THE DISTRIBUTION OF CRAYFISHES (Decapoda, Cambaridae) IN MINNESOTA[1]

by

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CONTENTS

Page

1. Introduction, methods and cooperators 3
2. Species descriptions 7
   a. *Cambarus diogenes diogenes* (Girard) 7
   b. *Orconectes immunis* (Hagen) 8
   c. *Orconectes propinquus propinquus* (Girard) 9
   d. *Orconectes rusticus rusticus* (Girard) 11
   e. *Orconectes virilis* (Hagen) 15
   f. *Procambarus acutus acutus* (Girard) 16
3. Species summary sheets (Figs. 1-6) 18
   Fig. 1. *Cambarus d. diogenes* 18
   Fig. 2. *Orconectes immunis* 19
   Fig. 3. *Orconectes propinquus* 20
   Fig. 4. *Orconectes rusticus* 21
   Fig. 5. *Orconectes virilis* 22
   Fig. 6. *Procambarus acutus acutus* 23
4. Maps of crayfish species distributions in Minnesota (Fig. 7-11) 24
   Fig. 7. *Cambarus d. diogenes* & *Procambarus acutus acutus* 24
   Fig. 8. *Orconectes immunis* 25
   Fig. 9. *Orconectes propinquus* 26
   Fig. 10. *Orconectes rusticus* 27
   Fig. 11. *Orconectes virilis* 28
   Fig. 12. Earlier ranges maps 29
5. Figs. 13 a-e. Geographic distributions of crayfish in the U.S.A. 30
   Figs. 13 a,b. *Cambarus d. diogenes*, *Orconectes immunis* 30

Page

Figs.13 c,d. *Orconectes propinquus, Orconectes rusticus* 31

Figs.13 e,f. *Orconectes virilis, Procambarus acutus acutus* 32

6. The *Orconectes rusticus* problem.......... 33

7. The potential impact of crayfish on wild rice.......... 39

8. Crayfish as a potential product.......... 42

9. Terms & features for identifying crayfish (Terms list & Fig. 20).......... 45

Fig. 20. Structures used in identification of crayfish.......... 48

10. Two taxonomic keys to Minnesota crayfish.......... 49

a. Key based on sexually mature males.......... 51

b. Key when mature males are lacking.......... 53

11. Tables of locations of each species in Minnesota (Tables 1-6).......... 55

Table 1. *Cambarus d. diogenes*.......... 55

Table 2. *Orconectes immunis*.......... 56

Table 3. *Orconectes propinquus*.......... 58

Table 4. *Orconectes rusticus*.......... 59

Table 5. *Orconectes virilis*.......... 60

Table 6. *Procambarus. acutus acutus*.......... 69

12. Appendix I, list of cooperators.......... 70

13. Appendix II, survey sheets and mailings used.......... 73

a. Survey mailings.......... 73

b. How to collect and preserve crayfish, crayfish project ideas.......... 78

14. Appendix III, dBase file structures.......... 87

15. Appendix IV, supply house insert.......... 89

16. Bibliography.......... 90

17. Figure credits.......... 94

18.. Photographs of crayfish structures (Figs. 14-19).......... 95ff
(Figure legends and pagination on pp. 95 and 96)

INTRODUCTION

This is a report on the distribution of six species of crayfish in Minnesota, *Cambarus diogenes diogenes* (Girard 1852), *Orconectes immunis* (Hagen 1870), *O. propinquus* (Girard 1852), *O. rusticus* (Girard 1852), *O. virilis* (Hagen 1870), and *Procambarus acutus acutus* (Girard 1852). The report describes the present and previously known ranges of these species, with ranges extended for *O. rusticus*, *O. propinquus* and *O. immunis*. Earlier work (Creaser 1932) listed four species of crayfish in Minnesota: *Cambarus d. diogenes*, *Orconectes immunis*, *Orconectes virilis*, and *Procambarus acutus acutus*. *Orconectes rusticus* is now found in several areas of the state: near the southern border, in the St. Croix River drainage, in the Leech Lake and Detroit Lakes area, and in northeastern Minnesota in the Ely area. *Orconectes propinquus* is now found in northeastern and southeastern Minnesota.

The report includes a description of each species with figures and photographs, and two taxonomic keys designed for the identification of the crayfish found in Minnesota: one key based on mature male reproductive structures, the other based on other characters including the female reproductive structures. There are state distribution maps from this survey for each Minnesota species, and U.S. range maps from the work on Wisconsin crayfish by Horton Hobbs and Joan Jass (1988). The locations of each species are listed from the database. Issues addressed are the effects of *O. rusticus* on the aquatic system and its potential for hybridization, herbivory by crayfish and potential for damage to cultivated wild rice, and some questions on the suggested harvesting of crayfish as an exportable product. The discussions will point to areas where further research is needed.

METHODS AND COOPERATORS

This survey could not have been carried out without the joint financial assistance of the Minnesota Department of Natural Resources Nongame Wildlife Program and the Science Museum

of Minnesota. Many cooperators and collectors provided needed assistance, contacts, and crayfish. They are listed in Appendix I. Their interest and collections are gratefully acknowledged as they were the heart of this survey. Especially helpful was Jim Underhill, who included crayfish collections in his stream fish survey work, and who devoted considerable time to sorting and labelling before this survey was even funded, because he knew the author had an interest in it. Also, Joan Jass, Assistant Curator at the Milwaukee Public Museum, literally went extra miles to help verify identifications, sent specimens and many useful reprints as well as preprints of the upcoming book. Conversations with Joan were extremely helpful. Likewise, Horton Hobbs III has been very supportive and generous with preprints of material from The Crayfishes and Shrimp of Wisconsin. Thanks go to Wayne Barstad for the electroshocking field trip at the Science Museum's "Williamsport" stream site near the St. Croix River.

Central to the collections has been the cooperation of many DNR Fisheries people whose names are listed in Appendix I. These people were willing to add crayfish collections to their workday, and their collections throughout Minnesota were essential for the distribution maps. I'd especially like to thank Pete Eikeland, Finland Fisheries; Scott Gustavson, Walker Fisheries; Dean Ash, Detroit Lakes Fisheries; Doug Thompson, Ely Fisheries; the Waterville and Grand Rapids Fisheries personnel, Jim Lillienthal, Little Falls Fisheries; and Pete Ongstad, Duluth Fisheries. Thanks to the St. Olaf College Biology Department for much assistance in this project: to Jan Friesen, Cindy Landsteiner, Deanne Copley, Julie Rehmann and Kris Hoikka for many hours of entering the records onto the dBase III system.

The aid of cooperators was enlisted by many (hundreds of) mailings to a variety of nature centers, schools, fisheries offices, even SCUBA shops. Examples of some of the mailings sent are in Appendix II. The survey was announced in science teachers newsletters, in a SCUBA shop newsletter, and in Lacustrine Lessons (April, June 1986), an aquatic topics publication by the Minnesota Sea Grant. It is hoped these mailings helped raise awareness of the importance of aquatic nongame species and the Nongame Program.

While this approach was productive, in the future a systematic inclusion of crayfish in the lake and stream survey programs of the DNR is strongly recommended. It is also recommended that all nature centers make and keep baseline collections, not just of crayfish, but of all their wetland invertebrates, as there are no historical records for most of our wildlife refuges or natural areas.

Crayfish were preserved in various ways: some specimens were preserved in 10% formalin, some in 70-80% alcohol, some were frozen. Specimens in formalin were washed and transferred to 80% alcohol, usually denatured ethanol. Frozen specimens were very brittle while frozen, and fairly easily lost parts. However, freezing avoids use of preservatives at the site, and takes up less space when whirlpaks are used. Most of the collection is preserved in temporary plastic jars. These were used rather than glass because of the lower mailing costs and ease of use in the field. Mailings of sets of plastic jars and labels and instructions were made to all fisheries people and others who expressed a strong interest in collecting crayfish. The jars with preservatives and specimens were retrieved by driving to regional fisheries offices, to which the jars had been delivered (e.g., Grand Rapids, Aitkin, Walker, Bemidji, Montrose, Little Falls), or by picking them up at the St. Paul DNR office, the St. Paul Metro Hatchery and the Minnesota State Fairgrounds and other sites.

Crayfish were collected in various ways. For streams with a current and riffle areas, an Erickson-style net, originally designed in Jim Underhill's lab by Jim Erickson, was useful. Net frames were made by Wally Saatala (University of Minnesota), and 3/8" netting was attached to allow water flow with reduced drag. The Erickson net has a long wood handle attached to a 36" x 12" rectangular iron frame with deep rectangular net attached over the frame. The collector places the net in the current and kicks rocks so that crayfish are swept into the net. It is very effective in a current. In standing water, crayfish were collected by dip nets, sometimes at night. This is very effective in shallow water of lakes: with a flashlight on the crayfish, one places a dip net behind the crayfish, and "attacks" the crayfish with a stick so it flips back into the net. Crayfish were also collected by minnow traps baited with fish. Fisheries personnel collected crayfish as they did their fish surveys. Crayfish that were caught up in the trap nets, gill nets and/or seines were collected and kept. Crayfish near the Mississippi River were dug from burrows. This required digging out the burrow while constantly checking its direction and feeling for the bottom of the burrow and the crayfish. The crayfish are "in the dark" and seem sluggish, but become active as soon as they can see. In the clay bottom areas, one feels one is giving the earth a proctoscopic exam! Attempts by others to capture burrowing crayfish with inverted minnow traps over the burrows have met with limited success (Jass, pers comm).

Crayfish were identified using the keys and figures of Hobbs (1976, 1974), Crocker and Barr (1968), primary literature (listed with species descriptions), and the illustrations from Hobbs and Jass (1988). Very rarely distortions in the male reproductive structures suggested possible hybridization. The re-naming or relegation of the former *O. iowaensis* to *O. propinquus* is discussed in the description of *O. propinquus*. The need to observe reproductive structures of males and females is affirmed, e.g., *O. rusticus* in some areas lacks typical features like the "rusty" spot. The *Procambarus acutus acutus* needs confirmation with collections of males.

The crayfish records were entered into two files in dBase III (Ashton Tate), COLLLOC and CRAYSPEC. The COLLLOC file (see Appendix III for file structures) contains information about the collection site or location, including county, T, R, S, collectors, site name, DOW lake number from the Inventory of Minnesota Lakes (1968), and drainage system number from Hydrologic Atlas of Minnesota (1959). Some of the drainage systems were hard to determine from the Hydrologic Atlas. It would be useful to have the 39 drainage systems encoded by 1/4 sections on a computer system, so anyone could call up the correct system with location information.

The information on the specimens was entered into the CRAYSPEC file, one record for each specimen examined in a collection. A common "collection code" (COLLCODE) number unites the two files. In this way, site information can be entered just once for all specimens gathered at a site. Then one can "lookup" information between the two files as needed. The CRAYSPEC file contains information on species, sex, maturity, reproductive structures, size of carapace, whether damage is present, other characters (see Appendix III for file structure), and notes. dBase III allows for notes, which is useful in collections. The records are all contained on one 320 K floppy disc. It should be relatively easy to expand a collection to several discs which could then all be put on to a hard disc to be accessible as one large collection.

By using the lookup function, one can "lookup" all the locations for, say, *O. virilis* in the state, or one could lookup its sizes, or one could lookup by county which species were found in that county. The list of locations given in Table 1-6 was generated from the dBase files as just described.

SPECIES DESCRIPTIONS

The species found in Minnesota will be described individually, primarily as an aid in distinguishing among the six species. For each species, the reader will be referred to a summary of characters with figures (Figs. 1 to 6), to photographs taken with Minnesota specimens, and to distribution and range maps. For more complete descriptions and references, the work by H.H. Hobbs and J. Jass, The Crayfishes and Shrimp of Wisconsin (1988), and works such as Hobbs (1976), Crocker and Barr (1968), and additional sources given with each description will provide useful and more detailed information on the crayfish.

The specific locations of the specimens collected are listed in Tables 1-6 from the database record. The statewide distributions of each species in Minnesota are illustrated by distribution maps (Figs. 7 to 11). Finally, the current ranges of each species in the United States are given in Figure 13, the range maps constructed by Hobbs and Jass (1988) who included in their maps the Minnesota distributions from this survey. The state of the range maps for some specimens prior to this survey is given in Figure 12 from Hobbs and Jass before the inclusion of the Minnesota survey.

1. *Cambarus diogenes diogenes* Girard, 1852. See Hobbs (1942), Hobbs and Jass (1988). According to Crocker and Barr (1968), the paratype is at the Academy of Natural Science,

Philadelphia. (See Faxon, 1914).

Cambarus d. diogenes is a robust crayfish, with maximum carapace size in this survey of 55 mm. A semi-terrestrial species, it constructs burrows to the water table, the burrows often topped with mud chimneys of several inches height. In Minnesota, *C. d. diogenes* has been found in burrows by Mississippi backwaters and by trapping in shallow lakes and ponds (Table 1) not connected to the Mississippi River. Its distribution (Fig. 7) in Minnesota is in ponds near tributaries to the Mississippi and Minnesota Rivers, and in ponds and lakes in the Northeastern area of the state. So far it has not been found in western Minnesota. In the U.S., the range of *C. d. diogenes* is east of the Rockies with its range primarily spreading from the Mississippi River drainage (see Figure 13a from Hobbs and Jass 1988), plus a distribution along the east coast east of the Appalachians.

The diagnostic features for *C. d. diogenes* are summarized in Figure 1. The male's gonopod is very distinctive (Figs. 14a, b) with the stout central and mesial processes at almost 90^{o} angles to the main shaft. The central process has a sclerotized blade-like end. A key feature is the closed areola (Fig. 14g), that is, there is no areola along the midline. The dactyl of many Minnesota specimens appears excised; the robust chela has a distinct concave curvature over its lateral surface (Fig. 14f). The rostrum is distinct in lacking lateral rostral spines. The female's annulus ventralis (Fig. 14c) is quite shallow and not distinctive. The diagonal cervical groove on the lateral carapace is uninterrupted (Fig. 14e).

2. *Orconectes immunis* (Hagen)

According to Crocker and Barr (1968), the type and paratypes are in the Museum of Natural History in Paris (see Faxon 1914).

Orconectes immunis is successful in muddy-bottomed ponds and pools, and is sometimes found in fish-rearing ponds and cultivated wildlife paddies. More tolerant of depressed oxygen levels than *O. virilis* (Bovbjerg 1970), it is able to burrow if the pond dries down. Bovbjerg's elegant study demonstrated that *O. immunis* would prefer the rocky-bottomed habitat of *O. virilis* but is competitively displaced to mud-bottomed ponds to which it has adapted quite well. A project by Steve Thearle, a student at St. Olaf College, suggested that *O. immunis* would "lose out" in competition with *O. rusticus*, but that it may be able to consume greater amounts of plant material per time of feeding once it gets onto the plants. More research here is needed. A project on the feeding and growth rates of this species could be very interesting.

In Minnesota, *O. immunis* was found in shallow ponds and some lakes (Table 2). The distribution encompasses almost the entire state (Fig. 8), although it has not yet been collected in the southeastern or northwest corners of the state. This survey extends the range of *O. immunis* to the Canadian border of Minnesota (compare Fig. 12a with Fig. 13b of Hobbs and Jass) from its previous range to central Minnesota.

The description of *O. immunis* as "fragile looking" by Crocker and Barr (1968) results mostly from the less robust, more elongated chela (Figs. 15e, f). The largest individual's carapace measured 43.1 mm. The excision of the dactyl is a definite character, visible in young specimens. The central and mesial processes of the mature male gonopod curve strongly ventrally (Figs. 2, 15b, c), and the mesial process curves abruptly at the distal end. The female's annulus ventralis is distinctive even in young females. The major fossa (a pit or depression in the annulus) is laterally displaced to the female's right, giving the annulus a distinct asymmetric appearance (Figs. 2, 15a). Occasionally the annulus is reversed. The rostrum has reduced or lacks lateral rostral spines. The areola widens in the posterior half, a distinct pattern. The chela makes this species easy to identify, but the gonopods or the annulus ventralis should always be observed. Color variants ocur, and populations sometimes have a small percentage of red morphs. Whether these have any adaptive value is unknown.

3. *Orconectes propinquus propinquus* (Girard)

According to Crocker and Barr (1968) the types are lost.

Orconectes p. propinquus is a smaller crayfish occuring in Minnesota in two widely separated areas, northeastern Minnesota in lakes, and southeastern Minnesota in the drainage streams of the Root River (Table 3, Fig. 9). Maximum carapace length was 41.2 mm. The population in southeastern Minnesota was earlier classed as *O. iowaensis* (Phillips 1980). Page (1985) relegated *O. iowaensis* to *O. propinquus* after examination of Iowa *O. iowaensis* compared with Illinois *O. propinquus* in which he could find no major differences in gonopod or annulus ventralis between the the states' collections. The key distinction between the two species in Hobbs (1976, p., 83) was in the shape of the mesial process: "acute apex" for *O. propinquus* and "truncate or spatulate apically" for *O. iowaensis*. Several of the first specimens collected for this survey from northeastern Minnesota keyed, on this basis, to *O. iowaensis*. The mesial process was truncate, definitely, in some, appearing more like that pictured for *O. obscurus* in Crocker and Barr (1968), but in other specimens the crayfish would be called *O. propinquus*. Based on the examination of the collections from both areas of Minnesota, Joan Jass of the Milwaukee Museum agreed with a designation of *O. propinquus*, and Horton Hobbs III and Gary Phillips agree with the relegation of *O. iowaensis* to *O. propinquus* (pers. comm.).

This report extends the distribution of *O. propinquus* into northeastern Minnesota, a range not unexpected from its distribution in Wisconsin (see Figs. 12b and 13c). Crocker and Barr (1968) reported *O. propinquus* in many sites in eastern Ontario, but only one location just east of Lake-of-the-Woods, in western Ontario. Dr. Walter Momot at Thunder Bay, Ontario reports that *O. propinquus* is "not found in that region" (pers. comm.), so there is a need for more information on possible locations of *O. propinquus* along the Canadian-Minnesota border before we can understand the origin of the populations in northeastern Minnesota. While an origin from northwestern Wisconsin is most likely, a Canadian crossing can't be ruled out because it has been found at the border (Bass Lake). This species has spread northwards in Wisconsin since 1932 when Creaser (1932) recorded its distribution in southern and eastern Wisconsin. It is now distributed through the entire state of Wisconsin (Hobbs and Jass 1988), apparently displacing *O. virilis* (see Capelli 1982). It may be displaced by *O. rusticus*. Berrill (1985) found *O. propinquus* produced hybrid young with *O. rusticus* in the laboratory, but their viability to reproductive stage isn't known. Berrill calls for biochemical tests to assess the closeness of these two species.

There is a considerable amount of variability in both the male and female reproductive structures, especially in the annulus ventralis in the northeastern populations. These would merit further study. The gonopod of the male *O. propinquus* is distinctly different from the other species of Minnesota crayfish: the central and mesial processes are short, stout and parallel, not curved ventrally. There usually is a shoulder present, although this is not a feature in Hobbs (1976) (see Figs. 3, 16d, e). The female annulus ventralis varies, is shallow, and is not distinctive enough for diagnosis (Fig. 3, 16a).

A key feature is the medial carina of the rostrum (Fig. 16b). This raised ridge is not prominent in many specimens, but is usually present. The areola is distinctly wide, and sometimes shows an elevation along the midline (Fig. 16h). The chela of large males can look like those of *O. rusticus* (Figs. 16f, g). There are black tips on the chela and dactyl and the dactyl develops a sinuosity that creates a definite gap between the dactyl and the immovable chela, very much like the enlarged chela of dimorphic male *O. rusticus*. The chela of females are stout and black-tipped (Fig. 16h). The strong sexual dimorphism was more apparent in specimens from lakes in northeastern Minnesota than in those from the Root River drainage in the southeast. There were definite color differences in the two populations, the southeastern *O. propinquus* an even bronze/tan color, the northeastern ones with a light tan and brown pattern, which actually made them quite visible.

4. *Orconectes rusticus rusticus* (Girard)

According to Crocker and Barr (1968), the types were probably destroyed in the Chicago fire in 1871, the paratype (?) is in the Academy of Natural Science in Philadelphia (see Faxon (1914).

Orconectes rusticus is a robust crayfish with a maximum carapace size of 61 mm from this survey. The first dated collection of *O. rusticus* was in 1967 from Otter Creek, Lyle, in Mower County. In 1984`it was collected in the Shagawa River between Shagawa and Fall Lakes by Jim Underhill's crew. Doug Thompson collected large *O. rusticus* with *O. virilis* from Shagawa Lake at Ely, MN and Dean Ash from Detroit Lakes Fisheries found *O. rusticus* in Big Elbow Lake. The latter specimens were relayed through the State Fair DNR employees' facility and handed to me by Smokey the Bear!

This survey is the first report of the distribution of *O. rusticus* in the entire state of Minnesota. At first, its extent was unknown, although reports were made of its distribution in the West Fork of the Des Moines River and in the Cedar River drainages (Phillips 1980, Phillips and Reis 1979, in Fig. 1 of the latter, the symbols for *O. rusticus* and *O. iowaensis* distribution in southeastern Minnesota should be reversed, affirmed by personal communication with Gary Phillips). Knowing its distribution in Iowa and Wisconsin (see Hobbs and Jass 1988), it was not surprising to find it in tributary streams to the St. Croix River north of Stillwater. Clearly it would be expected to be moving across the southern and eastern borders of the state.

The almost alarming report of its presence in the Shagawa River and Shagawa Lake at Ely at the edge of the Boundary Waters in northeastern Minnesota, and in the Detroit Lakes area in north-central Minnesota indicated a much wider distribution of *O. rusticus* here than expected. The distribution at present (Fig. 10) indicates *O. rusticus* is now established in southern, north-central and northeastern Minnesota and in the St. Croix drainage. It is fully expected that additional sites will be found.

More investigations are needed to clarify the possible origins of the current distribution. Is this distribution human-dispersed or has *O. rusticus* invaded naturally across the borders? If so, has it moved from the St. Croix River to the northwest towards the Leech Lake area? Or has it entered in a southwesterly direction across our "leaky" border with Canada? We need to know of records of *O. rusticus* in Canada along our border. Crocker and Barr (1968) refer to records from one area of western Ontario, in Lake-of-the-Woods (Reed Narrows, Long Bay, 1964). They attribute that to possible transport of crayfish by fisherman. Walter Momot at Thunder Bay reports that the *O. rusticus* in Lake-of-the-Woods "doesn't seem to have widely expanded its range [in western Ontario} from what Crocker and Barr provided in 1968". He reports his first collection of *O. rusticus* in the Thunder Bay are in 1986 "from a lake on Sibley Peninsula" (pers. comm.). A report in Lodge, Kratz and Capelli (1986, p. 994) that *O. rusticus* "now also occurs in lakes on the Ontario-Minnesota border (S. Serns, Wisconsin DNR Northeast Headquarters, Woodruff, WI 54568, pers. comm.)" could not be verified as Mr. Serns is, unfortunately, deceased. According to DNR personnel at Woodruff, collections and records were not made, but Mr. Serns observed *O. rusticus* in lakes on a trip. Finally, this crayfish has clearly expanded its range into most of Wisconsin where it has caused varying degrees of damage (see section on the *O. rusticus* problem). Estimates are it may have been present in Wisconsin for 20 to 30 years. There is no way to tell yet how long *O. rusticus* has been in Minnesota, especially in the North-central and northeastern areas. The number of locations found so far (Table 4) suggests that, at the least, it has been here for many years, and is here to stay.

Diagnostic features of *O. rusticus*

Observation of the reproductive structures is essential in the identification of *O. rusticus* . The shape of the mandible is also considered a key feature of this species. The male gonopod in sexually mature form (Figs. 4, 17c, d) has central and mesial processes almost as delicate as those of *O. virilis*. The mesial process tends to curve back towards the central process, or be almost parallel to it. Unlike *O. virilis*, it does not curve ventrally. Once several males of each species have been examined, the difference is clear. The annulus ventralis of the female is distinct and can be used for identification (Figs. 4, 17a, b). The upper or anterior protuberances or knobs are the largest and become more exagerated, with a deeper fissure between them, as the female becomes larger. In contrast, in the annulus of *O. virilis* the upper and lower protrusions are of similar height, or the lower one is more enlarged in larger females. Sometimes the anterior enlarged protrusions in *O. rusticus* stand out in color (e.g., orangish) while the lower ones stand out as solid white in *O. virillis*.

The mandible can be useful in distinguishing *O. rusticus* from the other species of *Orconectes* in Minnesota (Fig. 4). The main cutting blade or incisor area is smooth or even-edged rather than being crenate or divided into small lobes (from comments made by Horton Hobbs, Jr.

of the Smithsonian Institution to J. Jass 1979). Horton Hobbs Jr. has stated that, besides the reproductive structure, the mandible is the "very best character" for distinguishing *O. rusticus*. It will be useful for those who are identifying *O. rusticus* in Minnesota to check the mandible to affirm if this holds true for the *O. rusticus* here. The mandibles examined so far from central, northeastern and eastern Minnesota *O. rusticus* show a smooth blade on both left and right mandibles. However, those from the west fork of the Des Moines River and from Big Elbow Lake (Becker County) show a strong indentation in the left mandible "incisor" area.

Other features of *O. rusticus* include the rostrum, areola, chela and color patterns. The rostrum is deeply concave and the lateral edges curve slightly inward in dorsal view and arch a bit dorsal-ventrally, making it look rather strong. There are lateral rostral spines, and never is there a carina. The areola is distinctly wider in relation to the narrow areola of *O. virilis*, but not as wide as that of *O. propinquus*. The chela are strongly sexually dimorphic, or enlarged in larger sexually mature males (Figs. 17e, f, g). They are large enough in some to look like they might be an impediment, and only beneficial during the aggressive interactions during the mating period. Females are, apparently, more successful without these enlarged structures to haul around. In large males the dactyl becomes more sinuous, creating a definite gap between the dactyl and the main chela. A similar shape is seen in large male *O. propinquus* from northern Minnesota. The chela in both sexes and young *O. rusticus* usually have distinct black bands at the tips, but somtimes these are not present. This strong sexual dimorphism was not evident in *O. rusticus* from the Des Moines River.

Finally, the color pattern of the "rusty" spot which gives the colloquial "rusty crayfish" its name may or may not be present or visible (Fig. 17h). This roundish spot, roughly 1/4 inch or more in diameter, is reddish or brick-rust-colored, and located on the posterior-lateral sides of the carapace. The position may vary: in some it is free of the posterior margin, in others it fuses with it. The spot can be completely masked by very blackish body color, as in the *O. rusticus* populations in the St. Croix River tributaries, or not visible at all as in the brownish specimens from the West Fork of the Des Moines River. However, Gary Phillips said *O. rusticus* from this region can have spots, so there may be seasonal differences or masking from deposits. Only the gonopods and annulus ventralis make these specimens recognizable as *O. rusticus*. The *O. rusticus* from the north-central and northeastern lakes have distinct "rusty" spots. It is unknown if these color differences represent local adaptations of a genetic nature. If so, they might be useful in showing different origins of the *O. rusticus* in Minnesota.

5. *Orconectes virilis* (Hagen)

According to Crocker and Barr (1968) the types and paratypes are in the Museum of Natural History in Paris, the Wurzburg Museum, and the Australian Museum in Sydney (See Faxon 1914).

In a state with more than 10,000 lakes, this is the dominant species of crayfish, and the one most likely to be displaced locally by *O. rusticus* or *O. propinquus*. The largest carapace noted in this survey was 67.9 mm. This species prefers rocky-bottomed rivers, streams and lakes, but has been found in sand-bottomed lakes. It does not burrow and does not tolerate the mud bottom or lower oxygen conditions tolerated well by *O. immunis* (Bovbjerg 1970), and appears to have displaced *O. immunis* competitively from the rocky-bottomed habitat to shallow ponds.

O. virilis is found throughout Minnesota (Fig. 11), probably in all drainages, although not all have been surveyed. The present survey, thanks to the collections of Jim Underhill in the southwestern part of Minnesota, extends the previous distribution to most of the state (Figs. 12d, 13e). Nationally, *O. virilis* is common through the midwest into central and eastern Canada, and in New England, with sporadic occurrences in the west.

Diagnostic features of *O. virilis*

The reproductive structures are essential for diagnosis. In the mature male, the central and mesial processes curve ventrally gracefully. They appear almost delicate. The mesial process does not curve sharply distally, as it does in *O. immunis* nor does it curve back towards the central process as it can in *O. rusticus* (Figs. 5, 18b). The mesial process can be very spatulate or not, it varies. If there is any ambiguity in identifying *O. virilis* from *O. immunis* or *O. rusticus*, check the female annulus ventralis (Figs. 5, 18a). The annulus ventralis is distinctive, especially in larger females. The major fossa is usually just to the female's right of the annulus center, although it is reversed in some specimens. The lower protuberance of "lip" enlarges in larger females. This annulus is distinctly different from *O. immunis* and *O. rusticus* (see descriptions.)

The rostrum is strong as in *O. rusticus*, but tends to have parallel margins. It has lateral rostral spines and never has a carina. The areola is the narrowest of the Minnesota species of *Orconectes*, allowing only 1-2 (sometimes 3) rows of punctae (dots) in its narrowest region. The chela dactyl is usually quite straight (Figs. 18c, d), however, in some mature larger males it develops some sinuosity, and a gap appears in the chela, but this is never as exaggerated as it is in large male *O. rusticus* or *O. propinquus*. It never has black chela tips.

The mandible, according to Hobbs (Hobbs and Jass 1988) is not entirely smooth-edged in the large blade-like part, but has some scalloping. A study of this character in Minnesota *O. virilis* is recommended to be sure this is the case. Then it can be used to distinquish *O. virilis* from *O. rusticus* which has a smooth or even mandible incisor blade when the identification is ambiguous.

Color variation occurs in *O. virilis* and would merit study, especially if it aids in understanding movement of local populations. Fisheries workers have reported a wide color range in the Leech Lake area. *O. virilis* near Itasca State Park have beautiful blue markings.

6. *Procambarus acutus acutus* (Girard)

(See Hobbs and Jass 1988 for references.)

This species was found only in the extreme southeastern part of Minnesota, in a backwater of the Mississippi River (Figs. 7, 13f). Because its collection was so limited, it will be treated only briefly. The reader is referred to Hobbs and Jass (1988) for more information.

This species is reported by Page (1985) to be common in Illinois in permanent standing water heavy with vegetation, in stream pools and slow mud or sand-bottomed ponds. It is probably not common in Minnesota, but further collections are needed. The male gonopod as pictured in Hobbs (1976) is thick throughout and has five every short projections (Fig. 6). Male specimens from Minnesota are needed. The female annulus, of the two females collected, is not as pictured in Hobbs (1974). The most elevated knob or protuberance is to the female's right of the main fossa (Figs. 19b, c). More specimens are needed to characterize the annulus ventralis.

The chela are delicate, elongated, and may have a very slight excision (Figs. 19a, d). It is possible that a ratio of chela length to width in females could be used to distinguish from *O. immunis* but caution is needed because of the sexually dimorphic changes in chela shape in many male crayfish. Reproductive structures are still preferred. The dactyl bends slightly in towards the chela in its basal part. It is amazing these females could burrow into the clay with such delicate-looking chela. Perhaps the elongation allows a piercing of the substrate.

Figure 1. Characteristics of <u>Cambarus diogenes diogenes</u>.

1. <u>Cambarus diogenes diogenes</u> (Girard)

a. <u>Male gonopod</u>

Central projection bent at 90° angle from main shaft, central process bladelike at end. Mesial process a conical mound ending in rounded tip, almost 90° from shaft.

b. <u>Female annulus ventralis</u>

About as long as wide. Not as deeply depressed as <u>O. virilis</u>. See photograph. Not a strong character for identification.

<u>Other characters</u>

Has triangular suborbital ridge, i.e., the carapace below the eye has an angular forward projection rather than rounded edge. Lateral cervical groove on carapace is continuous. Last two characters distinguish from <u>C. fodiens</u>.

<u>Rostrum</u>

Distinct in lacking rostral lateral spines so appears smooth rather than pointed.

c. <u>Areola</u>

Distinct because is closed or "obliterated" in midline, i.e., has no width in midline.

d. <u>Chela</u>

Dactyl can appear excised because it has a broad concavity on basal half. Stout, laterally curved over dorsal surface.

<u>Habitat</u>

Semi-terrestrial, burrows in clay near Mississippi River backwaters, but also found in ponds and lakes not connected with Mississippi.

e. <u>Mandible</u>

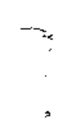
Definitely lacking smooth cutting blade.


1a


1b


1c


1d


1e

2. Orconectes immunis (Hagen)

a. Male gonopod

Central and mesial processes strongly curved ventrally, much more so than O. virilis, and more stout. Mesial process abruptly curved distally.

b. Female annulus ventralis

Very asymmetric with major depression or fossa usually to female's right. Wider overall than long. Reversed in some specimens.

Rostrum

The rostrum is longer than wide, appears narrow. Lateral rostral spines very small, indistinct.

c. Areola

The narrowest spacing is in the upper or anterior part of the areola, which widens out in the posterior half. Cervical groove laterally discontinuous, interrupted. Mandible unevenly edged.

d. Chela

Dactyl straight, excised on inner margin, a definite character for O. immunis. Chela not as robust as that of C. diogenes, more narrow and elongated, but not as much as in P. acutus.

Habitat

Usually found in shallow muddy-bottomed ponds, sometimes in similar habitat in lakes. Burrows if pond dries down. Tolerates lower O_2 levels. Occurs occasionally in large numbers in fishery rearing ponds and cultivated wild rice paddies. Can destroy vegetation in this situation.

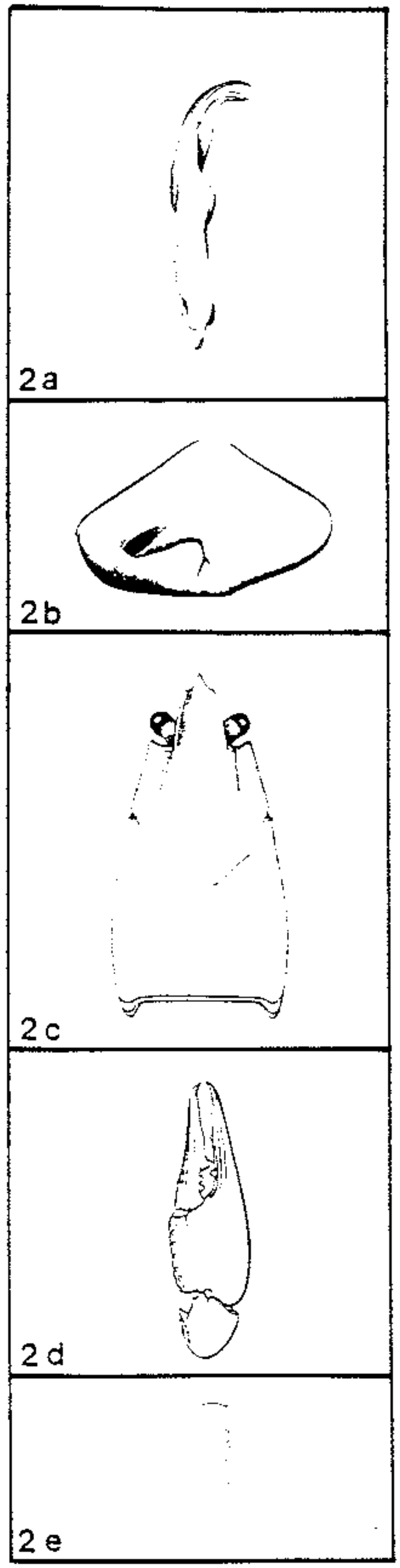


Figure 3. Characteristics of *Orconectes propinquus*.

3. *Orconectes propinquus* (Girard)

a. Male gonopod

Gonopod has two stout straight short processes. Shoulder can be present. Not as pictured in Hobbs, 1976 (his Fig. 65e). Mesial process often stout, not finely tapered, can be truncate or acute at end.

b. Female annulus ventralis

Annulus can vary. May be somewhat shallow compared with *O. virilis*. Not as unique for diagnosis.

Rostrum

The presence of a medial carina or raised ridge is diagnostic for *O. propinquus*. Not present in all specimens, or may be reduced. May be felt with a probe when hardly visible. Eyes can appear stalked.

c. Areola

Distinctly wider than that of *O. virilis* and *O. immunis*. Sometimes has an elevation along the midline.

d. Chela

Dactyl can develop sinuousity in large males, causing a gap between the dactyl and the main claw. This plus the presence of black bands on the chela tips results in chela similar to *O. rusticus*. Chela of females stout, black-tipped.

Habitat

Lakes in NE Minnesota, streams in the Southeast. The two widely separated populations differ in color patterns.

e. Mandible

Usually left mandible deeply incised, right manidible varies, usually incised but sometimes almost smooth - bladed. More Minnesota specimens should be examined.

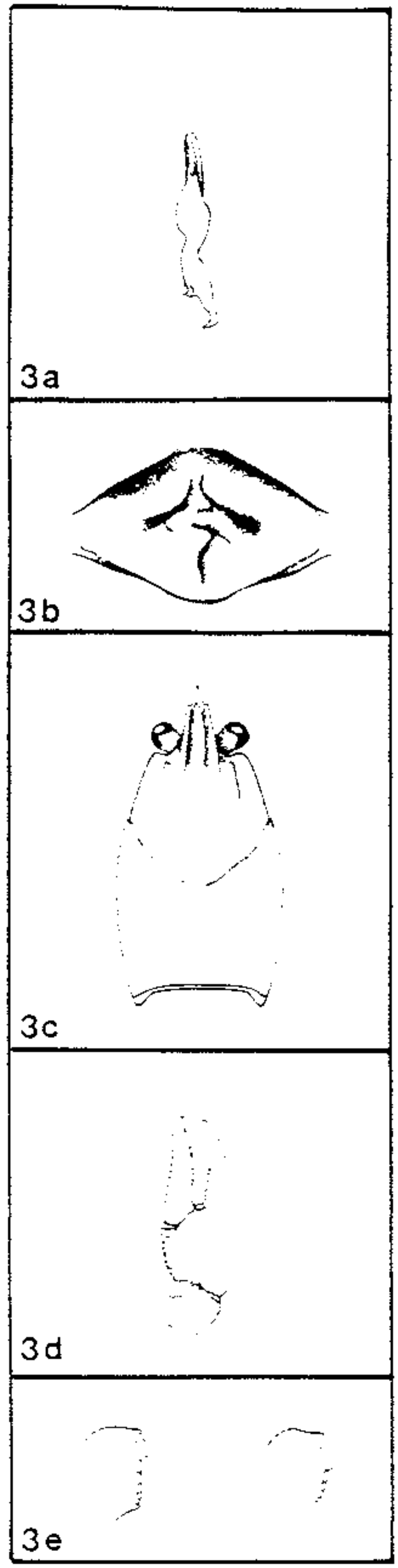
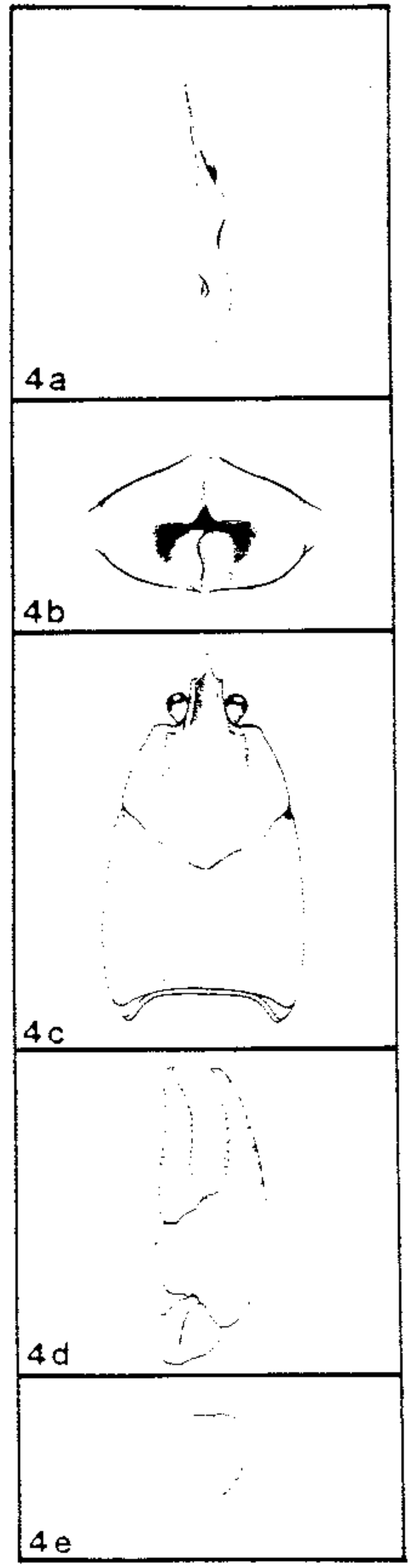


Figure 4. Characteristics of Orconectes rusticus.

4. Orconectes rusticus rusticus (Girard)



a. Male gonopod

Mesial process either parallel to central process or curved slightly in a dorsal direction. Not curved ventrally as in O. virilis.

b. Female annulus ventralis

In more mature, larger females the annulus is diagnostic with strong high protuberances on the anterior end of the annulus. In large mature O. virilis and greater protuberance is the lower or posterior edge of the annulus. Sometimes the O. rusticus annulus is orangish.

Rostrum

The rostrum is stout, deeply concave, with lateral edges curved slightly inwards in dorsal view. Viewed laterally, the margins are in the anterior-posterior direction.

c. Areola

The edges run parallel through the middle region. Not as narrow as O. virilis nor as wide as O. propinquus.

d. Chela

Black chela tips may or may not be present. Chela are similar to those seen in O. propinquus. Dactyl in large males strongly sinuous, making a large gap in the chela, which becomes very enlarged in older males.

Habitat

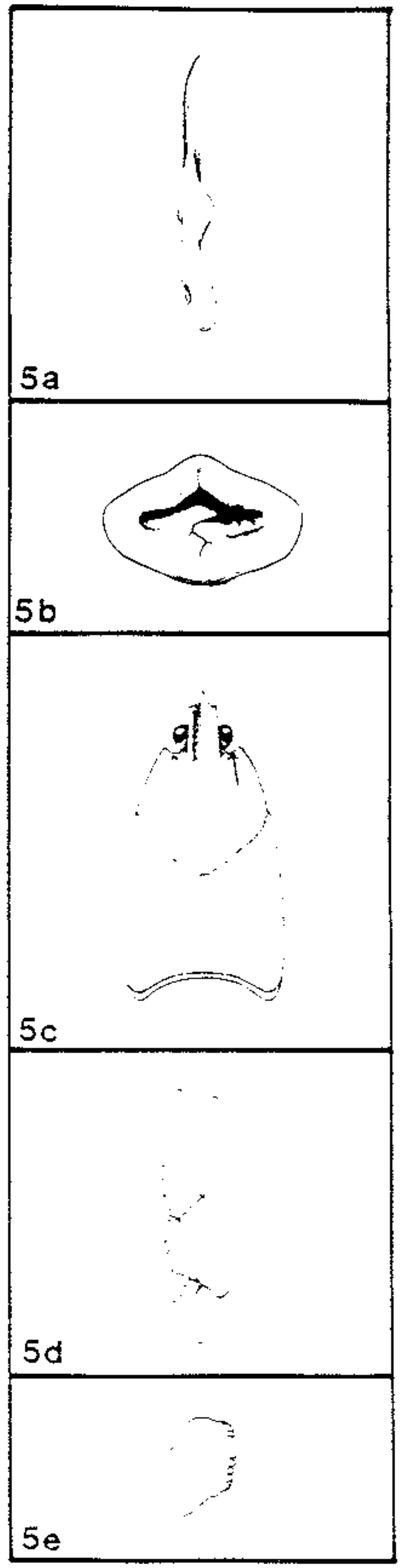
Lakes and streams, not yet seen in shallow ponds.

e. Mandible

Distinctive. It has a smooth-edged anterior cutting blade. Specimens from Big Elbow Lake (Becker Cty) and W. Fork Des Moines R. have indention in left mandible.

Figure 5. Characteristics of Orconectes virilis.

5. Orconectes virilis (Hagen)



a. Male gonopod

Central and mesial processes are curved ventrally. Mesial process does not curve abruptly distally as it does in O. immunis, but does curve ventrally. If the gonopod is not distinguishable from O. rusticus, use other features such as the mandible and the annulus ventralis.

b. Female annulus ventralis

Major depression is usually to the female's right, but reversed in some specimens in Minnesota. Anterior protuberance not excessively enlarged in larger females, as it is in female O. rusticus. The posterior or lower protuberance can be enlarged in older females.

Rostrum

The rostrum is concave, has lateral rostral spines, and the margins are usually straight.

c. Areola

The areola is narrow, with the narrowest portion midway along its length. Narrowest part has 1-2 rows of punctae.

d. Chela

The dactyl is not excised, is usually straight, but can be somewhat sinuous in larger males, though not as seen in large males of O. rusticus or O. propinquus. Can be enlarged or elongated in mature males.

Habitat

O. virilis is ubiquitous in lakes and rivers and streams, not usually found in ponds. Prefers rocky bottom.

e. Mandible

Usually large blade is uneven, not smooth-edged.

Figure 6. Characteristics of *Procambarus acutus acutus*.

6. *Procambarus acutus acutus* (Girard)

a. Male gonopod

Gonopod with very short projections as pictured. Uniquely different from any species so far in Minnesota. Male specimens from Minnesota are needed.

b. Female annulus ventralis*

Not as pictured in Hobbs, 1974. More specimens from Minnesota are needed to characterize the female's annulus.

Rostrum

Tapers anteriorally. Lateral margins convex, i.e., margins "bulge out".

c. Areola

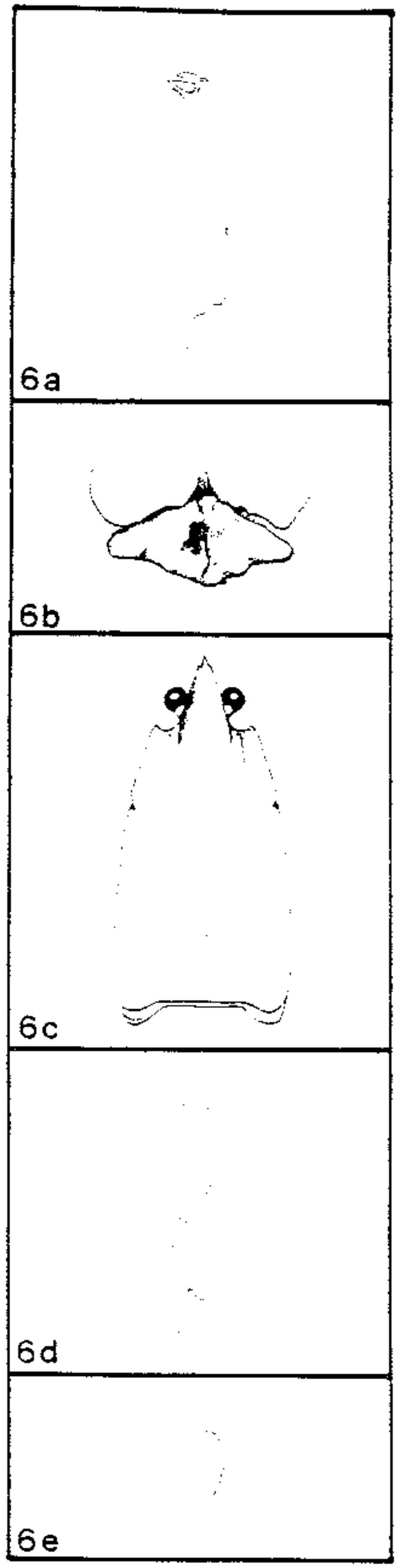
Moderately wide.

d. Chela

Long, tapered, delicate in appearance. Basal area of dactyl bends in towards main chela.

Habitat

Reported in Illinois as common in permanent standing water heavy in vegetation, also in stream pools and slow runs with mud and sand bottoms (Page, 1985). Not common in Minnesota, where it was found in burrows next to a Mississippi River backwater.



*Annulus ventralis pictured is from Hobbs & Jass, 1988.

Figure 7. Distribution of Cambarus diogenes diogenes and Procambarus acutus acutus in Minnesota. C. d. diogenes also occurred at the site designated for P. acutus acutus.

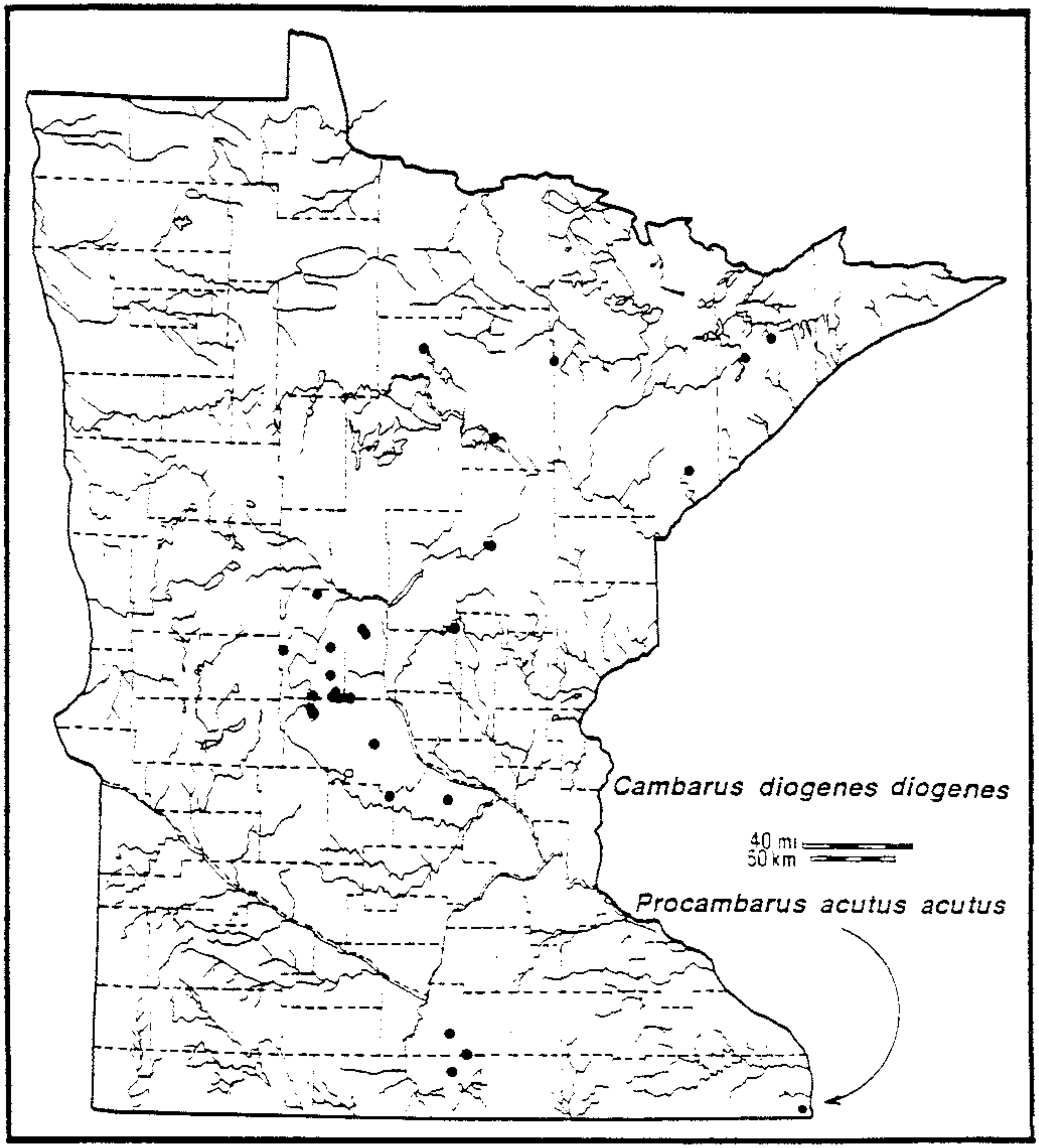


Figure 8. Distribution of Orconectes immunis in Minnesota.

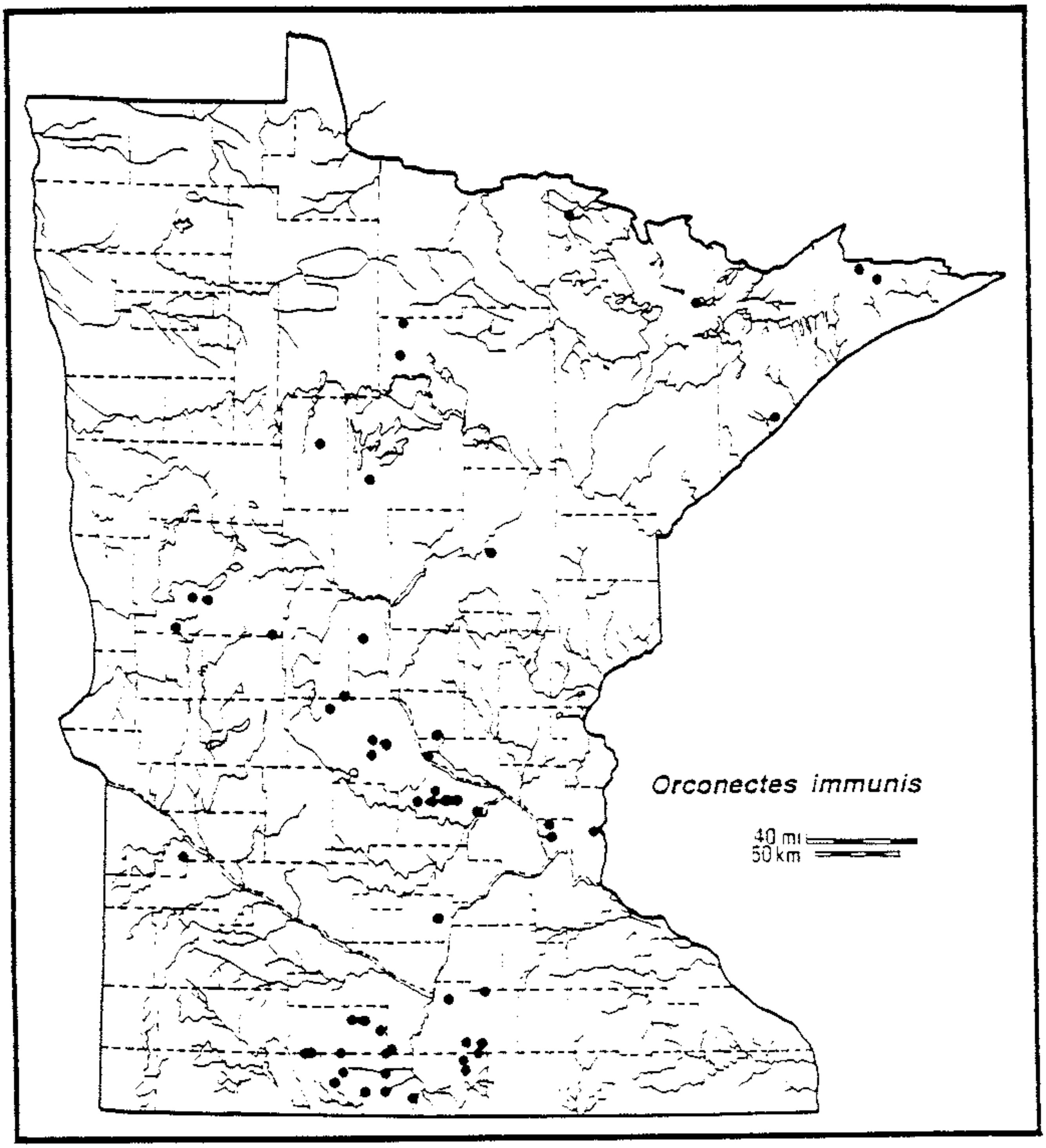


Figure 9. Distribution of Orconectes propinquus in Minnesota.

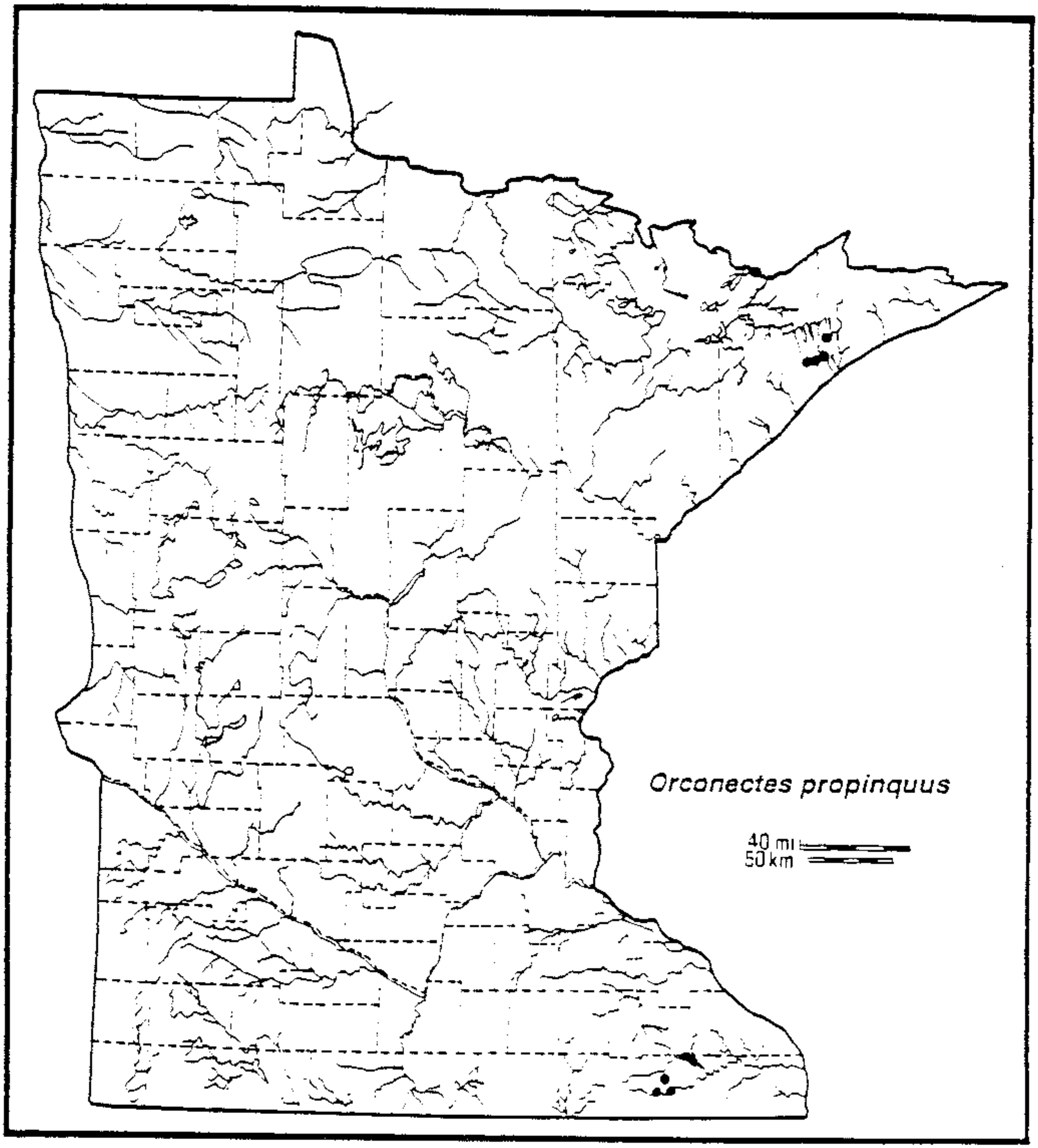


Figure 10. Distribution of Orconectes rusticus in Minnesota.

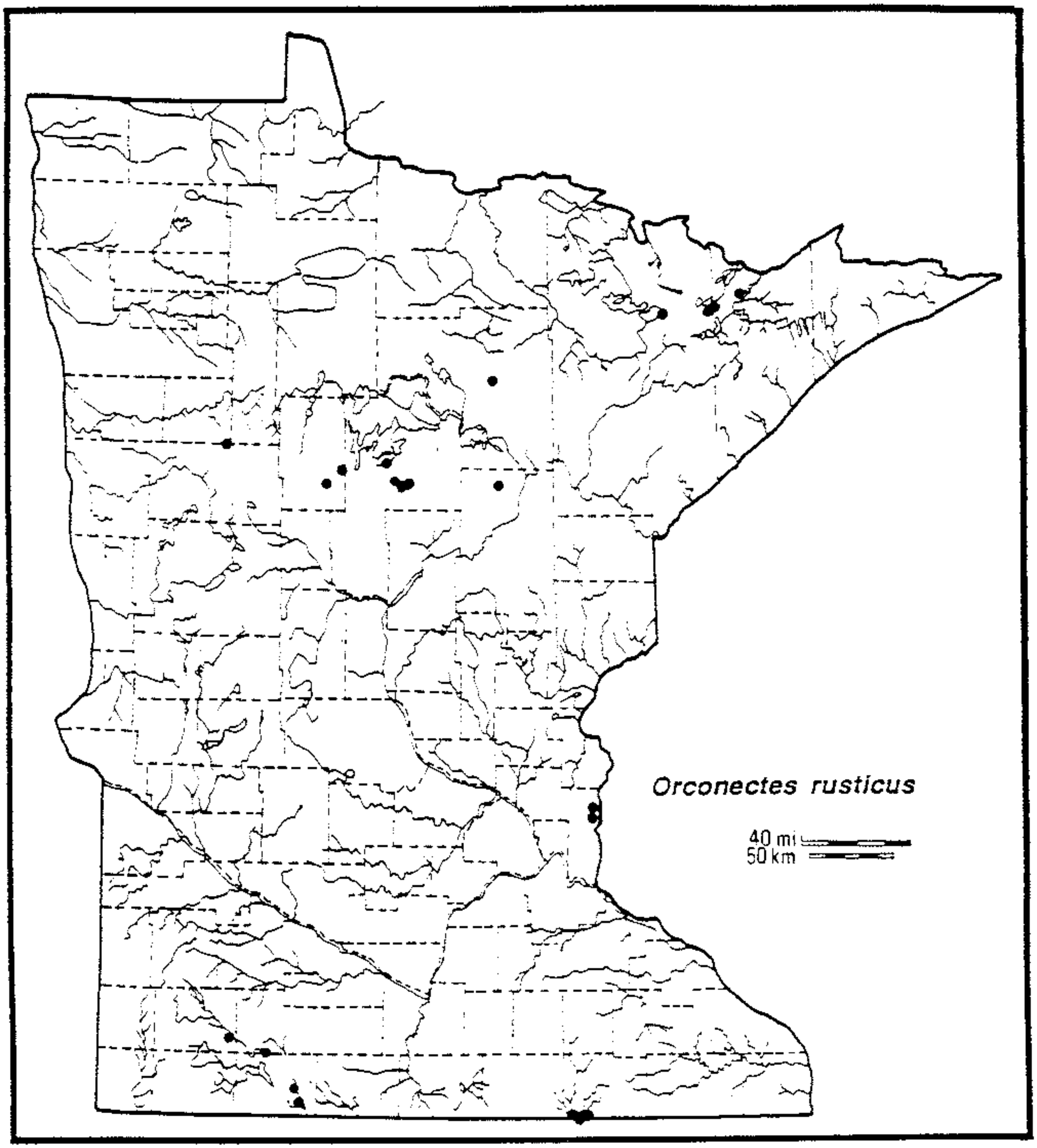


Figure 11. Distribution of Orconectes virilis in Minnesota.

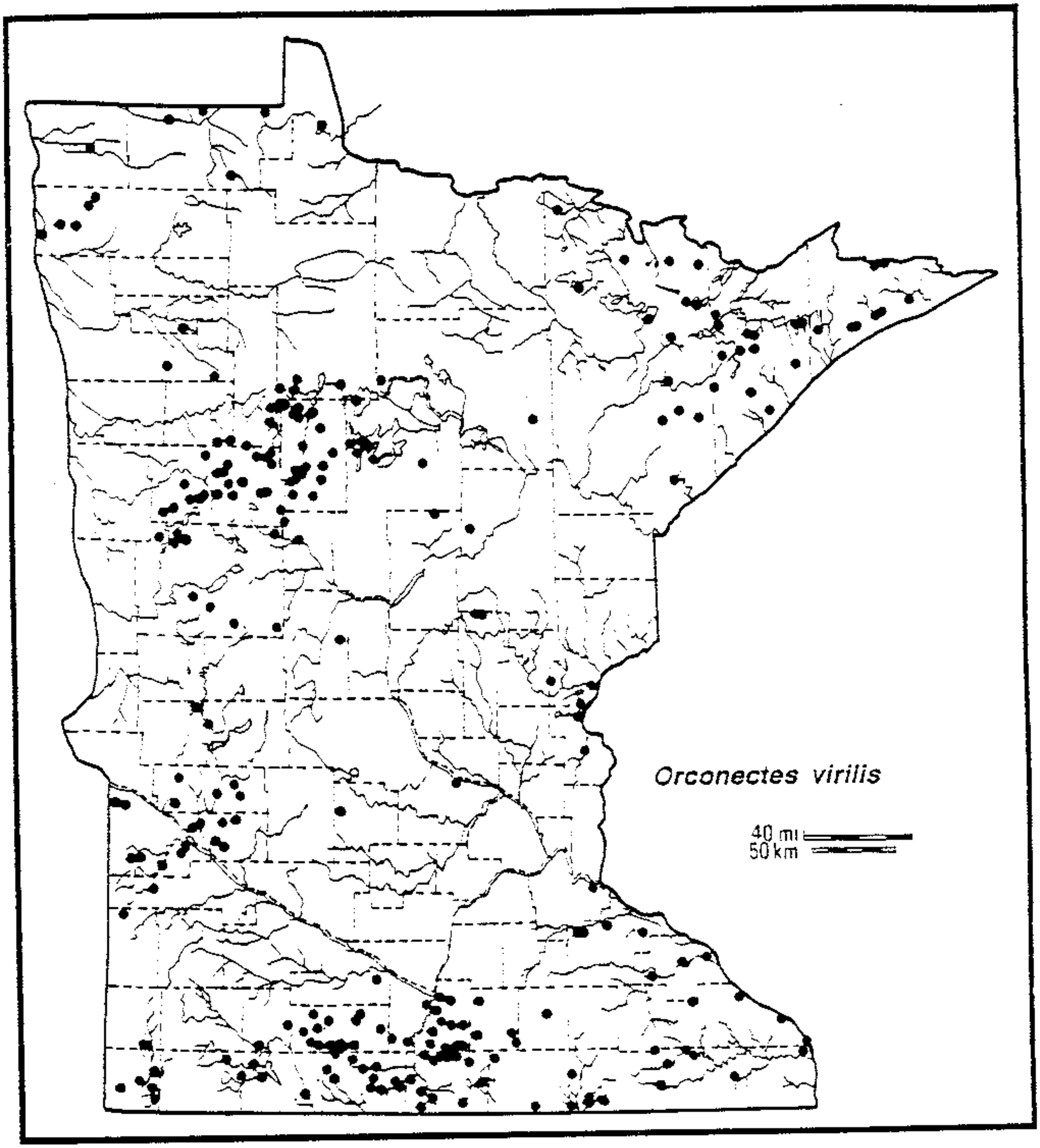
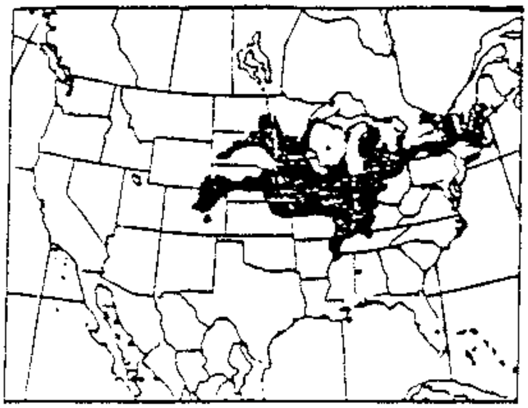
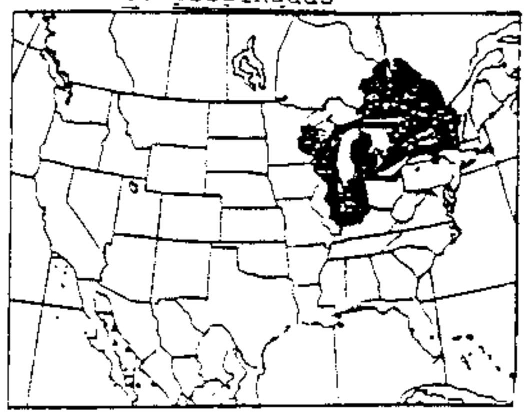


Figure 12. Previous range maps before addition of Minnesota crayfish survey constructed by Jass and Hobbs (see Fig. 13 for current range maps).

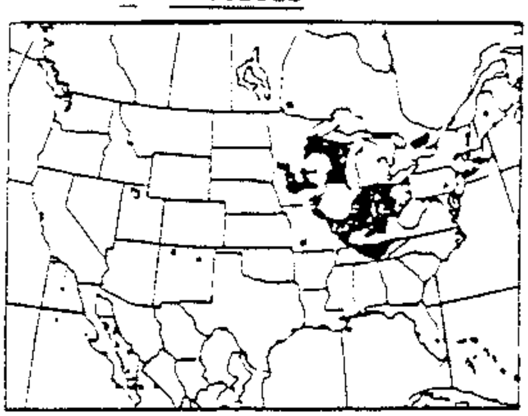
12a. _O. immunis_



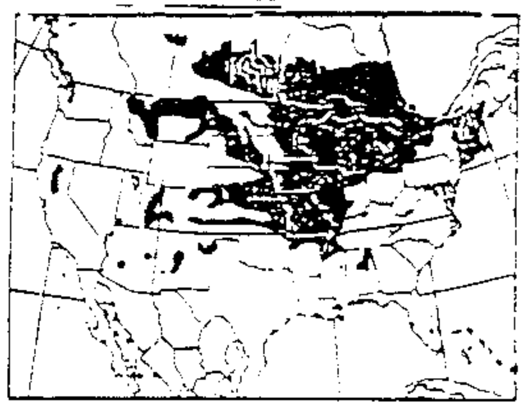
12b. _O. propinquus_



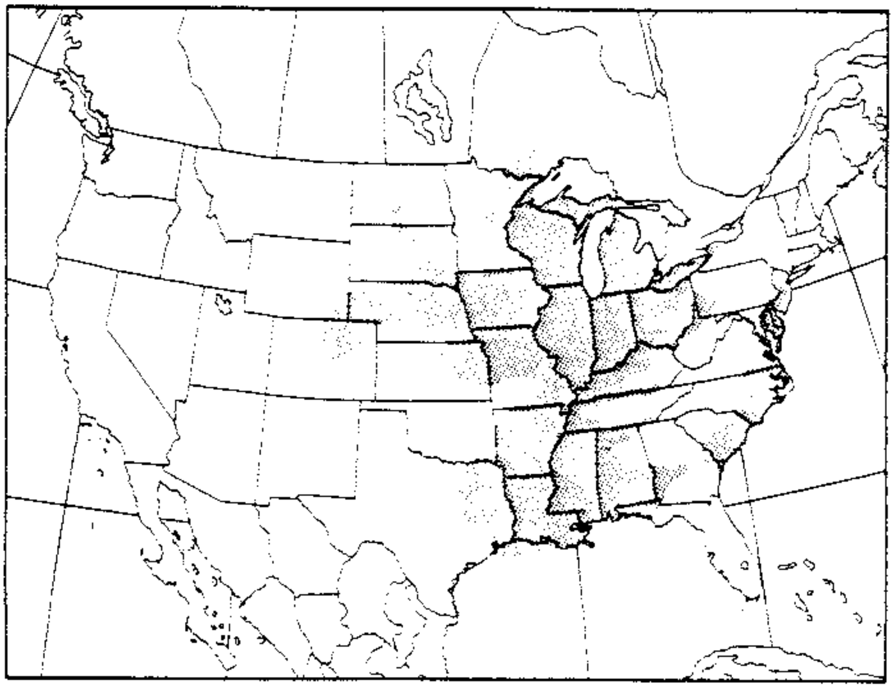
12c. _O. rusticus_



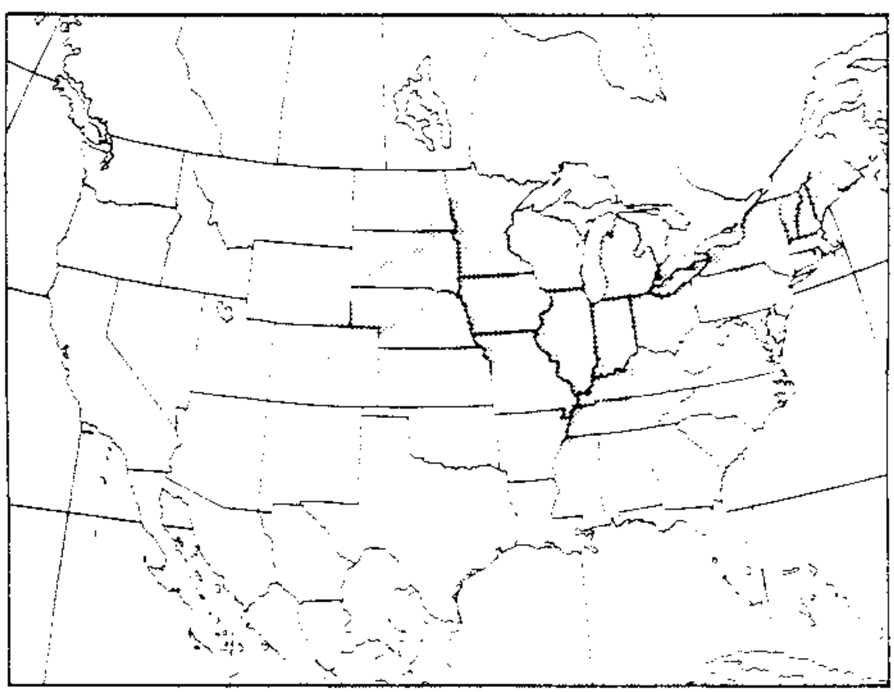
12d. _O. virilis_



Figures 13 a - f. Current U.S. range maps of crayfish after inclusion of the Minnesota survey, from Hobbs and Jass (1988, maps as of Nov., 1987).

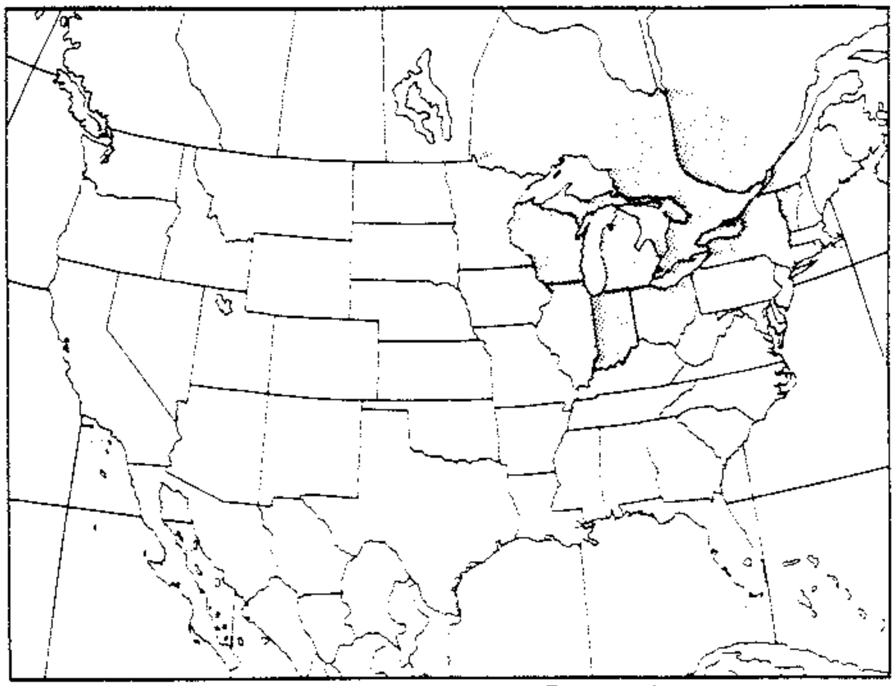


13a Geographic distribution of *Cambarus* (L.) *diogenes*.

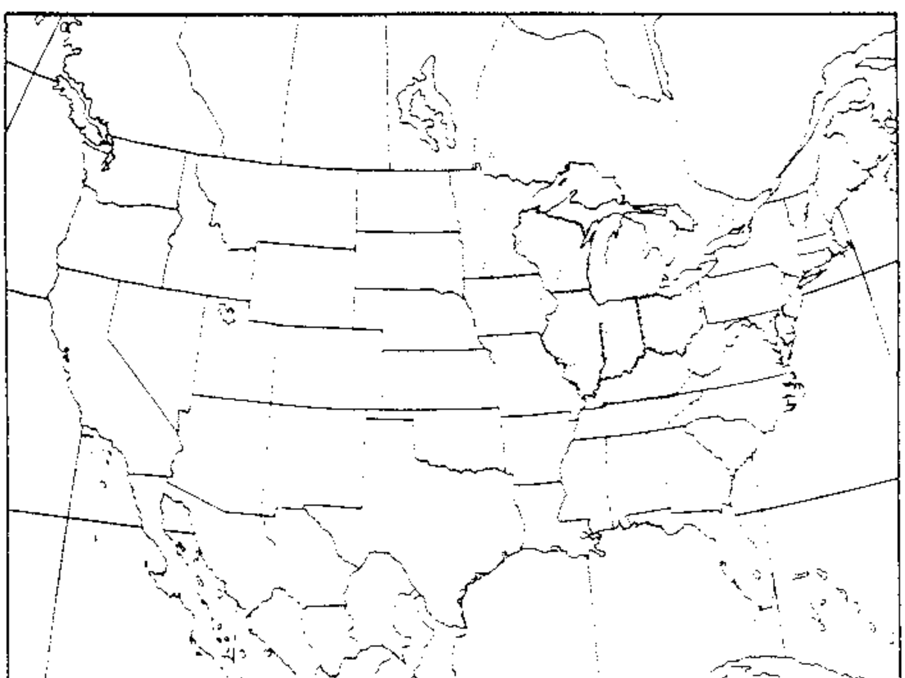


13b Geographic distribution of *Orconectes* (G.) *immunis*.

Figure 13 a - f (con)

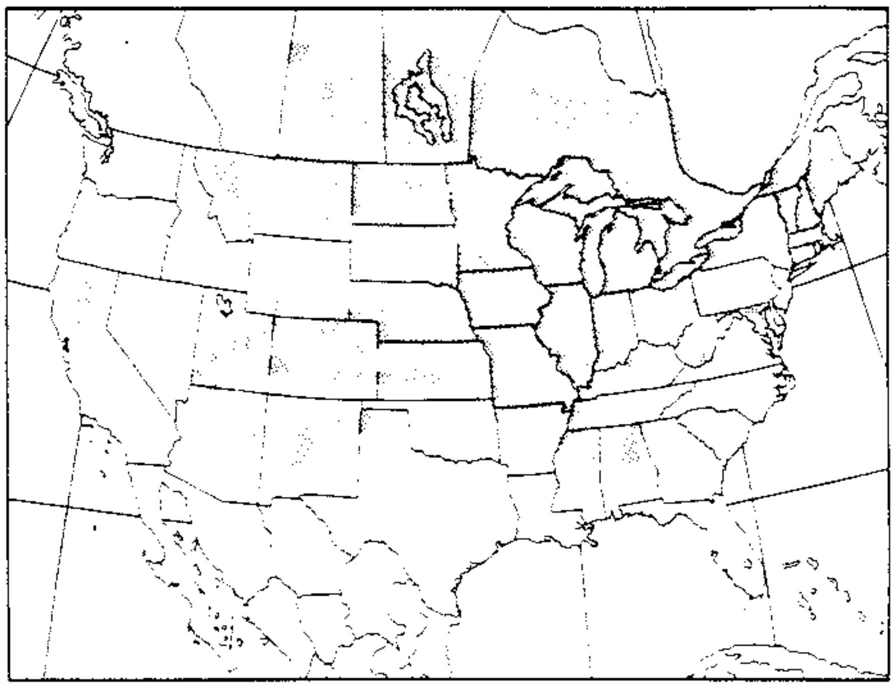


13c Geographic distribution of *Orconectes* (C.) *propinquus*.

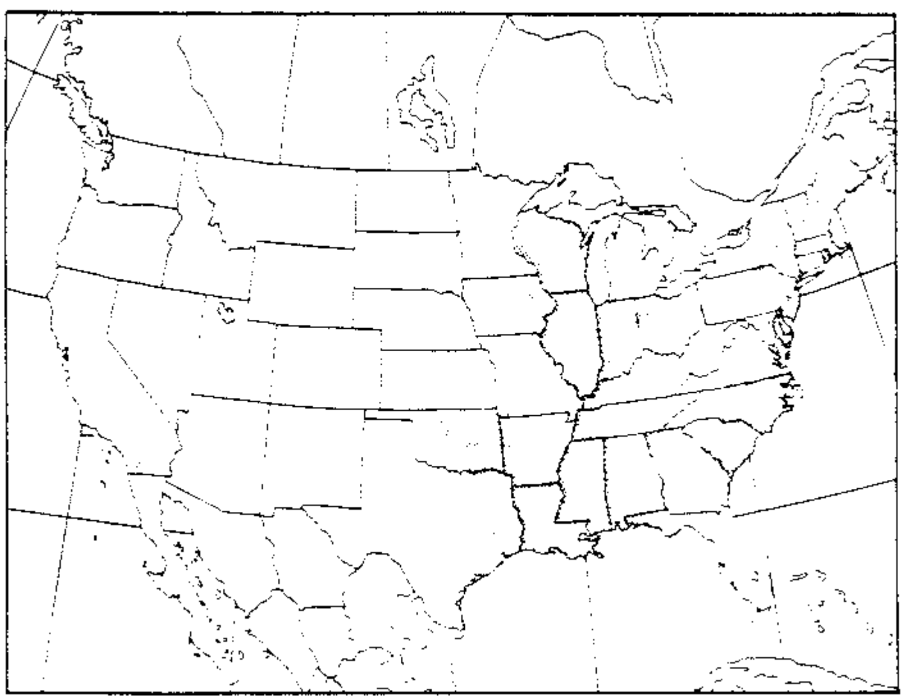


13d Geographic distribution of *Orconectes* (P.) *rusticus*.

Figure 13 a - f (con)



13e Geographic distribution of *Orconectes* (G.) *virilis* in North America.



13f Geographic distribution of *Procambarus* (O.) *acutus acutus*.

The *Orconectes rusticus* problem

The range of *O. rusticus* in the U.S. has previously centered in Michigan, Ohio, Indiana, Kentucky, Tennessee, southern Ontario and as introduced in Massachusetts (as reported in Hobbs 1974). The type locality described by Girard (1852) was the Ohio River at Cincinnati, Ohio, and it is common in the Ohio River drainage (Prins 1968). The range as of 1987-88 includes locations in Missouri, Iowa, Minnesota, New Mexico, New York, New Jersey, Pennsylvania, and all the New England states except Rhode Island (Fig. 13d; see also Hobbs and Jass, 1988). There were no certain records of *O. rusticus* before 1932 in Wisconsin (Creaser 1932), only *O. virilis* and *C. diogenes* were found in the lake district of Villas County. At least by 1970, *O. rusticus* was observed as abundant in northern Wisconsin (Capelli 1975 cited in Capelli 1982) lakes. Recently, Kent Van Horn (Wisconsin DNR, Woodruff, undated report) has reported an expansion of *O. rusticus* into lakes that did not contain *O. rusticus* in the report by Capelli and Magnuson (1983). The Van Horn report lists 46 lakes in three counties in northern Wisconsin that contain *O. rusticus* populations.

The first report of *O. rusticus* in Minnesota was by Phillips and Reis (1979) indicating its presence in very southern Minnesota, in the Des Moines and Cedar River drainages. The earliest record in the collection for Minnesota was in 1967 from Otter Creek, Lyle, Mower County in southern Minnesota. A concern was raised in 1982-1983 by Mark Ebbers, a Fisheries Specialist with the Minnesota DNR, about the "rusty crayfish". Aware of the potential for damage to aquatic vegetation and fisheries, Mr. Ebbers tried to initiate a survey of this species, but funding was unavailable at the time. The present survey indicates a fairly widespread distribution in Minnesota (Fig. 10), with locations in northeastern, north central, and southern Minnesota and in some of the St. Croix River tributaries.

There is no information on the dispersal route into Minnesota by *O. rusticus*, although it has clearly been extending its range. The distribution in southern Minnesota and along its eastern borders is expected because this crayfish has moved into most of Wisconsin and north central Iowa (Fig. 13d). The occurrence in the Detroit Lakes and Leech Lake regions is unexpected, as is that at

Ely and in the northeastern area of the state. To show that natural migrations are occurring, we need information on *O. rusticus* in Canada along the Minnesota border, and crayfish species found in the area running northwest of the St. Croix towards Leech Lake, including the Kettle and Snake River drainages.

There is no real information on human-caused dispersal of *O. rusticus* in Minnesota. Fisherman using crayfish as live bait have been implicated, but there is no data either on the extent of use of crayfish in northern and north central Minnesota (most fisherman use leeches and minnows), nor on the species of crayfish sold by live bait dealers in the state. *O. rusticus* has been shipped live by a biological supply house to a college biology department. A warning is now included not to release live specimens into the environment (Appendix IV). Capelli and Magnuson (1983) found in northern Wisconsin that only *O. rusticus* showed a significant correlation of abundance with human activities, where their index of human activities scaled houses, resorts and three qualities of public access to the lake.

The success of *O. rusticus* can be attributed to its greater aggressivity, its fecundity, its slip speed and its day activity. Intraspecific aggression in *O. rusticus* increases most when shelter sites are limited, and to a lesser extent when food is limited (Capelli and Hamilton 1984). Interspecific competition between *O. rusticus* and *O. virilis* or *O. propinquus* clearly showed *O. rusticus* outcompeting *O. virilis* for shelter sites, and *O. propinquus* almost as successful a competitor against *O. virilis*. These laboratory experiments are the basis for the concern that *O. rusticus* may displace our major native species, *O. virilis*.

Mating in *O. rusticus* occurs late in summer into fall and winter (see Hobbs and Jass 1988). A spring mating can occur as soon as the water warms to 4° C (Berrill and Arsenault 1982) and egg extrusion by females occurred at 6° and 12° C, usually in April or May in Wisconsin, close to the time of the ice thaw (Lorman 1980). *O. virilis* also mates primarily in the late summer and fall, the females extruding their eggs in late April or May when water temperatures are 10-15° C (see Hobbs and Jass 1988 for a summary of life history information). The fecundity of *O. rusticus* is great, and increases with the body size. Average ovarian egg counts of 276 and ranges of 54-357 have been reported (Hobbs and Jass 1988). In *O. virilis*, reported ovarian egg counts are lower, with averages of 162 and 214, and ranges of 92-156 (Hobbs and Jass 1988).

O. rusticus (and *O. propinquus*) can tolerate a faster current than can *O. virilis* (and *O. immunis*): the slip speeds of the former are 30-40 cm s^{-1}, the latter under 30 cm s^{-1} (Maude and Williams 1983). I find no literature, only conversational reports, on day-activitiy patterns *O. rusticus* in comparison with other species, so research on this would be worthwhile. The majority (60%) of aggressive encounters between *O. rusticus* in aquaria occurred at night, but this says nothing about comparative day activities, nor feeding times in the field.

The alarm raised over an "invasion" by *O. rusticus* is based on its potential for impact on lake vegetation, on eggs laid by fish, and for displacement of native species which may be less destructive. Known more as scavengers or detrivores, crayfish are actually excellent herbivores, capable of consuming aquatic macrophytes and terrestrial vegetation. Crayfish can control or reduce aquatic vegetation when the animals are at a threshold density (>69g m^{-2}) but these densities were not natural (Flint and Goldman 1975). There was an anecdotal report of the clogging of canals in Holland after the crayfish plague hit Europe, and a documented reduction in macrophytes by a dense population of *Astacus astacus* in Sweden, followed by a sharp increase in vegetation after the disease eliminated the crayfish there (Abrahamsson 1966). In New Mexico, *O. causeyi* caused a progressive decline of aquatic vegetation in three small lakes over a period of five years (Dean 1969). In another study, fish culture ponds with dense populations of crayfish lacked any vegetation, while those ponds that were vegetated had few crayfish (Rickett 1974).

O. rusticus has been reported to reduce macrophytes in Long Lake in Wisconsin by observation of associations of low macrophyte densities with high crayfish densities, and vice versa (Magnuson et al. 1975). In experiments with *O. rusticus* in enclosures, macrophyte densities were significantly reduced relative to exclosure densities in Upper Sugarbush Lake in Wisconsin (Lodge and Lorman 1987). Some of the observed reduction was the result of clipping of stems which causes the plant material to float out of the crayfishes' reach. Crayfish damage may be greater on single-stemmed plants than on rosulate species, and probably greater damage would be expected to occur in submergent than in emergent macrophytes, perhaps largely because of harder stems in the emergent plants. Wild rice plants are most susceptible in the pre-emergent stage (see section on wild rice). I have received no reports on *O. rusticus* impact on natural lake or pond vegetation in Minnesota, but the potential for impact in Minnesota has not been assessed.

The impact of *O. rusticus* on fisheries, particularly on eggs or spawning beds of fish, is not well documented in the scientific literature, although crayfish will consume fish eggs when presented them, and they are strongly suspected to prey on fish eggs in nature (see Magnuson et al. 1975). Some Wisconsin DNR personnel note losses of weed beds and walleye reproduction as in Lake Metonga, but other lakes with *O. rusticus* continue to have walleye reproduction. Lake substrate, such as an abundance of rugged rubble, may be important in this connection. It may allow walleye eggs to escape predation. The crayfish may be more concentrated in a rocky substrate area and if this is limited in the lake, and if the rubble is the preferred spawning habitat for walleye, there could be localized impact. This certainly merits research. It is expected that walleye and other species of fish that do not protect their eggs may be more susceptible to crayfish predation. I know of no information whether crayfish will consume the strings of yellow perch eggs. Certainly there may be profound indirect effects on centrachids by the destruction of the macrophyte beds. Whether *O. rusticus* (or other crayfish) may directly prey on bass and panfish nesting sites is, I believe, not yet documented in field situations. Native crayfish consumed trout eggs in enclosure studies on rocky and bare substrates (Horn and Magnuson 1981).

It is unknown yet whether *O. rusticus* is replacing native crayfish species in Minnesota, partly because of a lack of previous records for lakes where they are now dominant. Certainly, in Wisconsin they have replaced native species (Capelli and Magnuson 1983) as well as in other areas (see Butler and Stein 1985 for other citations). Two recent works discuss the hypothesis that competitive exclusion by *O. rusticus* on the native species would cause displacement of the native type, and in both works alternative causes for replacement are considered more important. In Ohio, *O. rusticus* is replacing *O. sanborni*, probably because of the greater reproductive success of *O. rusticus* with more gravid females, more eggs, a more rapid growth rate in *O. rusticus* young of the year (YOY), and better YOY survival when predators are present and shelters limiting (Butler and Stein 1985).

In Wisconsin *O. rusticus* can displace *O. virilis* or *O. propinguus* in some lakes, while in others it may remain at a certain percentage over many years. In Trout Lake, *O. propinquus* was dominant in 1973, then *O. virilis* increased greatly. In the late '70's, *O. rusticus* entered Trout Lake and by 1983 it was found in low percentages in just 2 of 13 sampling areas (Lodge and Kratz 1986). The competition hypothesis doesn't apply here, because *O. propinquus* wins more aggressive interactions than *O. virilis*. The authors speculate the smaller size of *O. propinquus* makes it more susceptible to predation by smallmouth bass. John Quinn (1987 ASLO presentation) suggested *O. virilis* young, similar in size to *O. propinquus* adults, are more susceptible to perch predation and more likely to be displaced from shelter sites. *O. virilis* compensates with greater fecundity.

While hybridization among species of crayfish is considered rare, it has occurred between *O. rusticus* and *O. limosus* in nature (Smith 1981), between *O. rusticus* and *O. propinquus* in the lab (Berrill 1980) and in streams in southern Ontario (Berrill, pers comm 1986). A few of the lab-induced hybrids were raised to sexual maturity (Berrill, pers comm 1986). There is a possibility *O. rusticus* females attract males of other species: males of *O. sanborni* (Butler and Stein 1985), and of *O. propinquus* (Tierney and Dunham 1984) will mate with *O. rusticus* females. *O rusticus* males mate predominantly with their own species. If hybrids form, one would expect invading *O. rusticus* to show characteristics of the native population.

One hypothesis for reproductive isolation among crayfish suggests that chemical detection among species that have co-existed for long periods of time is developed so there is species recognition and correct mate selection. Species that haven't co-existed may lack strong "chemoethological" isolating mechanisms, resulting in incorrect mate selection and possible hybridization (see Tierney and Dunham 1982, 1984, Butler and Stein 1985). More research could be done in this area.

Regulation of Crayfish usage

I would propose that Minnesota move fairly quickly to impose a ban on the sale of live crayfish and on the transport and introduction of live crayfish within the state. Bait dealers should be required to list the live species they sell, and required not to sell *O. rusticus*. It should be illegal to transport or plant *O. rusticus* into natural or artificial ponds, i.e., it should not be farmed for sale. Whether *O. rusticus* harvest should be allowed in a regulated way from a designated list of already infested lakes should be discussed. There are people interested in harvest and export.

If a system is set up for export of crayfish, the temptation to move the *O. rusticus* to ponds or lakes to "seed" them will increase. There should be a set of regulations in place before this might happen. Whether such regulations will control the expansion of *O. rusticus* is an open question, but there should be an attempt to check any human-caused spread of this crayfish.

Regulations in Wisconsin, in effect since January 1, 1983 banned the possession of live crayfish "while on any inland water of the state, except the Mississippi River", and the deposition or introduction of any live crayfish into any water in the state (from a letter by James Addis, December 7, 1982, Director of Wiconsin Bureau of Fish Management). The information on the ban was sent to all Wisconsin biological supply houses. Apparently, the ban of possession of live crayfish on inland waters is not very enforceable, because it is allowable to remove crayfish from inland waters under other regulations. Clearly an analysis of the Wisconsin regulations and their usefulness will be helpful in formulating any regulations for Minnesota. The difficult areas for regulation, if any, will be on the harvest or removal of crayfish from natural or artificial waters. Restrictions on use for fish bait, on aquaculture of *O. rusticus*, and on transport and introductions should be more straightforward. Now that we know *O. rusticus* is definitely in Minnesota, regulations on crayfish uses need to be considered, composed and enacted.

The potential impact of crayfish on wild rice (*Zizania palustris*) and comments on crayfish herbivory

As discussed in the section on the *O. rusticus* problem, crayfish can be herbivorous. They have been observed to destroy littoral zone macrophytes in lakes, and may reduce macrophyte species richness. An impact on vegetation may be the major effect of crayfish in aquatic systems. The loss of crayfish by disease has caused dramatic increases in pond vegetation (Abrahamsson 1966). In a study on crayfish feeding preferences, Lodge found greatest preference for *Potamogeton gramineus, P. zosteriformis, Elodea canadensis*, less preference for *Ceratophyllum demersum, Megalodonta beckii, Myriophyllum exalbescens, P. amlifolius, P. richardsonii, P. robinsii*, and *Vallisneria americana*, and lowest preference for *Eleocharis acicularis, Gratiola lutea, Isoetes* sp., and *Lobelia dortmanna* (D. Lodge, unpublished Ph.D. research by pers comm). Tests on wild rice, *Zizania palustris*, were not made. Analysis of plant tissue content was expected to show crayfish preferring macrophytes of greater protein content, but surprisingly, Lodge found they preferred plants of higher cellulose content. Cellulose-digesting abilities have not been demonstrated, but a search for native cellulase enzymes or a microbial flora assisting in the process could be interesting.

It is surprising, in a way, that crayfish can consume wild rice plants. The emergent character, the rigid but hollow and non-woody stem, and the possibility that anti-herbivore silica bodies may be present in *Zizania palustris* leaves make it seem potentially undesirable. However, our native wild rice, in contrast to the endangered perennial *Z. texana*, is an annual, reseeding itself every year. The germinating seed puts out a corkscrew root that pulls the seed down into the preferred mud substrate (Mel Duvall, U. MN., pers comm). A typical pattern of development in Minnesota from day of germination is 12 days to emergence under water of roots and the first leaves, 29 days to the floating leaf stage where waxy-surface floatable leaves have been generated, and 39 days to the aerial leaf stage of emergence out of the water (Oelke et al, 1982). This could be early or mid June, depending on water tempeartures. Although there has been no direct study, it appears the young seedlings are most susceptible to crayfish herbivory in the spring before the plants are fully emergent or "aerial".

At present, damage to wild rice plants is known to occur in Aitkin County, in cultivated rice paddies, primarily those of George Shetka. There is no evidence yet of damage to wild rice by crayfish in natural wild rice stands, but this has not been researched. Crayfish were not found below Big Elbow Lake in Little Bemidji, Many Point and Round Lake. These are positioned between the *O. rusticus* dominated Big Elbow Lake and natural wild rice lakes in the Otter Tail River drainage (Dwight Wilcox 1987 survey by minnow traps, White Earth Indian Reservation). However, the lakes below these, Little Flat, Chippewa, Blackbird, Rice, Height of Land, and Hubbel Pond could be checked, as presumably these are in natural ricing areas.

The local destruction of wild rice by crayfish in cultivated wild rice paddies can be extensive where very dense populations of crayfish, predominantly *O. immunis* with a few *Cambarus d. diogenes* develop (collections by Scott Walker, St. Olaf College). *O. immunis* cuts the leaves, so areas of damage show floating masses of cut leaves, and the area of plant destruction becomes more and more an open water area, until the rice production of a substantial area is lost. *O. immunis* prefers mud or clay-bottomed ponds, is able to burrow when the water drops, and tolerates lower O_2 levels than, say *O. virilis*. Almost no *O. virilis* were collected in the rice paddies, nor does it build chimneys or burrow, so it is quite likely the report of *O. virilis* as a pest in rice paddies was actually *O. immunis* (Oelke et al. 1982, p. 26 describing *O. virilis* activities in wild rice fields).

There is a need for non-lethal crayfish control in the areas of impact. Uses of pesticides have caused massive die-offs of crayfish, and also apparent mortalities of birds such as blue herons (anecdotal information). The problem is perhaps built into the system of wild rice cultivation, that is, shallow water (6-14") is preferred to reduce competition from other plants and weeds, including aquatic plants, and the water is typically drained off each year 2-3 weeks before harvest (Oelke et al 1982). The critical time for a water level of at least 6" depth is the first 8-10 weeks, thereafter the level can drop. This means that important predators of juvenile YOY crayfish, such as fish, will not be present.

The major difference between the shallow cultivated rice paddies and the natural lake and river stands is undoubtedly the absence of predators in cultivation habitats. This needs assessment, as one rice paddy area with no crayfish damage had young bowfin, *Amia culva*, present, but whether fish of a size that could prey on and control young crayfish were present is unknown. It is known that bowfin can consume crayfish, and these are recommended here as one possible non-lethal control. *Amia culva* can tolerate extremely low oxygen levels, because of its retention of the pharyngeal connection to the air bladder. A pilot project using this ancient nongame fish for juvenile crayfish control could be valuable.

The possibility of co-culturing crayfish in rice paddies and harvesting the crayfish as a product has been suggested. However the crayfish could eliminate the rice crop. Another suggested was that crayfish consumption of wild rice might be useful during a time of change of seed variety, e.g., from shattering to non-shattering varieties. Two to three years of allowing endemic seeds to germinate and cutting down the plants before they can produce seed is necessary before a new type of rice can be planted. I strongly recommend against the introduction of crayfish into wild rice paddies. Once they are established, they would be difficult, if impossible, to remove.

Crayfish as a potential product

There is a market in Scandinavia for crayfish where the crustaceans are consumed in quantity in festive dinners late in the summer. There are aparently special tools for dissection of the abdominal and chela meats which are carefully piled on slices of fresh French bread. The whole crayfish bring a high price. After the crayfish plague eliminated most native crayfish, the Swedish people have been importing crayfish from Turkey, but now this source has dwindled. The taste of northern U.S. species is preferred over the southern Louisiana species, so contacts are being made here for export of crayfish to Sweden where the crayfish are prepared by special recipes with dill before they are marketed. The market opens August 12 and the crayfish must be a minimum size of 3 1/2" total length. A typical single shipment for export to Sweden should be around 2,000 pounds. The Swedish business people could import 300-600 tons of crayfish annually for their markets.

In a recent teleconference set up by the Minnesota Sea Grant Office (November 1987), when I suggested aquaculture of *O. immunis* as a possibility, a food science professor and consultant from Cornell University said it is not economically feasible unless "polyculture" with fish was carried out, and that the Swedish business people are looking for harvest of wild populations in the upper Midwest. The potential for impact on natural populations and for indirect effects on predators like perch and bass which forage heavily on crayfish must be explored.

There is very little information on available crayfish biomass by age (or size) of crayfish in habitats comparable to those in Minnesota. In Momot's work on production of *Orconectes virilis* in two small lakes near Thunder Bay, Ontario (Momot 1986), an estimated range of 300-800 age 2 males, and 300-1300 age 2 females was available in Dock Lake (1.2 ha) over 1977-1984. The numbers of age 3 animals were always low, under 100 per lake in any year, and numbers of age 1 were higher than age 2. While data on weight by age group are not given, estimates of total (ages 1, 2, 3 combined) biomass by year range from 0.6 kg to 22.44 kg males. In the most productive year, 1984, female plus male biomass was estimated at 36.2 kg. A ton of crayfish would weigh

907.2 kg. Clearly, even if all size ranges were to be harvested to produce one 2,000 pound shipment, many lakes would have to be harvested. Then consider the low numbers of age 3 *O. virilis* present (less than 100 per lake), and the undetermined percentage of the biomass (certainly less than 1/3 of the total) they represent, and the number of lakes to be harvested increases. If there were 12 kg biomass of age 3 crayfish per lake, then all of the age 3 crayfish would have to be harvested from 76 lakes to attain a shipment. But trapping captures a range of percentages of the available age 3 crayfish (0-100%) in each year (Momot 1986). In addition, trapping is biased in favor of males, so female crayfish may not be as "available" for harvest. Finally, if predators are present, even fewer crayfish will be harvested because crayfish trapability can decline when predators are present (Collins et al 1983). These speculative estimates are based on harvesting 36 kg of crayfish, the mean annual production in Dock Lake (1.2 ha). Estimates of standing crop of *O. virilis* in other lakes range from 46-226 kg/ha (see Momot, Gowing and Jones 1978), but these are from northern Michigan and Massachusetts. Interestingly, estimates of *O. immunis* standing crop ranges higher, to 345 and 909 kg/ha in southern Michigan. In another report, Jones and Momot (1981) class "large" adult *O. virilis* as 10-15 g wet weight. If 15 g sized adult *O. virilis* were harvested, a one ton shipment would consist of over 60,000 crayfish. Clearly, more information on the density and biomass of "exportable" ($\geq$ 3 1/2") sizes of crayfish is needed, as well as estimates on the impact of regular removal.

According to Momot (1986, p. 154),

> "The absence of dramatic density dependent compensation in growth combined with a limited fecundity response inhibits the detection of growth overfishing in crayfish populations at northern latitudes. As a result, populations could easily be exploited to the recruitment overfishing stage. Such populations...could undergo unpredictable stock reductions...."

One needs to consider the role of crayfish as a forage for perch, bass and other fish, and the fact that crayfish would not be managed or restocked as sport fish are. Crayfish have been called a keystone predator by some and may play an integral role in the healthy aquatic system. While I would recommend attempts at shallow-pond aquaculture of *O. immunis* (but <u>not</u> of *O.*

rusticus), I do not recommend large-scale harvesing of wild populations of crayfish in Minnesota until we know the impact. Whether local regulated harvesting of designated lakes infested with *O. rusticus* would be ecologically sound and economically feasible should be explored.

TERMS

Annulus ventralis: Female's sperm receptacle location on ventral surface between last two pairs of walking legs (or pereiopods). A blind pitted and grooved structure where sperm plug attaches after copulation and before the female release the eggs. Also called seminal receptacle. Tends to be flatter and less defined in young females, grooves and pits deepen, knobs enlarge in larger females.

Antennal scale: Lateral blade-like scales, one at each antennal base.

Anterior: Towards the head end or front, away from the tail end.

Areola: An area on the lengthwise middle of the dorsal surface of the carapace bounded by edges of the carapace which mark the limits of the gill chambers. In a "closed" areola the edges lie together. Sometimes the length of the areola in relation to carapace length is important. Pits called punctae are seen in the areola area.

Basal: At the base, near the base.

Carapace: The exoskeletal covering of the anterior part of the crayfish, or cephalothorax (head-thorax) as distinct from the abdomen.

Carina: A dorsal raised ridge along a medial or central surface line of the rostrum.

Central projection or process: In a gonopod with its two processes, the central projection lies dorsal-laterally to the mesial process or projection. This process shows the most extensive orangish cornification characteristic of sexually mature males. Sometimes longer than the mesial process. Contains the sperm canal, helps guide sperm to the female's annulus ventralis during mating. See also mesial process.

Cervical groove: A diagonal lateral groove that marks the separation of the head region (cephalic) from the more posterior thoracic region.

Chela: The grasping claw, composed of a movable dactyl and main chela (or propodus).

Dactyl: In the chela, the movable part of the chela, like a "thumb". Can be excised or sinuous or straight.

Distal: Located away from the body, towards the free end of a structure.

Dorsal: On the upper or back side.

Excised: Cut away, making a curved indentation.

Gonopod: The male structures for sperm transfer to the female. Also called the copulatory stylet. Located ventrally posterior to the last walking legs. The gonopod is a modified abdominal appendage (or pleopod).

Lateral: Located on the side, or viewed from the side rather than from the midline.

Lateral rostral spines: Two lateral spines located at the base of the tip of the rostrum, one to each side of the rostrum.

Mandible: The pair of very hard cutting mouth parts, usually solid white with clear sclerotized tan cutting edges.

Median: On the midline, usually lengthwise.

Mesial process: The process of the male's gonopod located more ventrally and more towards the midline. See also central process.

Posterior: Towards the tail end, away from the head.

Protuberance: A raised mound or knob.

Proximal: Towards the body, the basal end, as opposed to distal.

Punctae: Small pits in the exoskeleton that look like dots. Some occur in the areola.

Rostrum: The anteriormost dorsal extension of the carapace, partly covers eyestalks. The foremost tip and the two corners of the lateral base may carry spines.

Seminal receptacle: See annulus ventralis.

Sinuous: "S" shaped. The more sinuous the dactyl, the greater the gap between the dactyl and the main chela.

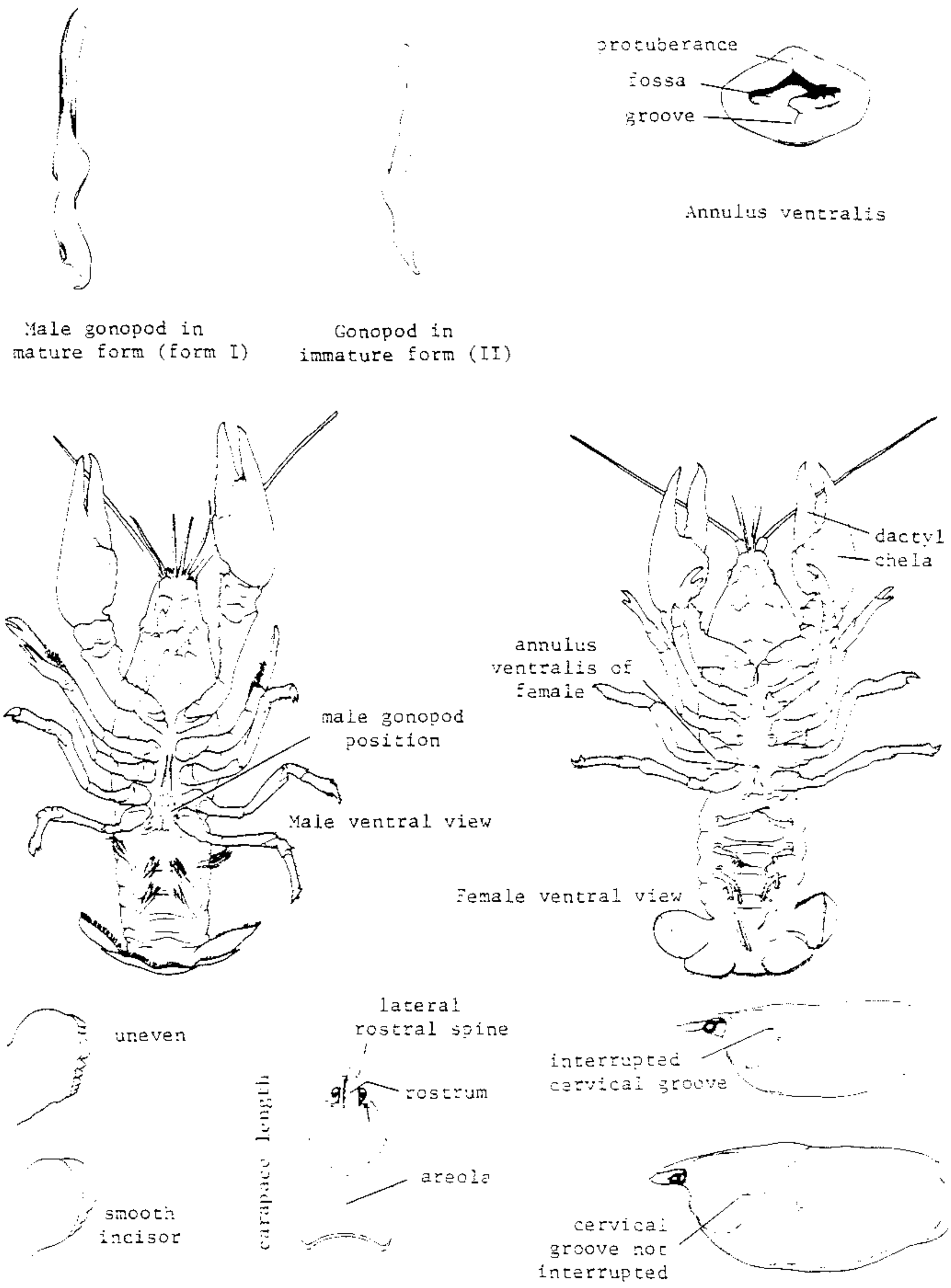
Spatulate: In the mesial process of the male gonopod, a distal widening into a spoon-like or cupped spatula shape.

Suborbital projection: An angular forward pointing projection of the edge of the carapace just below the eye.

Truncate: Appearing as if cut off abruptly at the end, either squared or at an angle, as opposed to tapering to an acute point.

Ventral: On the underside or surface below and away from the body. i.e., on the "stomach" side as opposed to the back side.

Figure 20. Structures useful in identification of crayfish



TWO KEYS TO MINNESOTA CRAYFISH

Introduction

To understand the terminology used in the keys, refer to the diagram (Fig. 20) and the glossary of terms. It is important to be aware these keys work only for the selected species found so far in Minnesota, and it is possible more species are present than reported here. Therefore, the more serious taxonomist should use the keys in Hobbs and Jass (1988), and also Hobbs (1976), Crocker and Barr (1968), and other literature listed in the bibliography. In the work by Hobbs and Jass (1988), the only additional crayfish found in Wisconsin is *Procambarus gracilis* and only in the extreme southeast of the state.

Two keys are presented, one based on sexually mature males, the other on other features. The use of sexually mature males is preferred not just because the taxonomic literature is based on them, but also because the structures are species-specific. Males are sexually mature when the gonopods are most highly cornified and developed. The cornified processes take on an orange-brown color. Unfortunately, males are in the sexually mature form only during the reproductive season, and they molt back to an immature form after that. Therefore, outside the breeding season, such as midsummer, one can find large males with immature gonopods. See Hobbs and Jass (1988) for data on reproductive seasons for each species. Generally males will be mature in fall and spring.

The annulus ventralis of the female is also species specific, and is sometimes useful in immature females, although its features become more distinct, i.e., knobs or protuberances are more elevated, depressions more deeply pitted, grooves more deeply cut, as the female grows. The annulus ventralis is especially characteristic or distinct in *O. immunis* where it is very asymmetrical in a lateral direction, with the major pit or depression displaced to her right usually. The annulus is usually wider than long. In *O. rusticus*, the anterior or upper knobs or protrusions above the depression become larger as the females grow. This pair of protruding knobs is a distinct feature of *O. rusticus*. The annulus of *O. virilis* is also distinct, with the major pit or depression usually just to the right of the midline. In both *O. immunis* and *O. virilis* one occasionally sees the annulus reversed. For more information on the use of the annulus as a taxonomic feature, see Tierney (1982). The annulus ventralis is characteristic, but not as useful in *C. diogenes*, *O. propinquus* and *P. acutus*.

The areola is useful in distinguishing *Cambarus d. diogenes* from other species, as it is closed along its midline, whereas in the other 5 species it has a definite width. The narrowness of the areola in *O. virilis* is a distinctive feature, as is the wide areola of *O. propinquus*. The pattern of the areola in *O. immunis* is distinct, with a widening out in the lower half of its areola.

The chela varies a great deal in size and shape between females and especially in large mature males, so some caution is advised on using chela characters. However, the basal excision of the dactyl in *O. immunis* is a distinct character. *C. d. diogenes* in Minnesota usually have an excision or broad concavity in the basal half, but the chela is distinctly more robust than that of *O. immunis*. The dactyls of *P. acutus acutus* can have a minor excision, but the chela is distinctly elongated and more delicate in appearance than that of *O. immunis*.

Black color bands can be seen on the tips of the chela of *O. rusticus* and *O. propinquus*, but these do not show clearly in all specimens sometimes because of an overall blackish color in *O. rusticus*, but not always. Sometimes the bands are just absent.

The rusty or reddish lateral spots on the posterior sides of the carapace are characteristic of *O. rusticus*. These can be obscured by blackish body color, or not present. The spots are particularly evident in specimens from the lakes in Northern and central Minnesota, they are obscured by the dark coloration in ones from the drainage to the St. Croix River, and were not evident in the brownish *O. rusticus* from the drainage of the West Fork of the Des Moines River.

Key to Minnesota crayfish based on sexually mature males

(This key is valid only for this subset of crayfish)

Refer to the figures given with individual species descriptions which follow this key, and to the general crayfish diagram and definitions of terms which precede it.

1.a. Gonopod with two processes only, the central and mesial processes........................ 2

1.b. Gonopod with more than two processes. Processes are very short. See Figures 6, 19b, c. Chela long, tapered, chela well over 3 times as long as wide (Figs. 6, 19a, d). Basal area of dactyl bends in towards main chela.

Procambarus acutus acutus (Fig. 6)

2.a. Gonopod central and mesial processes short, thick, projecting at about a 90° angle ventrally from the main shaft (Figs. 1, 14a, b). Central process blade-like. Mesial process a conical mound ending in a narrow rounded tip. Areola closed along midline (Fig. 14g). Cervical groove on side of carapace is continuous, carapace has triangular suborbital projection (Figs. 14e, g).

Cambarus diogenes diogenes (Fig. 1)

2.b. Gonopod otherwise 3

3.a. Central process curves ventrally, central and mesial processes do not appear as two short straight processes. Medial carina never present 4

3.b. Central and mesial processes straight, short, stout in appearance (Figs. 3, 16d, e). Mesial process can be acutely tapered or truncate at tip, but not curved and stout. Medial rostral carina usually present (Fig. 16b). May be difficult to see, try feeling with a probe. Black usually present on chela tips (Fig. 16c).

Orconectes propinquus (Fig. 3)

4.a. Central and mesial processes curve ventrally fairly evenly over length, look graceful (Figs. 5, 18b). Mandible anterior main blade usually not smooth edged. Areola very narrow.

Orconectes virilis (Fig. 5)

4.b. Central and mesial processes curve abruptly near the distal end (Figs. 2, 15b, c), processes more stout in appearance than the grace of *O. virilis*. Clear excision present in the dactyl of the chela (Figs. 2, 15e, f). Mandible main blade not smooth-edged.

Orconectes immunis (Fig. 2)

4.c. Mesial process tends to curve back towards the central process, or be almost parallel to it (Figs. 4, 17c, d). Processes thinner, more like those of *O. virilis* in size but not curvature. Mandible main blade smooth-edged. Large rusty or red-colored spot may be visible on the lateral posterior side of the carapace (Fig. 17h). Chela may be definitely tipped with black (Figs. 17e, f).

Orconectes rusticus (Fig. 4)

Key to Minnesota crayfish when mature males are lacking

(This key is valid only for this subset of crayfish)

Refer to figures given with individual species descriptions which follow this key, and to the general crayfish diagram and definitions of terms which precede it.

1.a. Areola closed along midline, lateral cervical carapace groove a continuous line (Figs. 1, 14g), chela may be excised (Figs. 1, 14f). Lacks lateral rostral spines. Triangular suborbital projection present.

Cambarus diogenes diogenes (Fig. 1)

1.b. Areola open all along midline 2

2.a. Chela with dactyl definitely excised, female annulus ventralis very asymmetric laterally (Figs. 2, 15a), usually with the major pit or depression to her right. Annulus wider than long. Areola narrowest part in upper or anterior part, areola broadening out in lower or posterior half. Lateral rostral spines reduced or absent. Chela length to width ratio well under 3.0 (Figs. 2, 15e, f).

Orconectes immunis (Fig. 2)

2.b. Dactyl of chela not excised, may be sinuous in shape or not. If dactyl excised, it is a minor excision in a very narrow chela 3

3.a. Chela elongated, narrow, delicate in appearance, with chela length to width ratio well over 3.0 (Figs. 6, 19a). Basal area of dactyl bends towards chela, dactyl may have a minor excision. Female annulus not well characterized (Figs. 19b, c). More MN specimens are needed. Largest protuberance to female's right of fossa or depression, which may lie just posterior to the midline.

Procambarus acutus acutus (Fig. 6)

3.b. Chela otherwise, may have black tips or not 4

4.a. Female annulus has strongest two protuberances on upper or anterior end above the depression, these are especially large in larger females, with a deep medial fissure (Figs. 4, 17a, b). Rostral media carina never present. Mandible main blade usually smooth-edged, a single curved blade. May have red or rust- colored 1/4" spots on the posterior lateral sides of the carapace (Fig. 17h). Chela may be definitely black-tipped or banded (Figs. 17e, f). *Orconectes rusticus* (Fig. 4)

4.b. Female annulus ventralis not as in 4.a. 5

5.a. Median carina on rostrum usually present, though may be hard to see (Figs. 3, 16b). Try feeling with a probe. Sometimes may not be present, but is a diagnostic feature. Areola wide. Chela may be black-tipped (Figs. 16c, g). No rust or red spots on sides of carapace. Mandible main blade uneven. Female annulus ventralis more shallow, not as distinct as in *O. virilis* (Figs. 3, 16a).

Orconectes propinquus (Fig. 3)

5.b. Median carina never present. Areola narrow, allowing just 1-2 rows of punctae in its narrowest region (Fig. 5). Chela not black-tipped, but may have reddish or orange on tips (Fig. 18d). Female annulus ventralis distinctive (Figs. 5, 18a), posterior lower edge enlarges in larger females.

Orconectes virilis (Fig. 5)

Table 1. Locations of *Cambarus d. diogenes*. Drainsys = drainage system, DOW = lake number. See text.

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
St.Louis	Gansey Lake	59	21	19,20	15	69-913	0081
Itasca	Lily Lake	55	25	27,28	15	31-375	0085
Itasca	Schoolhouse II	149	27	27	05	31-881	0086
Stearns	Cedar Lake	126	33,34	6,1	19	73-255	0164
MilleLacs	Bass Lake	43	27	30	18	48-18	0165
Stearns	Cedar Lake	126	33,34	1,6	19	73-255	0168
Todd	Schriers Pond	127	32	25,30	19	77-2	0170
Morrison	Overlook Pond	131	31	12	19	49-109?	0171
Stearns	Cedar Lake	133	33,34	6,1	19	73-255	0173
Todd	Bunker Lake	127	33	16	19	77-101	0180
Todd	Trace Lake	127	32	6,7	19	77-9	0184
Stearns	Zimmer Pond	124	29	18,19	19	73-66	0189
Meeker	Betsy Lake	120,121	29	23,24	19	47-42	0195
Wright	Angus Lake	120	26	1	15	86-133	0197
Todd	Long Lk	130	32,33	6,7,12	16	77-86	0198
Todd	Loken Pond	129	32	5	16,19	77-36	0199
Stearns	McCormic Lake	126,127	34	24,13	19	73-273	0202
Todd	Owen Pond	133	33	9	16	77-140	0205
Morrison	Overlook Pond	131	31	12	16,18	49-108?	0218
Morrison	Stoney Pond	127	31	19	19	49-84	0219
Todd	Clotho Pond	129	35	3	16	77-197	0220
Lake	Lena Lake	60	8	5,6	03	38-424	0257
St.Louis	Normanna Pond	52	13	8	02	69-122	0259
Lake	Lena Lake	60	8	5,6	01	38-424	0269
Itasca	Schoolhouse II	149	27	27	05	31-881	0272
Houston	Mississippi River	101	4	23	36	S	0322
Houston	Mississippi River	101	4w	23	36	S	0329

Table 1. (*C. d. diogenes*, con.).

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Lake	Wampus Lake	60	10	32,33	03	S	0346
Aitkin	Wildrice paddles	48	26	var	15	S	0350
BlueEarth	Little Cobb River	106	25	7	27	S	0516
Faribault	Big Cobb River	104	24	24	27	S	0531
Faribault	Rice Creek	104	27	4	27	S	0535
Waseca	Lake Elysian	108	24	28	27	S	0539
Waseca	Big Cobb River	105	24	29	27	S	0543

Table 2. Locations of *Orconectes immunis*. See Table 1.

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Cass	Diamond Pond	141	30	34	15	11-396	0080
Itasca	Island Lake Pond	148	28	5	05	31-913	0087
Ottertail	Hanson Pond	131	42	3	21	56-585	0127
Ottertail	Silver Lake	133	40	17,18	08	56-302	0141
Itasca	Island Lake	150	28	var	05	31-913	0167
Morrison	WestPond EnchantedLk	131	31	14	19	49-113?	0169
St.Louis	Little Long Lake	63	12	9, 16-20	03	69-66	0174
St.Louis	Little Long Lake	63	12	15	03	69-66	0178
Benton	Skuza Pond	36	29	22	19	S	0179
Todd	Bunker Lake	127	33	16	19	S	0181
Ramsey	Bennett Lake	29	23	2,11	33	62-48	0187
Wright	Ring Pond	120	26	2	17	86-118	0188
Ramsey	Goose Lake	30	22	22,23	33	62-34	0190
Stearns	Merdan Pond	125	30	34	19	73-116	0192
Wright	Edwards Lake	120	27	8,9	15,19	86-211	0193
Wright	Otter Lake	121	26	19,30		S	0194

Table 2. (*O. immunis*, con.).

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Wright	Angus Lake	120	26	1	15	86-133	0196
Todd	Buckhorn Lake	127	32	9,10	19	77-11	0200
Stearns	Stub Lake	127	33	32,33	19	73-252	0203
Stearns	Hermit Pond	124	30	33	19	73-113?	0206
Sherburne	Cater Lake	34	30	1	19	71-157	0208
Wright	Strew Pond	120	28	2,3	17	86-260?	0210
Cook	Gunflint Lake	65	19-24	var	03	16-356	0211
Ottertail	Mary Lake	131	36	22	16	56-10	0216
Morrison	W.Pond,Enchanted Lk	131	331	14	16,19	49-111	0217
Hubbard	Nelson Lake	143	33	34	15	29-131	0248
LeSeuer	Rearing Pond	109	23w	28	34	S	0274
Hennepin	Hassan Park Reserve	120	23	19	17	S	0294
Washington	Brown Creek	30	20	20	34	S	0316
Lake	Lax LAke	56	8	12,13,14	02	S	0338
Lake	Lax Lake	56	8	12,13,14	02	S	0348
Aitkin	Rice paddy(Shetka's)	48	26	6,7,13,14	15	S	0349
BlueEarth	Bull Run Creek	106	25	13	27	S	0505
BlueEarth	Big Cobb River	105	25	35	27	S	0517
BlueEarth	Perch Creek	105	29	7	27	S	0518
BlueEarth	Bull Run Creek	106	25	13	27	S	0519
BlueEarth	ditch near Eagle Lk	108	25	7	27	S	0520
Faribault	Badger Creek	102	28	13	27	S	0534
Faribault	Cobb Creek	104	24	11	27	S	0536
Waseca	Little Cobb River	106	24	33	27	S	0537
Waseca	Big Cobb River	105	24	29	27	S	0540
Martin	South Creek	102	29	3,4	27	S	0545
Martin	Elm Creek	103	33	23	27	S	0548
Martin	Elm Creek	103	32	2	27	S	055[illegible]
Martin	Elm Creek	103	29	5,6	27	S	0555
Martin	Willow Creek	104	32	13	27	S	0556

Martin	Lily Creek	103	31	35,26	27	S	0559
Cottonwood	Watonwon River	105	34	25,26	27	S	0561
Cottonwood	see 566	105	34	25,26	27		
Watonwon	Peach Creek	105	30	26	37	S	0565
Watonwon	Peach Creek	105	30	26	37	S	0580
Watonwon	Watawon River	105	32	19	37	S	0582
Watonwon	Unnamed creek	105	33	26,27	37	S	0584
Watonwon	Butterfield Creek	107	31	30,29	37	S	0585
Watonwon	Spring Branch Creek	106	30	15,22	37	S	0588
Watonwon	Spring Branch Creek	106	30	15,22	37	S	0590
Watonwon	Spring Branch Creek	106	30	24	37	S	0591
Watonwon	St James Creek	107	31	28,33	37		

Table 3. Locations of *Orconectes propinquus*. See Table 1.

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Lake	Basswood Lake	64,65	9.10	var	03	38-645	0070
Fillmore	Deer Creek	103	13	17	36	S	0321
Fillmore	S branch Root River	102	12	22	36	S	0325
Fillmore	N branch Root River	104	11	6	36	S	0326
Houston	Mississippi River	101	4w	23	36	S	0328
Fillmore	S branch Root River	102	13	26	36	S	0330
Fillmore	Root River	104	11	16	36	S	0331
Lake	Hare Lake	59	6	11	03	S	0336
Lake	Nine Mile Lake	59	6	21,22	03	S	0345
Cook	Four Mile Lake	60	5w	9,10,16,	02	S	0347
Cook	Four Mile Lake	60	5w	var	02		0243
Lake	Basswood Lake	64,65	9.10	var	03	38-645	0070
Lake	Hare Lake	59	6	11,14	03		0252
Lake	Nine Mile Lake	59	6	20,21,22	03		0232

Table 4. Locations of *Orconectes rusticus*.

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Mower	Otter Creek	101	17	31	37	S	0034
Mower	Otter Creek,Lyle	101	17		37	S	0037
Washington	Marine on St. Croix	31	19	1	32	S	0047
Becker	Big Elbow Lake	142	38,39	5,6,11,12	08	3-159	0052
St.Louis	Shagawa L.	63	12	var	03	69-69	0068
Hubbard	Crow Wing River	140N	33W	12	16	S	0073
Cass	Wabedo Lake	140W	28W	var	15	11-171	0079
Cass	Leech Lake(no loc)	141-4	28-32	var	15	11-203	0084
Cass	Woman Lk	140,141	28,29	var	15	11-201	0155
Cass	Woman Lk	140,141	28,29	var	15	11-201	0163
Itasca	Three Island Lake	59	25,26	19,24	05	31-542	0226
Hubbard	11th Crow Wing Lake	141	32	14,15,var	16	29-36	0237
St.Louis	Shagawa Lake	63	12	var	03	69-69	0275
St.Louis	Shagawa Lake	63	12	var	03	69-69	0275
Washington	Williamsport Stream	31	20	12	34	s	0281
Hubbard	Crow Wing River	140	33	12	16	s	0285
St.Louis	East Vermillion Lk	61-63	14-16		01	69-378	0306
Lake	Triangle Lake	63	10		03	38-715	0308
Cass	McKeown Lake	140	29	10	15	S	0333
Jackson	DesMoines River	102	35	25	38	S	0341
Cottonwood	Des Moines River	105	37	21	38	S	0343
Jackson	Des Moines River	103	35	28	38	S	0344
Becker	Big Elbow Lake	142	38,39	6,7;1,12	08	3-159	0056
Mower	Otter Creek	101	17	31	37	S	0022
St.Louis	Shagawa R.	63	11	19	03	S	0025
Mower	Otter Creek	101	17	31	37	S	0034

Table 5. Locations of Orconectes virilis.

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Becker	Big Elbow Lake	142	38,39	6,7;1,12	08	3-159	0056
Clearwater	Miss.R.headwaters	144	36	35	15	S	0074
Beltrami	Cass Lake	146	30,31		15	4-30	0075
St.Louis	Little Long Lake	63	12	9,16-20	03	69-66	0076
Cass	Leech Lake	142	29,30	var	15	11-203	0077
Beltrami	Andrusia Lake	146	31	8,18,19	15	4-38	0078
Mower	Woodbury Cr,Cedar R.	101	18	33	37	S	0003
Hubbard	unnamed stream	141	35	36	16	S	0007
Ottertail	Redeye R.	137	36	25	16	S	0009
Becker	Shell L.	140	37,38	var	16	3-102	0010
Becker	Indian Creek	141	36	11	16	S	0011
Beltrami	Grant Creek	147	34	33	15	S	0012
Beltrami	Miss.R.Headwaters	146	34	24	15	S	0013
Beltrami	Moose L.Creek	146	35	16	15	S	0014
Becker	Hay Creek	141	36	3	16	S	0015
St.Louis	Berry Creek	55	12	6	01	S	0016
Fillmore	Bear Creek	103,104	12,13		36	s	0019
Goodhue	Belle Creek	113	16	34	34	S	0020
Goodhue	Prairie Creek	112	18	16	34	S	0021
Lake	S.fork Kawishiwi R.	62	11	33	03	S	0024
St.Louis	East Two R.	62	15	32	03	S	0026
St.Louis	Picket R.	66	17	36	03	S	0027
St.Louis	Elbow R.	64	19	34	03	S	0028
St.Louis	Moose R.	65	14	14	03	S	0029
St.Louis	Lester R.	52	14	35	02	S	0030
St.Louis	N.Branch WhitefaceR.	56	14	23	01	S	0031
St.Louis	St.Louis R.	58	14	33	01	S	0032
Lake	Cloquet R.	57	9	16	01	S	0033
Mower	Otter Creek	101	17	30	37	S	0035
Rock	Beaver Creek	102	46	14	39	S	0038
Rock	Kanaranzi Creek	101	44	13	39	S	0039

Table 5 (*O. virilis*, con)

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Lake	Weiss Creek	60	9	27	03	S	0054
Lake	Little Isabella R.	60	9	27	03	S	0055
Clearwater	Mississippi R.	144	36	9	15	S	0057
Becker	Straight R.	140	36	29	16	S	0058
Becker	Shell R.	140	36	30	16	S	0059
Becker	Dinner Creek	142	36	26	16	S	0060
Wadena	Redeye R.	137	34	31	16	S	0061
Hubbard	Miss R. headwaters	145	35	5	15	S	0062
Beltrami	Miss.R. headwaters	146	34	23	15	S	0063
Becker	Indian Creek	142	37	35	16	S	0064
Mower	Otter Creek	101	17	29	37	S	0040
Rock	Rock R.	103	44	19	39	S	0041
Rock	Elk Creek	102	44	30	39	S	0042
Rock	Champepaden Creek	103	44	20	39	S	0043
Pipestone	Chanarambie Creek	105	44	27	39	S	0045
Chisago	Sunrise R.	35	20	17	32	S	0048
Lake	Weiss Creek	60	9	27	03	S	0053
Wadena	Blueberry Creek	138	35	7	16	S	0065
Becker	Indian Cr.	141	36	3	16	S	0066
Hubbard	Schoolcraft R.	143	34	5	15	S	0067
St.Louis	Shagawa L.	63	12	var	03	69-69	0068
Becker	Bad Medicine L.	142	37	4	16	3-85	0071
Hubbard	Crow Wing R.	140	33	29	16	S	0072
Itasca	Swan Lake	55-6	22-3	var	15	31-67	0082
Beltrami	Cass Lake	146N	30,31W	not given	15	4-30	0083
Swift	see location notes	120	39	18	23	S	0088
LacQuiParle	Yellow Bank River	120	46	24	10	S	0089
LacQuiParle	N Fork Yellow Bank R	120	46	21	20	S	0090
Swift	Pomme de Terre River	120	43	13	21	S	0091
Jackson	Jack Creek	104	37	31	38	S	0092

Table 5 (O. virilis, con)

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Jackson	Jack Creek	104	37	31	38	S	0092
LacQuiParle	LacQuiParle River,MN	118	42	27	22	S	0093
LacQuiParle	LacQuiParle River,MN	118	42	27	22	S	0093
LacQuiParle	LacQuiParle River,MN	118	42	27	22	S	0093
Swift	Pomme de Terre River	122	42	30	21	S	0094
Jackson	Okabena Cr.	103	37	7	38	S	0095
Cottonwood	DesMoines River	105	37	28	38	S	0096
Swift	Mud Creek	122	37	34	23	S	0097
Chippewa	Chippewa River	119	14	1	23	S	0098
Chippewa	unnamed trib to Shak	119	38	8	23	S	0099
Lincoln	LacQuiParle River	113	45	18	22	S	0100
Freeborn	Goose Cr,CedarRdrain	101	20	31	37	S	0101
Jackson	Okabena Cr.	103	38	10	38	s	0102
Nobles	Jack Creek	104	39	32	38	S	0104
Chippewa	Dry Weather Creek	118	41	11	23	S	0105
YellowMedicine	LacQuiParle River	114	44	5	22	S	0106
LacQuiParle	LacQuiParle River	117	42	26	22	S	0107
LacQuiParle	LacQuiParle River	117	45	12	22	S	0108
LacQuiParle	LacQuiParle River	117	45	17	22	S	0109
LacQuiParle	Ten Mile Creek	118	42	26	22	S	0110
LacQuiParle	S.Fork Yellow Bank R	119	46	11	22	S	0111
LacQuiParle	LacQuiParle River	116	43	18	22	S	0112
Hubbard	Schoolcraft River	145	34	35	15	S	0119
Mower	Rose Creek	102	17	33	37	S	0120
Hubbard	Schoolcraft River	145	34	24	15	S	0121
Hubbard	Schoolcraft River	145	34	24	15	S	0121
Hubbard	Fish Hook River	140	35	25	16	S	0122
Hubbard	Hennepin Creek	145	35	2	15	S	0123

Table 5 (*O. virilis*, con).

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Hubbard	Alcohol Creek	144	34	22	15	S	0124
Ottertail	Block Lake	131	38	17,8,16	08	56-79	0125
Swift	Mud Creek	121	38	35	23	S	0113
Hubbard	Kabekona Creek	143	33	11	15	S	0116
Hubbard	Schoolcraft River	144	34	21	15	S	0118
Ottertail	Jones Lake	133	41	3,10	08	56-447	0126
Ottertail	Block Lake	131	38	8,6,17	08	56-79	0128
Ottertail	Big Pelican Lake	137	42	var	08	56-786	0129
Ottertail	Lizzie Lake	136,137	42	var	08	56-760	0130
Ottertail	Franklin Lake	137	42	27	08	56-759	0131
Ottertail	Franklin Lake	137	42	27	08	56-759	0132
St.Louis	Bear Creek	60	15	12	01	S	0133
Mower	Turtle Creek	103	18	32	37	S	0134
Hubbard	Shell R.	139	35	18	16	S	0135
Swift	unnamed trib Chippew	121	40	22	23	S	0136
Chippewa	ChippewaR diversion	118	41	16	23	S	0137
Ottertail	West Battle Lake	132,133	39,40	30	08	56-239	0138
Ottertail	Crystal	136	42	var	08	56-749	0139
Ottertail	Block Lake	131	38	17	08	56-79	0140
Cass	Leech Lake AgencyBay	141-4	28-32	7	15	11-203	0142
Roseau	Sprague Creek	163N	39W	8	14	S	0143
Cass	Leech Lk	142	30	7	15	11-203	0144
Cass	Leech Lake	143	30	23	15	11-203	0145
Cass	Leech Lk	142	30	6	15	S	0146
Marshall	Middle River	156	47	23,4	12	S	0147
Marshall	Tamarac River	157	46	9	12	S	0148
Marshall	Snake River	157	50	35	12	S	0149
LakeoftheWoods	Morris Point	162-8	32-7	16	06	39-2	0150
Cass	Leech Lake	142	31	9	15	11-203	0151

Table 5 (O. virilis, con).

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Kittson	Two Rivers	160.161	45,47	5,25	13	S	0152
Marshall	Snake River	157	50	35	12	S	0153
Cass	Leech Lk	142	31	9	15	11-203	0154
St.Louis	Kabetogama Lk	69,70	19-22	32	03	69-485	0156
LakeoftheWoods	Lake of the Woods	163-8	32-37	var	06	39-2	0157
Cass	Leech Lk	143	30	18	15	11-203	0158
Olmsted	N.Fork White Water R	107	11	1	36	S	0159
Steele	Turtle Creek	107	20	33	34	S	0160
Marshall	Middle River	156	48	15	12	S	0162
Cass	Leech Lk	143	30	23	15	S	0166
Cass	Mable lake	141	27	3,10	15	11-121	0172
CrowWing	Roosevelt Lake	138	26	4,8	15	11-43	0176
							0177
Todd	Pine Island Lake	131	32	33,34	16	77-67	0182
Cook	Bigsby Lake	61	2,3W	30,31,36	02	16-344	0183
Cook	Mink Lake	62	2E				
Ramsey	Lake Josephine	29,30	23	7,8,12	02	16-46	0185
Meeker	Peterson Lake	120	32	34,33	33	62-57	0186
Ottertail	Mary Lake	131	36	29	17	47-198	0191
Cook	Kimball Lake	62	2	22	16	56-10	0204
Cook	Aspen Lake	64	1w	7,8,17	02	16-45	0213
Becker	Buffalo Lake	140,141	40,41	11	02	16-204	0214
Becker	Height of Land Lake	139,140	39	var	09	3-350	0221
Becker	Bad Medicine Lake	142	37	var	08	3-195	0222
Polk	Sarah Lake	148	42	var	08,16	3-85	0223
Polk	Spring Lake	147	39	var	10	60-202	0224
Cook	Pike Lake	61	2	33	17	60-12	0225
Cook	Poplar Lake	64	1W,2W	15-19	02	16-252	0227
Cook	Devil's Track Lake	62	1E,1W	var	02	16-239	0228
Cook	Caribou Lake	60,61	3W	25-29	02	16-143	0229
Becker	Strawberry Lake	141,142	40	var	02	16-360	0230
Lake	Ninemile Lake	59	6	var	10	3-323	0231
				20,21,22	02	38-33	0233

Table 5 (O. virilis, con)

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Becker	Island Lake	140	38,39	var	08	3-153	0234
Becker	Little Cormorant Lk	139,138	42	4,5,32,33	08	3-506	0235
Mahnomen	Tulaby Lake	142,143	39	2,3,34,35	08	44-3	0236
Becker	Big Toad Lake	139	38	var	08	3-107	0238
Becker	Big Cormorant Lk	138	42,43	var	08	3-576	0239
Becker	Cotton Lake	139,140	40	36	08	3-286	0241
Becker	Pickerel Lake	139,140	40	9	08	3-287	0242
Hubbard	Lower Bottle Lake	141	34	11,15,23	16	29-180	0244
Lake	Lax Lake	56	7,8w	var	02	38-406	0245
St.Louis	Whiteface Reservoir	55,56	14,15w	var	01	69-375	0246
Cook	Finger Lake	60,61	5w	5,32	02	16-646	0247
Hubbard	Big Sand Lake	141	34	var 22-35	16	29-185	0249
Hubbard	East Crooked Lake	141	33w	var	16	29-101	0250
Hubbard	Blue Lake	141	34	16,17	16	29-184	0251
Lake	Sand Lake	59	10,11	var	03	38-735	0253
St.Louis	Whiteface Reservoir	55,56	14,15	var	01	69-375	0254
St.Louis	Whiteface Reservoir	55,56	14,15	var	01	69-375	0255
Lake	Flathorn Lake	60	9	22-27	03	38-568	0256
St.Louis	Whiteface Reservoir	55,56	14,15	var	01	69-375	0258
MilleLacs	Mille Lacs Lake	42,45	25-8	var	18	48-2	0260
Lake	Sand Lake	59	10,11	var	03	38-735	0263
Lake	Grouse Lake	60	9	10,14,15	03	38-557	0262
Lake	Windy Lake	61	6w	26-8,34	02	38-68	0261
MilleLacs					18		0264
Lake	Mitawan Lake	60	9	var	03	38-561	0266
Lake	Silver Island Lake	61	6w	var	03	38-219	0265
Lake	Middle McDougal	59	10	1	03	38-658	0267
St.Louis	Whiteface Reservoir	55,56	14,15	var	01	69-375	0268
Lake	August Lake	61	10	var	03	38-691	0270
Itasca	Kenogama Lake	146,147	29	var	15	31-928	0271
Hubbard	Benedict Lake	142	32	1-3,11,12	15	29-48	0273
St.Louis	Shagawa Lake	63	12	var	03	69-69	0276

Table 5 (O. *virilis*, con)

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Becker	Big Elbow Lake	142	38,39	var	08	3-159	0277
St.Louis	Little Long Lake	63	12	17	03	69-66	0278
CrowWing	Roosevelt Lake	138	26	8,9	15	11-43	0279
St.Louis	Picket Lake	64	12	14,15	03	69-79	0282
Wright	Channel8atEcolResSta	121	25	2	19	s	0283
Wright	Channels at MERS	121	25	4	19	s	0284
Roseau	Hayes Lake	160	38	36	14	S	0286
Roseau	Hayes Lake	160	38	33.34	14	S	0287
Roseau	Roseau River	160			14	S	0288
Goodhue	Prairie Creek	112	18	29	34	S	0289
Pine		39	22		31	S	0290
Brown	Little Cottonwood R.	109	31		26	S	0292
Dakota	Rebecca Lake	115	17	20,21	33	19-3	0293
Pope	Chippewa River	125	40	17	23	S	0295
RedLake	Hill River	150	41	7	11	S	0296
Stevens	Chippewa River	126	41	12	23	S	0297
Pine	Snake River	39	19	31	31	S	0298
Becker	Ottertail River	141	38	18	08	S	0299
Becker	Ottertail River	141	39	27	08	S	0300
Becker	Ottertail River	141	38	6	08	S	0301
Becker	Ottertail River	141	38	18	08	S	0302
Chippewa	Chippewaa River	118	40	15	23	S	0303
Fillmore	Bear Creek	103	13	6	36	S	0304
Mower	Otter Creek	101	17	31	37	S	0305
St.Louis	Pine Lake	57,58	11,12	1,6,31,36	01	69-001	0307
Wabasha	Zumbro River	110	10	22	35	S	0309
Wabasha	Zumbro River	110	11	31	35	S	0310
Houston	Root River	104	4	32	36	S	0311
Houston	Pine Creek	104	4	16	36	S	0312
Winona	Big Trout Creek	106	5	7	36	S	0313
Winona	Rollingstone Creek	108	7 or 8	2	36	S	0314
Wabasha	Zumbro River	109	13	6	35	S	0315
Chisago	Rock Creek	37	20	8	34	S	0317
Chisago	Rush Creek	37	20	31	34	S	0318

Table 5 (O. virilis, con)

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Fillmore	Middle Branch Root R	104	11	17,18	36	S	0319
Fillmore	S Fork Root River	102	9	25	36	S	0320
Fillmore	S Fork Root River	102	9	25	36	S	0323
Fillmore	Deer Creek	103	13	17	36	S	0324
Fillmore	N branch Root river	104	11	6	36	S	0327
Lake	Lax Lake	56	8	12,15,14	02	S	0339
Jackson	Des Moines River	102	35	25	38	S	0342
Aitkin	Wildrice paddies	48	26	6,7,13,14	15	S	0351
BlueEarth	LeSeuer River	108	27	34,35	27	S	0500
BlueEarth	Maple River	106	27	10	27	S	0501
BlueEarth	Big Cobb River	106	26	4,9	27	S	0502
BlueEarth	LeSeuer River	108	25	30	27	S	0503
BlueEarth	LeSueur River	108	26	34	27	S	0504
BlueEarth	Big Cobb River	105	25	17	27	S	0506
BlueEarth	Little Cobb River	106	25	10	27	S	0507
BlueEarth	Big Cobb River	106	26	23	27	S	0508
BlueEarth	Big Cobb River	107	26	30	27	S	0509
BlueEarth	Maple River	105	26	28	27	S	0510
BlueEarth	Rice Creek	105	27	15	27	S	0511
BlueEarth	Blue Earth River	107	27	6	27	S	0512
BlueEarth	Marble Creek	105	28	6	27	S	0513
BlueEarth		notgive			27		0514
BlueEarth	Perch Creek	105	29	7	27	S	0515
Faribault	Blue Earth River	102	25	33,34	27	S	0521
Faribault	Foster Creek	103	24	35	27	S	0522
Faribault	W. Fork Blue Earth R	101	27	18,19	27	S	0523
Faribault	Coon Creek	102	27	28,29	27	S	0524
Faribault	Badger Creek	102	28	13	27	S	0525
Faribault	Rice Creek	104	27	4	27	S	0526
Faribault	Cobb Creek	104	24	11	27	S	0527
Faribault	Maple River	104	26	11	27	S	0528

Table 5 (O. virilis, con).

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Faribault	Maple River	104	26	11	27	S	0528
Faribault	Maple River	104	25	15	27	S	0529
Faribault	Rice Creek	104	27	15	27	S	0530
Faribault	South Creek	103	28	19	27	S	0532
Faribault	Big Cobb River	104	24	24	27	S	0533
Waseca	LeSueur River	105	22	10,15	27	S	0538
Freeborn	Cobb Creek	104	23	17	27	S	0541
Waseca	LeSueur River	106	22	32	27	S	0544
Martin	Elm Creek	104	30	32,33	27	S	0546
Martin	Center Creek	103	29	28,29	27	S	0547
Martin	Center Creek	102	30	5	27	S	0549
Martin	Elm Creek	103	31	3,4	27	S	0550
Martin	Elm Creek	103	33	5,6	27	S	0551
Martin	Watawon River	104	33	2,3	27	S	0553
Martin	Lily Creek	103	31	26,35	27	S	0554
Martin	Elm Creek	103	33	14,23	27	S	0557
Martin	South Creek	102	29	3,4	27	S	0558
Martin	Willow Creek	104	32	13	27	S	0560
Cottonwood	Watonwon River	107	34,35	19,24	27	S	0563
Cottonwood	Unnamed stream	105	34	17,18	27	S	0564
Cottonwood	Watonwon River	105	34	25,26	27	S	0566
Cottonwood	Watonwon River	106	34	11	27	S	0567
Cottonwood	Watonwon River	106	35	15,16	27	S	0568
Cottonwood	Watonwon River	106	34	16-21	27	S	0569
Cottonwood	Watonwon River	105	34	25,26	27	S	0571
Watonwon	Unnamed creek	105	33	26,27	37	S	0581
Watonwon	Watonwon River	107	33	30	37	S	0583
Watonwon	Spring Branch Creek	106	30	15,22	37	S	0586
Watonwon	Watonwon River	107	31	19,20	37	S	0587
Watonwon	Watonwon River	105	32	13,14	37	S	0589

Table 6. Location of *Procambarus acutus acutus*. See Table 1.

COUNTY	SITENAME	T	R	S	DRAINSYS	DOW	COLLCODE
Houston	Mississippi River	101	4w	23	36	S	0334

APPENDIX I. Cooperators and Collectors for Crayfish Survey

(Names given as last name only were taken from collection sample labels)

Anderson	U. of Minnesota
Arthur	Monticello EPA Ecological Research Station
Barstad	MN DNA
Biden	
Blackburn	
Bohlander	Montrose Fisheries
Buck	St. Olaf College student
Bulen	
Cambell	
Carter	
Chelberg	
Clymer	MN DNR
Condiff	
Davidson	
Dieterman	MN DNR
Donat	
Duerr	
Ebbers	MN DNR
Ekstrom	MN DNR
Emerson	MN DNR
Ensign	Wisconsin DNR
Ernst	MN DNR
Erickson	St. Olaf College
Fieldsend	
Fierstine	MN DNR
Gates	MN DNR
Gordon	
Graf	U. of Minnesota
Guegel	MN DNR
Gustafson	MN DNR
Hagen	
Hannay	MN DNR

Har	
Peter Harris	Isabella Environmental Learning Center
Harrison	
Haugstad	MN DNR
Haukost	
Helgen	Carleton College
Hobbs III	Wittenberg University
Holmbeck	
Honyl	St. Olaf College
Houkas	EPA
Huberty	MN DNR
Hugill	MN DNR
Jannett	Science Museum of Minnesota
Jass	Milwaukee Public Museum
Jeseritz	MN DNR
Johnson	MN DNR
Johnson	MN DNR
Jones	St. Olaf College
Kallemeyn	Voyageurs National Park
Koenen	
Kollar	MN DNR
Kukar	
Lake Itasca Field Biology Station	U. of Minnesota
Lanesboro Fisheries	
Larson	MN DNR
Latvala	Retired, MN DNR
Lawrenz	MN DNR
Lee	Carlos Avery Wildlife Refuge
Lilienthal	MN DNR
Lodge	Notre Dame University
Luthens	MN DNR
Malzahn	
David Maus	St. Olaf College
McCormack	EPA
Mead	
Mistelske	

Mix	MN DNR
Moffat	St. Olaf College
Momot	Lakewood University, Thunder Bay, Canada
Muller	
Nelson	MN DNR
Nordman	MN DNR
Olson	St. Olaf College
Ongstad	MN DNR
Ostgarden	MN DNR
Persons	MN DNR
Peterson	MN DNR
Post	Reed College
Putz	
Ringle	Leech Lake Indian Reservation
Rivard	Maple Grove
Rohach	St. Olaf College
Rosinger	MN DNR
Schneider	MN DNR
Shephard	MN DNR
Shepperd	Leech Lake Indian Reservation
Shetka	Grower of wild rice
Schultenover	St. Olaf College
Smith	
Storland	MN DNR
Sundmark	
Thearle	St. Olaf College
Thompson	MN DNR
Traun	U. of MN Lake Itasca Field Station
Treat	
Bergen	MN DNR
Walker	St. Olaf College
Wallmow	
Watson	MN DNR
Wilcox	White Earth Indian Reservation
Underhill	U. of Minnesota
Yliniemi	MN DNR

Appendix II. Examples of mailings and survey sheets used to reach potential collectors.

ANNOUNCING

A SURVEY OF THE CRAYFISH OF MINNESOTA

Did you know that Minnesota is experiencing an invasion of the "rusty" crayfish, Orconectes rusticus? Did you know that Wisconsin has instituted a ban on the use of live crayfish as fishbait because of rusty crayfish damage to fish nests and to aquatic plants? We would like to know the distribution of our native species before the rusty crayfish becomes widespread.

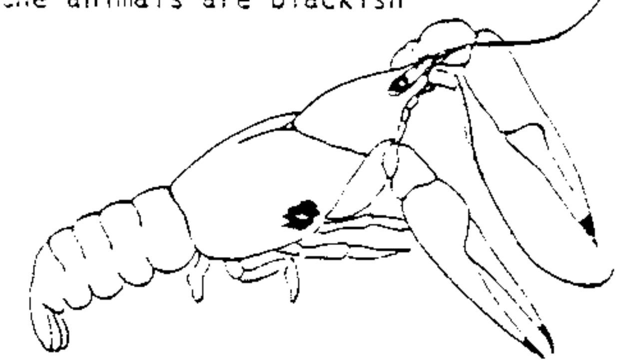
Did you know that crayfish are very sensitive to acidification of our lakes? If the pH drops to 5.0, all the crayfish in a lake may die out. We would like to document crayfish presence in acid sensitive lakes now as historical records!

The Science Museum and the DNR Nongame Wildlife program are sponsoring my survey of Minnesota crayfish. If you have any interest in participating as a collector, if you would like more information, or can provide me with ideas for collection sites, please mail me the enclosed checklist, or call me at St. Olaf College.

My addresses: Biology Department
St. Olaf College
Northfield, MN 55057
My office: 663-3955 until May 30,
663-3398 after that
Biology Office: 663-3100

Dr. Judy Helgen
1934 Shryer Avenue West
St. Paul, MN 55113
612-636-6544

The rusty crayfish, Orconectes rusticus can be identified by the rusty spots on each side of the carapace, and by the presence of black bands on the tips of the dactyl and the chela of the claws. When the animals are blackish in color, these markings are difficult to observe.



CRAYFISH SURVEY CHECKLIST

________ I would be interested in collecting some crayfish in my area.

________ I know of sites with abundant crayfish (please describe site and county).
site, county ____

________ I know of lakes that have lost or are losing their submerged weed beds.
lake, county ____

________ I know of sites that have mud "chimneys" visible above ground.
site, county ____

________ I know of lakes that used to have crayfish but don't seem to now.
site, county ____

________ I would like more information on crayfish (please indicate kind of information, i.e. species, ecology, etc.)

Please mail to:

Dr. Judy Helgen (through July 10)
Biology Department
St. Olaf College — 507-663-3395 through May 30
Northfield, MN 55057 — 507-663-3398 after May 30

Dr. Judy Helgen (after July 10)
1934 Shryer Avenue West
St. Paul, MN 55113 — 612-636-6544

May 26, 1986
Biology Dept.
St. Olaf College
Northfield, MN 55057
507-663-3102 or 3100

Dear

Thanks for your willingness to collect crayfish for the Survey of Minnesota crayfish. I am enclosing bottles and/or plastic bags ("Whirlpaks") for your use. Please label with pencil or India ink on the outer taped labels on the jar. Permanent Sharpie pens are ok if the alcohol doesn't contact the ink. In addition, because there is a danger of losing exterior labels, could you also put the collection information in pencil on the cards enclosed here. The collection cards I sent last year are not useful because they can become soft in the preservative.

For those of you who are freezing specimens, the printed cards are useful. Please record the collection information with pencil or permanent Sharpie pen or India ink on the cards, and insert them into the Whirlpak.

The information to record is

County — Date
Collector's name — Pres (= preservative, 70% alcohol or 10% formalin)
Location
(site name, nearest town, route #'s, etc)

T R S

For those of you who have requested additional information, I will send you materials separately. Also, I will communicate with you during the summer about picking up any samples. I sincerely want to thank you for your participation in this effort.

Judy Helgen
Home address: 1934 Shryer Ave. W.
St. Paul, MN 55113
612-636-6544

To: DNR Area Fisheries Supervisors — Fall, 1986

From: Judy Helgen, St. Olaf College

Last spring I sent you some information about the Survey of the Crayfish of Minnesota I am conducting, and a "checklist". You indicated an interest in collecting and preserving crayfish, and I have sent many of you some plastic jars and/or whirlpaks for specimens.

I would now like to collect any samples you may have obtained during this past season. As you are probably aware, the DNR is definitely interested in understanding the distribution of the rusty crayfish, _Orconectes rusticus_, and my interest in it, and in the native species of Minnesota, continues.

We need to work out the pick-up location for your samples. Could you please fill out the following questionnaire, and return it to me! I'd appreciate a phone number.

Thanks for your continued interest and cooperation!

Judy Helgen

Biology Department
St. Olaf College
Northfield, MN 55057
507-663-3102, 3100

1934 Shryer Ave. W.
Roseville, MN 55113
612-636-6344

Checklist for Cooperating DNR Area Fisheries Fall, 1986

Name______________________________

Address:

Phone number ______________________________

__________ We have collected crayfish

__________The specimens are preserved in formalin, alcohol (circle one)

__________The specimens are frozen

__________ The crayfish can be picked up at the address used for this mailing

__________ The crayfish could be transported to the St. Paul DNR building (I'd suggest leaving them in the office of the Nongame Wildlife Program)

________ By which date?

__________ The crayfish could be sent to the Regional Fishery offices

Location:

By which date__________________

__________ They could be brought to the Twin Cities area:

____________ date

Address (and phone #):

I would prefer a Twin Cities location for pick-up of the crayfish. If you can get them to either the DNR or some other Twin Cities address please indicate which you prefer, and I will assume they will go to that location.

June, 1986

TO:

FROM: Judy Helgen
Biology Department, St. Olaf College
507-663-3102 or 3100
612-636-6544 (home)

Thanks for expressing an interest in the DNR/Science Museum survey of Minnesota crayfish species. Any specimens of any species collected anywhere in Minnesota will be valuable for the distribution records that will result from the survey. As I mentioned, the distributions may be changing because of the invasion of O. rusticus (the "rusty" crayfish). At present, rusty crayfish have been collected from Mower County south of Austin, from the drainage to the St. Croix north of Stillwater, from the Detroit Lakes area (Elbow Lake) in Becker County, and from Shagawa Lake by Ely. They are probably in the chain of Crow Wing Lakes, Hubbard County. Since O. rusticus has been present in Wisconsin for perhaps 20 years or more, we'd expect to find it along the eastern border. Also it has been reported in Ontario, so it's possible the Ely population came in from the northeast. The potential for damage by this species is greatest in northern Minnesota hard-bottomed lakes. This species can consume walleye and panfish eggs, and can eliminate a lake's weed beds.

It is possible that we will see some hybrids between O. rusticus and our native species. Also, records of any crayfish presence in acid-sensitive lakes are important since acidification, if it worsens here, can cause the loss of crayfish populations.

I am sending you some information on:

1. How to collect and preserve crayfish — Page 1
2. How to identify our common species — Page 4
3. A brief bibliography — Page 6
4. Some information on crayfish ecology and life history — Page 7
5. Some ideas for crayfish projects — Page 8

1. HOW TO COLLECT AND PRESERVE CRAYFISH

Collection

Streams

Crayfish often prefer rocky substrates, and seek "shelter" under rocks. In streams they can be collected by minnow seine (1/4" mesh or less) placed in the stream with the collector kicking rocks immediately upstream. Standard aquatic dip nets can be swept through tufts of vegetation in streams. I have had made some large stream long-handled metal-frame nets ("Erickson" nets) with a 14 x 30" metal frame opening. Because of the wide opening, these are very effective in streams. Of course, electroshocking is effective but requires the gear and permits.

Ponds, Marches

Minnow traps with a 1.5" opening work for crayfish especially when baited with fish material. You will probably need to weight them with a small rock inside. I have used metal traps, but plastic should be okay. They may need to stay out 3-4 days, but could be checked periodically, and re-baited as needed. I've collected large adult dysticid beetles while trapping for crayfish so you may have some surprises! If you have a seine (1/4" or less) and two people to walk it, that should be effective also. Workers in the Carlos Avery Refuge have found crayfish associated with floating cattail mats.

Lakes

Crayfish often come in close to shore to feed in the evenings and can be hand-collected in shallow water with a flashlight at night. However, since they do also love to eat aquatic plants, use of a sieve or minnow traps in vegetated areas will work. Area fisheries supervisors have been finding larger specimens of crayfish caught on their trap nets and gill nets.

Minnow traps tend to collect more male crayfish than females, so keep this in mind if you are doing a population study. For the species distribution lists this is fine because the taxonomy is mostly based on male characteristics.

Mud Chimney Sites

These occur near sloughs of rivers or shorelines of ponds and lakes. They are above ground, a few inches high, and cylinders made of mud. The crayfish burrow to the water table, so the "tunnel" may only go two feet down. It may go straight down or it may angle towards the water. You can dig to get the crayfish which will not dig away from you. Look for what else is in the water around the crayfish. These burrows sometimes act as a refuge for other aquatic species.

The common Orconectes immunis can burrow into the mud, and succeeds well in mud-bottomed ponds because it can tolerate lower oxygen levels than the common lake and stream species O. virilis.

I have not yet collected or received any specimens of the cambarid crayfish which burrows near major rivers. It is very important to include these species in the Minnesota distribution survey.

There are no regulations in Minnesota for crayfish collection and transport. Next year I will work with the DNR to ban the use of live crayfish in fishing. Wisconsin has such a ban already.

There are other crayfish traps. Dean Ash, the area Supervisor in Detroit Lakes (Dept. of Natural Resources, Fisheries Headquarters, PO Box 823, Detroit Lakes, MN 56501) has made his own traps. You could perhaps design your own, based on their strong need to seek sheltered areas (they love flowerpots in aquaria) and their attraction to fish material.

If you know of any unique methods of collecting crayfish, please write them down and send them to me. My dad, for instance, remembered an Indian friend in Idaho who could spear crayfish with a fork, by stabbing down just behind the crayfish which, of course, escapes backwards. When using a dip net, one should set it down behind a crayfish, then scare the crayfish by hand from the front so it backs into the net. A New Prague man remembered hanging a dead frog in a stream, and when raised later, the frog had crayfish hanging onto it. One source mentions wrapping fish entrails in old gill netting and weighting the package. Crayfish get tangled in the netting.

HOW TO PRESERVE AND LABEL CRAYFISH

A collection is from one site on one date. You may put all the crayfish from one collection in one sample jar and label it.

Labelling and Site Information

It is of utmost importance to know the exact location of the collection, otherwise it is of no value.

Information needed for a collection:

1. County
2. Date (day, month, year)
3. Collector's name
4. Location:
   Site name (name of stream or lake)
   Habitat type (i.e. rocky stream, muddy river, cattail marsh, pond, lake)
   Location (nearest town, road names, T, R, S numbers [from County map])
5. Preservative (10% formaldehyde or 80% alcohol)

Labels

I prefer a label in pencil or India ink, on clear index card or high cotton paper, placed inside the collection jar or bag. Another label, preferably in India ink or pencil (which is not alcohol soluble), on water-resistant tape, should go on the outside of the jar. If you use permanent sharpee pen on the outside, you have to be careful if alcohol spills on it. The label might be lost. Pencil survives better. The label in pencil inside is the important one. Be careful the pencil writing is definite and not smudged.

Preservative

It is best to preserve crayfish initially in 5-10% formaldehyde, and later to transfer them to 80% alcohol, ethyl or isopropyl. However, if you prefer not to use formaldehyde, you may preserve in 70-80% alcohol.

Jars

Be sure these are leak-proof, especially if you are using formaldehyde. Test them. Mayonnaise and canning jars should work well. If jars are a problem, I may be able to send you some plastic jars. Let me know.

Freezing As An Alternative

Crayfish specimens can be frozen, just use air-tight bags like zip-lock freezer bags, and be sure to put a collection label or card inside the bag. I use bags called "whirlpaks" which are water-tight, but zip-lock freezer bags should be fine.

The problem with freezing samples is in routing the specimens to me. We will have to work out a way for me to pick up your collections in either case. After final identification these will become part of the Science Museum's new collections of aquatic invertebrates.

How To Get The Collection To Me

When you have samples, please let me know so we can access them to me and then to the Science Museum. I will do some travelling to pick up samples this August. Samples could be routed through some of the DNR Area Fisheries offices; they could be left at the Science Museum in St. Paul; I've picked up samples at the DNR booth at the State Fair (left in employee's area upstairs). I could do another pick up trip in mid December.

What To Collect and Preserve

All species are needed from all areas of the state, not just *O. rusticus*. As I mentioned, taxonomic keys are mostly based on the sexually mature males. However, it's okay to keep all types collected. Sometimes the females can be used to identify the species. Also a collection of any kind establishes the presence of crayfish in a habitat. In addition, rusty crayfish can be tentatively identified in the juvenile state.

When To Collect

In a way it's like pruning shrubs, you do it when you can. However, most native crayfish are night-active. (Rusty crayfish can be day active.) Sexually mature males may not be prevalent in June, they may be more common towards the end of summer, fall, and perhaps early spring. After the breeding season males molt back to a non-mature state or "Form II" and can't be identified.

2. IDENTIFICATION OF CRAYFISH

Characters Used

The keys rely heavily on the ventral gonopod structures of the sexually mature males. These are cornified (brownish at ends) and more defined in the sexually mature Form I. In Form II, they are not cornified and are simpler in shape and can't be used for species identifications. The blind sperm storage structure of the female, the annulus ventralis, can be used, but less easily, for species identifications.

I am enclosing photocopies of male gonopods and the annulus ventralis of females, plus ventral views of crayfish to locate these structures.

Other characters that are used to distinguish the crayfish are chela (claw) characters, areola (see picture) proportions, and some coloration.

To distinguish among *O. virilis*, *O. immunis* and *O. rusticus* in a tentative way:

O. rusticus usually has 2 dark rusty spots laterally on the thorax as if you picked up the crayfish with paint on your forefinger and thumb. It also has black bands near the tips of the dactyl and the claw of the chela (see drawing). However, when the specimens are very dark, almost black, these color markings may be obscured.

Very large *O. rusticus* have a distinct gap at the base of the dactyl and the claw (see drawing). This may not distinguish *O. rusticus* from *O. propinquus*.

O. immunis has a distinct notch in the dactyl on its inner edge (see drawing).

So far, I am finding three to four orconectids in Minnesota:

Orconectes virilis (streams, lakes, common)
Orconectes immunis (mud bottom ponds)
Orconectes rusticus (streams, lakes, will probably displace some O. virilis populations)

plus, on the border of Canada (Basswood Lake) and in Southeastern MN

Orconectes propinquus of which I need more specimens. This had previously not been reported in Minnesota until we agreed *O. iowensiis* from SE MN is *O. propinquus*.

In his forthcoming work on crayfish of Wisconsin, Horton Hobbs III lists these species for Wisconsin:

**Cambarus diogenes* (burrows in wet meadows and marshes)
**Fallicambarus fodiens* (burrows in streams and standing water)
**Procambarus gracilis* (burrows)
Orconectes immunis
Orconectes propinquus
Orconectes rusticus
Orconectes virilis

Those starred are the species that burrow in wet meadows and marshes, or in or near streams or rivers. We have few collections of any of these, so these are greatly needed.

3. BIBLIOGRAPHY

Sources that are useful for identifying crayfish are:

D.W. Crocker and D.W. Barr. 1968. *Handbook of the Crayfishes of Ontario*. Life Sciences Miscellaneous Publications, Royal Ontario Museum, University of Toronto Press.

H.H. Hobbs, Jr. 1976. Crayfishes (Astacidae) or North and Middle America. U.S. Environmental Protection Agency. Water Pollution Control Research Series 18050 ELD 05/72 (Second printing).

H.H. Hobbs, Jr. 1974. A Checklist of the North and Middle American Crayfishes (Decapoda: Astacidae and Cambaridae). Smithsonian Contributions to Zoology, Number 166. Smithsonian Institute Press. Washington, D.C.

R. Pennak. 1978. Fresh-water Invertebrates of the United States. John Wiley, N.Y.

A most useful source will be that of H.H. Hobbs III, The Crayfishes of Wisconsin, which should be published in 1986.

Other sources relevant to life history, acidification, or the rusty crayfish problem, behavior and ecology:

R. Bovbjerg. 1970. Ecological isolation and competitive exclusion in two crayfish (Orconectes virilis and Orconectes immunis). Ecology. 51:225-236.

G. Capelli. 1982. Displacement of northern Wisconsin crayfish by *Orconectes rusticus* (Girard). Limnology and Oceanography. 27(4):741-745.

G. Capelli and B. Munjal. 1982. Aggressive interactions and resource competition in relation to species displacement among crayfish of the genus Orconectes. Journal of Crustacean Biology 2(4):468-492.

See Crocker and Barr above.

David Lodge, A. Beckel and J.J. Magnuson. August 1985. "Lake Bottom Tyrant." Natural History. 94, 8:32-37.

See R. Pennak above.

D. Schindler, et al. 1985. Long-term ecosystem stress: the effects of years of experimental acidification on a small lake. Science Vol. 228:1395-1401.

4. CRAYFISH ECOLOGY AND LIFE HISTORY

Because there is not time to write anything comprehensive, I refer you to the bibliography enclosed. Some life history highlights follow. Crayfish undergo successive molts to grow. the male molts to a sexually mature state, and after reproduction molts back to a sexually immature state. The female holds the eggs by a glue-like substance and broods the young exteriorally on her ventral abdomen until they can feed. Females carrying eggs on the abdomen are "in berry." Please report this if you see it, and when. Crayfish store extra $CaCO_3$ in a stomach gastrolith, sometimes almost pea-sized. This is apparently not enough $CaCO_3$ to harden the exoskeleton after the molt, and the effect of low pH (or acid) is perhaps the inability to take up the Ca++ needed for hardening. Crayfish in acidifying lakes have soft exoskeletons, and not just after the molt when they are normally soft. You would also expect crayfish populations to be reduced in low calcium lakes.

Surveys of the biota in many lake studies often use techniques for sampling zooplankton (tow nets, plankton traps), for emerging insects (floating net emergent traps), for benthic organisms (dredges or guzzler pump samplers) that simply do not collect crayfish. Crayfish may be more important in aquatic ecology than the research indicates. Their biomass or productivity may be a substantial part of the benthic biomass. Their role in control and consumption of macrophytes (aquatic weeds) is known to only a few. When the crayfish plague hit Europe, and crayfish died off in masse, certain canals became choked with aquatic plants. Longer term studies of weed distribution in lakes experiencing rusty crayfish invasions have shown progressive elimination of the weed beds of the entire lake. It can start in one bay and spread. Loss of the aquatic plants is serious, and vastly changes the ecology of a lake or pond because of the many other invertebrates and vertebrates (especially juvenile fish) dependent on the weed beds.

David Lodge's work on plant preferences of crayfish (to be published) surprised him in that the crayfish preferred not the high-protein plants as he had predicted, but the high-cellulose plants. This suggests to me that crayfish may have some ability to digest cellulose.

Certainly crayfish will consume dead fish, amphibians, etc., in their well-known role as scavengers. They are even sometimes cannibalistic. When small they are preyed on by bass and other vertebrates. I have seen crayfish parts in presumed otter scats. Let me know what evidence you find of predation on crayfish. Crayfish are most vulnerable right after they molt. I believe mortality from all causes is highest at this time.

Crayfish competition does affect species distribution. Studies on aggressive encounters for occupation of shelter sites have shown *O. rusticus* more aggressive than *O. virilis* and *O. virilis* more aggressive than *O. immunis*, the "pacifist". While *O. immunis* would prefer the gravelly rocky substrate occupied by *O. virilis* it loses out in the competition, and has retreated to mud bottoms where its superior ability to tolerate low O_2 levels, coupled with its burrowing capability, which *O. virilis* lacks, have made it quite successful in the pond habitat. It is *O. virilis* that may be displaced by *O. rusticus*.

I am interested in aquatic "pheromones" or chemical signals within and between species. There is a possibility that crayfish of one species can detect the sex of another crayfish by chemical signal. However, males are known to attempt copulation with any crayfish. Also, they may react to "foreign" species' chemical signals. One study showed tank water from one species caused aggressive posturing by another species whose own species-conditioned water caused little reaction. There's a suggestion that species that have evolved together or have shared the same area over a long time may be reproductively isolated from each other by their ability to sense chemicals from the other species. This "chemoethological" isolating mechanism may not have evolved between species that have not been in the same areas. The suggestion here is that a new invading species may not be sensed as well (chemically) as a "foreign" species so the reproductive isolation doesn't work as well and the invader hybridizes with the native species. There is certainly a need for research on this idea. *O. rusticus* has been shown to hybridize with native species in the lab and I am definitely interested in finding any hybrids in areas where *O. rusticus* is spreading.

5. CRAYFISH PROJECT IDEAS

Crayfish can be kept alive in aquaria provided you use a regular water filter and periodically "vacuum" the bottom with a siphon hose. They prefer a gravel bottom and lots of sheltering rocks or clay pots laid sideways. They feed actively on Romaine lettuce or natural aquatic weeds like Elodea. I'd feed them once or twice a week, or as needed. When you give them animal food like fish, I'd move them to a separate container so they don't foul the water. You could do this once in awhile. I don't think they tolerate very high densities. Probably 4-6 per 10 gallon aquarium is already an unnatural density. Some projects I think of could best be done in plastic wading pools, but space is always a problem. Some of the biological suppliers are shipping rusty crayfish (naturally, they're more robust, etc.). I've spoken with a couple of them, and they do include an insert telling the buyer to destroy all live species when they're finished using them.

1. Compare feeding rates of different sizes and different species of crayfish. *Elodea* is a preferred plant but they also love Romaine lettuce. A student of mine found evidence that *O. immunis* could feed faster than *O. rusticus*, but when the two species were together, *O. rusticus* "won" the plant and therefore ate more. *O. rusticus* particularly cuts the stems of Elodea. Stem cutting activity could be compared. This may be partly how they destroy weed beds.

2. Mark and recapture study to show dispersal distance, range, sex differences in range. Do habitat locations change over the season?

3. Temperature tolerance in *O. virilis* compared with *O. immunis*. The idea is based on Bill Schmid's findings that terrestrial frogs have evolved an "antifreeze" to tolerate freezing while aquatic frogs have no frost tolerance. They burrow in the pond mud. By analogy, might stream-dwelling *O. virilis* be subject to freezing and have evolved some tolerance mechanism while *O. immunis*, the burrower, has not?

4. Food choice studies would be interesting. Might preference relate to ability to sense or "smell" the food? Could you present crayfish with water from foods and test the response? Some work has suggested they will always choose fish. Does a fish over plant choice always hold? Does it relate to degree or satiation? Size? Sex? Species?

5. If you find a lake with two species of crayfish in it, how are they distributed? Does one tend to be in the weeds, one in the rocks, or is it random? Is one bay dominated by one species only? What species are in the inlet and outlet streams?

6. Search for hybrids in areas known to have *O. rusticus*. Call me or write if you'd like precise locations.

7. Shelter competition studies are interesting. Include young and females. Too often these studies have focussed on males, and actually the skill of the females and young to sequester themselves in extremely important for species survival and fitness.

8. What happens when the choice is food versus shelter?

9. Descriptions of cambarid burrows. Depth, contents of water around crayfish. When are burrows active? Describe locations.

10. Respiration or metabolism in burrowing crayfish versus non-burrowing *O. virilis* at low and high (normal) oxygen levels. Do the burrowers metabolize at a normal rate in low O_2?

11. Comparison of response to scent of other crayfish: to own species versus other species. Responses could be 1) crawls towards conditioned water inflow tube; 2) postures aggressively to conditioned water; 3) no response; 4) moves away (avoidance). You can thing of your own, and the controls necessary (e.g. test inflowing water that had no crayfish).

12. Biomass or density estimates of different lakes or habitats. If you have SCUBA, this could be easier, by direct observation. Otherwise you'd need to perform the estimates by using the "catch per unit effort" approach where you sample each area with a similar effort (e.g. 5 minnow traps-one every 100 yards-for 4 days baited with the same bait; or equal numbers of seining efforts in streams). Distribution of most aquatic species, even plankton, is patchy, so density estimates are difficult to achieve.

13. I know of no research on this, but crayfish out of water make a clicking sound. Do they make this sound underwater? Is it a stress signal? Can it be recorded underwater? Does the pattern differ in any way in different species? Does the pattern change when a situation changes (i.e. when presented with another species, when picked up, when starving and presented with food, when competing for a shelter site)?

14. Genetics of color differences and of dorsal color pattern vary. Some lakes have crayfish of the same species but differing colors or patterns, some of which are genetically based. What are the frequencies of these? How might they be adaptive? Remember color will only show in live specimens, so photography is in order here. Blue crayfish have been found in Leech Lake. Please let me know if you find any blue crayfish or any unusual colors or white (albino) crayfish.

Appendix 3. dBase III file structures for COLLLOC (collection location information) and CRAYSPEC (specimen information) files.

```
. list structure
Structure for database : B:collloc.dbf

                              12/18/87
Field  Field name   Type        Width    Dec
    1  COLLCODE     Character       4
    2  NUMSPECS     Character       3
    3  COUNTY       Character      14
    4  T            Character       7
    5  R            Character       7
    6  S            Character       9
    7  DRAINSYS     Character       5
    8  COLLDATE     Character       8
    9  COLLECTOR    Character      20
   10  COLLSNUM     Character       8
   11  SITENAME     Character      20
   12  DOW          Character       7
   13  LOCATION     Character      45
   14  HABNOTES     Character      65
   15  COLLNOTES    Character     100
   16  ACRES        Numeric         7
** Total **                       330

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Appendix 3 (con.).

Structure for database : B:crayspec.dbf

12/18/87

Field	Field name	Type	Width	Dec
1	COLLCODE	Character	4	
2	SPECNUM	Character	3	
3	SPECIES	Character	3	
4	SEX	Character	3	
5	MAT	Character	3	
6	BL	Numeric	5	1
7	CL	Numeric	4	1
8	ARL	Numeric	4	1
9	ARW	Numeric	3	1
10	PUNCT	Character	3	
11	GONL	Numeric	4	1
12	CPRL	Numeric	4	1
13	MESP	Character	10	
14	GONNOTE	Character	20	
15	ANVENMM	Numeric	7	1
16	ANVENNOTE	Character	25	
17	RUSTSPOT	Character	10	
18	BLCHBD	Character	7	
19	CHGAP	Character	7	
20	COLOR	Character	25	
4	SEX	Character	3	
5	MAT	Character	3	
6	BL	Numeric	5	1
7	CL	Numeric	4	1
8	ARL	Numeric	4	1
9	ARW	Numeric	3	1
10	PUNCT	Character	3	
11	GONL	Numeric	4	1
12	CPRL	Numeric	4	1
13	MESP	Character	10	
14	GONNOTE	Character	20	
15	ANVENMM	Numeric	7	1
16	ANVENNOTE	Character	25	
17	RUSTSPOT	Character	10	
18	BLCHBD	Character	7	
19	CHGAP	Character	7	
20	COLOR	Character	25	
21	CARAHARD	Character	2	
22	DAM	Character	1	
23	DRAW	Character	1	
24	DISPLAY	Character	1	
25	NOTES	Character	100	
** Total **			260	

Appendix IV. Handout given with crayfish shipments by a supplier.

WARNING!

Please do not release these Crayfish into nature!

These are "Rusty" Crayfish (Orconectes rusticus). They are not native to Minnesota and our surrounding states. If they become established in our lakes and streams they tend to crowd out other native plants and animals.

Tips on maintaining crayfish in the laboratory:

1. Use spring water, clear aquarium water, clear pond water, aged well or tap water.

2. Remove crayfish from the packing material (moss) and Place in a container with water. We find that crayfish keep well in ½ - 2" of water.

3. Crayfish are scavengers and will eat a wide variety of food such as beef liver, raw or frozen fish, dog food, and earthworms. Feed approximately twice a week.

4. Change water after feeding and whenever it becomes cloudy.

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Phone 1-612-484-4488

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Figure Credits

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1. From Hobbs and Jass, 1988:

Figs 1c (Fig. 23j), 1e (23h), 2c (32j), 2e (32g), 3c (36j), 3d (36m), 3e (36h,o), 4c (46j), 4d (46m), 4e (46k), 5c (52k), 5d (52o), 5e (52f), 6a (69f), 6b (69d), 6c (69g), 6d (69j), 6e (69k), 13a (29), 13b (35), 13c (45), 13d (51), 13e (62), 13f (72), 20 (23c, 46k, 52c, 52f, 52k).

2. From Crocker and Barr, 1968:

Figs 1a (27), 1b (45 for annulus), 2a (22), 2b (40), 2d (61), 3a (25), 3b (43), 4a (24), 4b (42), 5a (23), 5b (41), 20 (2, 3, 23, 41).

Figure legends for photographs

		Page
Fig. 14a	C. d. diogenes male gonopod	97
Fig. 14b	C. d. diogenes male gonopod.	97
Fig. 14c	C. d. diogenes female annulus ventralis.	97
Fig. 14d	C. d. diogenes dorsal view.	97
Fig. 14e	C. d. diogenes lateral view.	98
Fig. 14f	C. d. diogenes chela.	98
Fig. 14g	C. d. diogenes dorsal view, note areola.	98
Fig. 15a	O. immunis female annulus ventralis.	98
Fig. 15b	O. immunis male gonopod.	99
Fig. 15c	O. immunis male gonopod.	99
Fig. 15d	O. immunis dorsal view.	99
Fig. 15e	O. immunis chela.	99
Fig. 15f	O. immunis chela.	100
Fig. 16a	O. propinquus female annulus ventralis.	100
Fig. 16b	O. propinquus rostrum, note carina.	100
Fig. 16c	O. propinquus chela.	100
Fig. 16d	O. propinquus male gonopod, mesial view.	101
Fig. 16e	O. propinquus male gonopod, lateral view.	101
Fig. 16f	O. propinquus dorsal view, northern specimen.	101
Fig. 16g	O. propinquus chela.	101
Fig. 16h	O. propinquus dorsal view, southern specimen.	102
Fig. 17a	O. rusticus female annulus.	102
Fig. 17b	O. rusticus female annulus.	102
Fig. 17c	O. rusticus male gonopod.	102
Fig. 17d	O. rusticus male gonopod.	103

		Page
Fig. 17e	Q. rusticus chela, rostrum.	103
Fig. 17f	O. rusticus chela, dimorphic.	103
Fig. 17g	O. rusticus dorsal view.	103
Fig. 17h	O. rusticus lateral view.	104
Fig. 18a	O. virilis female annulus.	104
Fig. 18b	O. virilis male gonopod.	104
Fig. 18c	O. virilis dorsal view.	104
Fig. 18d	O. virilis chela.	105
Fig. 18e	O. virilis female in berry.	105
Fig. 19a	P. acutus acutus chela.	105
Fig. 19b	P. acutus acutus female annulus.	105
Fig. 19c	P. acutus acutus female annulus.	106
Fig. 19d	P. acutus acutus dorsal view.	106

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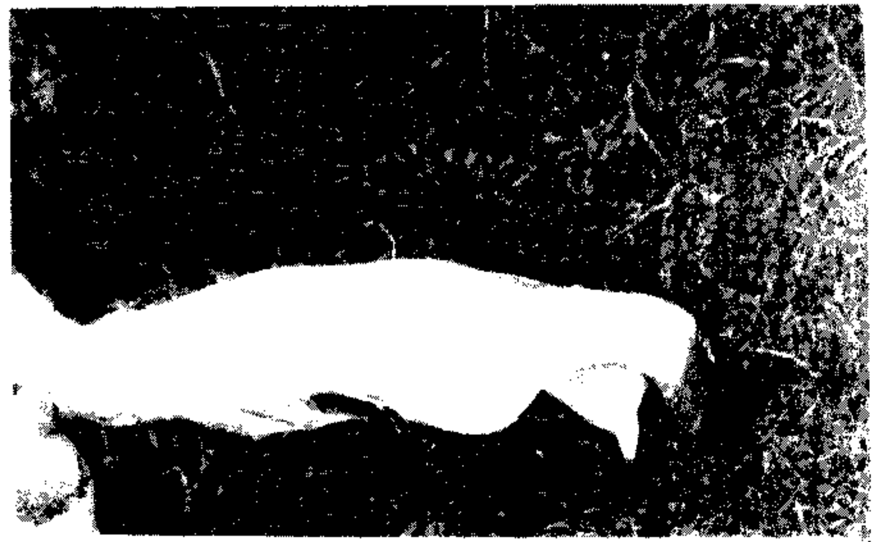

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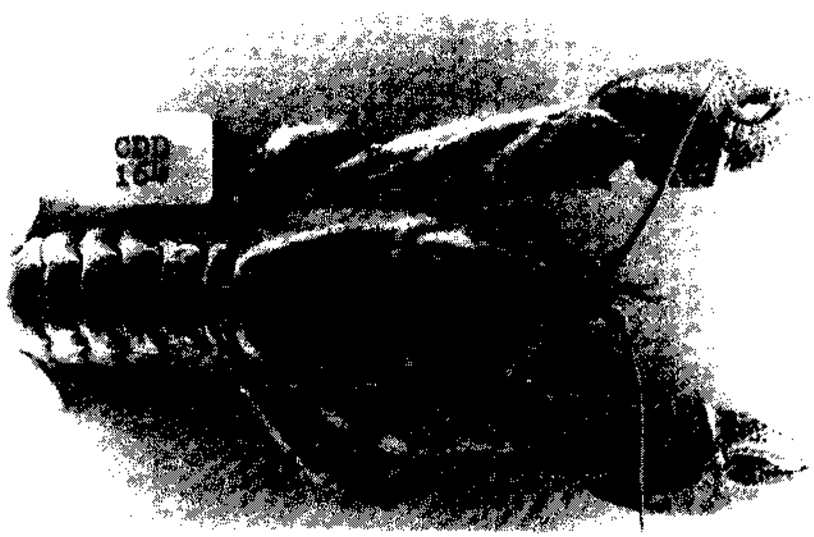

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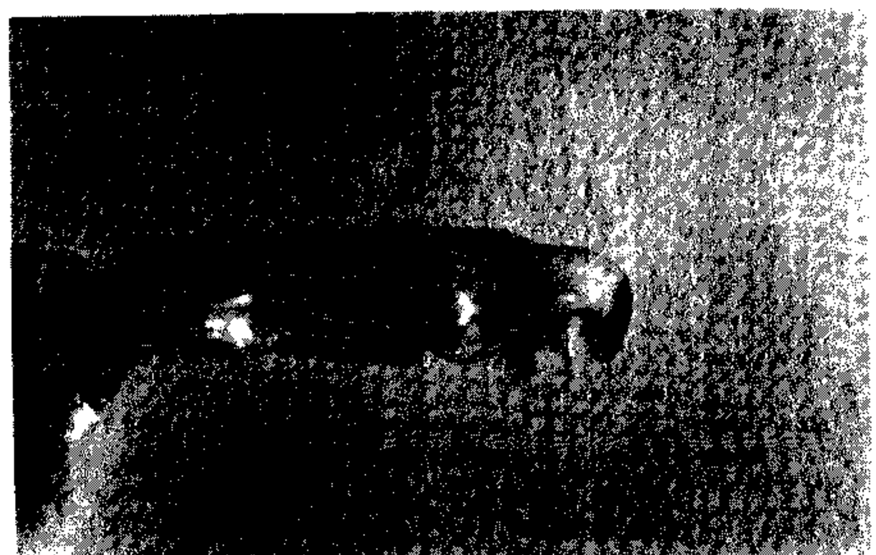

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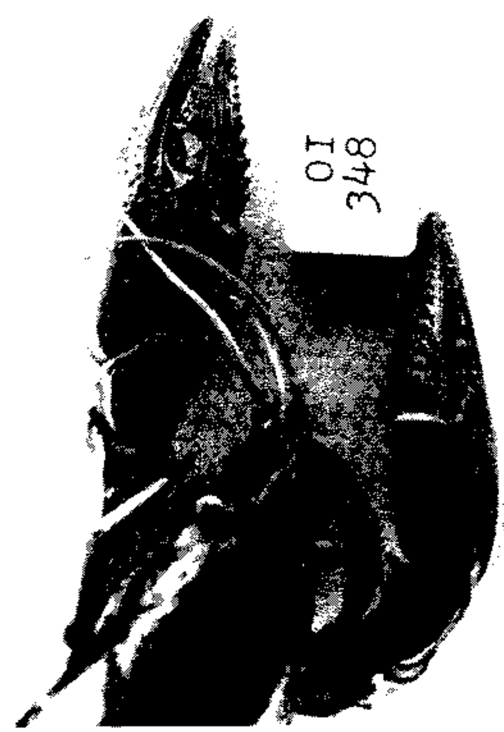
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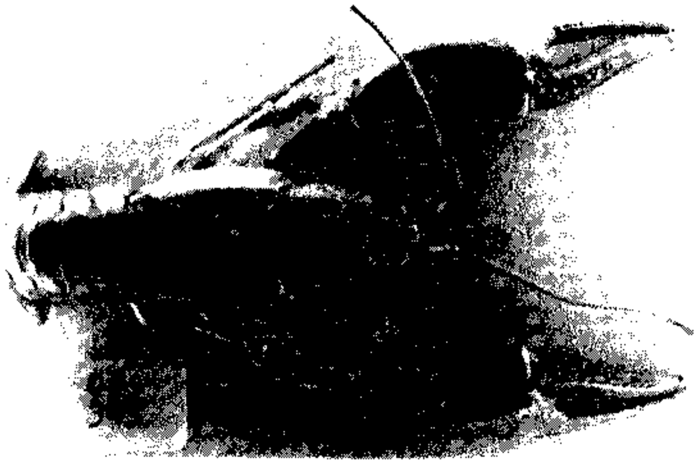

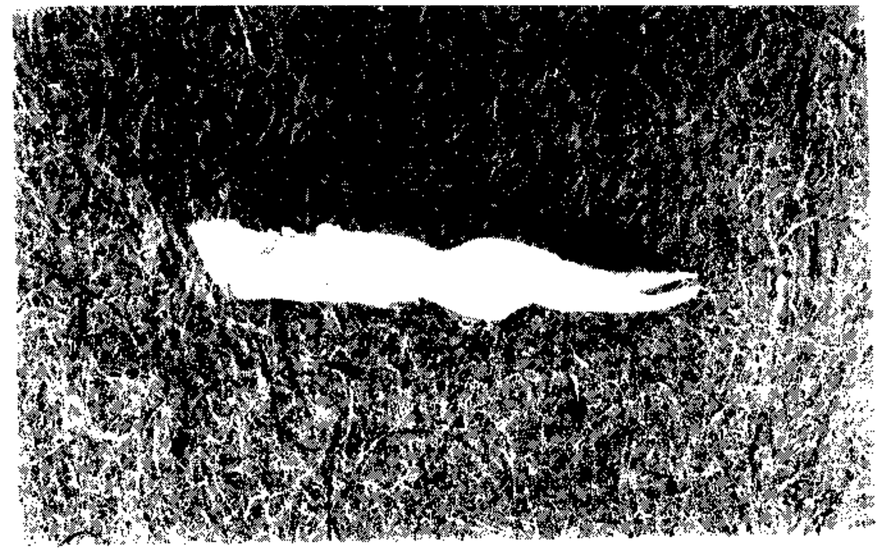

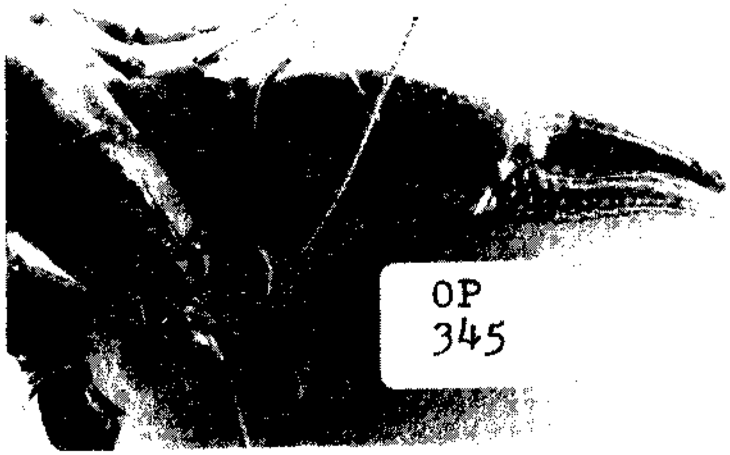
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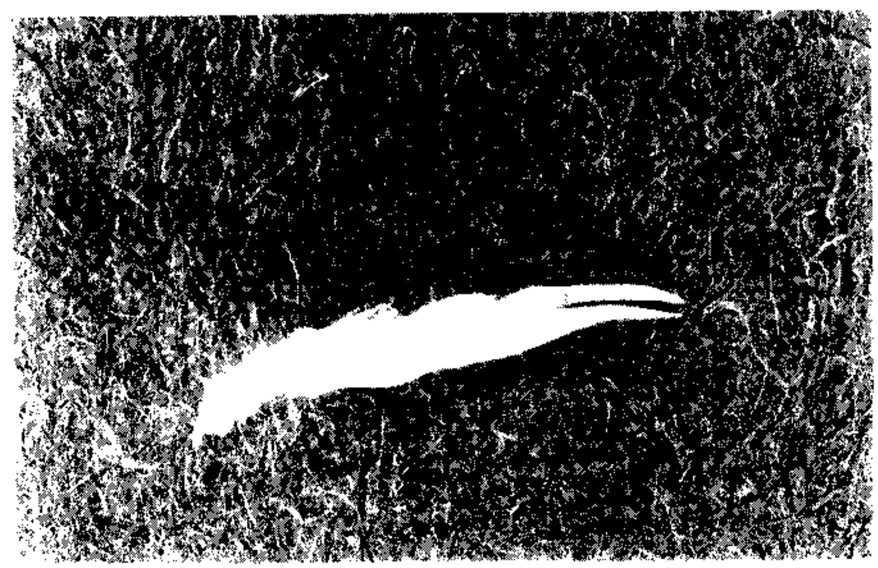

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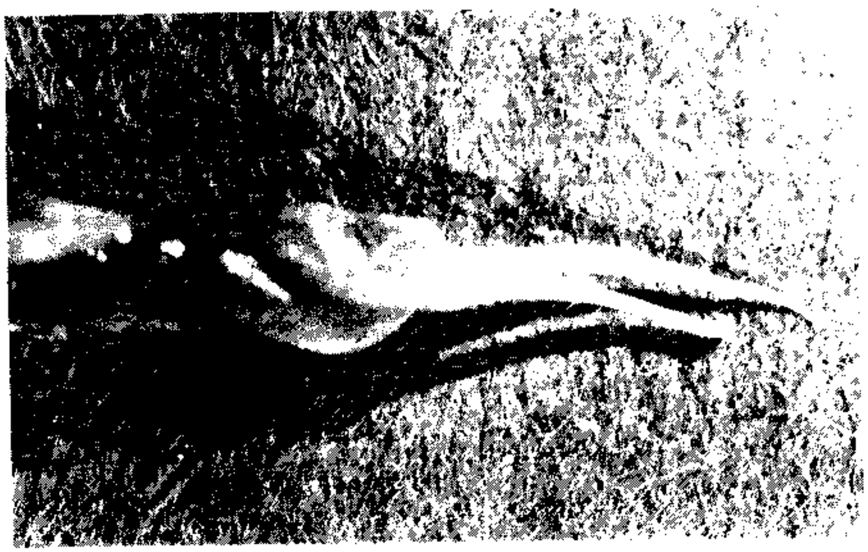

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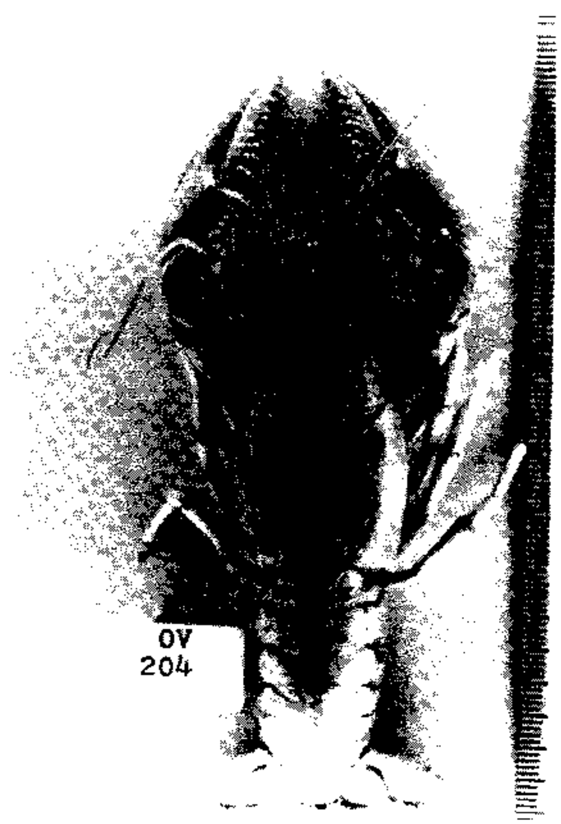
OV
204

204