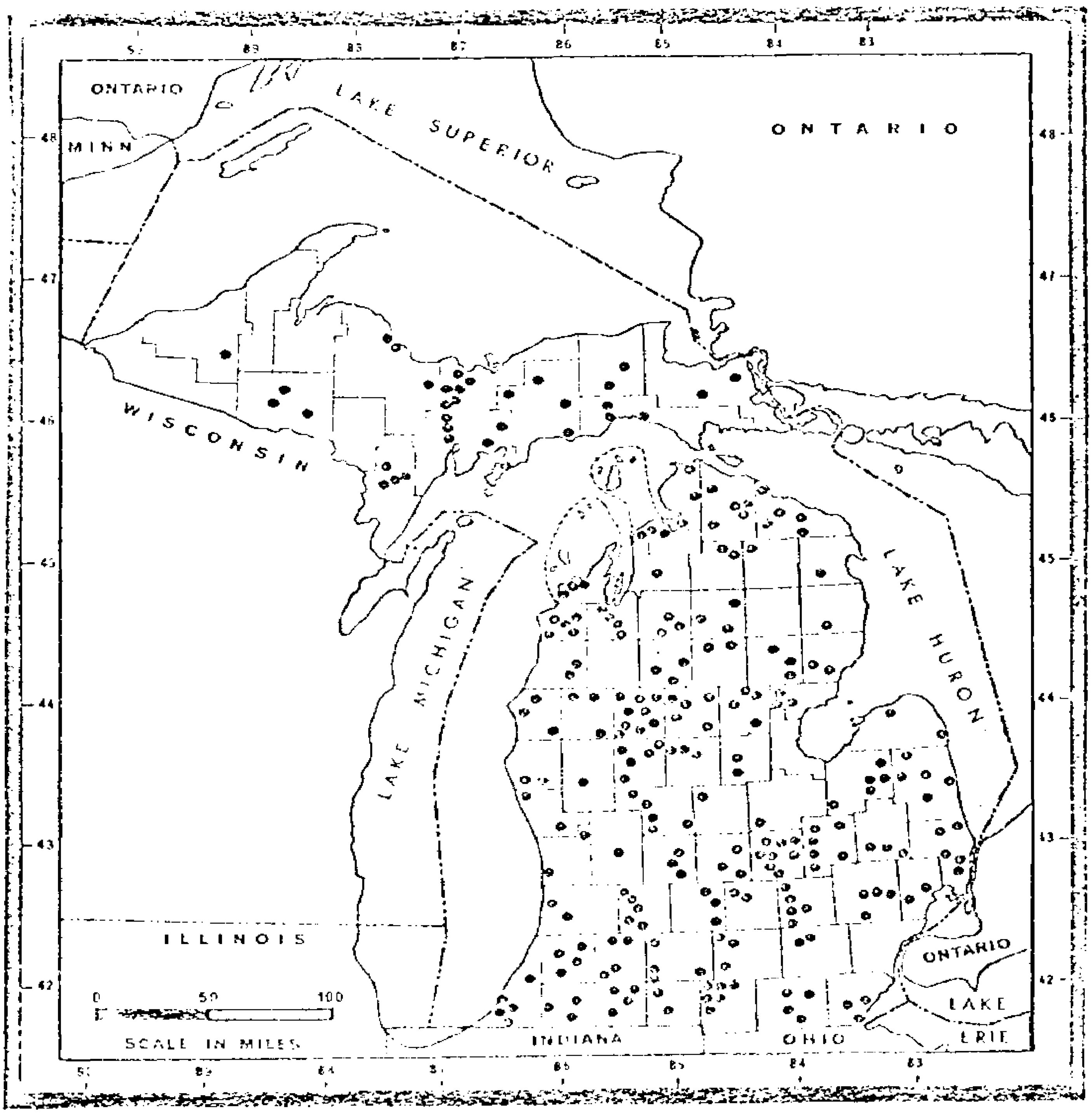

Figure 46. Distribution of *Orconectes propinquus* in Michigan.

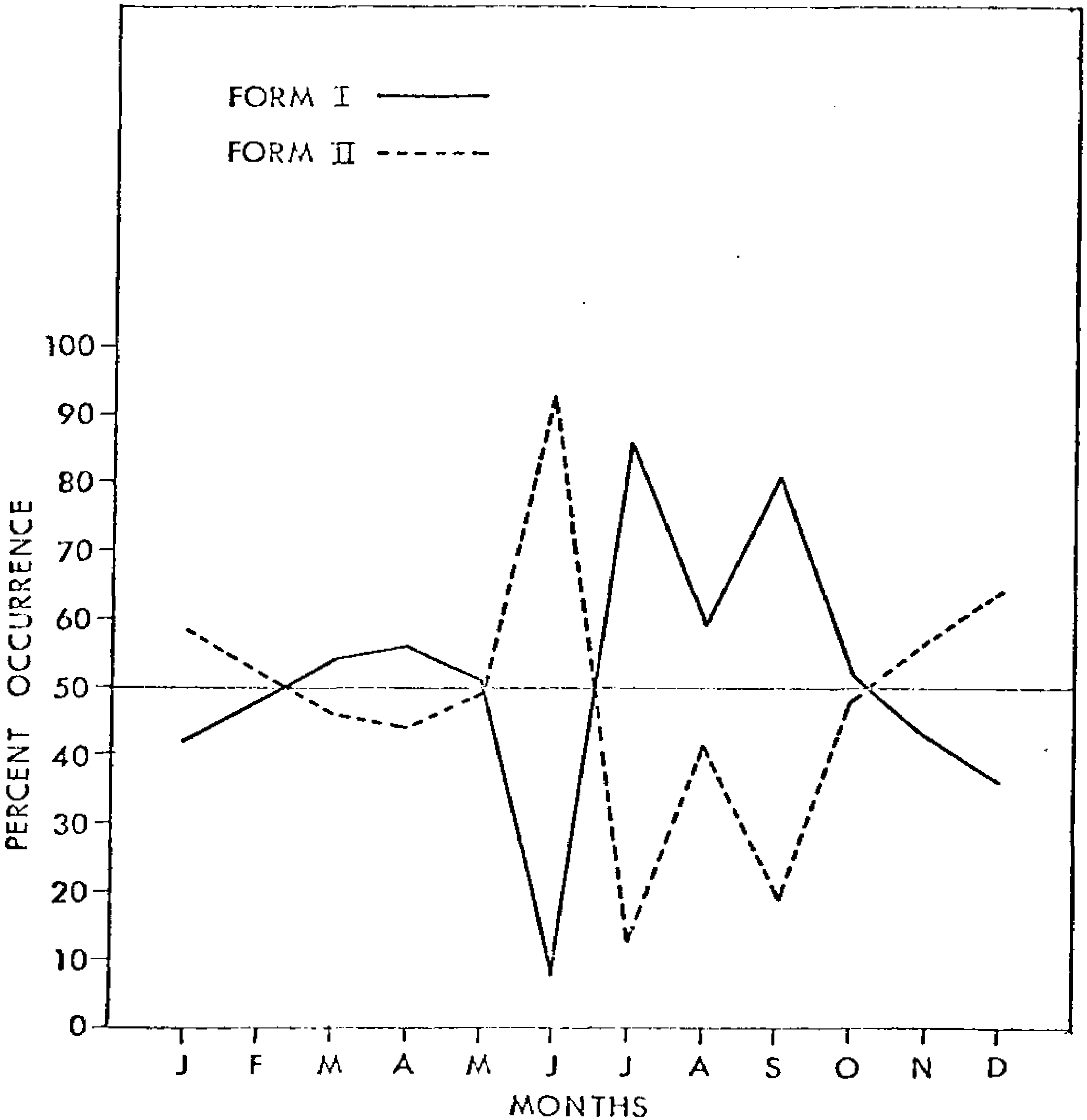

Figure 47. Frequency occurrence of form I and form II *Orconectes propinquus*.

are all second form, the non-copulatory phase.

The females spawn in the spring from April to June and their eggs are carried for approximately two weeks. Hatching occurs from mid-April through mid-June (Fig. 48). Eggs of 54 ovigerous females ranged from 40 to 314, with a mean of 127 per individual. Figure 49 shows the correlation between the number of eggs carried per individual and the length of the cephalothorax.

O. propinquus, widely distributed throughout Michigan in a variety of habitats, often occurs with other crayfish species. There is a general correlation of association with the other species based on the habitat preference and the relative abundance of those species. *Orconectes virilis*, the second most widely-distributed species in Michigan and one which has similar habitat preferences as that of *O. propinquus*, was found to be associated with *O. propinquus* in 20 percent of the collections. *Orconectes rusticus*, found in fewer numbers and less widely-distributed, occurred with *O. propinquus* in 6 percent of the collections. A corresponding 6 percent of association was also observed with *C. robustus*. The frequency of association declined between *O. immunis*, *C. diogenes*, and *O. propinquus*. This may be explained by the limited distribution of *O. immunis* and by the ability of *O. immunis* to tolerate lower dissolved oxygen concentrations and generally more adverse environmental conditions than *O. propinquus*. *C. diogenes* is usually not found in open water, except during the time of copulation and

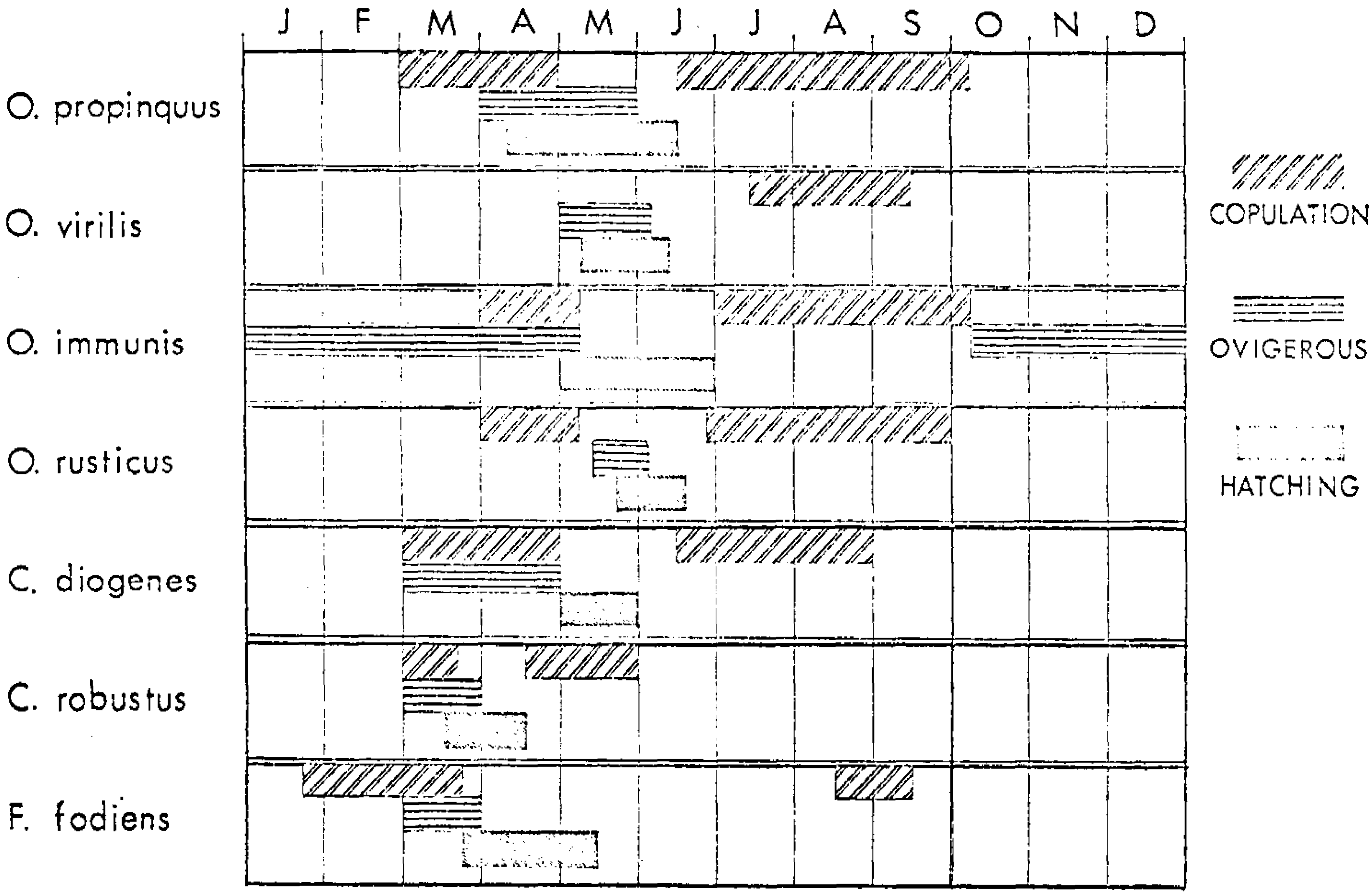

Figure 48. Summarization of life cycle information of Michigan crayfish species.

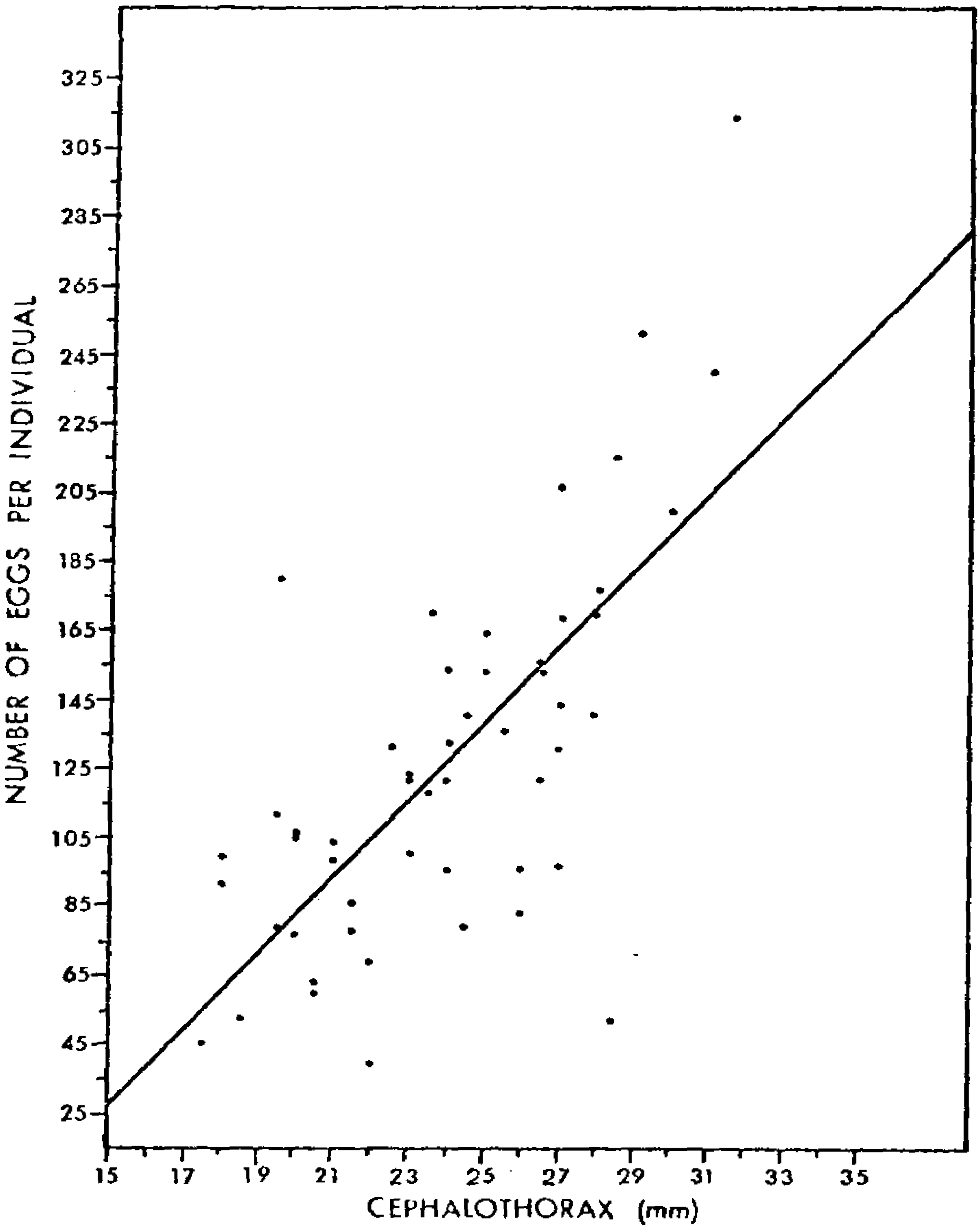

Figure 49. The relationship between number of eggs carried and cephalothorax size in *Orconectes propinquus*.

subsequent hatching of the young. Therefore, their association with other species is limited.

O. propinquus is widely distributed throughout Ontario, Quebec, Canada; Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, and Wisconsin (Hobbs, 1972b).

Orconectes propinquus (Girard)

Locality Records in Michigan

ALCONA: E. Br. Pine R., Mikado Twp., T.25N: R.8E: S.3, 6 June 1968, 1 ♂ I.

ALGER: Deer L., Onota Twp., T.47N: R.21W: S.17, 25 August 1965, 2 ♂♂ I, 9 ♀♀; W. Br. Whitefish R., Mathias Twp., 5.44N: R.21W: S.30, 29 August 1965, 3 ♂♂ I, 2 ♂♂ II, 3 ♀♀; Dems Cr., Limestone Twp., T.45N: R.22W: S.30, 23 May 1968, 3 ♀♀; Scotts Cr., Mathias Twp., T.44N: R.21W: S.19, 24 May 1968, 3 ♂♂ I, 7 ♂♂ II, 3 ♀♀ (1 gravid); Dexter Cr., Limestone twp., T.45N: R.21W: S.31, 24 May 1968, 4 ♂♂ I, 3 ♀♀ (2 gravid); Brown's Cr., Onota Twp., T.47N: R.21W: S.34, 24 May 1968, 3 ♂♂ II, 1 ♀.

ALLEGAN: Swan Cr. Dam, Valley Twp., T.2N: R.14W: S.17, 22 July 1964.

ALPENA: Wolf Cr., Wilson Twp., T.30N: R.7E: S.32, 6 June 1968, 7 ♂♂ II, 1 ♀.

ANTRIM: Cedar R., Kearney Twp., T.30N: R.7W: S.19, 4 June 1968, 2 ♂♂ II.

ARENAC: Rifle R., Clayton Twp., T.20N: R.4E: S.18, 6 May 1968, 3 ♂♂ II, 6 ♀♀ (2 gravid); Rifle R., Deep River Twp., T.19N: R.4E: S.5, 6 May 1968, 1 ♂ I, 1 ♂ II; Wells Cr., Moffatt Twp., T.20N: R.3E: S.21, 6 May 1968, 2 ♂♂ II, 2 ♀♀ (gravid); Au Gres R., Au Gres Twp., T.19N: R.6E: S.12, 6 May 1968, 2 ♂♂ I, 1 ♀ (gravid).

BARRY: Fish L., Orangeville Twp., T.2N: R.10W: S.21, 27 June 1964, 6 ♂♂; Wall L., Hoppe Twp., T.2N: R.9W: S.32, 23 May 1965, 2 ♂♂; Baker Cr., Yankee Springs Twp., T.3N: R.10W: S.3, 27 July 1967, 2 ♂♂ I, 9 ♀♀; Upton Rd. Bridge, Yankee Springs Twp., T.3N: R.10W: S.2, 27 July 1967, 1 ♀; Duncan Cr., Thornapple Twp., T.4N: R.10W: S.15, 28 July 1967, 1 ♂ I, 8 ♀♀.

BENZIE: Platte R., Homestead Twp., T.26N: R.14W: S.16, 5 September 1966, 6 ♂♂I, 1 ♂ II, 2 ♀♀; Betsie R., Colfax Twp., T.25N: R.13W: S.2, 5 September 1966, 1 ♂ I, 3 ♀♀; Herring Cr., Blaine Twp., T.25N: R.16W: S.14, 14 May 1968, 2 ♂♂II, 4 ♀♀ (1 gravid); Platte R., Homestead Twp., T.26N: R.14W: S.8, 14 May 1968, 1 ♂ I, 1 ♂ II, 1 ♀; Platte R., Homestead Twp., T.26N: R.14W: S.13, 14 May 1968, 1 ♂ I, 1 ♂ I, 1 ♂ II, 2 ♀♀.

BERRIEN: Mill Cr., Watervliet Twp., T.4S: R.17W: S.2, 7 August 1967, 2 ♂♂ I, 1 ♂ II, 4 ♀♀; L. Michigan (near Shoreham), St. Joseph Twp., T.4S: R.19W: S.9, 2 August 1967, 1 ♂ I, 1 ♂ II, 5 ♀♀; E. Br. Galien R., Weesaw Twp., T.7S: R.19W: S.15, 19 October 1967, 1 ♂ I, 1 ♀; Hickory Cr., Royalton Twp., T.6S: R.19W: S.3, 19 October 1967, 1 ♂ II, 1 ♀; Yellow Cr., Sodus Twp., T.5S: R.18W: S.18, 19 October 1967, 2 ♀♀.

BRANCH: St. Joseph R., Union Twp., T.5S: R.7W: S.4, 25 October 1967, 1 ♀; S. Br. Swan Cr., Bethel Twp., T.7S: R.7W: S.5, 12 July 1968, 1 ♂ II.

CALHOUN: Harper Cr., Emmett Twp., T.2S: R.7W: S.29, 27 July 1964; Wabascon Cr., Bedford Twp., T.1S: R.8W: S.10, 14 October 1966, 4 ♂♂ I, 2 ♀♀; Nottawasseppee R., Burlington Twp., T.4S: R.7W: S.16, 25 October 1967, 1 ♂ I, 1 ♀; Kalamazoo R., Homer Twp., T.4S: R.4W: S.8, 3 January 1968, 1 ♂ I, 4 ♂♂ II, 3 ♀♀.

CASS: Christiann Cr., Calvin Twp., T.7S: R.14W: S.9, 19 October 1967, 2 ♂♂ I; Dowagiac Cr., Wayne Twp., T.5S: R.15: S.36, 19 October 1967, 1 ♂ II, 1 ♀; Dowagiac Cr., Pokagon Twp., T.6S: R.16W: S.30, 19 October 1967, 1 ♂ II, 1♀.

CHARLEVOIX: Advance Cr., Evangeline Twp., T.33N: R.6W: S.32, 1 September 1966, 2 ♀♀; Mason Cr., Marion Twp., T.32N: R.8W: S.14, 31 August 1966; Loeb Cr., Marion Twp., T.33N: R.8W: S.11, 4 June 1968, 2 ♂♂ II, 3 ♀♀ (1 with young).

CHEBOYGAN: Beebe Cr., Ellis Twp., T.34N: R.2: S.31, 24 July 1966, 2 ♂♂ I, 3 ♀♀; Black R., Forest Twp., T.34N: R.1E: S.3, 5 June 1968, 4 ♂♂ II, 1 ♀; Black R., Waverly Twp., T.35N: R.1E: S.29, 5 June 1968, 6 ♂♂ II; Milligan Cr., Forest Twp., T.34N: R.1E: S.6, 5 June 1968, 1 ♂ II, 1 ♀.

CHIPPEWA: S. Br. Charlotte R., Bruce Twp., T.45N: R.1E: S.36, 24 May 1968, 1 ♂ I, 1 ♂ II, 1 ♀; Pine R., Rudyard Twp., T.44N: R.3W: S.5, 24 May 1968, 3 ♂♂ II, 3 ♀♀ (1 gravid).

CLARE: W. Br. Clam R., Winterfield Twp., T.20N: R.6W: S.17, 16 April 1968, 2 ♂♂ I, 2 ♂♂ II, 2 ♀♀ (1 gravid); Green Cr., Redding Twp., T.19N: R.6W: S.3, 16 April 1968, 1 ♂ I, 1 ♂ II, 1 ♀ (gravid); Little Norway Cr., Redding Twp., T.19N: R.6W: S.22, 16 April 1968, 1 ♂ I; McCuran Cr., Grant Twp., T.17N: R.4W: S.13, 16 April 1968, 3 ♂♂ I, 5 ♂♂ II; Mid. Br., Cedar R., Hamilton Twp., T.19N: R.3W: S.11, 16 April 1968, 1 ♂ II, 2 ♂♂ II, 1 ♀.

CLINTON: Little Maple R., Ovid Twp., T.7N: R.1W: S.28, 20 October 1964; Little Maple R., Ovid Twp., T.7N: R.1W: S.20, 20 October 1964; Park L. Cr., Dewitt Twp., T.5N: R.2W: S.10, 23 October 1964, 2 ♀♀; Vermillion Cr., Bath Twp., T.5N: R.1W: S.24, 2 May 1965, 3 ♂♂ I, 1 ♀ (gravid).

CRAWFORD: S. Br. Au Sable R., South Branch Twp., T.26N: R.1W: S.29, 6 June 1968, 1 ♀ (gravid); E. Br. Big Cr., Lovells Twp., T.27N: R.1W: S.23, 6 June 1968, 1 ♀; Au Sable R., Grayling Twp., T.26N: R.4W: S.12, 6 June 1968, 1 ♀.

DELTA: Rapid R., Masonville Twp., T.42N: R.21W: S.19, 29 August 1965, 2 ♂♂ I, 2 ♀♀; Tacoosh R., Masonville Twp., T.41N: R.21W: S.19, 29 August 1965, 3 ♂♂ I, 1 ♂ II, 4 ♀♀; Garden Cr., Garden Twp., T.39N: R.18W: S.22, 30 August 1965, 29 ♂♂ I, 1 ♂ II, 21 ♀♀; Fishdam R., Garden Twp., T.42N: R.18W: S.17, 22 May 1968, 10 ♀♀ (4 gravid); Sturgeon R., Nahm Twp., T.42N: R.19W: S.33, 22 May 1968, 2 ♂♂ II; Inman Cr., Masonville Twp., T.41N: R.21W: S.17, 22 May 1968, 1 ♂ I, 1 ♂ II.

EATON: Grand R., Dimondale Dam, Windsor Twp., T.4N: R.3W: S.15, 20 September 1964, 10 ♂♂, 5 ♀♀; Thornapple R. trib., Benton Twp., T.3N: R.4W: S.10, 28 October 1967, 1 ♂ II, 2 ♀♀; Springbrook Cr., Hamlin Twp., T.1N: R.3W: S.28, 28 October 1967, 4 ♂♂ I, 7 ♂♂ II, 5 ♀♀.

EMMET: Carp L. River, Wawatam Twp., T.39N: R.4W: S.29, 31 August 1965, 1 ♂ I, 1 ♂ II, 4 ♀♀; Maple R., Maple River

Twp., T.36N: R.4W: S.24, 23 July 1966, 1 ♂ II; Bear Creek Twp., T.34N: R.5W: S.16, 1 September 1966, 2 ♂♂ I, 1 ♂♂ II, 4 ♀♀.

GENESEE: Jones Cr., Gaines Twp., T.6N: R.5E: S.17, 3 April 1968, 2 ♂♂ I, 4 ♂♂ II, 7 ♀♀; Mistequay Cr., Clayton Twp., T.7N: R.5E: S.17, 3 April 1968, 2 ♀♀; Cole Cr., Flushint Twp., T.8N: R.5E: S.34, 3 April 1968, 1 ♂ I, 1 ♂ II, 2 ♀♀; Cole Cr., Flushing Twp., T.8N: R.5E: S.27, 3 April 1968, 2 ♂♂ I, 2 ♂♂ II, 5 ♀♀; Butternut Cr., T.8N: R.7E: S.1, 3 April 1968, 10 ♂♂ I, 10 ♂♂ II; Thread R., Grand Blanc Twp., T.6N: R.7E: S.12, 3 April 1968, 5 ♂♂ I, 4 ♂♂ II, 8 ♀♀.

GLADWIN: Molassess R., Grim Twp., T.18N: R. 2E: S.7, 19 April 1968, 9 ♂♂ II, 8 ♀♀; W. Br. Tittabawassee R., Bourret Twp., T.20N: R.2E: S.7, 19 April 1968, 2 ♀♀; Chapman Cr., Clement Twp., T.20N: R.1E: S.3, 19 April 1968, 1 ♂ I, 1 ♂ II; Sugar R., Butman Twp., T.20N: R.1W: S.22, 19 April 1968, 1 ♂ I.

GRAND TRAVERSE: Boardman R., Garfield Twp., T.27N: R.11W: S.3, 22 July 1966, 1 ♂ I; Boardman R., East Bay Twp., T.26N: R.10W: S.15, 5 September 1966, 2 ♂♂ I, 3 ♂♂ II, 1 ♀; Boardman R., Blair Twp., T.26N: R.11W: S.13, 14 May 1968, 1 ♂ I, 1 ♀; Boardman R., Garfield Twp., T.27N: R.11W: S.22, 14 May 1968, 1 ♂ II; Betsie R., Grant Twp., T.25N: R.12W: S.6, 15 May 1968, 1 ♀.

GRATIOT: W. Br. Pine R., Arcada Twp., T.11N: R.3W: S.6, 6 May 1968, 4 ♂♂ II, 4 ♀♀.

HILLSDALE: St. Joseph R., Litchfield Twp., T.5S: R.4W: S.15, 3 January 1968, 1 ♂ I; Sand Cr., Litchfield Twp., T.5S: R.4W: S.8, 3 January 1968, 1 ♂ II, 1 ♀; Sand Cr., Litchfield Twp., T.5S: R.4W: S.27, 3 January 1968, 8 ♂♂ I, 6 ♂♂ II, 6 ♀♀; Kalamazoo R., Scipio Twp., T.5S: R.3W: S.8, 3 January 1968, 2 ♂♂ I, 3 ♂♂ II, 9 ♀♀; St. Joseph R. trib., Litchfield Twp., T.5S: R.4W: S.25, 1 ♀; Sand Cr., Allen Twp., T.6S: R.4W: S.11, 3 January 1968, 1 ♂ I, 4 ♂♂ II, 8 ♀♀.

HURON: Rock Falls Cr., Sand Beach Twp., T.16N: R.15E: S.24, 24 April 1968, 1 ♂ I, 3 ♂♂ II, 1 ♀; Taff Drain, Hume Twp., T.18N: R.12E: S.33, 24 April 1968, 2 ♂♂ I, 2 ♀♀.

INGHAM: Red Cedar R., Meridian Twp., T.4N: R.1W: S.19, 22 September 1964, 2 ♂♂ I, 1 ♀; Red Cedar R., Williamston Twp., T.4N: R.1E: S.27, 7 October 1964, 3 ♂♂, 11 ♀♀.

IONIA: Prairie Cr., Ionia Twp., T.7N: R.6W: S.16, 13 May 1967, 1 ♂ I; Prairie Cr., Ionia Twp., T.7N: R.6W: S.9, 13 May 1967, 1 ♂ I; smal trib. Grand R., Portland Twp., T.6N: R.5W: S.20, 13 May 1967, 1 ♂ I.

IOSCO: Au Gres R., Reno Twp., T.22N: R.5E: S.27, 7 May 1968, 2 ♂♂ II, 1 ♀ (gravid); Sand Cr., Grant Twp., T.22N: R.6E: S.34, 7 May 1968, 1 ♀.

IRON: Michigamme R., Mansfield Twp., T.43N: R.31W: S.31, 22 May 1968, 1 ♂ I, 1 ♀ (gravid); Paint R., Bates Twp., T.44N: R.34W: S.36, 23 May 1968, 2 ♀♀; Hemlock R., Crystal Falls Twp., T.44N: R.33W: S.15, 23 May 1968, 1 ♂ II.

ISABELLA: Delaney Cr., Coldwater Twp., T.16N: R.6W: S.27, 20 December 1967, 4 ♂♂ I, 3 ♂♂ II, 5 ♀♀; Coldwater R., Gilmore Twp., T.16N: R.5W: S.29, 20 December 1967, 1 ♂ I, 1 ♂ II, 2 ♀♀; N. Br. Chippewa R., Gilmore Twp., T.16N: R.5W: S.24, 20 May 1967, 1 ♂ I, 3 ♂♂ II, 4 ♀♀.

JACKSON: McKay Brook, Sandstone Twp., T.2S: R.2W: S.20, 28 October 1967, 3 ♂♂ II, 1 ♀; N. Br. Kalamazoo R., Hanover Twp., T.4S: R.2W: S.4, 28 October 1967, 1 ♂ I, 2 ♀♀; Spring Brook, Springport Twp., T.1S: R.3W: S.3, 2 ♂♂ I, 1 ♀.

KALAMAZOO: Gull L. Outlet, Charleston Twp., T.2S: R.9W: S.6, 23 June 1964, 2 ♂♂, 3 ♀♀; Augusta Cr., Ross Twp., T.1S: R.9W: S.22, 23 June 1964, 19 ♂♂, 26 ♀♀; Gull L., Ross Twp., T.1S: R.9W: S.6, 25 June 1964, 1 ♂, 2 ♀♀; Gull L., Ross Twp., T.1S: R.9W: S.6, 30 April 1965, 4 ♂♂ I; Comstock Twp., T.2S: R.10W: S.17, 24 June 1965, 2 ♂♂ II, 4 ♀♀; Portage Cr., Kalamazoo Twp., T.2S: R.11W: S.34, 9 April 1966, 1 ♂ I, 3 ♂♂ II, 1 ♀.

KALKASKA: N. Br. Manistee R., Excelsior Twp., T.27N: R.6W: S.24, 15 May 1968; 1 ♂ I; N. Br. Boardman R., Kalkaska Twp., T.27N: R.7W: S.11, 15 May 1968, 1 ♂ I, 1 ♀ (gravid); Manistee R., Garfield Twp., T.25N: R.7W: S.32, 15 May 1968, 1 ♂ I, 3 ♂♂ II, 2 ♀♀ (1 gravid).

KENT: Bear Cr., Cannon Twp., T.8N: R.10: S.20, 13 May 1967, 1 ♂ I.

LAKE: Little Manistee R., Ellsworth Twp., T.19N: R.11W: S.18, 11 April 1968, 4 ♂♂ I, 2 ♀♀; Cool Cr., Elk Twp., T.20N: R.14W: S.8, 11 April 1968, 1 ♂ I, 5 ♂♂ II, 2 ♀♀; Mid Br. Pere

Marquette R., Chase Twp., T. 17N: R.11W: S.15, 11 April 1968, 4 ♂♂ I, 2 ♂♂ II, 3 ♀♀.

LAPEER: Clinton R.c Almont Twp., T.6N: R.12E: S.22, 24 April 1968, 4 ♂♂ I, 1 ♂♂ II, 1 ♀; S. Br. Flint R., Lapeer Twp., T.7NP R.10E: S.23, 24 April 1968, 2 ♂♂ I, 7 ♂♂ II, 5 ♀♀; Pine Cr., Lapeer Twp., T.7N: R.10E: S.24, 24 April 1968, 2 ♂♂ I, 2 ♂♂ II.

LEELANAU: Crystal R., Glen Arbor Twp., T.29N: R.14 W: S.23, 6 Spetember 1966, 2 ♂♂ I, 2♀♀; Sucker Cr., Cleveland Twp., T.29N: R.13W: S.4, 6 September 1966, 1 ♂ I, 4 ♀♀; Crystal R., Glen Arbor Twp., T.29N: R.14W: S.14, 14 May 1968, 2 ♂♂ I, 1 ♀.

LENAWEE: River Raisin, Raisin Twp., T.6S: R.4E: S.29, 7 October 1964, 1 ♂: Wolf Cr., Adrian Twp., T.6S: R.3E: S.28, 11 May 1965, 4 ♂♂ I; Wolf Cr., Adrian Twp., T.6S: R.3E: S.28, 8 August 1965, 8 ♂♂ I, 9 ♂♂ II, 11 ♀♀; S. Br. River Raisin, Madison Twp., T.7S: R.3E: S.3, 10 November 1967, 1 ♂ I, 3 ♂♂ II, 5 ♀♀; Black Cr., Ogden Twp., T.8S: R.4E: S.5, 10 November 1967, 1 ♂ I.

LIVINGSTON: Mid. Br. Cedar R., Handy Twp., T.3N: R.3E: S.22, 31 October 1964; W. Br. Cedar R., Iosco Twp., T.2N: R.3E: S.21, 21 March 1968, 2 ♀♀; Williamsville L. Cr., Unadilla Twp., T.1N: R.3E: S.29, 21 March 1968, 4 ♂♂ I, 3 ♂♂ II, 5 ♀♀; Mid. Br. Cedar R., Handy Twp., T.3N: R.3E: S.34, 21 March 1968, 1 ♂ II, 2 ♀♀; Shiawassee R., Marion Twp., T.2N: R.4E: S.3, 21 March 1968, 1 ♂ I, 1 ♀.

LUCE: Teaspoon Cr., Pentland Twp., T.45N: R.10W: S.3, 24 May 1968, 4 ♂♂ I, 1 ♂ II, 3 ♀♀ (2 gravid); W. Br. Murphy Cr., Millan Twp., T.47N: R.9W: S.16, 24 May 1968, 1 ♂ I.

MACKINAC: Millecoquins R., Garfield Twp., T.43N: R.9W: S.30, 30 August 1965, 1 ♂ II, 3 ♀♀; Hog Island Cr., Hudson Twp., T.43N: R.8W: S.34, 30 August 1965, 13 ♂♂ I, 3 ♀♀; Millecoquins Cr., Garfield Twp., T.43N: R.10W: S.14, 22 May 1968, 3 ♂♂ I, 4 ♂♂ II, 5 ♀♀ (1 gravid).

MACOMB: Healy Drain, Washington Twp., T.4N: R.12E: S.24, 23 April 1968, 2 ♂♂ II, 3 ♀♀; Clinton R., Ray Twp., T.4N: R.13E: S.22, 23 April 1968, 3 ♂♂ I, 2 ♂♂ II, 2 ♀♀.

MANISTEE: Bear Cr., Dickson Twp., T.22N: R.14W: S.7, 4 June 1968, 1 ♂ II, 4 ♀♀ (1 gravid); Big Beaver Cr., Maple Grove Twp., T.23N: R.14W: S.21, 4 June 1968, 5 ♂♂ II, 1 ♀ (gravid); Betsie R., Springdale Twp., T.24N: R.14W: S.3, 4 June 1968, 4 ♂♂ II, 5 ♀♀ (2 gravid).

MARQUETTE: Harlow Cr., Marquette Twp., T.49N: R.25W: S.19, 26 August 1965, 9 ♂♂ I, 7 ♂♂ II, 10 ♀♀; Dead R., Marquette Twp., T.48N: R.25W: S.10, 26 August 1965, 1 ♂ I, 1 ♂ II; Chocolay R., West Branch Twp., T.46N: R.24W: S.1, 1 ♂ II, 1 ♀.

MASON: Carr Cr., Logan Twp., T.17N: R.15W: S.14, 11 April 1968, 1 ♂ I, 1 ♂ II, 3 ♀♀; N. Br. Lincoln R., Victory Twp., T.19N: R.17W: S.20, 11 April 1968, 1 ♂ I, 1 ♀ (gravid); Big Sable R., Grant Twp., T.20N: R.17W: S.27, 11 April 1968, 4 ♂♂ I.

MECOSTA: Little Muskegon R., Aetna Twp., T.13N: R.10W: S.25, 21 July 1966, 2 ♂♂ I; MuskegonR., Green Twp., T.16N: R.10W: S.15, 20 December 1967, 2 ♂♂ I, 1 ♀; Ryan Cr., Colfax Twp., T.15N: R.9W: S.5, 20 December 1967, 4 ♂♂ II, 4 ♀♀; Rattail Cr., Fork Twp., T.16N: R.7W: S.15, 20 December 1967, 1 ♂ I; N. Br. Chippewa R., Fork Twp., T.16N: R.7W: S.15, 20 December 1967, 3 ♂♂ I, 2 ♀♀ II.

MENOMINEE: Forty-seven Mile Cr., Harris Twp., T.38N: R.25W: S.8, 22 May 1968, 2 ♂♂ I, 2 ♂♂ II, 4 ♀♀ (1gravid); Wilson Cr., Harris Twp., T.38N: R.25W: S.7, 22 May 1968, 4 ♂♂ I, 1 ♂ II, 6 ♀♀ (4 gravid); Big Cedar R., Spalding Twp., T.38N: R.26W: S.9, 22 May 1968, 4 ♂♂ I; Little Cedar R., Meyer Twp., T.39N: R.27W: S.34, 22 May 1968, 1 ♂ II, 1 ♀.

MIDLAND: N. Br. Carroll Cr., Jerome Twp., T.15N: R.1W: S.34, 7 May 1968, 1 ♂ I, 1 ♂ II, 2 ♀♀; S. Br. Carroll Cr., Lee Twp., T.14N: R.1W: S.3, 7 May 1968, 2 ♂♂ II.

MISSAUKEE: Muskegon R., Reedsburg Dam, Enterprise Twp., T.23N: R.5W: S.25, 1 November 1964, 2 ♂♂, 2 ♀♀; W. Br. Muskegon R., West Branch Twp., T.23N: R.6W: S.25, 15 May 1968, 1 ♀ (gravid); Clam R., Clam Union Twp., 21N: R.6W: S.20, 15 May 1968, 2 ♂♂ I, 2 ♂♂ II, 1 ♀ (gravid); Clam R., Riverside Twp., T.21N: R.7W: S.6, 15 May 1968, 2 ♂♂ I, 1 ♂ II, 1 ♀.

MONROE: Woodchuck Cr., Monroe Twp., T.7S: R.9E: S.25, 13 August 1965, 4 ♂♂ I; Erie Marsh, Erie Twp., T.8S: R.8E: S.15, 1 May 1965, 3 ♂♂ I; Otter Cr., Lasalle Twp., T. 7S: R.8E: S.15, 10 November 1967, 2 ♂♂ I, 5 ♂♂ II, 5 ♀♀.

MONTCALM: Hunter L., Pine Twp., T.11N: R.8W: S.33, 16 July 1966, 1 ♂ I; Fish Cr., Bloomer Twp., T.9N: R.5W: S.12, 13 May 1967, 1 ♂ I; Wabasis Cr., Eureka Twp., T.9N: R.8W: S.33, 20 December 1967, 8 ♂♂ II, 9 ♀♀; Flat R., Eureka Twp., T.9N: R.8W: S.33, 20 December 1967, 6 ♂♂ I, 6 ♂♂ II, 6 ♀♀; Flat R., Montcalm Twp., T.10N: R.8W: S.18, 20 December 1967, 3 ♂♂ II, 4 ♀♀; Tamarack Cr., Reynolds Twp., T.12N: R.10W: S.26, 20 December 1967, 13 ♂♂ I, 9 ♂♂ II, 20 ♀♀.

MONTMORENCY: Black R., Montmorency Twp., T.32N: R.1E: S.21, 6 June 1968, 1 ♀.

MUSKEGON: Crockery Cr., Casnovia Twp., T.10N: R.13W: S.30, 14 December 1967, 2 ♂♂ II, 2 ♀♀; White R. Rochdale Dam, Blue Lake Twp., T.12N: R.16W: S.6, 14 December 1967, 2 ♂♂ I, 3 ♂♂ II, 4 ♀♀.

NEWAYGO: White R., Lincoln Twp., T.14N: R.13W: S.30, 14 December 1967, 4 ♂♂ I, 4 ♂♂ II, 5 ♀♀.

OAKLAND: Frnaklin R., Franklin, T.2N: R.10E: S.6, 31 May 1965, 5 ♂♂; Paint Cr., Oakland Twp., T.3N: R.11I: S.4, 15 September 1965, 6 ♂♂, 1 ♀; Sash-abow Cr., Independence Twp., T.4N: R.9E: S.26, 21 March 1968, 2 ♂♂ I, 1 ♂ II, 6 ♀♀; Paint Cr., Oakland Twp., T.3N: R.11E: S.4, 21 March 1968, 1 ♂ II, 2 ♀♀.

OCEANA: Carlton Cr., Grant Twp., T.13N: R.17W: S.21, 14 December 1967, 2 ♂♂ II, 5 ♀♀; N. Br. White R., Otto Twp., T.13N: R.16W: S.3, 14 December 1967, 2 ♀♀.

OGEMAW: Rifle R., Cumming Twp., T.23N: R.3E: S.27, 9 July 1967, 1 ♂ I, 2 ♀♀; Nester Cr., Logan Twp., T.22N: R.4E: S.22, 7 May 1968, 8 ♂♂ I, 8 ♀♀ (3 gravid); Au Gres R., Logan Twp., T.22N: R.4E: S.11, 7 May 1968, 1 ♂ I, 3 ♂♂ II, 2 ♀♀ (1 gravid).

ONTONAGON: Merriweather Cr., Bergland Twp., T.48N: R.43W: S.11, 23 May 1968, 2 ♂♂ I, 2 ♀♀ (1 gravid).

OSCEOLA: Johnson Cr., Richmond Twp., T.17N: R.10W: S.7, 16 April 1968, 1 ♂ I, 3 ♂♂ II, 1 ♀; Lincoln Cr., Lincoln Twp., T.18N: R.10W: S.15, 16 April 1968, 1 ♂ I, 2 ♂♂ II, 3 ♀♀ (1 gravid); E. Br. Hersey R., Lincoln Twp., T.18N: R.10W: S.10, 16 April 1968, 1 ♂ I; E. Br. Pine R., Bordell Twp., T.20N: R.10W: 2.21, 16 April 1968, 1 ♂ II, 1 ♀ (gravid); Beebe Cr., Highland Twp., T.20N: R.8W: S.27, 16 April 1968, 3 ♂♂ I, 1 ♀; Middle Branch R., Highland Twp., T.20N: R.8W: S.35, 16 April 1968, 3 ♂♂ I, 1 ♂ II, 1 ♀ (gravid); Big Stone Cr., Evart Twp., T.17N: R.8W: S.29, 16 April 1968, 3 ♂♂ I, 2 ♂♂ II; Chippewa R., Orient Twp., T.17N: R.7W: S.11, 16 April 1968, 2 ♂♂ I, 1 ♂ II, 1 ♀; Middle Branch R., Marion Twp., T.20N: R.7W: S.21, 16 April 1968, 3 ♂♂ I, 1 ♀.

OTSEGO: Pigeon R., Corwith Twp., T.32N: R.1W: S.20, 6 June 1968, 1 ♂ II; Black R., Corwith Twp., T.32N: R.1W: S.34, 6 June 1968, 3 ♂♂ II, 1 ♀.

OTTAWA: N. Br. Crockery Cr., Chester Twp., T.9N: R.13W: S.4, 14 December 1967, 1 ♂ I, 7 ♂♂ II, 9 ♀♀; Tenhaden Cr., Port Sheldon Twp., T.6N: R.16W: S.27, 23 December 1967, 1 ♀.

PRESQUE ISLE: Black Mallard R., Bearinger Twp., T.36N: R.3E: S.1, 5 June 1968, 1 ♂ II, 3 ♀♀ (3 gravid); Ocqueoc R., Case Twp., T.34N: R.3E: S.9, 5 June 1968, 4 ♂♂ II; Trout R., Rogers Twp., T.35N: R.5E: S.30, 5 June 1968, 1 ♂ I, 1 ♂ II, 3 ♀♀ (2 gravid); Swan R., Pulawski Twp., T.34N: R.6E: S.17, 5 June 1968, 6 ♂♂ II; N. Br. Thunder Bay R., Elowski Dam, T.33N: R.6E: S.30, 5 June 1968, 5 ♂♂ II, 2 ♀♀ (1 gravid).

ROSCOMMON: S. Br. Au Sable R., AuSable Twp., T.24N: R.1W: S.21, 7 May 1968, 1 ♂ I; Higgins Lake Cut, Gerrish Twp., T.24N: R.3W: S.34, 7 May 1968, 2 ♂♂ II, 1 ♀.

SAGINAW: S. Fork Bad R., Chapin Twp., T.9N: R.1E: S.1, 6 May 1968, 2 ♂♂ I, 1 ♂ II.

ST. CLAIR: Belle R., China Twp., T.4N: R.16E: S.15, 23 April 1968, 1 ♂ I, 5 ♂♂ II, 1 ♀ (gravid); Pine R. trib., Clair Twp., T.5N: R.16E: S.26, 23 April 1968, 3 ♂♂ II; Smiths Cr., Kimball Twp., T.6N: R.16E: S.30, 23 April 1968, 2 ♀♀ (1 gravid); Jeddo Cr., Burtchville Twp., T.8N: R.17E: S.12, 23 April 1968, 10 ♂♂ I, 1 ♂ II, 6 ♀♀ (5 gravid); Silver Cr., Grant Twp., T.8N: R.16E: S.7, 23 April 1968, 3 ♂♂ I, 2 ♀♀ (1 gravid).

ST. JOSEPH: Portage R., Park Twp., T.5S: R.11W: S.23, 30 July 1964; Nottawa Cr., Leonidas Twp., T.5S: R.9W: S.29, 28 June 1965, 1 ♀; Prairie R., Lockport Twp., T.6S: R.11W: S.34, 25 October 1967, 1 ♂ I, 2 ♀♀; Nottawa Cr., Leonidas Twp., T.5S: R.9W: S.16, 25 October 1967, 1 ♂ I, 1 ♂ II, 13 ♀♀.

SANILAC: White Cr., Lamotte Twp., T.12N: R.12E: S.6, 24 April 1968, 4 ♂♂ I, 3 ♀♀ (2 gravid); N. Br. Cass R., Greenleaf Twp., T.14N: R.12E: S.12, 24 April 1968, 2 ♂♂, 2 ♀♀; Black R., Wheatland Twp., T.13N: R.14E: S.25, 24 April 1968, 1 ♂ I, 3 ♂♂ II; Elk Cr., Elk Twp., T.10N: R.14E: S.3, 24 April 1968, 1 ♂ I, 2 ♂♂ II; L. Michigan trib., Sanilac Twp., T.12N: R.16E: S.22, 24 April 1968, 1 ♂ I, 2 ♂♂ II.

SCHOOLCRAFT: Ferina Cr., Doyle Twp., T.42N: R.14W: S. 25, 22 May 1968, 2 ♂♂ II; N. Br. Stutts Cr., Hiawatha Twp., T.45N: R.17W: S.18, 24 May 1968, 1 ♂ II, 1 ♀; Walsh Cr., Seney Twp., T.46N: R.15W: S.33, 24 May 1968, 1 ♂ I.

SHIAWASSEE: Mondell Cr., Bennington Twp., T.6N: R.2E: S.36, 3 April 1968, 1 ♂ I; Looking Glass R., Bennington Twp., T.6N: R.2E: S.25, 3 April 1968, 2 ♂♂ II, 1 ♀; Maple R., Bennington Twp., T.6N: R.2E: S.3, 3 April 1968, 3 ♂♂ I, 1 ♂ II; Maple R. trib., Bennington Twp., T.6N: R.2E: S.4, 3 April 1968, 1 ♂ I, 3 ♀♀; Shiawassee R., Rush Twp., T.8N: R.2E: S.13, 3 April 1968, 9 ♂♂ I, 1 ♂ II, 3 ♀♀; Shiawassee R. trib., New Haven Twp., T.8N: R.3E: S.18, 3 April 1968, 1 ♂ I, 3 ♂♂ II, 1 ♀; Six Mile Cr., New Haven Twp., T.8N: R.3E: S.20, 3 April 1968, 3 ♂♂ I, 3 ♂♂ II, 9 ♀♀; Shiawassee R., Caledonia Twp., T.7N: R.3E: S.26, 3 April 1968, 2 ♂♂ II.

TUSCOLA: Cass R., Novesta Twp., T.13N: R.11E: S.7, 24 April 1968, 3 ♂♂ I, 1 ♂ II, 1 ♀; N. Br. White Cr., Novesta Twp., T.13N: R.11E: S.30, 24 April 1968, 4 ♂♂ I; Sucker Cr., Wells Twp., T.12N: R.10E: S.7, 24 April 1968, 2 ♂♂ I, 3 ♂♂ II, 2 ♀♀ (1 gravid); Sucker Cr., Drain, Wells Twp., T.12N:

R.10E: S.7, 24 April 1968, 4 ♂♂ I, 1 ♂ II, 1 ♀; Perry Cr., Tuscola Twp., T.11N: R.7E: S.33, 24 April 1968, 6 ♂♂ I, 1 ♂ II.

VAN BUREN: White Cr., Lawrence Twp., T.3S: R.15W: S.10, 9 August 1967, 1 ♂ II, 3 ♀♀; Paw Paw R. trib., Waverly Twp., T.2S: R.14 W: S.10, 10 August 1967, 1 ♂ I, 1 ♂ II, 3 ♀♀; Campbell Cr., Almena Twp., T.2S: R.13W: S.2, 9 August 1967, 2 ♂♂ I, 2 ♂♂ II, 1 ♀; Paw Paw R. trib., Waverly Twp., T.2S: R.14W: S.23, 9 August 1967, 2 ♂♂ I, 2 ♂♂ II, 5 ♀♀; Paw Paw R., Almena Twp., T.2S: R.13W: S.16, 19 October 1967, 1 ♂ I, 1 ♀.

WASHTENAW: Huron R., Scio Twp., T.2S: R.5E: S.5, 10 November 1967, 1 ♂ I, 5 ♀♀; Mill Cr., Scio Twp., T.2S: R.5E: S.6, 10 November 1967, 1 ♂ I, 5 ♀♀.

Orconectes rusticus (Girard, 1852)

O. rusticus is a moderately large species, easily identified by the rust-colored maculations on the sides of the cephalothorax and the long, narrow, concave rostrum.

O. rusticus inhabitats small, swift-flowing streams to large, slow-moving rivers with rocky bottoms and is often found in impoundments and old millponds in large numbers. It does not construct distinct burrows, but may be found in shallow excavations under large rocks. Langlois (1936) reports that females, subsequent to copulation, burrow horizontally into the levees of fish ponds as much as two and one-half feet. There is no indication, however, that *O. rusticus* burrows in Michigan which may be due to the fact that collections were limited generally to streams in Michigan.

O. rusticus was first described from the Ohio River at Cincinnati (Hobbs, 1967). Faxon (1884; 1898) recorded *O. rusticus* from Lake Michigan, Saginaw and Tiffin, Michigan. Creaser (1931) doubts the validity of Faxon's distributional records for *O.rusticus* in Michigan and indicates that *O. rusticus* occupies only the extreme southern edge of Michigan in Lenawee County. Pearse (1910) reported that *O. rusticus* is not a common species in Michigan, if it occurs at all at the present time.

Several collections of *O. rusticus* from Michigan have been deposited in the U.S. National Museum by Holt, Hubbs and Vander Schalie, Creaser and Hankinson, and Goodrich. The majority of the specimens were collected from the southern

Michigan counties of Hillsdale, St. Joseph, and Lenawee. However, Holt, as recently as 1960, collected *O. rusticus* from a tributary of the Au Sable River in the northeast county of Oscoda.

During the course of this study *O. rusticus* was collected throughout Michigan from 19 counties (Table I), including the Upper Peninsula (Fig. 50).

O. rusticus has two primary mating seasons, based on percentage occurrence of sexually mature males (form I), during April to the middle of May, and a second longer mating season from June through the middle of November (Fig. 51). Langlois (1936) reports that the principle mating season occurs during the descending temperatures of latter September and October in fish ponds in Ohio.

The females spawn within a short period during the latter part of May to early June, hatching occurs from late May to mid-June (Fig. 48). Extruded eggs were counted from nine females and the number of eggs ranged from 26 to 260 per individual (Table II).

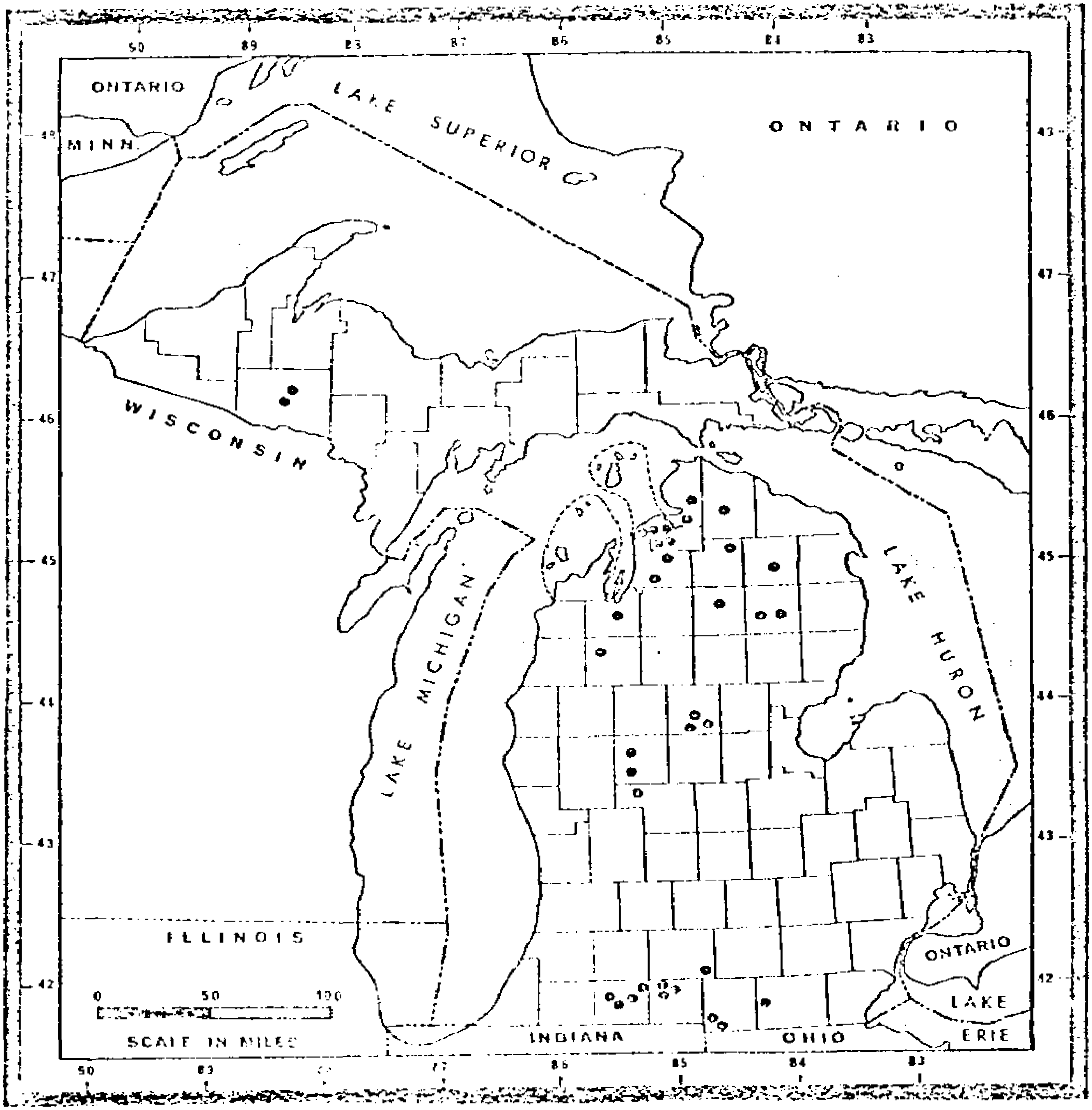

Figure 50. Distribution of *Orconectes rusticus* in Michigan.

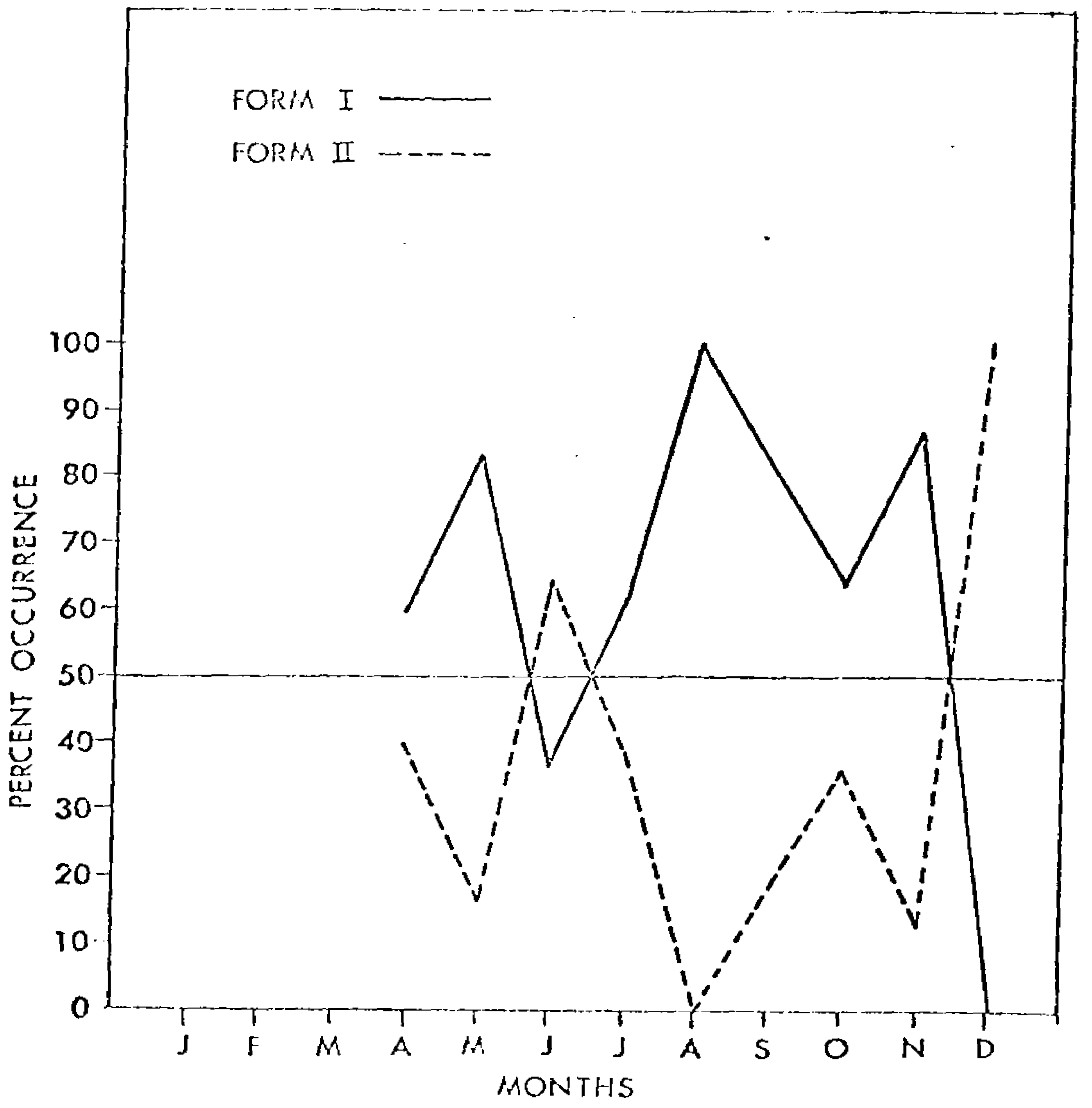

Figure 51. Frequency occurrence of form I and form II *Orconectes rusticus*.

TABLE II

NUMBER OF ATTACHED EGGS CARRIED BY *Orconectes rusticus*

Cephalothorax Length (mm)	No. of Eggs
25.0	55
25.0	161
27.0	168
30.0	26
30.0	54
33.0	206
33.5	95
37.5	260
40.0	236

O. rusticus occurred with *O. propinquus* in 43 percent of the collections, and was associated with *O. virilis* 16 percent of the time, and with *C. robustus* in 8 percent of the collections. The percentage association with *O. propinquus*, *O. virilis* and *O. robustus* is proportional to the relative abundance of those species in Michigan.

O. rusticus has a limited distribution in Ontario and is found in Illinois, Indiana, Kentucky, Maine, Massachusetts, Michigan and Ohio. Hobbs (1972b) questions the records for Iowa and New Mexico.

Orconectes rusticus (Girard)

Locality Records in Michigan

ANTRIM: Cedar R., Kearney Twp., T.30N: R.7W: S.19, 4 June 1968, 1 ♀ (gravid); Jordan R., Jordan Twp., T.31N: R.6W: S.20, 4 June 1968, 3 ♀♀ (1 gravid).

BRANCH: Coldwater R., Union Twp., T.5S: R.7W: S.4, 25 October 1967, 2 ♂♂ I, 2 ♂♂ II, 2 ♀♀; St. Joseph R., Union Twp., T.5S: R.7W: S.4, 25 October 1967, 1 ♂ I.

CALHOUN: Kalamazoo R., Homer Twp., T.4S: R.4W: R.4W: S.8, 3 January 1968, 1 ♀.

CHARLEVOIX: Deer Cr., South Arm Twp., T.32N: R.7W: S.25, 22 July 1966, 2 ♂♂ I, 2 ♂♂ II, 5 ♀♀; Advance Cr., Evangeline Twp., T.33N: R.6W: S.32, 1 September 1966, 1 ♂ II, 1♀; Mason Cr., Marion Twp., T.33N: R.3W: S.14, 31 August 1966, 1 ♂ I, 2 ♀♀; Porter Cr., Wilson Twp., T.32N: R.6W: S.5, 1 September 1966, 4 ♂♂ I, 5 ♀♀; Loeb Cr., Marion Twp., T.33N: R.8W: S.11, 4 June 1968, 1 ♂ II.

CHEBOYGAN: Pigeon R., Ellis Twp., T.34N: R.2W: S.2, 5 June 1968, 1 ♂ I, 2 ♂♂ II, 1 ♀ (gravid).

CLARE: Tobacco R., Grant Twp., T.17N: R.4W: S.30, 16 April 1968, 1 ♂ I, 1 ♀; S. Br. Tobacco R., Grant Twp., T.17N: R.4W: S.33, 16 April 1968, 1 ♂ I, 5 ♀♀; McCuran Cr., Grant Twp., T.17N: R.43W: S.13, 16 April 1968, 1 ♂ I, 2 ♂♂ II, 1 ♀.

CRAWFORD: E. Br. Au Sable R., Lovells Twp., T.28N: R.2W: S.30, 6 June 1968, 12 ♂♂ II, 15 ♀♀.

EMMET: Maple R., Maple River Twp., T.36N: R.4W: S.24, 23 July 1966, 1 ♀; Bear R., Bear Cr. Twp., T.34N: R.5W: S.16, 1 September 1966, 3 ♂♂ I, 2 ♂♂ II, 3 ♀♀.

GRAND TRAVERSE: Boardman R., East Bay Twp., T.26N: R. 10W: S.15, 5 September 1966, 3 ♂♂ I, 3 ♀♀.

HILLSDALE: St. Joseph R., Camden Twp., T.8S: R.4W: S.22, 12 July 1968, 2 ♂♂ II, 3 ♀♀; St. Joseph R., Amboy Twp., T.9S: R.3W: S.8, 12 July 1968, 2 ♂♂ II, 1 ♀.

IRON: Hemlock R., Crystal Falls Twp., T.44N: R.33W: S.17, 23 May 1968, 3 ♂♂ I; Hemlock R., Crystal Falls Twp., T.44N: R.33W: S.8, 23 May 1968, 1 ♂ II, 2 ♀♀.

LENAWEE: Fitts Cr., Rollin Twp., T.6S: R.1E: S.17, 10 November 1967, 5 ♂♂ I, 6 ♀♀.

MECOSTA: Little Muskegon R., Aetna Twp., T.13N: R.10W: S.25, 21 July 1966, 10 ♂♂ I, 5 ♂♂ II, 11 ♀♀; Muskegon R., Green Twp., T.16N: R.10W: S.15, 20 December 1967, 1 ♂ II.

MONTCALM: Tamarack Cr., Reynolds Twp., T.12N: R.10W: S.26, 20 December 1967, 2 ♀♀.

MONTMORENCY: Thunder Bay R., Briley Twp., T.30N: R.2E: S.12, 6 June 1968, 1 ♂ II, 3 ♀♀.

OSCODA: Au Sable R., Mentor Twp., T.26N: R.3E: S.10, 6 June 1968, 2 ♂♂ II, 1 ♀; Au Sable R., Mentor Twp., T.26N: R.3E: S.7, 6 June 1968, 2 ♂♂ I, 2 ♂♂ II, 2 ♀♀ (2 gravid).

OTSEGO: Pigeon R., Corwith Twp., T.32N: R.1W: S.20, 6 June 1968, 1 ♂ II, 2 ♀♀ (2 gravid).

ST. JOSEPH: St. Joseph R., Lockport Twp., T.6S: R.11W: S.2, 30 July 1964, 4 ♂♂ I; St. Joseph R., Lockport Twp., T.6S: R.11W: S.11, 3 August 1964; St. Joseph R., Lockport Twp., T.6S: R.11W: S.11, 26 June 1965, 1 ♂ I, 3 ♂♂ II, 6 ♀♀; St. Joseph R., Nottawa Twp., T.6S: R.10W: S.7, 28 June 1965, 1 ♀; Nottawa Cr., Leonidas Twp., T.5S: R.9WP S.16, 25 October 1967, 1 ♂ I, 1 ♀.

WEXFORD: Manistee R., Hanover Twp., T.24N: R.11W: S.31, 5 September 1966, 1 ♂ I, 2 ♀♀.

Orconectes virilis (Hagen, 1870)

O. virilis is a widely distributed species in Michigan, and second only to *O. propinquus* in abundance (Fig. 52; Table I). It inhabits both lentic and lotic habitats and often occupies the deeper regions of lakes. Creaser (1934b) reported *O. virilis* from nets set in 104 feet of water in Green Bay, Lake Michigan. Momot and Gowing (1972) report that female *O. virilis* seasonally migrate from shallow to deep waters in August.

O. virilis is a commonly encountered species, in the rapids regions of streams where it maintains its position among large rocks in the rapids. It is also common in streams outside of the rapid regions where there are rubble-strewn bottoms and in deep pools behind dams.

O. virilis is a highly adaptive species as indicated by its ability to inhabitat a wide range of environments. Aiken (1967) reports that *O. virilis* is the only species of crayfish found in Alberta, Canada, where it is able to survive severe winter conditions by moving into deeper water. Schwartz, Rubelmann and Allison (1963) discussed the ecological population expansion of *O. virilis* in the Patapsco River drainage, Maryland. *O. virilis* were collected by Schwartz et al. from the Patapsco River, Maryland in which the water temperatures ranged from 5 to 31 C, the pH from 5 to 9.5 and the dissolved oxygen ranged from 2 to 12 ppm. Kendall and Schwartz (1964) reported that *O. virilis* is able to tolerate salinities of 33 ppt (full strength sea water)

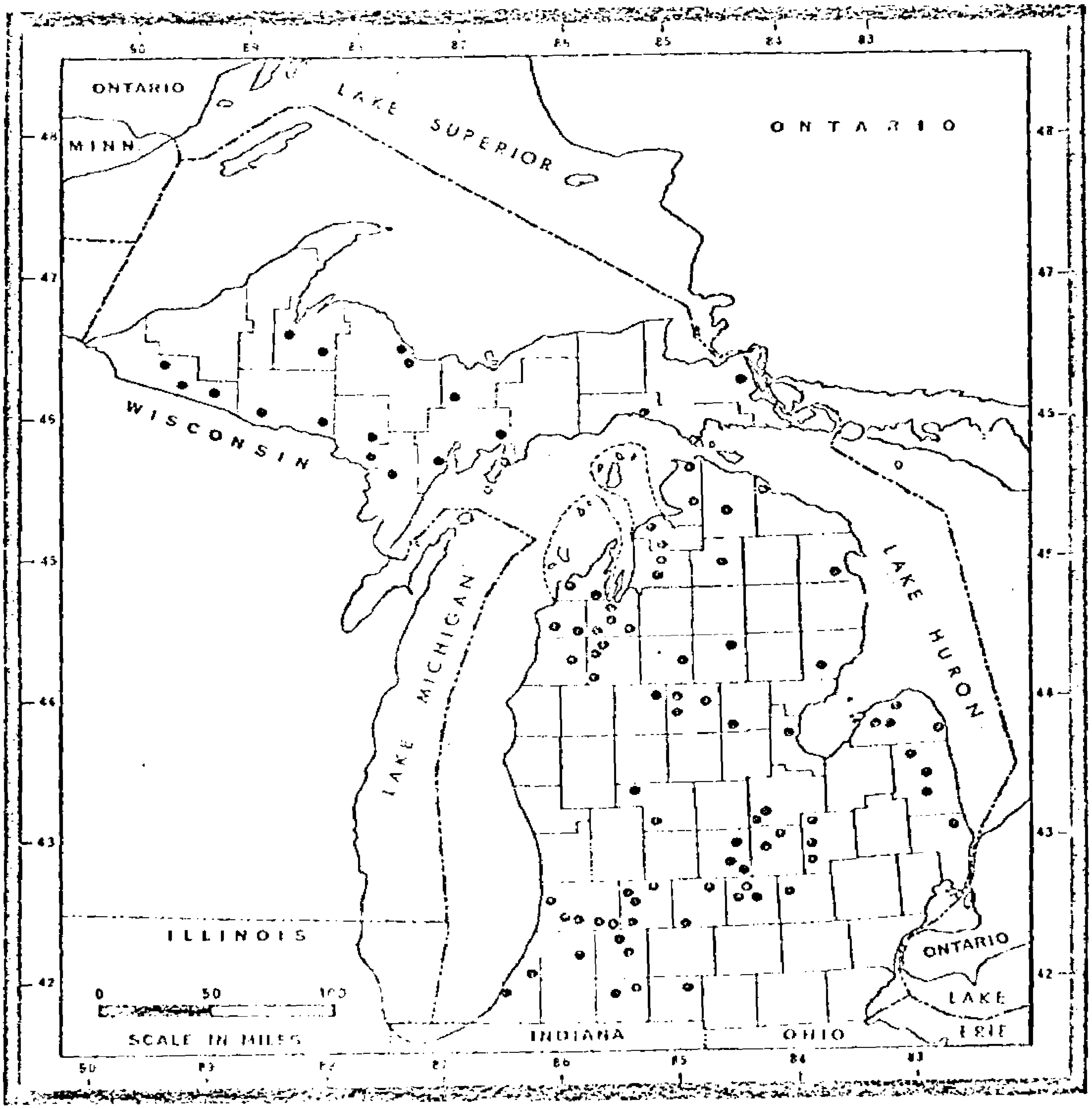

Figure 52. Distribution of *Orconectes virilis* in Michigan.

under laboratory conditions for up to 96 hours.

Mating occurs from mid-July through mid-September as indicated by the presence of sexually active (form I) males only during that period (Fig. 53). These data concur with Momot (1967) who observed copulation of *O. virilis* pairs from mid-August through September in West Lost Lake, Otsego County, Michigan. Females with eggs were observed from May through early June (Fig. 48). The extruded eggs from six *O. virilis* females were removed and counted. The number of eggs ranged from 61 to 528 per female as indicated in Table III.

TABLE III

NUMBER OF ATTACHED EGGS CARRIED BY *Orconectes virilis*

Cephalothorax length (mm)	No. of eggs
21.0	61
27.5	232
30.0	281
32.5	251
35.0	357
38.5	528

Momot (1967) reported that the average number of ovarian eggs counted from *O. virilis* females from West Lost Lake, Michigan was 162 and the mean number of eggs attached to the abdomen of females in 1963 was 94. The mean number of

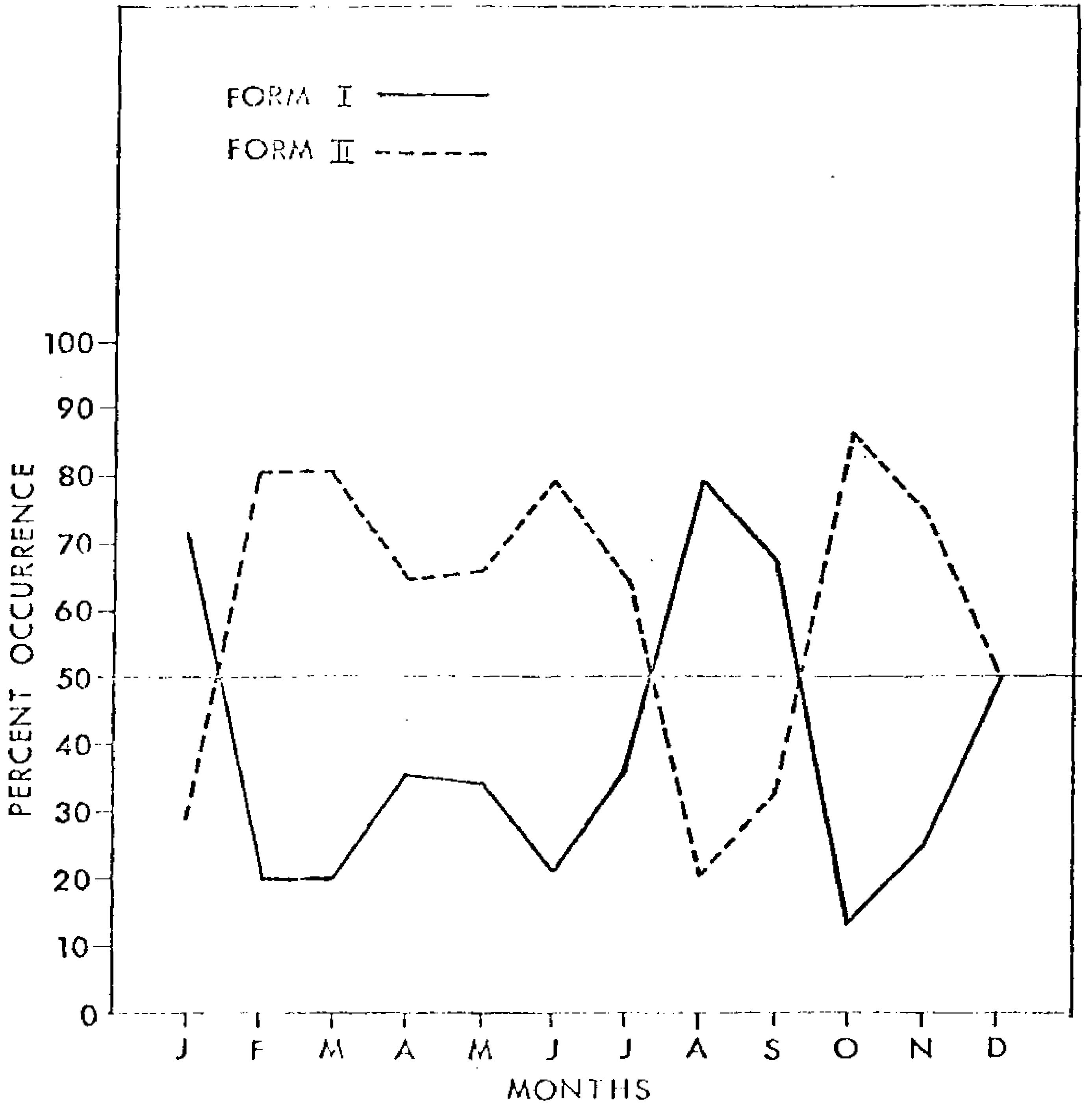

Figure 53. Frequency occurrence of form I and form II *Orconectes virilis*.

attached eggs per female calculated during the present study is 285. The number of ovigerous females utilized to obtain this mean is much too small to be statistically significant. However, the ovigerous females were collected from several areas in Michigan and the relatively high number of eggs per female as compared to those from West Lost Lake may indicate that the *O. virilis* population in West Lost Lake may have a lower reproductive capacity when compared to the Michigan population as a whole.

O. virilis, as indicative of its ability to inhabit a wide range of environments, occurred with all other crayfish species except *F. fodiens*.

O. virilis has been reported in a discontinuous distribution across North America from Maine to California, and northward from the Mississippi valley to Ontario, Manitoba, and Saskatchewan, Canada (Aiken, 1968). Hobbs (1972b) records *O. virilis* from Alberta, Manitoba, Ontario, Quebec, Saskatchwean, Canada; Arizona, Arkansas, California, Colorado, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, New Hampshire, New Mexico, New York, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Wisconsin, and Wyoming.

Orconectes virilis (Hagen)

Locality Records in Michigan

ALGER: Scotts Cr., Mathias Twp., T.44N: R.21W: S.19, 24 May 1968, 1 ♀.

ALLEGAN: Swan Cr., Valley Twp., T.2N: R.14W: S.17, 22 July 1964; Kalamazoo R., Manlius Twp., T.3N: R.15W: S.17, 28 June 1965, 2 ♂♂ II; Kalamazoo R., Trowbridge Dam, Otsego Twp., T.2N: R.12W: S.6, 18 September 1965, 4 ♂♂ I, 2 ♂♂ II, 7 ♀♀; Kalamazoo R., Allegan L., Allegan Twp., 18 September 1968, 2 ♂♂ I, 1 ♀; Pine Cr., Otsego Twp., T.1N: R.12W: S.32, 1 ♂ I.

ALPENA: Lower S. Br. Thunder Bay R., Wilson Twp., T.30N: R.7E: S.22, 6 June 1968, 1 ♀ (gravid).

ANTRIM: Intermediate R., Echo Twp., T.31N: R.7W: S.27, 22 July 1966, 1 ♀; Cedar R., Kearney Twp., T.30N: R.7W: S.19, 4 June 1968, 1 ♂ I, 1 ♂ II.

BARAGA: Plumbago Cr., L'anse Twp., T.49N: R.33W: S.18, 11 July 1964, 1 ♂ II; Canal Town Cr., Spur Twp., T.48N: R.31W: S.17, 23 May 1968, 1 ♂ I.

BARRY: Lawrence L., Barry Twp., T.1N: R.9W: S.27, 10 March 1966, 3 ♂♂ II, 3 ♀♀; Little Thornapple R., Carlton Twp., T.4N: R.8W: S.13, 5 May 1966, 3 ♂♂ II, 8 ♀♀; Thornapple R. trib., Yankee Springs Twp., T.3N: R.10W: S.2, 27 July 1967, 1 ♂ II, 1 ♀; Duncan Cr., Thornapple Twp., T.4N: R.10W: S.15, 28 July 1967, 1 ♂ II, 2 ♀♀.

BAY: Tebo Drain, Fraser Twp., T.16N: R.4E: S.8, 6 May

1968, 1 ♂ I, 2 ♂♂ II, 2 ♀♀.

BENZIE: Betsie R., Colfax Twp., T.25N: R.13W: S.2, 5 September 1966, 8 ♂♂ II, 9 ♀♀; Betsie R., Benzonia Twp., T.26N: R.15W: S.34, 14 May 1968, 1 ♀.

BERRIEN: Mill Cr., Bainbridge Twp., T.4S: R.17W: S.2, 7 August 1967, 3 ♀♀; L. Michigan Shore, St. Joseph Twp., T.4S: R.19W: S.9, 2 August 1967, 1 ♀.

BRANCH: Hog Cr., Quincy Twp., T.6S: R.5W: S.13, 12 July 1968, 1 ♂ II, 1 ♀.

CHARLEVOIX: Mason Cr., T.33N: R.8W: S.14, Marion Twp., T.33N: R.8W: S.14, 31 August 1966, 1 ♀; Deer Cr., Wilson Twp., T.32N: R.6W: S.30, 28 August 1966, 1 ♀.

CHIPPEWA: Beaver Cr., Bruce Twp., T.45N: R.2E: S.6, 6 August 1964, 1 ♂ II.

CLARE: Long L., Frost Twp., T.20N: R.4W: S.27, 1 November 1966, 1 ♂ I, 3 ♂♂ II, 3 ♀♀; W. Br. Clam R., Winterfield Twp., T.20N: R.6W: S.17, 16 April 1968, 1 ♂ I; Little Norway Cr., Redding Twp., T.19N: R.6W: S.22, 16 April 1968, 1 ♂ I.

CLINTON: Little Maple R., Ovid Twp., T.7N: R.1W: S.20, 20 October 1964; Park Lake Cr., Dewitt Twp., T.5N: R.2W: S.10, 23 October 1964, 2 ♀♀; Burke L., Bath Twp., T.5N: R.1W: S.23, 7 October 1964, 2 ♂♂.

DELTA: Garden Cr., Garden Twp., T.39N: R.18: S.22, 30 August 1965, 1 ♂ I; Fishdam R., Garden Twp., T.42N: R.18W: S.17, 22 May 1968, 1 ♂ II; Escanaba R., Wells Twp., T.39N: R.22W: S.7, 22 May 1968, 1 ♂ I.

DICKINSON: Sturgeon R., Waucedah Twp., T.40N: R.28W: S.23, 22 May 1968, 1 ♂ II; Sturgeon R., Waucedah Twp., T.41N: R.28W: S.25, 22 May 1968, 3 ♂♂ II, 5 ♀♀ (2 gravid).

EATON: Pine L., Walton Twp., T.1N: R.5W: S.31, 1 August 1964; Thornapple R. trib., Benton Twp., T.3N: R.4W: S.10, 28 October 1967, 6 ♂♂ II, 5 ♀♀.

EMMET: Carp Lake R., Carp Lake Twp., T.39N: R.4W: S.29, 31 August 1965, 2 ♂♂ I; Maple R., Maple River Twp., T.36N: R.4W: S.24, 23 July 1966, 1 ♂ II.

GENESEE: Jones Cr., Gaines Twp., T.6N: R.5E: S.17, 3 April 1968, 1 ♂ II; Cole Cr., Flushing Twp., T.8N: R.5E: S.27, 3 April 1968, 2 ♂♂ I, 1 ♀; Brent Run, Montrose Twp., T.9N: R.5E: S.15, 3 April 1968, 1 ♂ I.

GLADWIN: Rilett Drain, Beaverton Twp., T.17N: R.2W: S.18, 19 April 1968, 1 ♂ I.

GOGEBIC: Middle Br. Ontonagon R., Watersmeet Twp., T.45N: R.39W: S.27, 23 May 1968, 1 ♀ (gravid); Cisco Br. Ontonagon R., Watersmeet Twp., T.45N: R.41W: S.15, 23 May 1968, 1968, 3 ♂♂ II, 1 ♀; Marshall Cr., Marenisco Twp., T.46N: R.42W: S.4, 23 May 1968, 1 ♂ I.

GRAND TRAVERSE: Boardman R., Garfield Twp., T.27N: R.11W: S.3, 22 July 1966, 1 ♀: Boardman R., Garfield Twp., T.27N: R.11W: S.27, 5 September 1966, 2 ♂♂ I, 1 ♀; Betsie R., Grant Twp., T.25N: R.12W: S.6, 15 May 1968, 1 ♂ I; Jackson Cr., Paradise Twp., T.25N: R.10W: S.2, 15 May 1968, 2 ♂♂ I.

HURON: Rock Falls Cr., Sand Beach Twp., T.16N: R.15E: S.24, 24 April 1968, 1 ♂ II; Taff Drain, Hume Twp., T.18N: R.12E: S.33, 24 April 1968, 3 ♂♂ II; Bad Axe Cr., Chandler Twp., T.17N: R.11E: S.24, 24 April 1968, 1 ♂ II, 1 ♀; Pinnebog R., Chandler Twp., T.17N: R.11E: S.23, 24 April 1968, 1 ♂ II.

INGHAM: Red Cedar R., Meridian Twp., T.4N: R.1W: S.19, 22 September 1964, 2 ♂♂ I; Red Cedar R., Williamston Twp., T.4N: R.1E: S.27, 7 October 1964, 5 ♂♂, 6 ♀♀; Lansing, Meridian Twp., T.4N: R.1W: S.11, 7 October 1964, 1 ♂, 1 ♀.

IRON: Parks Cr., Mansfield Twp., T.43N: R.31W: S.27, 22 May 1968, 1 ♂ I, 1 ♀ (gravid); Iron R., Iron River Twp., T.43N: R.35W: S.17, 23 May 1968, 1 ♂ II, 2 ♀♀.

KALAMAZOO: Gull L. Outlet, Charleston Twp., T.2S: R.9W: S.6, 3 July 1964, 1 ♂, 3 ♀♀; Gull L. Outlet, Charleston Twp., T.2S: R.9W: S.3, 9 July 1964, 2 ♂♂, 3 ♀♀; Gull L. Outlet, Charleston Twp., T.2S: R.9W: S.6, 19 July 1964, 4 ♂♂ I, 1 ♂ II, 2 ♀♀; Gull L., Ross Twp., T.1S: R.9W: S.6, 30 April 1965, 4 ♀♀; Gull L., Ross Twp., T.1S: R.9W: S.6, 3 May 1965, 2 ♂♂ I, 2 ♀♀; Kalamazoo R., Morrow Pond, Comstock Twp., T.2S: R.10W: S.22, 21 March 1966, 1 ♂ II, 2 ♀♀.

LEELANAU: Crystal R., Glen Arbor Twp., T.29N: R.14W: S.23, 6 September 1966, 1 ♂ I, 2 ♂♂ II, 3 ♀♀; Cedar Run Cr., Elmwood Twp., T.28N: R.12W: S.21, 6 September 1966, 1 ♂ I, 1 ♀.

LIVINGSTON: Mid Br. Cedar R., Handy Twp., T.3N: R.3E: S.22, 31 October 1964.

MACKINAC: Hog Island Cr., Hudson Twp., T.43N: R.8W: S.34, 30 August 1965, 2 ♂♂ I, 1 ♂ II, 4 ♀♀; Moran R., Brevort Twp., T.40N: R.4W: S.10, 22 May 1968, 1 ♂ II.

MANISTEE: Big Beaver Cr., Maple Grove Twp., T.23N: R.14W: S.21, 4 June 1968, 1 ♂ II, 1 ♀ (gravid).

MARQUETTE: Harlow Cr., Marquette Twp., T.49N: R.25W: S.19, 26 August 1965, 1 ♂ II; Harlow L., Marquette Twp., T.49N: R.25W: S.19, 26 August 1965, 1 ♂ I, 1 ♀; Dead R., Marquette Twp., T.48N: R.25W: S.10, 26 August 1965, 5 ♂♂ I, 2 ♀♀.

MENOMINEE: Little Cedar R., Meyer Twp., T.39N: R.27W: S.34, 22 May 1968, 2 ♂♂ II.

MISSAUKEE: Muskegon R., Reedsburg Dam, Enterprise Twp., T.23N: R.5W: S.25, 1 November 1964, 2 ♂♂, 2 ♀♀.

MONTCALM: Tamarack Cr., Reynolds Twp., T.12N: R.10W: S.26, 20 December 1967, 1 ♂ I; Flat R., Eureka Twp., T.9N: R.8W: S.22, 20 December 1967, 1 ♂ II.

OSCEOLA: Middle Br. R., Marion Twp., T.20N: R.7W: S.21, 16 April 1968, 3 ♂♂ II.

PRESQUE ISLE: Black Mallard R., Bearinger Twp., T.36N: R.3E: S.1, 5 June 1968, 1 ♂ II, 1 ♀.

ROSCOMMON: S. Br. Au Sable R., Au Sable Twp., T.24N: R.1W: S.21, 7 May 1968, 1 ♂ I.

SAGINAW: S. Fork Bad R., Chapin Twp., T.9N: R.1E: S.1, 6 May 1968, 1 ♂ II, 2 ♀♀; Limbocker Cr., Chapin Twp., T.9N: R.1E: S.2, 6 May 1968, 2 ♂♂ II, 2 ♀♀.

ST. CLAIR: Jeddo Cr., Burtchville Twp., T.8N: R.17E: S.12, 23 April 1968, 2 ♂♂ I, 1 ♂ II.

ST. JOSEPH: Portage R., Park Twp., T.5S: R.11W: S.23, 30 July 1964, 1 ♀; Nottawa Cr., Leonidas Twp., T.5S: R.9W: S.16, 25 October 1967, 2 ♀♀.

SANILAC: N. Br. Cass R., Greenleaf Twp., T.14N: R.12E: S.12, 24 April 1968, 3 ♂♂ II, 2 ♀♀; Black R., Wheatland Twp., T.13N: R.14E: S.25, 24 April 1968, 1 ♂ I; Elk R., Elk Twp., T.10N: R.14E: S.3, 24 April 1968, 1 ♂ II.

SHIAWASSEE: Maple R., Bennington Twp., T.6N: R.2E: S.3, 3 April 1968, 1 ♂ II; Shiawassee R. trib., New Haven Twp., T.8N: R.3E: S.18, 1 ♂ II.

VAN BUREN: Wolf L. State Fish Hatchery, Almena Twp., T.2S: R.13W: S.14, 30 June 1965, 1 ♂ I; Paw Paw R. trib., Waverly Twp., T.2S: R.14W: S.10, 10 August 1967.

WASHTENAW: Saline R., Saline Twp., T.4S: R.5E: S.12, 25 September 1967, 1 ♂ I, 3 ♀♀.

WEXFORD: Wheeler Cr., Hanover Twp., T.24N: R.11W: S.31, 5 September 1966, 1 ♂ I; Burkett Cr., Springville Twp., T.23N: R.12W: S.1, 15 May 1968, 1 ♀ (gravid); Pine R., South Branch Twp., T.21N: R.12W: S.20, 15 May 1968, 1 ♂ II.

Orconectes immunis (Hagen, 1870)

O. immunis is a small to medium-sized species with a maximum cephalothorax length of approximately 40 mm.

O. immunis has been described as a mud-loving species by Pearse (1910). Caldwell and Bovbjerg (1969) refer to *O. immunis* as the pond crayfish and state that it inhabits both temporary and permanent ponds, as well as large sloughs, small muck-bottomed lakes, and slowly-moving soft-bottomed portions of rivers and smaller streams. Creaser and Ortenburger (1933) report that *O. immunis* prefers slowly-moving streams, ponds, or lakes with muddy bottoms and with an abundance of vegetation. Tack (1941) states that *O. immunis* has a decided habitat preference for mud bottoms and stagnant or very slowly moving water. He further substantiates this observation with the comment that very few *O. immunis* were found in a moderately-flowing, rubble bottomed stream adjacent to several ponds containing large populations of *O. immunis*.

Hobbs and Marchand (1943) in their study of the Reelfoot Lake area indicate that, in marked contrast to observations of other investigators, *O. immunis* is a stream inhabitant and does not invade the lowland ponds in that area.

The habitats from which *O. immunis* were collected in Michigan are characteristic of those cited by Caldwell and Bovbjerg (1969). An entry in my journal for *O. immunis* collected in Eaton County, Michigan typifies the environment for this species - a small tributary of Battle Creek. Slow flow, almost stagnant, very mucky with patches of *Elodea* and a heavy mat of *Spirogyra* growing on the surface. Crayfish specimens taken by sweeping a net through the *Elodea* and mud.

The life history of *O. immunis* has been documented by Tack (1941) and summarized, with annotations, by Hobbs and Marchand, 1943; Williams and Leonard, 1952; Williams, 1954; Crocker and Barr, 1968; Caldwell and Bovbjerg, 1969.

The sexually active male (form I) demonstrates a bimodal occurrence between early April and mid-May with a second peak between late June and early November (Fig. 54). Copulation takes place during this time with field observations indicating the greatest period of intensity between July and October (Fig. 54).

Spawning occurs during October and November. The females retain their extruded eggs through the winter until the hatching period from April to early June (Fig. 48).

The mean number of eggs carried by *O. immunis* females was 170. Table IV indicates the cephalothorax length of each individual and the number of attached eggs per female.

One female, cephalothorax 35 mm, whose eggs had hatched by 6 April 1967 had 236 young clinging to her pleopods.

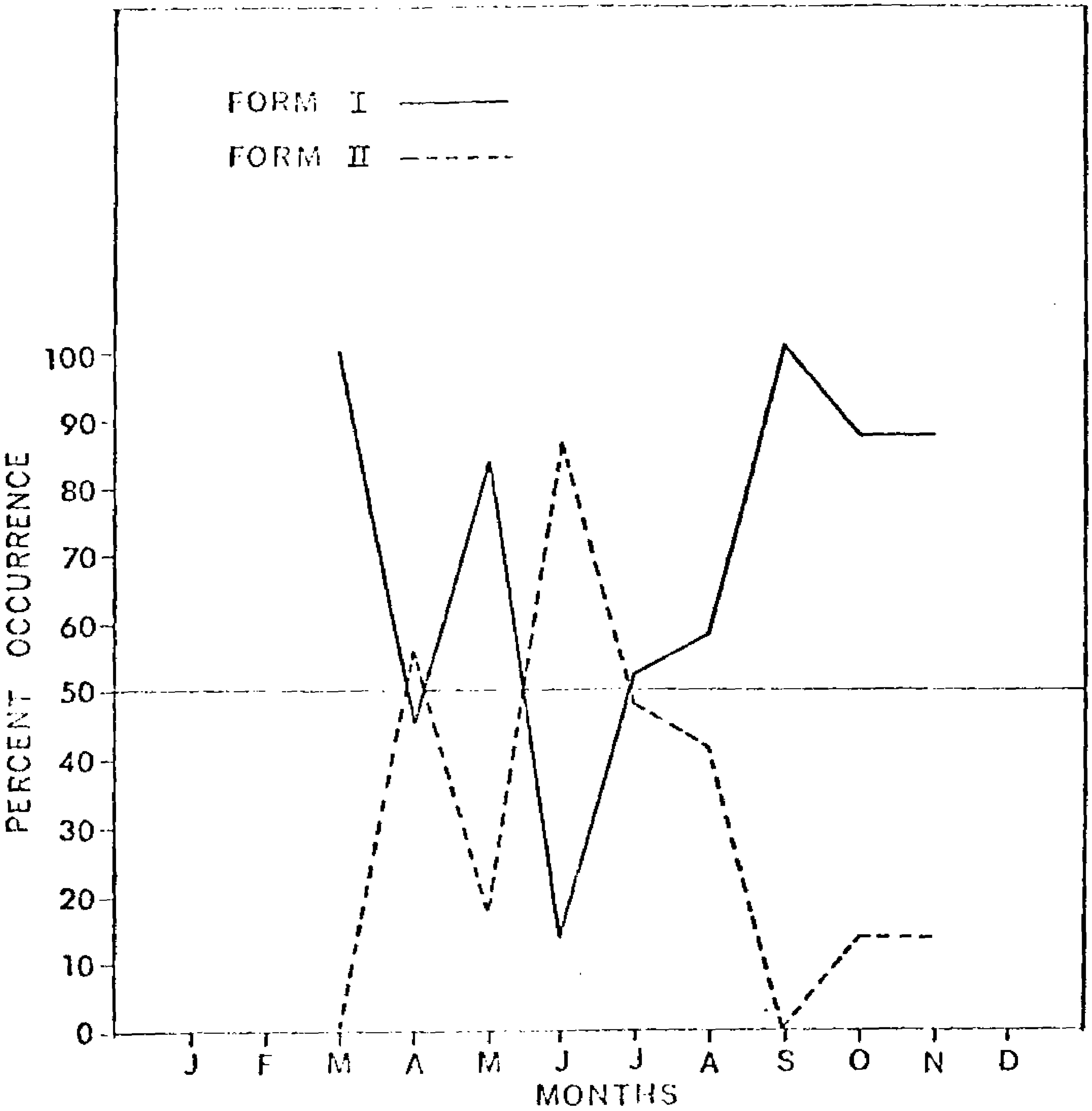

Figure 54. Frequency occurrence of form I and form II *Orconectes immunis*.

TABLE IV

NUMBER OF ATTACHED EGGS CARRIED BY *Orconectes immunis*

Cephalothorax Length (mm)	No. of Eggs
26.5	111
27.0	175
29.0	133
29.0	199
29.5	122
29.5	190
30.5	245
31.0	151
31.0	201

O. immunis is not an abundant or widely distributed species in Michigan. It was abundant, however, in large numbers at the Wolf Lake State Fish Hatchery, Van Buren County, Michigan and less so at the Saline Fish Hatchery ponds at Saline, Washtenaw County, Michigan.

The distribution map (Fig. 55) and county checklist (Table I) for *O. immunis* shows that this species is confined to the southern portion of the Lower Peninsula. The map probably does not reflect the actual extent of distribution of *O. immunis* in Michigan as the potential habitats of this species have not been adequately investigated.

O. immunis was collected in association with *O. propinquus*, *O. virilis*, *C. diogenes*, and *F. fodiens*.

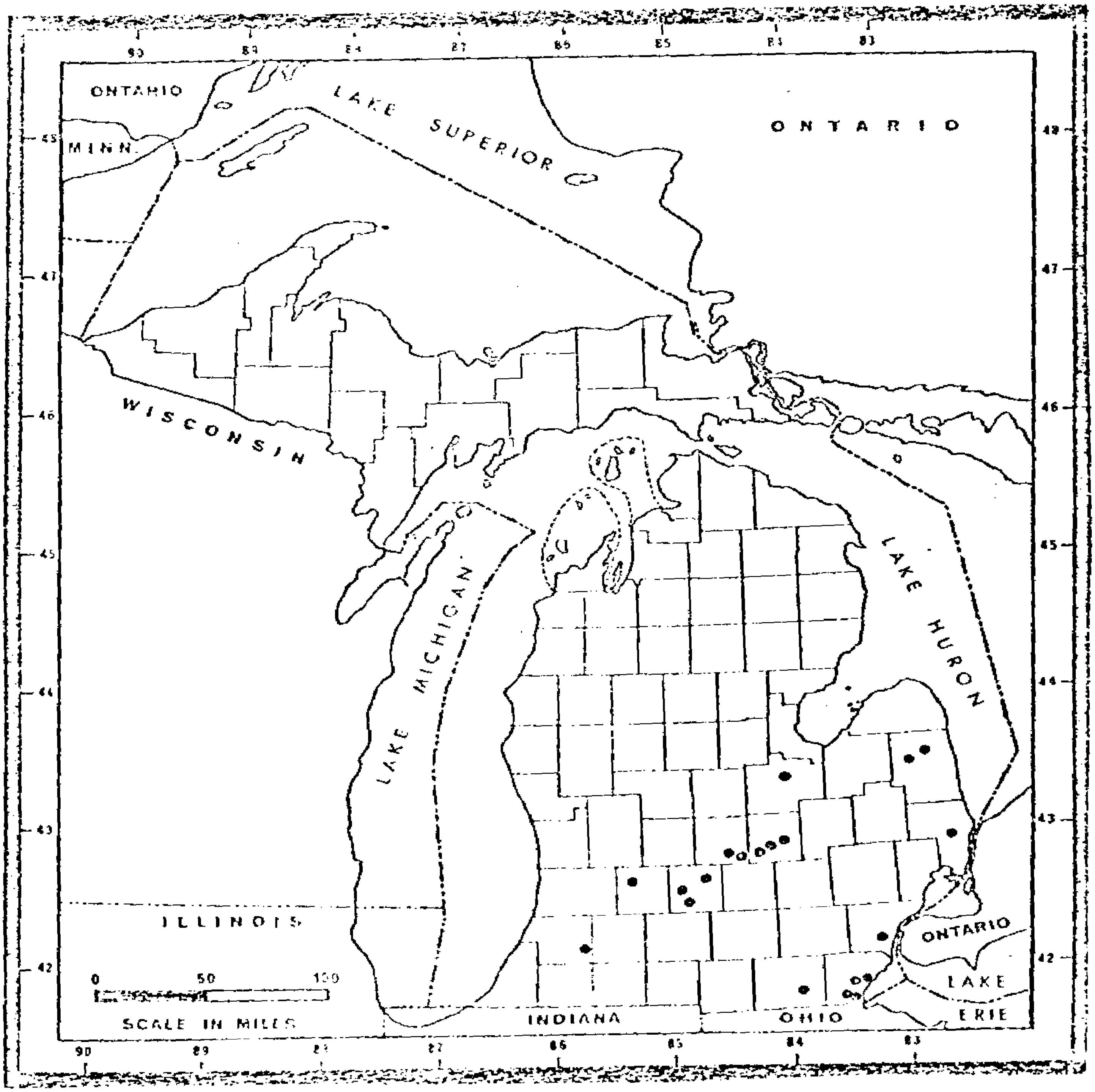

Figure 55. Distribution of *Orconectes immunis* in Michigan.

Hobbs (1972) and Crocker and Barr (1968) record the presence of *O. immunis* in Ontario, Canada; Alabama, Colorado, Connecticut, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New York, North Dakota, Ohio, South Dakota, Tennessee, Wisconsin, and Wyoming.

Orconectes immunis (Hagen)

Locality Records in Michigan

BARRY: Hall L., Yankee Springs Twp., T.3N: R.10W: S.28, 21 June 1965, 1 ♂ II.

CLINTON: Park Lake Cr., Dewitt Twp., T.5N: R.2W: S.10, 23 October 1964, 1 ♂, 2 ♀♀; Pond near Vermillion Cr., Bath Twp., T.5N: R.1W: S.24, 15 October 1965, 1 ♀.

EATON: Battle Creek R. trib., Carmel Twp., T.2N: R.5W: S.27, 10 May 1965, 1 ♂ II, 1 ♀; Battle Creek R. trib., Bellevue Twp., T.1N: R.6W: S.23, 17 May 1965, 1 ♀: Thornapple R. trib., Benton Twp., T.3N: R.4W: S.10, 28 October 1967, 1 ♀.

LENAWEE: River Raisin trib., Adrian Twp., T.6S: R.3E: S.36, 19 April 1966, 1 ♂ I, 1 ♂ II, 2 ♀♀.

MONROE: Colburn Drain, Berlin Twp., T.5S: R.9E: S.36, 25 April 1966, 1 ♂ I, 1 ♂ II, 1 ♀; Swan Cr., Berlin Twp., T.5S: R.9E: S.36, 25 April 1966, 1 ♂ I; North Maumee Bay, Erie Twp., T.8S: R.8E: S.15, 14 September 1964, 4 ♂♂ I, 2 ♀♀; North Maumee Bay, Erie Twp., T.8S: R.8E: S.15, 1 May 1965, 1 ♂ I.

SAGINAW: Limbocker Cr., Chapin Twp., T.9N: R.1E: S.2, 6 May 1968, 1 ♀.

ST. CLAIR: Pine R. trib., St. Clair Twp., T.5N: R.16E: S.26, 23 April 1968, 2 ♂♂ II, 1 ♀.

SANILAC: White Cr., Lamotte Twp., T.12N: R.12E: S.6, 24 April 1968, 1 ♂ II; N. Br. Cass R., Greenleaf Twp., T.14N: R.12E: S.12, 24 April 1968, 1 ♂ II.

SHIAWASSEE: Mondell Cr., Bennington Twp., T.6N: R.2E: S.36, 3 April 1968, 1 ♂ I; Shiawassee R. trib., New Haven Twp., T.8N: R.3E: S.18, 3 April 1968, 1 ♂ II; Six Mile Cr., New Haven Twp., T.8N: R.3E: S.20, 3 April 1968, 3 ♂♂ II.

VAN BUREN: Wolf Lake State Fish Hatchery, Almena Twp., T.2S: R.13W: S.14, 30 June 1965, 125 ♂♂, 160 ♀♀.

WAYNE: Sines Drain, Canton Twp., T.2S: R.8E: S.27, 23 April 1968, 1 ♂ I, 1 ♀.

LABORATORY STUDY

Thermal Tolerance

In an effort to discern the habitat preferences of crayfish, the median tolerance level (TLm) of four species of *Orconectes* was investigated. The TLm may be employed as a taxonomic tool because it may be of value in indicating the presence or absence of genetic similarities between species that are phenotypically different (Fry, 1957).

Two groups of *O. propinquus* were acclimated to two temperature regimes, 25 C (N=95) and 32 C (N=54) for at least 48 hours. In a series of 15 replicate tests the organisms were subjected to a range of test temperatures from 34 C to 36 C for 24 hours. The percent mortality is shown in Figure 56. The 24-hour TLm value for *O. propinquus* acclimated at 25 C is 34.5 C. The group acclimated at 32 C show a 24-hour TLm value of 35.7 C. Bovbjerg (1952) reported on a study designed to evaluate the degree to which *O. propinquus* and *C. fodiens* could adapt physiologically to increased temperatures. Groups of crayfish were slowly brought to 34 C during the initial 24 hours and then maintained between 34 C and 35 C for a period of seven days. At the termination of the experiment 53 percent of each species remained alive. The TLm level, although not indicated precisely, was approximately 35 C, which closely approaches the findings in the current study.

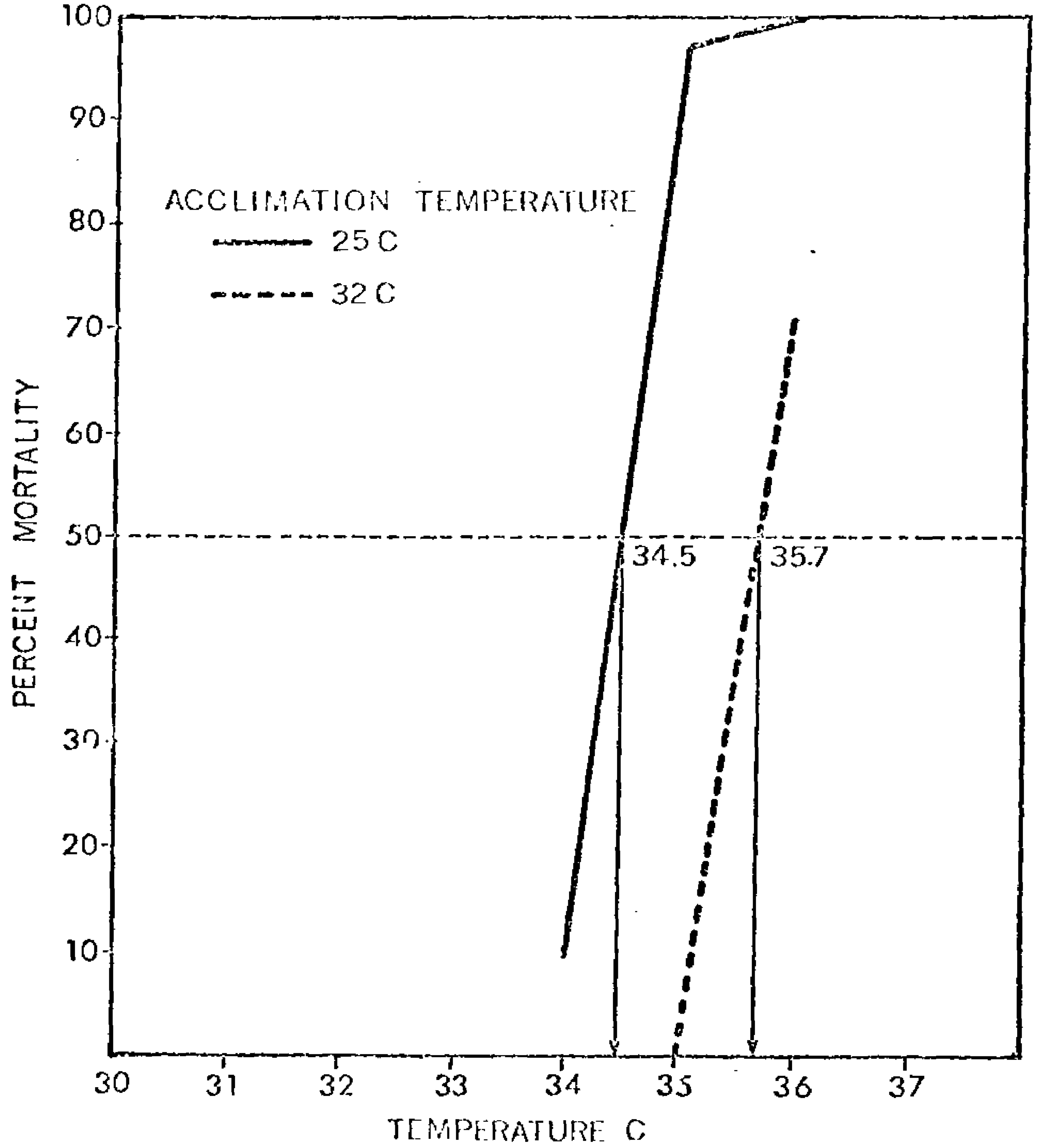

Figure 56. The median tolerance level (Tlm) of *Orconectes propinquus* acclimated at 25 C and 32 C.

Subsequent to exposure at a given constant test temperature for 24 hours, the animals were placed in a recovery tank for five days at ambient temperatures between 22 and 25 C. The percentage mortality for *O. propinquus* held in the recovery tank during this investigation was 9.5, as contrasted to the mortality for all species, held in recovery, of 31.5 percent.

One group of *O. virilis* (N=26) was acclimated at 32 C and subjected to a range of test temperatures from 35 C to 36 C. Figure 57 shows a 24-hour TLm value of 35.7 C. The mortality rate of those specimens held in the recovery tank subsequent to the thermal test was 27 percent.

O. rusticus was also tested in the same manner as the above species. *O. rusticus* (N=50) were acclimated at 33 C and subjected to a range of temperatures between 35 C and 37 C in a series of four replicate tests. Figure 58 indicates the 24-hour TLm of *O. rusticus* acclimated at 33 C for a minimum of 24 hours is 36.2 C. Spoor (1955) indicated in his paper on the heat-tolerance of *O. rusticus* that specimens acclimated between 22 C and 26 C had a 24-hour TLm of 35.6 C. The mortality rate of *O. rusticus* held in the recovery tank was 36 percent.

The fourth species, *O. immunis,* was tested in a similar manner as the three preceeding species. Two acclimation temperatures were utilized during these tests. A group of *O. immunis* (N=24) were obtained during the winter and were, therefore, environmentally conditioned to a low temperature.

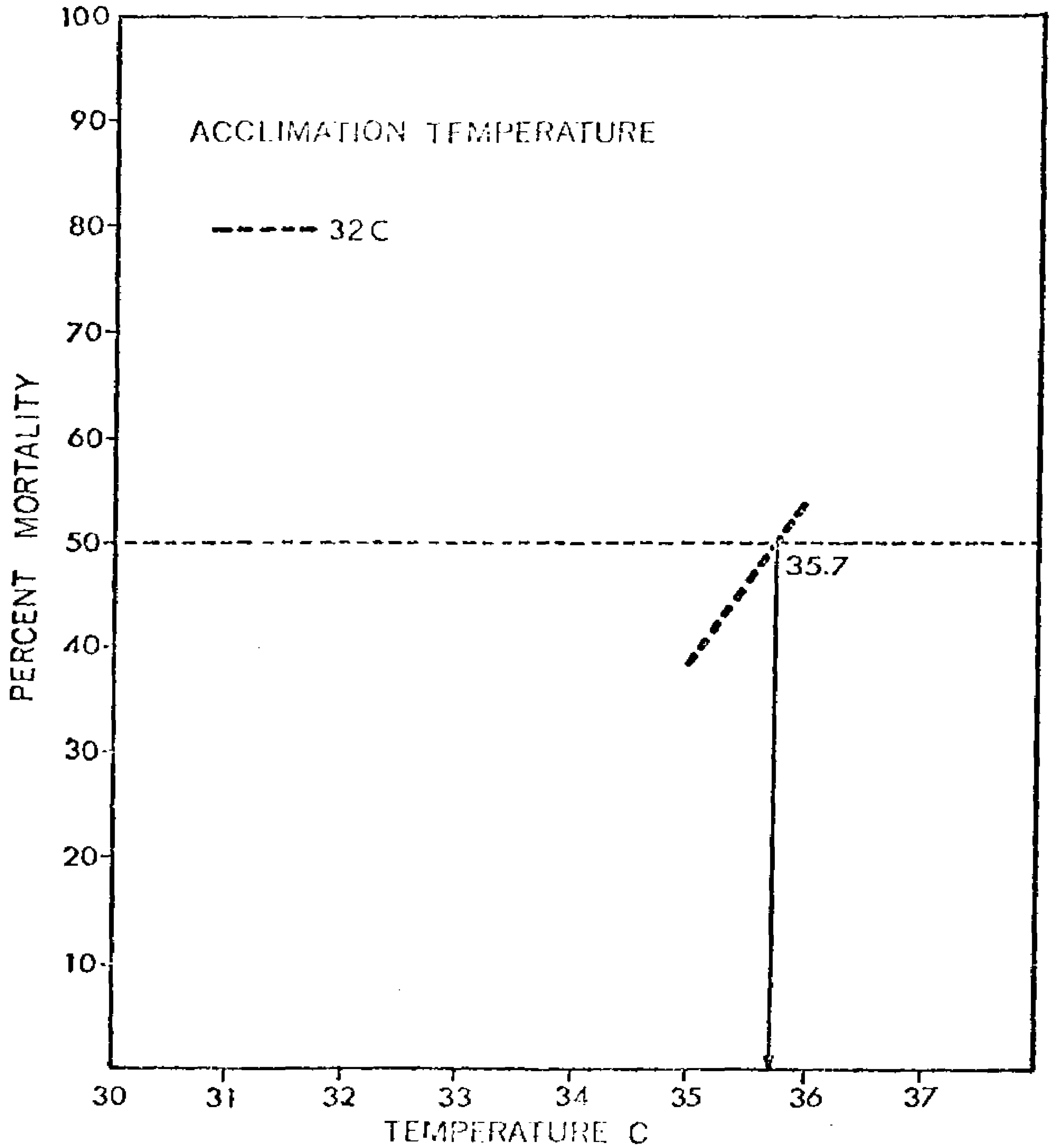

Figure 57. The median tolerance level (Tlm) of *Orconectes virilis* acclimated at 32 C.

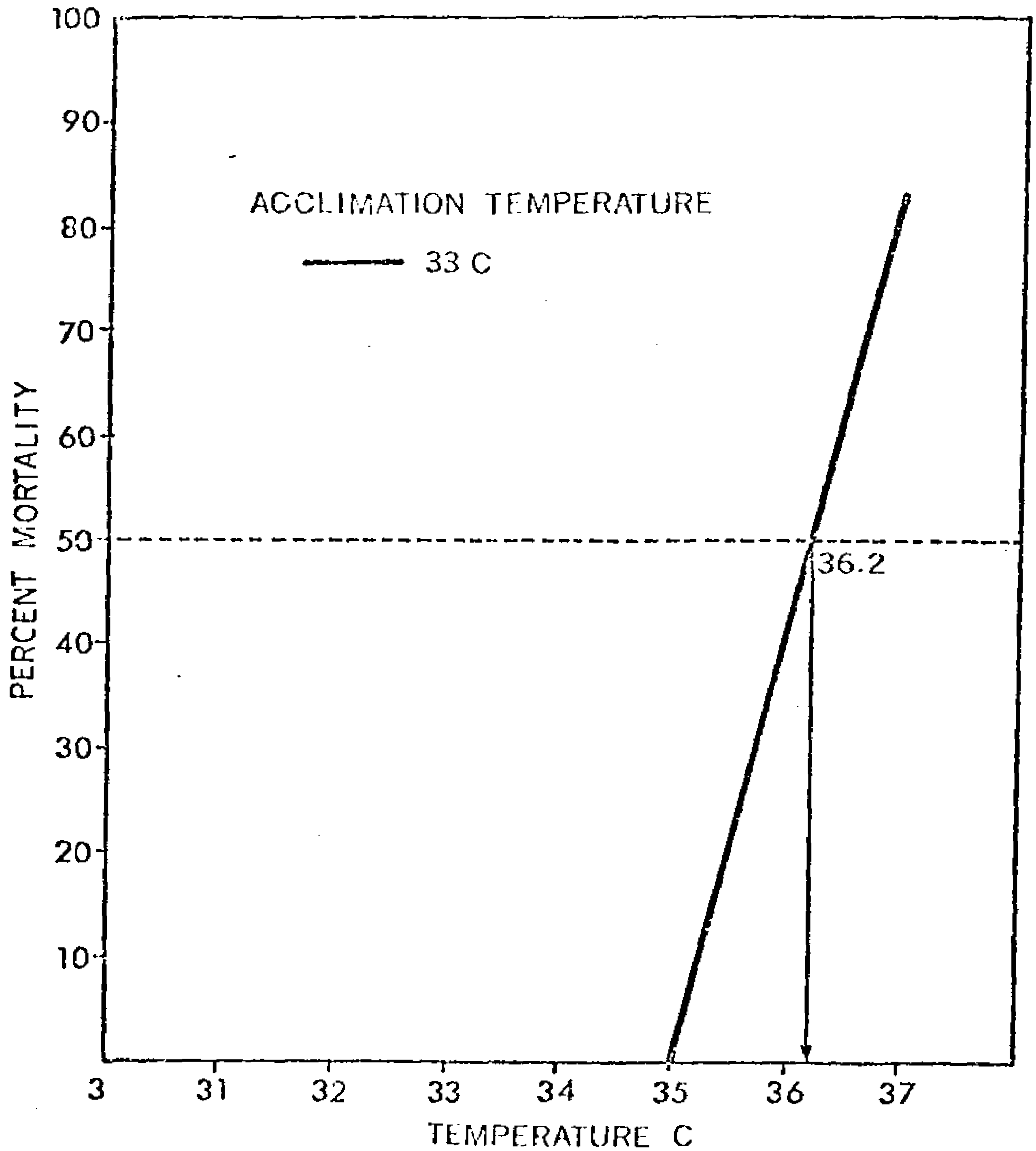

Figure 58. The median tolerance level (Tlm) of *Orconectes rusticus* acclimated at 33 C.

The winter-collected species were acclimated in the laboratory at 7 C. A second group of *O. immunis* (N=150) collected during August and early September were acclimated at 30 C. The specimens acclimated at 7 C were exposed to a range of temperatures from 30 C to 35 C in a series of three replicate tests. The second group of *O. immunis* which were acclimated at 30 C were exposed to a temperature range of 35 C - 37 C in a series of nine replicate tests. Figure 59 demonstrates that the 7 C acclimated specimens had a 24-hour TLm of 34.3 C. Those acclimated at 30 C were more heat tolerant and had a 24-hour TLm of 36.2 C.

The one most obvious manifestation of stress observed in all species during heat tolerance experiments was turgidity. The first abdominal segment separated from the carapace and the exposed tissue was bloated. The cause was probably the inability of the organism to osmoregulate at a normal rate and maintain their hyperosmatic concentration relative to the ambient medium under incipient lethal temperature levels. Fry (1947) discussed abnormal osmotic pressure as a consequence of an environmental factor which places an undue burden (loading stress) on an organism, necessitating the rapid or steady release of energy.

No relation between size, sex and thermal tolerance could be discerned. All specimens were either sub-adults or adults and ranged in cephalothorax length between 10 and 49.5 mm, with an average cephalothorax length of 27.9 mm. The stage of the molt cycle was not determined, however several crayfish

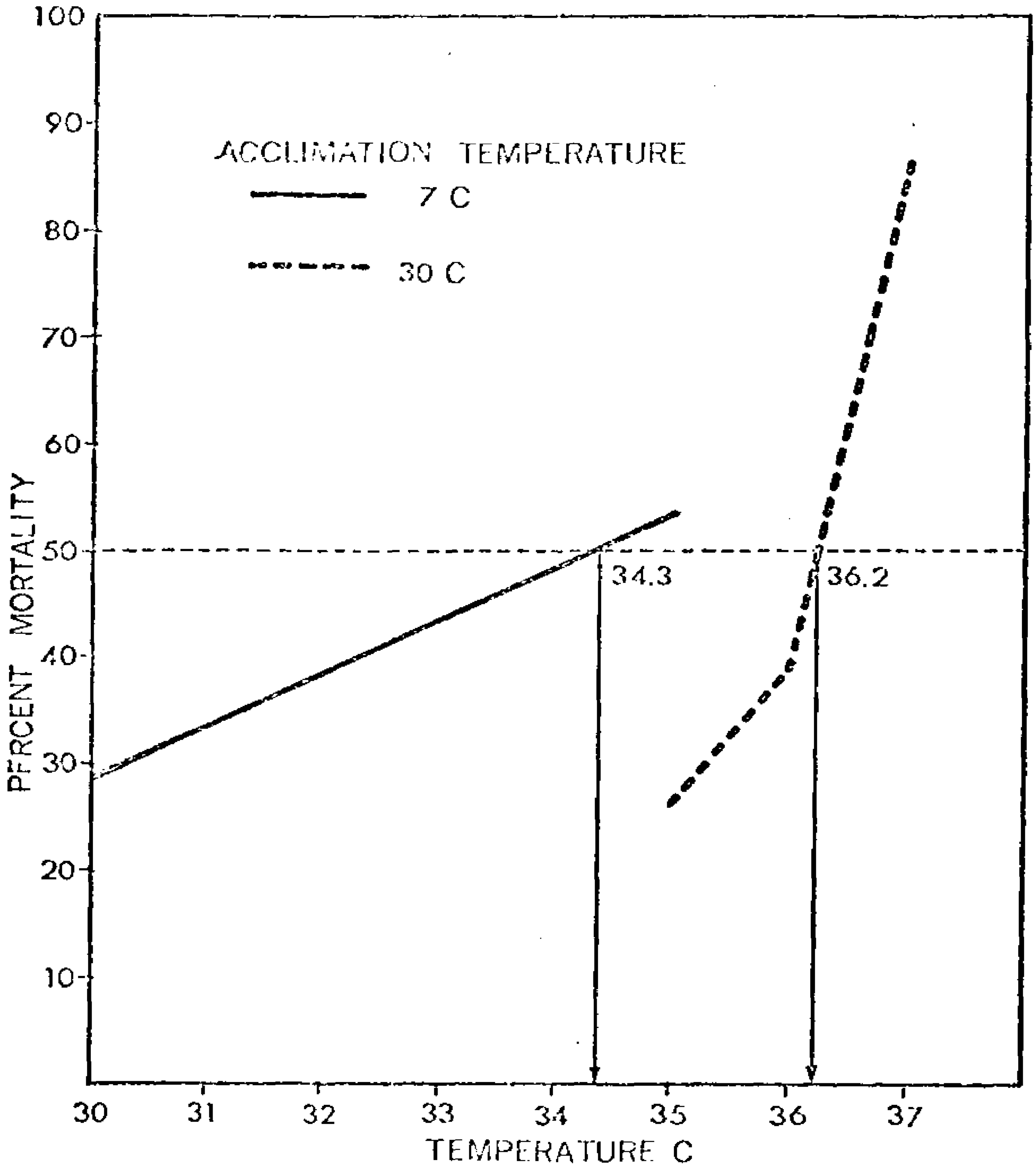

Figure 59. The median tolerance level (Tlm) of *Orconectes immunis* acclimated at 7 C and 30 C.

molted successfully during acclimation during the course of the tests and while being retained in the recovery tank.

The Effect of Decreasing Oxygen Concentration Relative to Mortality.

A series of tests were run utilizing three species of *Orconectes; O. propinquus, O. virilis* and *O. immunis*. Field observations of these species indicate that *O. propinquus* prefers highly-oxygenated water such as that found in trout streams, moderate-to-swift-flowing rivers and the shores of lakes. *O. virilis,* while often found in similar habitats, predominately inhabits rivers with moderate to slow currents, impoundments and the deeper portions of lakes. *O. immunis* is most often collected in ditches, sluggish creeks, or ponds.

The tests were designed to evaluate the concentration of dissolved oxygen required to sustain life for each species. *O. propinquus* was the most sensitive species tested in terms of its ability to survive at low O_2 concentrations. No deaths occurred above 2.6 mg O_2/l; however at 2.5 mg O_2/l mortality was observed in *O. propinquus*. A rather uniform mortality curve was obtained for this species with death occurring from 2.5 to 0.1 mg O_2/l with the greatest percentage mortality occurring between 0.6 to 1.5 mg O_2/l (Fig. 60A).

O. virilis demonstrated a higher tolerance for decreased O_2 concentration than *O. propinquus*. Figure 60B shows that

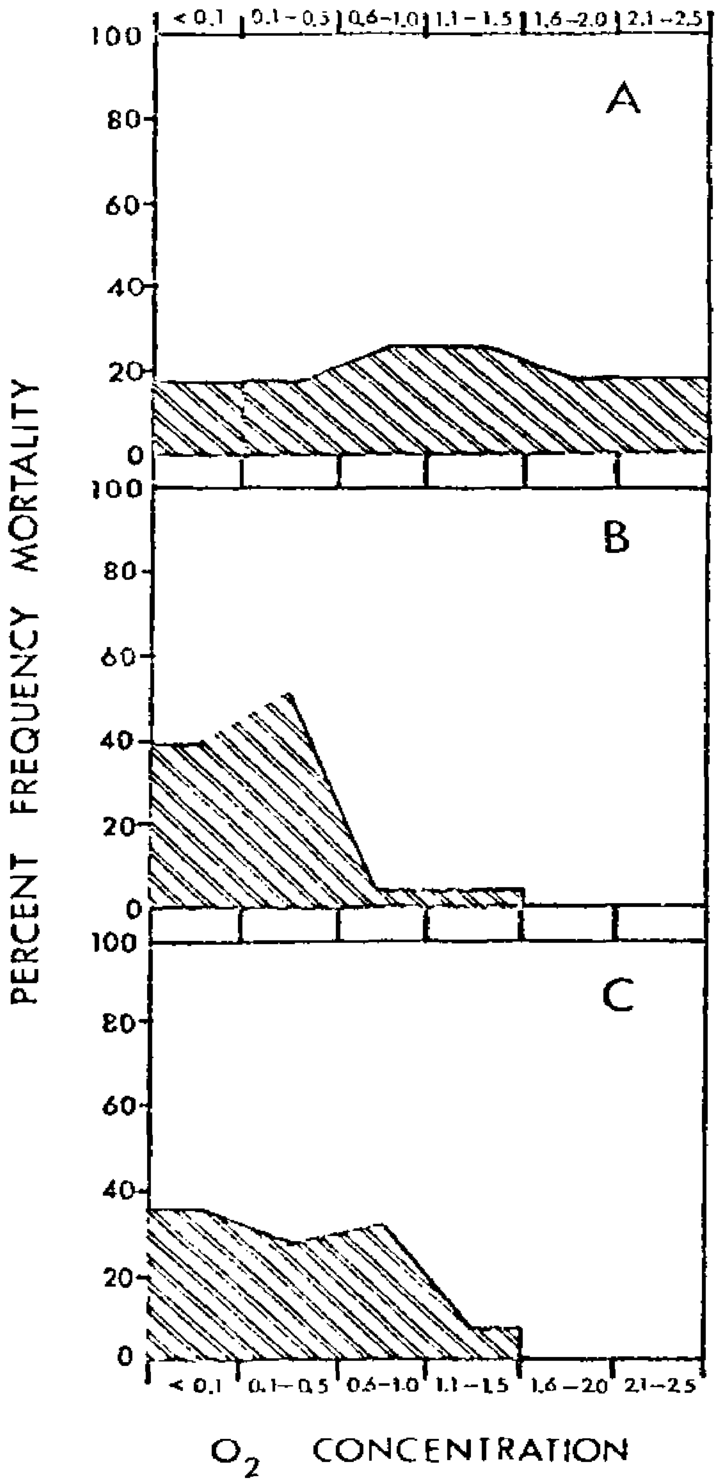

Figure 60. Oxygen tolerance of A, *Orconectes propinquus*; B, *Orconectes virilis*; C, *Orconectes immunis*.

no mortalities occurred until the O_2 concentration decreased to 1.5 mg O_2/l. Only 8.7 percent of the deaths occurred between 0.6 and 1.5 mg O_2/l. A precipitous increase in mortality took place as the concentration of oxygen decreased to 0.5 mg O_2/l, with a peak mortality discernible at approximately 0.3 mg O_2/l. A significant number (39 percent) of *O. virilis* died at an oxygen concentration which was virtually undectable and was recorded as <0.1 mg O_2/l.

O. immunis shows a similar pattern to that of *O. virilis* (Fig. 60C). However, a slightly greater percentage of mortality occurred in the higher oxygen range between 0.6 and 1.5 mg O_2/l. 36 percent of the deaths occurred at <0.1 mg O_2/l.

Oxygen Consumption. The oxygen consumption rates of *O. propinquus, O. rusticus, O. virilis,* and *C. robustus* were determined in the modified Mount degasser over a temperature range of 10 C to 35 C. Temperature greatly affected the oxygen consumption of all species, with a noteable increase in oxygen consumption with an increase in temperature.

Figure 61 shows the oxygen consumption of *O. propinquus* and *C. robustus,* species generally found in swift-flowing streams, or high-energy habitats. The oxygen consumption of *O. virilis* and *O. rusticus,* species which typically inhabit ponds, lakes, and slow-moving streams, are also indicated in Figure 61.

The two species which inhabit fast-flowing streams, *O. propinquus* and *C. robustus,* exhibit a similar pattern of

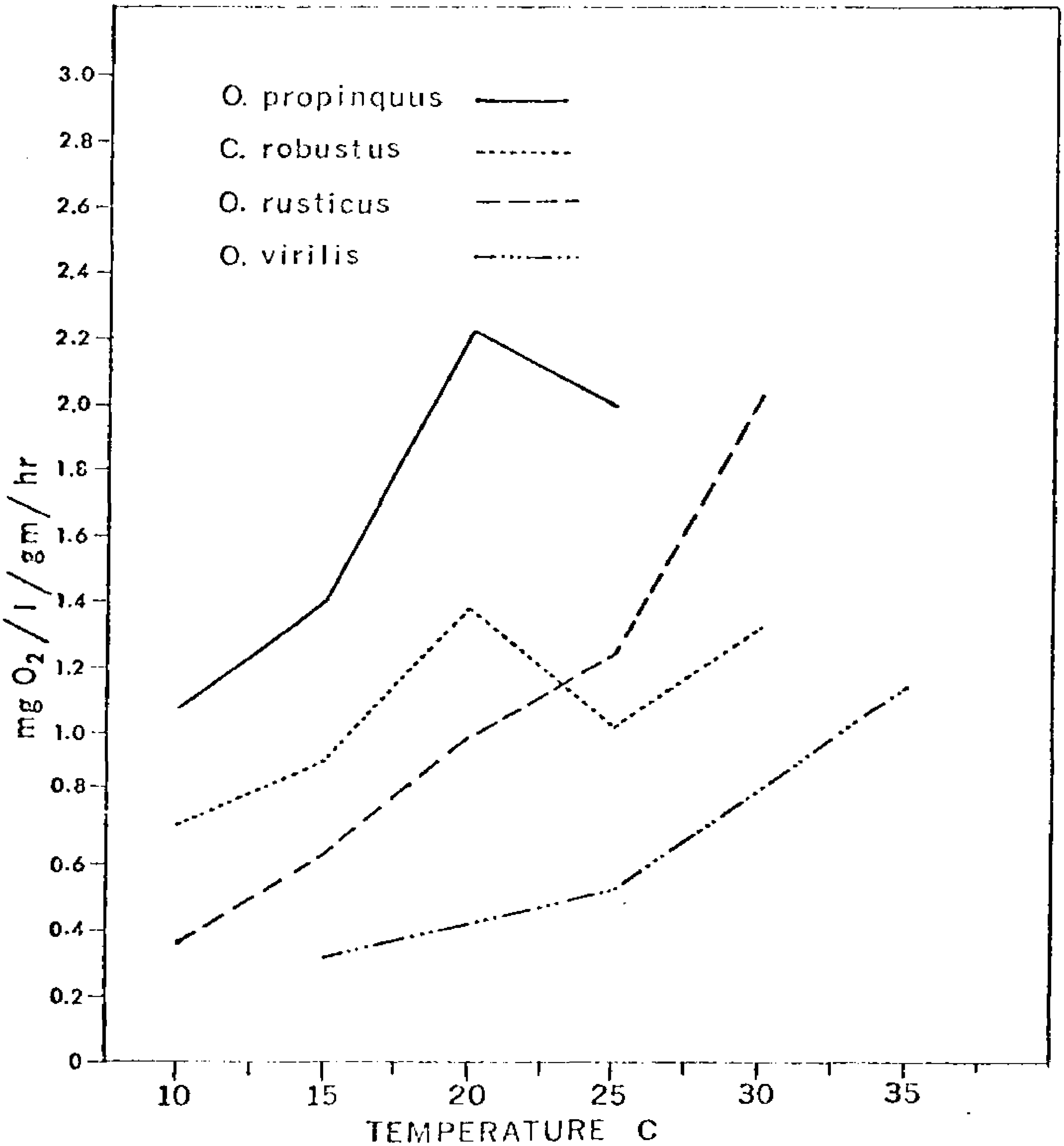

Figure 61. Rate of oxygen consumption of *Orconectes propinquus*, *Orconectes virilis*, *Orconectes rusticus*, and *Cambarus robustus*.

oxygen consumption. Their increase in oxygen consumption correlates with the rise in temperature up to 20 C. Oxygen consumption decreases significantly in both species as the temperatures rise above 20 C. It is difficult to state with confidence why oxygen consumption plateaus at 20 C and then declines as temperatures are increased. One possibility is that these species enter into a stress condition caused by the synergistic effect of reduced oxygen concentration and increased temperature.

O. rusticus and *O. virilis*, species which often inhabitat slow-moving streams and impoundments, show a distinct increase in oxygen consumption with rising temperatures. There is no indication of stress at any temperature up to 35 C relative to a reduction in oxygen consumption.

Diurnal Oxygen Consumption Rhythm of *Orconectes rusticus*.

The 24-hour oxygen consumption rate of *O. rusticus* was determined, utilizing the modified Mount degasser. Figure 62 shows that the maximum rate of oxygen consumption occurs between 2000 hours and 0400 hours. These times coincide with darkness during the summer months in Michigan.

Observations made during field collections on *O. rusticus* and other species support the higher rate of activity as evidenced by the increased oxygen consumption, during the period of darkness. Typically, *O. rusticus* is active during the night in its natural habitat. It is often seen in large numbers crawling about the bottom searching for food and in

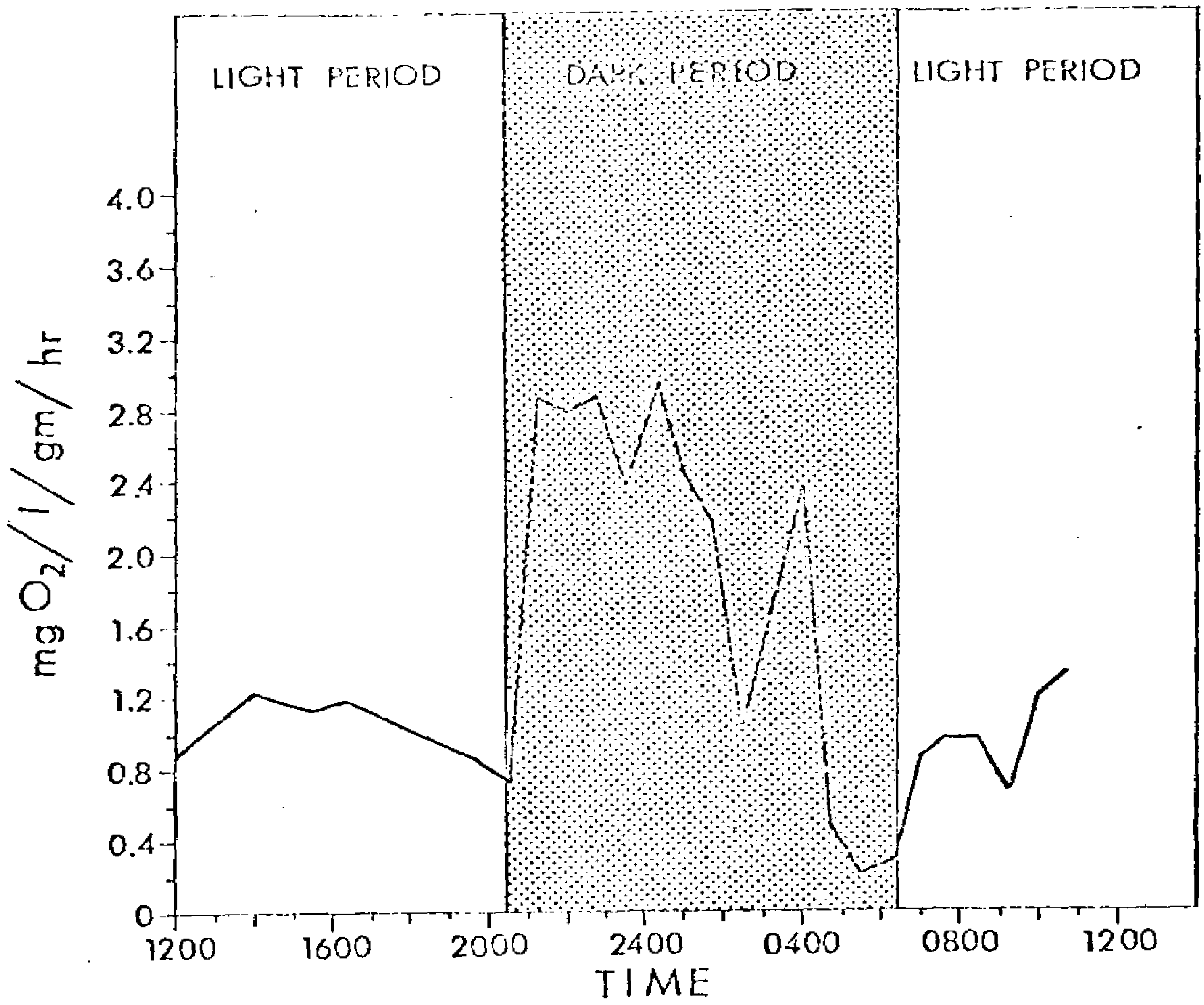

Figure 62. Twenty-four hour rhythm of oxygen consumption of *Orconectes rusticus*.

copulation. During the daylight hours *O. rusticus* normally lies concealed and remains quiescent.

SUMMARY

Field Study

The distribution of the crayfish of Michigan was investigated to determine the number of species extant, their habitat preference, species interaction and salient life history information, including selected physiological aspects.

Two earlier studies of Michigan crayfish were conducted by Pearse (1910) and Creaser (1931). Both writers recorded eight species in Michigan, one of which, *Procambarus (Ortmannicus) acutus acutus* (Hobbs, 1972a) *(=Procambarus blandingii acutus)* was substantiated by one living specimen, obtained by Creaser, from Berrien County in extreme southern Michigan.

Seven species are now recorded for Michigan, no collections of *Procambarus a. acutus* were obtained during this study. A concerted effort was made to collect this species in Michigan including visits to the location cited by Pearse for his record of *Procambarus a. acutus.*

Fallicambarus fodiens and *Cambarus (Lacunicambarus) diogenes diogenes* remain the least understood species in Michigan in terms of distribution. Their secretive habits place great difficulties on the ability to obtain adequate collections on a state-wide basis. The locality records and distributional maps herein included indicate only a general pattern of their distribution. However, the data obtained and the distributional patterns described for *F. fodiens* and *C. diogenes* are similar to the distributional patterns reported by Creaser (1931).

C. robustus is a montane species in that its probable center of distribution is the Applachian mountains (Ortmann, 1905). Ortmann (1905) regarded *C. robustus* as a post-glacial form which has migrated westward from the St. Lawrence Basin. *C. robustus* shows a decided preference for mountain-like streams or brooks, a habitat type which is typified by the Rifle River and its tributaries in the eastern lower peninsula of Michigan. Creaser (1931) reports that *C. robustus* is found in greatest abundance at the headwaters of the various river systems, in accordance with its habitat preference. The distribution of *C. robustus*, as delineated in this study, closely approximates that reported by Creaser (1931). *C. robustus* has not been successful in penetrating further west or north of the range first mapped by Creaser (1931). *C. robustus* has failed to establish itself in the Lake Michigan drainage system, as was also noted by Creaser in 1931. The rivers which flow into Lake Michigan are typified by low gradient, sandy-bottomed streams which are unlike the rocky-bottomed, swift, cool, streams usually frequented by *C. robustus*.

O. propinquus is found throughout Michigan in all the major river systems and has a broad range of habitat preference. *O. propinquus* may be found in the swift waters of a rocky riffle zone, in the back waters of a silt-laden meander, or along the rubble-strewn shores of a clear lake. *O. propinquus* is distributed almost homogeneously throughout Michigan and is the most ubiquitous species encountered in the state.

The major mating period of *O. propinquus*, based on the predominance of the sexually active form I male, is from July through September. Spawning occurs from April to June and the eggs hatch from mid-April through mid-June.

O. propinquus is found in varying degrees of association with all other species in Michigan except *F. fodiens*.

O. rusticus has radiated out of the south-central United States and has extended its range to the north and east. It is commonly found in southwestern Ohio in streams of the Ohio River drainage system (Rhoades, 1962). It is not known how *O. rusticus* has migrated into the St. Joseph River. Creaser (1931) suggests a movement of this species from streams of the Ohio River into streams of the Maumee River, which extends into southern Michigan during flood periods. The accidental introduction of *O. rusticus* by fishermen from Ohio and Indiana must also be considered as a viable mechanism for the appearance of *O. rusticus* in lower Michigan. The area immediately east of the Sturgis Dam on the St. Joseph River is a popular bass fishing spot favored by anglers from Ohio and Indiana. Langlois (1936) remarks that *O. rusticus* is widely used by anglers as bait for bass. Crocker and Barr (1968) report that *O. rusticus* is an introduced species in Ontario.

Apparently *O. rusticus* is a relatively recent addition to the crayfish assemblage of Michigan. It is difficult to determine how *O. rusticus* has become so successful in such a short span of time since Creaser's 1931 study. It is predictable that *O. rusticus,* if competively successful with other crayfish species, would slowly radiate out into lower Michigan over a long period of time. Turner (1926) states that *C. (=Orconectes) rusticus* represents a new and vigorous wave of the subgenus *Faxonius* which is pushing the older members of the propinquus group to the eastward. Turner comments further that *C. (=Orconectes) propinquus sanborni* may not be able to compete successfully with *O. rusticus* and, therefore, destined to completely disappear. Rhoades (1962) substantiates the tenacity of *O. rusticus* in his discussion of the association of *O. sloani* and *O. rusticus* and the environmental factors unfavorable to *O. sloani* by remarking that *O. rusticus* persists where *O. sloani* is suppressed.

The fact that *O. rusticus* is found currently throughout Michigan and is distributed disjunctively, tends to preclude the postulate that it is a relatively new species which slowly migrated into Michigan from areas to the south.

The northern populations of *O. rusticus* may be a relict fauna separated from the southern populations by a physical or biotic change in the environment and overlooked in previous studies.

The southern population which has recently appeared in lower Michigan is probably the result of natural immigration, reinforced by occasional introduction by fishermen from adjacent states.

O. virilis is not restricted to a discrete habitat type, but occupies a wide range of aquatic environments from small ponds and the depths of Lake Michigan, to the riffle areas of swift-flowing streams and the backwaters of dams. It is widely distributed throughout Michigan and is the second most abundant species after *O. propinquus*.

The major mating period of *O. virilis* occurs from mid-July through mid-September. The mean number of extruded eggs per female was 285, a significantly larger number than Momot (1967) found for *O. virilis* from West Lost Lake, Michigan.

Momot and Gall (1971) reported on a population of blue *O. virilis* from North Twin and South Twin Lakes, Otsego County, Michigan. One hundred and eleven blue color phase *O. virilis* were collected in these small marl lakes in 1968 and 1969. Momot and Gall estimated that the blue variant *O. virilis* comprised 0.2 to 0.8 percent of the total population in both lakes. During the course of the current study only one blue phase *O. virilis* was collected from the entire state.

O. immunis is confined to small mud-bottomed ponds and lakes and slowly-moving streams. *O. immunis* is not widely distributed throughout Michigan, nor is it particularly abundant except at the Wolf Lake State Hatchery, Van Buren County, Michigan.

Mating occurs between early April and mid-May and between late June and early November. The females lay their eggs in the fall and carry them until the following spring.

O. immunis may be more widely distributed than indicated in this study. The difficulties encountered in sampling ponds and lakes, in particular, where *O. immunis* generally occur, are reflected in the limited catch records for *O. immunis* in Michigan.

Laboratory Methods

The physiological requirements of a species greatly influences its behavior and ecological distribution. Wiens and Armitage (1961) state that *"the development of a variety of physiological mechanisms has allowed closely related animals to distribute themselves into habitats that are different in certain qualities. Although morphological differences are present, it is often physiological differentiation which has allowed radiation and eventual speciations to occur in many animals"*.

A limited comparative study of heat tolerance and oxygen consumption on selected species is presented in this paper in an attempt to contribute to a further understanding of crayfish distribution.

O. propinquus is the singularly most important species in Michigan in terms of distribution and relative numbers.

The median lethal tolerance of this species exceeds 35 C when acclimated at 32 C. The test temperatures exceed the average maxima recorded for most streams in Michigan (Mich. Water Res. Comm., 1963; U.S. Geol. Survey, 1968).

The three other species, *O. virilis*, *O. rusticus*, and *O. immunis* displayed similar tolerances between 35.7 C and 36.2 C.

Subsequent to each test the specimens were held in a recovery tank at ambient temperatures between 22 and 25 C. *O. propinquus* incurred only 9.5 percent mortality, while the percent mortality for *O. virilis*, *O. rusticus* and *O. immunis* ranged from 27 percent to 53.5 percent.

The results of the thermal tests indicate that the four species of *Orconectes* found in Michigan are relatively tolerant of high temperature regimes. *O. immunis* has the ability to adjust to high temperatures (30 C - 35 C) subsequent to a low acclimation temperature (7 C). It must be stated, however, that *O. immunis* had the highest mortality during recovery, under these conditions.

Another factor which must be considered, when interpreting the results of thermal tests, is the life-cycle stage of the individuals tested. All specimens tested were adults or sub-adults, based on size or evidence of sexual maturity. No pre-juveniles were utilized in these tests. Therefore, if one were to extrapolate these data for the purpose of demonstrating a high degree of tolerance to power plant effluents all stages of the species life cycle must be considered.

It is interesting to note that during the thermal tolerance tests, the commensal branchiobdellids, so closely associated with crayfish, were not nearly as tolerant to high temperatures as their hosts. The branchiobdellid worms relinquished their grasp on the crayfish and dropped to the bottom, where they at first crept about and then ultimately died in large numbers.

The oxygen tolerance tests performed on *O. propinquus, O. virilis,* and *O. immunis* demonstrate that *O. propinquus* is the least tolerant to low dissolved oxygen levels. *O. virilis* and *O. immunis* are more tolerant of low oxygen levels, which is consistent with their ecological distribution.

The oxygen consumption rates of four species, *O. propinquus, O. virilis, O. rusticus,* and *C. robustus* were determined utilizing the modified Mount degasser.

O. propinquus and *C. robustus* are often found in similar habitats where the waters are swift-flowing, or in the wave-swept, rubble-strewn areas of lakes. *O. virilis* and *O. rusticus* are typical inhabitants of back waters, ponds, and slow-moving streams.

O. propinquus and *C. robustus,* the two species most often found in highly oxygenated waters showed similar oxygen consumption rates. Their oxygen consumption showed a marked increase with temperatures to 20 C and a decrease thereafter. These species are apparently adjustors, in that their oxygen consumption varies, more or less proportionately with the oxygen tension of the surroundings (Van Weel, Randall, and Takata, 1954).

O. virilis and *O. rusticus,* two species found in less oxygenated waters showed an increase in oxygen consumption with an increase in temperature. Wiens and Armitage (1961) report that *O. immunis,* which has similar habitat preferences to *O. virilis* and *O. rusticus,* respond to temperature increases with a uniform increase of oxygen consumption up to 36 C. These species are probably partial regulators under moderate experimental stresses.

Considering both groups, there is a real difference in toleration to dissolved oxygen levels and increasing temperatures. *O. propinquus* and *C. robustus* are less tolerant to low dissolved oxygen levels, particularly as temperatures increase which may be important factors in their absence from static waters. *O. virilis* and *O. rusticus* are more tolerant of the same conditions which probably account for their ability to inhabit slow back waters and ponds.

The oxygen consumption rate of *O. rusticus* over a 24-hour period correlated closely with observations of their activity patterns in the field. Schalleck (1942) reports that *O. virilis* were more active at night than during the day. Edwards (1950) showed that the oxygen consumption of the fiddler crabs *Uca pugilator, U. pugnax,* and *U. minax* was normally higher at night than during the daytime. *O. rusticus,* similarly, showed a heightened activity pattern during the night as evidenced by its oxygen consumption. *O. virilis* and, to a lesser extent, *O. propinquus* have also been observed moving about stream bottoms at night with greater intensity than during the day.

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