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Paul Mayer, Editor

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Abstract

Fieldwork in Minnesota and Wisconsin is summarized, providing new distribution information for the fairy shrimps in these states. Each species found in the field surveys is illustrated in a Picture Key. Maps present Minnesota and Wisconsin locality records from specimens in the collections of the Milwaukee Public Museum (MPM) and the Science Museum of Minnesota (SMM). Distribution and natural history information for anostracans from other states in the Midwestern region are also included. By far the most common fairy shrimp in Minnesota and Wisconsin is *Eubranchipus bundyi*. Hatching phenomena and records of predators are discussed.

Introduction

A summary of the basic information about anostracan crustaceans, commonly known as fairy shrimps, of the Midwestern region has not been previously available. While the main focus here is on Minnesota and Wisconsin, data for the Midwestern states of Illinois, Indiana, Iowa, Michigan, Missouri and Ohio are also included. For records in the literature for individual counties in the states adjoining those of this region, see the summary of Jass and Klausmeier (2000).

In this Midwestern region, the most common fairy shrimp species, members of the genus *Eubranchipus*, are inhabitants of temporary ponds which fill in springtime with water from melting snow and spring rains. The invertebrate community structure of these ephemeral wetlands and their duration have been studied recently in Wisconsin (Schneider and Frost 1996, Schneider 1999, Schell et al. 2001).

The region's less common species from other genera, *Branchinecta*, *Streptocephalus* and *Thamnocephalus*, live in permanent bodies of water as well as temporary ones.

Basic fairy shrimp morphology is introduced in Plates I and II in which *Eubranchipus bundyi* is the example species used to provide an orientation to the anatomical terms that describe the traits of fairy shrimp adults.

Because there has been so little collecting of anostracans in the Midwest, additional work may reveal other fairy shrimp species in this area, a phenomenon which we hope to encourage by showing the meagerness of the data available to date.

Methods of Collecting and Photographic Techniques

In Minnesota Chelberg (1964a) conducted his doctoral research by beginning to sample ponds after several days of thawing weather in mid-

March and continuing this process until the end of May, usually at five day intervals. Anostracans were collected with a dipnet made of fine mesh nylon (90 threads/inch), fine enough to collect eggs and larvae. The net hauls were first examined in a large plastic dishpan of water from the pond site. After debris and predaceous insects were removed, the contents of the pan were poured into a gallon plastic jar and brought back to the laboratory.

A photographic technique was developed for recording and measuring live fairy shrimp in the laboratory. A rectangular vial designed for the culture of bacteria was modified for a measuring chamber. The vial was made of a clear plastic which had optical properties similar to that of water. A series of marks at one millimeter intervals was scratched into the plastic on the side which served as the bottom. The opposite side was removed leaving an open rectangular dish. A single lens reflex 35 mm camera was used to photograph the live shrimp in the dish. The camera lens was mounted on extension tubes, pointed vertically. Above the lens was a bellows which served as a light shield. The measuring chamber was mounted on a horizontal plate above the bellows. An electronic flash unit was placed so as to illuminate both the shrimp and the millimeter scale. After being measured and photographed, the shrimp were killed, fixed, and preserved. The resulting photographs were projected on a sheet of paper and enlarged 10 times for subsequent use including the preparation of illustrations. This photographic apparatus is shown in Plate III.

In the springs of 1956 (Chelberg 1958) and 1997, Chelberg also conducted statewide programs of collecting Minnesota fairy shrimps. The collection of the SMM is the repository for Chelberg specimens. Locality information in more detail than that reported here for these specimens may be obtained from that institution.

The MPM anostracan survey of Wisconsin was begun in 1992. Dipnets and sieves were used to collect adult fairy shrimps from temporary pond sites annually during the months of April and May. Specimens collected were preserved at the sites in 70% ethanol and were deposited in the MPM collection. A request was submitted for permission to collect in Menominee County whose borders also enclose the Menominee Indian Reservation, but it was not granted. The results of this fieldwork, along with MPM collections dating from 1971, were recorded on Wisconsin county-level maps. Detailed locality data for these specimens may be obtained from the first author.

For each anostracan included in our region, the records which follow combine information from the literature with specimen data from the MPM and SMM collections. These collections are composed chiefly of specimens collected in statewide surveys of Minnesota and Wisconsin, and therefore the distribution records presented here are more complete for those two states. However, we also summarize the known distribution data from the other states in our Midwestern region. In November 1999 a visit was made to the Invertebrate Zoology Collections, National Museum of Natural History (NMNH), Smithsonian Institution, to examine anostracans with the specific focus of retrieving additional data on Midwestern fairy shrimps collected in the past and deposited there.

Species Treatments

Each species recorded from the states of the Midwestern region is treated below under its appropriate family (a summary listing is given in Appendix I). A state-by-state review of species recorded appears in Appendix II. Appendix III locates the counties of Minnesota and Wisconsin, the states of major focus, followed by maps which give the county records for the anostracan species from each.

Following Appendix III is a Picture Key to six Minnesota and Wisconsin fairy shrimp species, created by Dale A. Chelberg following the procedure described in the Methods section above. The key therefore is confined to those species which were seen alive by the illustrator. For pictures of Midwestern species known only from records in the literature or from other than our two focus states, see the Published Illustrations noted in Jass and Klausmeier (2000). See also the recent review of North American fairy shrimp by Dodson and Frey (Thorp and Covich 2001).

Refer to Plates I-II for the details of fairy shrimp adult morphology. These plates pictorially introduce the pertinent anatomical features to observe when examining fairy shrimp specimens, along with the appropriate terms, using *Eubranchipus bundyi* as the example. To identify Midwestern fairy shrimp species, use these plates in conjunction with the Picture Key figures while examining preserved specimens under the microscope.

A full appreciation of the morphological differences between species is achieved only by viewing the specimens in question from several different angles. The views presented here are unique; they offer three-dimensional perspectives, not only of the species-identifying details of the heads of the males but of female traits as well.

The initial Picture Key figure shows lateral views of females and males of each of the six species included in the key for comparison of their relative sizes and postures when alive. Picture Key Figure 2 illustrates traits useful in distinguishing the three genera: *Branchinecta*, *Eubranchipus*, and *Streptocephalus*. Generic traits and species-specific traits are further revealed by perspective views of the heads of the males of each species, and dorsal and ventral views and lateral outlines of both males and females (Picture Key Figures 3-11).

Branchinectidae

Branchinecta lindahli Packard 1883

Belk and Brtek (1995) stated that the species ranges from Alberta, Canada, south through the Great Plains and western United States (U.S.) to northern Mexico. Dexter (1953) reported *Branchinecta lindahli* from an unspecified Iowa locality.

Eriksen and Belk (1999) characterized this as a fairy shrimp of cool-water pools which are low to moderate in dissolved solids, somewhat unpredictable as to when they appear, and short-lived. These authors have also summarized the details known of the life history of this species.

Branchinecta readingi Belk 2000

An unnamed species of *Branchinecta* was collected by Dale Chelberg (1972) in western Minnesota on 6 May 1971 in Lac Qui Parle County (Map 5). These specimens proved to be members of *B. readingi*, a new species from east of the North American Continental Divide that was recently described by Belk (2000). A lateral view of an adult female and male is given in Picture Key Figure 3. The 1971 Minnesota collecting site is an alkaline pool at the extreme eastern edge of the range of this species, whose type locality is Fleeinghorse Lake, Alberta, Canada (52°19'N, 110°11'W).

Chirocephalidae

Eubranchipus bundyi Forbes 1876

In the Appendix to his Crustacea of Illinois, Forbes (1876) named as a new species *Eubranchipus bundyi*, based on specimens sent to him from Jefferson [Jefferson County], Wisconsin by the collector, Professor Bundy. This original description of *E. bundyi* was not accompanied by plates, and omission of certain key characters led to much subsequent confusion.

In sufficient detail to differentiate *Eubranchipus bundyi* from two other congeners, Van Cleave and Hogan (1931) published original drawings of the male genitalia, including a magnified figure of the copulatory spicule, and lateral and dorsal views of the female ovisac in relation to thoracic and abdominal segments. They also figured the distinctive two pairs of pouches which extend prominently from the female's back, just anterior to the ovisac.

Figures 4-6 in the Picture Key compare this species with other Midwestern members of the genus. In Picture Key Figure 5, note especially the central knobbed projection between the bases of the two frontal appendages, a feature unique to this species. Picture Key Figure 6 compares the posterior segments of females, calling attention to the two pairs of dorso-lateral pouches (here termed "lappets") prominent in *E. bundyi*. Picture Key

Figure 7 gives lateral views of the adult female and male.

From specimens collected by Johansen (1924) on 21 April near Ottawa, Ontario, Sars (Johansen 1924) prepared figures of 1.5 mm and 2 mm long metanauplii of *Eubranchipus gelidus* (a species subsequently synonymized under *E. bundyi*). Johansen also included his own rough sketch of the older, 3 mm stage.

Combining laboratory investigations with fieldwork in central New York, Broch (1965) studied mechanisms that allowed *Eubranchipus bundyi* to survive in temperate temporary pond sites. Daborn (1976) found that most individuals in a temporary pond filled by snowmelt in Alberta lived 30-35 days, that females produced one clutch of an average of 22 eggs, and that high mortality of males preceded that of females.

Our Wisconsin data indicate that this species has the longest adult season, and that it is found over the broadest range of pond temperatures. It is usually dominant, in terms of numbers, when it is found with populations of other fairy shrimp species. In Wisconsin, matures have been found from 1 April to 31 May, in water temperatures ranging from near 0 to 19°C (mean=8.2°C). The pH at 23 sites ranged from a minimum of 6.1 to a maximum of 7.4 (mean=6.8).

State records from the region were established in the literature by Creaser (1930a) for Illinois, by Pearse (1918) for Indiana, by Dexter (1953) for Minnesota, and by Forbes (1876) for Wisconsin [type locality]. Although Van Cleave and Hogan (1931) indicated that subsequent correspondence from Creaser had corrected the location for his "Illinois" (1930a) specimens of this species to Indiana, Dexter (1953) cited 1948 and 1949 Champaign County localities from his own collecting in the state. Specimens received from T. Anton document a Cook County, Illinois, record for *Eubranchipus bundyi* (31 March 1999).

County-level records were established in the literature for Michigan by Pearse (1913b: Washtenaw), Creaser (1929: Oakland), Brtek (1966: Gratiot), Knight et al. (1975: Barry, Kalamazoo) and Porter (1991: Baraga, Clinton) and for Ohio by Dexter (1943: Geauga, Stark) and by Weeks and Marcus (1997: Franklin, Hardin, Portage).

Maps 1 and 2 locate the counties of Minnesota and Wisconsin, whose names are listed in Appendix III. The map for this species (Map 3) uses cross-hatching to depict the following Minnesota and Wisconsin county records. Each name marked with an asterisk represents a record not previously in the literature and is based on specimens kept in the MPM and SMM collections.

Minnesota: Anoka*, Beltrami*, Benton*, Big Stone*, Blue Earth*, Carver*, Cass*, Chippewa*, Chisago*, Clay*, Clearwater*, Cook*, Crow Wing*, Dakota*, Douglas*, Faribault*, Freeborn*, Hennepin

("Minneapolis"—University of Michigan Museum of Zoology Cat.No.52889, now at the NMNH), Houston*, Isanti*, Jackson*, Kanabec*, Kandiyohi*, Kittson*, Koochiching*, Lac Qui Parle*, Lake of the Woods*, Le Sueur*, Lincoln*, Lyon*, Marshall*, Martin*, McLeod*, Meeker*, Mille Lacs*, Morrison*, Mower*, Murray*, Nicollet*, Nobles*, Norman*, Otter Tail*, Pennington*, Pine*, Pipestone*, Polk*, Ramsey (Dexter 1953), Redwood*, Renville*, Rice*, Roseau*, St. Louis (Dexter 1953), Scott*, Sherburne*, Sibley*, Stearns*, Stevens*, Swift*, Todd*, Wadena*, Waseca*, Washington*, Watonwan*, Wilkin*, Wright*, Yellow Medicine*.

Wisconsin: Adams*, Ashland (University of Michigan Museum of Zoology Cat.No.52021, now at the NMNH), Barron*, Brown*, Buffalo*, Burnett (SMM)*, Calumet*, Chippewa*, Columbia*, Crawford*, Dane*, Dodge*, Door*, Dunn*, Florence*, Fond du Lac*, Forest*, Grant*, Green*, Green Lake*, Iowa*, Iron*, Jackson*, Jefferson (Forbes 1876), Juneau*, Kenosha*, Kewaunee*, Lafayette*, Langlade*, Lincoln*, Manitowoc*, Marquette*, Milwaukee*, Monroe*, Oconto*, Oneida*, Outagamie*, Ozaukee*, Pepin*, Polk*, Portage*, Racine*, Richland*, Rock*, Rusk*, St.Croix (SMM)*, Sauk*, Sawyer*, Shawano*, Sheboygan*, Trempealeau*, Vernon*, Vilas*, Walworth*, Washburn*, Washington*, Waukesha*, Waupaca*, Waushara*, Winnebago*.

Eubranchipus holmanii (Ryder 1879)

Herrick (1885) published an article on phyllopod Crustacea including "the common fairy shrimp" [Underwood (1886) citing Herrick, gave Minnesota as the state for this record.], which Herrick "assumed to be" *E.holmanii*, "although the oldest male seen differed in several particular[s] from the description of that species." Those particulars undoubtedly included the lack of these features on the antennal appendages: "cylindrical at their second third [second in relation to the first third, nearest the origin of the appendage], where about seven well-marked digitiform processes are found, the longest of which are about as long as twice the diameter of the proboscis [=appendage] at this point..." (Ryder 1879a). In Fig. 7 of Herrick's Pl.VIII and Fig. 1 of his Pl.X, the male antenna definitely lacks these characteristics and looks more like *E. bundyi*. Comparing Herrick's Pl.VII, Fig. 4 of the male copulatory organs to Brtek (1966) supports the view that the species whose development Herrick studied was probably *E. bundyi*. Perhaps this confused record accounts for prior reports of *E.holmanii* from Minnesota (Dexter 1959), but Belk and Brtek (1995) included Minnesota in the range of this species.

Dexter and Kuehnle (1948) reported *Eubranchipus holmanii* from a Stark County, Ohio, locality.

Eubranchipus intricatus Hartland-Rowe 1967

Daborn (1991) reproduced Hartland-Rowe's original figures of the female's thorax and the male's second antenna and added three drawings of his own with additional anatomical details. Though sharing many traits with *Eubranchipus bundyi*, the male *E. intricatus* lacks the knob-like protuberance on the labrum and possesses a small fan-like elaboration on the tip of the clasper. The female has large dorso-lateral extensions on the eleventh thoracic segment, in contrast to the tenth segment position for these in *E. bundyi*. Also, there is a broad diagonal sulcus on the lateral surface of the brood pouch in *E. intricatus*. Lateral views of the adult female and male are shown in Picture Key Figure 8.

The range of this species is given by Belk and Brtek (1995) as the provinces of Alberta, Saskatchewan and Manitoba and the state of Massachusetts.

The only reports from our region are from Minnesota (Map 5): 4 May 1997 for Meeker County, and 12 May 1997, a few miles east of Mora, Kanabec County. None of these SMM specimens were mature males.

Eubranchipus neglectus Garman 1926

Belk et al. (1998) have shown that *Eubranchipus vernalis* records from west of the Appalachian Plateau, such as those in Hay and Hay (1889), Pearse (1910), Van Cleave (1928), and Ferguson (1939), are probably *E. neglectus* Garman 1926. Such older *E. vernalis* records are not detailed here. An accurate and detailed definition of the range of *E. neglectus* in the Midwest awaits further collecting.

State records from the region were established in the literature by Brtek (1966) for Indiana (Marion County) and by Belk et al. (1998) for Michigan (Berrien County). Garman (1926) reported it from an unnamed Ohio locality, but more specific localities in the state were cited by Brtek (1966: Tuscarawas County) and Weeks and Marcus (1997: Butler, Columbiana, Cuyahoga, Franklin, Geauga, Hamilton, Hardin, Lake, Medina, Montgomery, Pickaway, Portage, Stark and Summit counties). Illinois records for Fayette (28 March 1998) and Vermilion (17 March 1999) counties are documented by specimens received from J.Petzing of the Illinois Natural History Survey. The MPM collection contains specimens from Indiana's Switzerland County, a record previously unreported in the literature.

Eubranchipus ornatus Holmes 1910

This species was described from waters "near Madison" Wisconsin by University of Wisconsin (UW) zoologist Samuel J. Holmes (1910). In his taxonomic treatment of the family Chirocephalidae, Brtek (1966) provided a description and detailed illustrations of *Eubranchipus ornatus*. Picture Key Figure 9 shows lateral views of the adult female and male.

Holmes (1910) also included comments on his experiments with the responses of this fairy shrimp to light. He concluded that their usual posture of swimming on their backs was due, in part at least, to their orientation with respect to the source of light.

In Wisconsin, *Eubranchipus ornatus* was found only in ponds that also contained *E. bundyi*. This phenomenon was originally observed by Holmes (1910). In this state mature *E. ornatus* have been found 3-20 April, in water temperatures ranging from 6 to 10°C (mean=8°C).

The range of this species was given by Belk and Brtek (1995) as the provinces of Alberta and Manitoba and in the U.S., Wisconsin west to Montana and south to Nebraska.

State records from the region were established in the literature by Creaser (1930a) for Minnesota and by Holmes (1910) for Wisconsin [type locality].

Map 4 depicts Minnesota and Wisconsin county records. Each of the following names marked with an asterisk represents a record not previously in the literature and is based on specimens in the MPM and SMM collections.

Minnesota: Anoka*, Hennepin*, Isanti*, Jackson*, Kandiyohi*, Lac Qui Parle*, Lesueur*, Marshall*, Martin*, Murray*, Ramsey*, Redwood*, Rice*, Scott*, Stearns*, Watonwan*, Wright*.

Wisconsin: Dane (Holmes 1910), Milwaukee*, Rock*, St.Croix* (SMM, 1—determined by Dale Chelberg, 14 November 1997), Trempealeau*.

Eubranchipus serratus Forbes 1876

The original description of this species by Forbes (1876) was based on specimens from an unnamed Illinois locality. In his monograph on the family, Brtek (1966) included illustrations showing that, in comparison with other *Eubranchipus*, *E. serratus* males have antennal appendages that are much more robust. The female has a brood pouch with three posterior lobes and a lateral fold on each side.

Picture Key Figures 5 and 6 show the extension of the posterior corners of the abdominal segments in both males and females of this species, a feature giving the marginal outline of the abdomen its distinctive serrated appearance. Each segment is dorso-ventrally flattened towards its lateral edges, and the last two before the cercopod are fused together. Lateral views of the adult female and male are shown in Picture Key Figure 10.

Dexter and Ferguson (1943) studied the life history and distribution of this species. Belk (1984) studied the mating behavior.

In Wisconsin, *Eubranchipus serratus* has been collected least often of the three *Eubranchipus* species found thus far. Mature specimens in the MPM collection were collected during the period 2-29 April. Water temperature data for Wisconsin collections of mature specimens of *E. serratus* range from 6 to 15°C (mean=10.5°C).

The range of this species was given by Belk and Brtek (1995) as British Columbia in Canada and in the U.S. from east to west coasts with southernmost populations in Arizona, Oklahoma and Virginia.

Initial state-level records were established in the literature by Forbes (1876) for Illinois [type locality], by Pennak (1953) for Wisconsin, and by Dexter and Ferguson (1943) for Ohio. More specific localities were given for Illinois by Dexter (1953: Champaign County); for Indiana by Dexter (1953: Jasper County, 1956: Tippecanoe County); and for Missouri by Pearse (1912: St. Louis County), Dexter (1953: St. Charles County), and Hazelwood and Hazelwood (1985: Howard County).

We examined former University of Michigan specimens (Cat. No.53393) now at the NMNH and verified a Charleston [Coles County] Illinois record for this species. Illinois records for Cass (25 March 1998) and Clark (29 March 1999) counties come from specimens received from J.Petzing of the Illinois Natural History Survey. Females of this species from Cook (31 March 1999) and Will counties (21 April 1999), Illinois, were received from T. Anton.

We examined one lot of Field Museum specimens of *Eubranchipus serratus* (previously identified as *E. vernalis*) from Cook County, Illinois, and found a fairly high proportion of gynandromorphic individuals among them (males=43, females=116, gynandromorphic=9). Dexter (1953) reported gynandromorphic specimens of this species from a pond on the campus of St. Joseph's College, Indiana.

Jass (1976) questioned prior Wisconsin records for this species, believing that there had been a mis-reading of the original Forbes (1876) description, in which Packard (1883) inserted the interpretative word "specimen" into Forbes' text, and thus mistakenly applied to *Eubranchipus serratus* a statement which Forbes had meant to be applied to *E. bundyi*. An authentic state record was established on 23 April 1993, when specimens of *E. serratus* were collected in Racine County, Wisconsin (Belk 1994). These voucher specimens are in the MPM collection, as are those from another southeastern Wisconsin locality in Waukesha County, COUNTY RECORD. On 29 March 1998, W. Suter (Carthage College) collected *E. serratus* from a temporary pond at Chiwaukee Prairie in Kenosha County, COUNTY RECORD. On 29 April 1998, *E. serratus* was collected on the grounds of the Milwaukee County Zoo, COUNTY RECORD. Map 5 depicts these southeastern Wisconsin county records, based on MPM specimens.

Streptocephalidae

Streptocephalus sealii Ryder 1879

Creaser (1930b) reviewed the North American members of this genus and included an illustrated key and distribution map for the then known species. Distinctive features of *S. sealii* are shown in Picture Key Figures 1-2 and 11.

Baqai (1963) studied the postembryonic development of this fairy shrimp. At the University of Wisconsin Laboratory of Limnology, Wiman (1979, 1981) examined the correlation between patterns of mating behavior and speciation in members of the genus *Streptocephalus*.

Belk and Brtek (1995) described the range of this species as widespread in North America from southern Canada through the U.S. into southern Mexico.

Midwestern state and county records in the literature were established for Illinois (Jackson and St. Clair counties) by Van Cleave (1928), for Minnesota (Ramsey County) by Dexter (1953) and Chelberg (1972: Hennepin County), and for Missouri by Dexter (1956: Cooper County) and Hazelwood and Hazelwood (1985: Boone County).

The relatively late (9 June) Minnesota collecting date (Chelberg 1972) may indicate differences in this species' reactions to physicochemical factors of the environment. Eriksen and Belk (1999) categorized it as an inhabitant of cold-water pools which are low in dissolved solids, predictable, and long-lived.

Streptocephalus texanus Packard 1871

Creaser (1930b) included in his review of the genus camera lucida drawings (Plate II, Figs. 5 and 6) of the elaborately developed second antenna and cercopods of the male *S. texanus*. The range of this species extends from the U.S. west of the Mississippi River south as far as the Mexican state of Oaxaca (Belk and Brtek 1995).

The first record in the literature for Missouri (Boone County) was established by Dexter (1956). Herpetological research in Iowa (Farrar and Hey 1997) has added this species to its state list. Personal communication with Farrar in 1997 confirmed that Denton Belk had provided species determinations for the fairy shrimps collected as part of this Iowa State University research project.

Eriksen and Belk (1999) categorized this as a species of warm-water pools which are moderate in dissolved solids, somewhat unpredictable as to when they appear, and short-lived.

Thamnocephalidae

Thamnocephalus platyurus Packard 1877

As all members of the genus *Thamnocephalus, T. platyurus* differs from our region's other anostracans by having the cercopods [posterior appendages] broad and flat and fused to the abdomen laterally (Fitzpatrick 1983).

Thamnocephalus platyurus ranges throughout the western U.S. and northern Mexico (Belk and Brtek 1995). The only records in the literature from our Midwestern region are for Missouri (Dexter 1956: Boone County) (Hazelwood and Hazelwood 1985: Howard County). This species was also reported from Iowa via personal communication from Dr. Eugenia Farrar of Iowa State University in 1997, whose research has added this species to the fairy shrimps from that state (determination by Dr. Denton Belk).

Eriksen and Belk (1999) included this species with those fairy shrimps found in the same category of warm-water pools that comprise the habitat of *Streptocephalus texanus*.

Fairy Shrimp Life History and Hatching Phenomena

Factors governing the hatching of the encysted eggs of fairy shrimp are the key to their survival in ephemeral habitats. The vernal ponds that are the most common habitat for Midwestern fairy shrimps may hold water for less than three months, during which the newly hatched larvae molt to adulthood and the adults reproduce and die, leaving behind only their encysted eggs. According to Baird (1850) the original 1803 description of the chirocephalid genus *Chirocephalus* was based on animals raised from larvae hatched out of dried mud. Most subsequent writers therefore assumed that encysted fairy shrimp eggs were able to survive desiccation. The nature of the resting state in various fairy shrimp species remains a very complex area of anostracan biology, with many questions still incompletely answered.

At a latitude similar to Minnesota's, Broch (1965) reported on physio-chemical conditions present at his *Eubranchipus bundyi* study site. At this temporary pond in young hardwood forest 10 miles east of Ithaca, New York, the drying of late summer and fall was found (Broch 1965) to increase oxygen tension and cause encysted eggs to pre-hatch. Pre-hatching was a term Broch used to describe an initial opening of the tertiary membrane, after which the embryo still remained within a cuticle which protruded from the ruptured cyst. This phase occurred at low temperatures in the moist forest litter at his temporary pond study site. Subsequent springtime inundation of the pond site with cool water decreased oxygen tension for pre-hatched eggs on the moist surface of ground that was destined to soon again become the pond bottom. This field data was compared to a laboratory study of egg development (Broch 1964).

Mossin (1986) also paired field measurements and laboratory experiments to identify the roles of temperature, pH, carbon dioxide and oxygen in inducing embryonic development and spring hatching of the European fairy shrimp *Eubranchipus (Siphonophanes) grubii*. These factors had to be at specific levels, in the correct sequence, in order for this northern fairy shrimp to be able to go through its annual life cycle. The last stage of the hatching process was triggered by the slow inundation by water from snow melt and spring rain, creating the necessary physicochemical environment. This situation provided a low but sufficient amount of oxygen for the hatching process. The rising amount of carbon dioxide was the final stimulus for a successful hatch, starting larvae on their fast track to maturation.

Although Chelberg's (1964a) work predated some recent studies such as Mossin's (1986) and was in the public record (Chelberg 1964b), key details revealed by Chelberg have not been generally available to subsequent researchers. Chelberg's Minnesota study of the life history of *Eubranchipus bundyi* was begun in the spring of 1960 with field observations and photography of the animals in the ponds and in the laboratory. The result was a detailed, photo-documented look at the life history stages of this species. For example, after pre-hatch had opened the exterior layer of the encysted egg, the larval stage inside was shown to be enclosed within a transparent vitelline membrane or cuticle (outlined in the lower right-hand specimen in Plate IV). Sequences of laboratory conditions of temperature and moisture were matched with conditions through the seasonal cycle at field sites, in order to determine which factors initiated *E. bundyi* egg development. For details of the laboratory portion of this study, see Chelberg (1964a).

A key factor in understanding the phenomenon of free-swimming larvae appearing shortly after ponds are filled with water in spring is the knowledge of the advanced phase of development the larvae have reached prior to this time (=Broch's (1964) autumnal pre-hatched phase). This leads to the expectation that if another inundation covered a larger area of soil containing larvae at the same pond site, an additional hatch would occur consisting of those pre-hatchlings newly inundated. Therefore collections from ponds filled in a step-wise manner should contain evidence of populations of mixed ages, the result of multiple hatches.

In the five Minnesota ponds that were the special focus of Chelberg's (1964a) doctoral research, he was able to follow the habitat factors which controlled the final hatching of *Eubranchipus bundyi* cysts in the field. These field studies were conducted in an area 40-60 mi north of Minneapolis in Isanti, Chisago, and Anoka counties (Plate V). They provided an excellent example of how limnological differences between such ephemeral wetlands can significantly affect the survival of their resident anostracan populations.

One of the ponds (Pond #1 or Carl's Pond) was in northern Isanti County (R23W T37N Stanchfield Township, Section 13) four miles south of the Kanabec County line and quarter mile from the Chisago County line. It was on slightly sloping land and its water seeped over the edge along the lower slope into a swamp. The pond, when full, measured 150 ft by 70 ft with a center depth of 20-24 inches, but by mid-July was completely dry.

Another pond (Pond #2 or John's Pond) was in Chisago County (R22W T37N Nessel Township, Section 18) and lay a mile east of the first pond in a depression that had been a small gravel pit 40 years before. The pond collected runoff from an area 100 ft by 300 ft and in 1960 covered an area 100 ft by 45 ft. Maximum depth was 24 inches. During most of the summer the center of the area remained soft and muddy.

Two East Isanti ponds were in southern Isanti County (R22W T35N Isanti Township, Section 12). The land was slightly rolling, with its highland 35-50 ft above its swamps. The two ponds lay close together in depressions on the side of a long gentle slope. The south, or main pond (Pond #3), was a comparatively large sheet of water in 1960, 250 ft by 150 ft, with a center depth of 18 inches. The north pond (Pond #4) was smaller, 25 ft by 50 ft, with about the same depth as the larger pond.

The last pond (Pond #5, W&W Pond) lay along state highway 65 in Anoka County (R23W T33N Bethel Township, Section 8), three and a half miles south of the Isanti County line. It lay in an elliptical depression 35 ft below the road level. The pond drained an area 150 yd by 400 yd and had some water in it most of the year. This was the only pond of the five which contained water (ice) in its center during the winter of 1960-1961.

The intensive study of these five ponds (Chelberg 1964a) produced a number of insights into the factors that govern the hatching phenomena of fairy shrimp cysts in differing habitats. Carl's Pond (Pond #1) showed a single group of shrimp passing through a "normal" pattern of growth. John's Pond (Pond #2) had two separate size classes and two growth curves. In the main or south pond (Pond #3) at the East Isanti location, there were four separate hatches. The first did not survive, the middle two corresponded chronologically to the two in John's Pond, and the fourth yielded relatively few individuals. The north pond (Pond #4) clearly showed one hatch, which corresponded in timing with the first hatch in the south pond. A second hatch was evident, but not subject to precise dating. W&W Pond (Pond #5) records revealed two hatches corresponding to the first two in the main East Isanti pond, but there was evidence in the first sample of an even earlier hatch. These records indicate that in four of the ponds there were multiple hatches, that is, there were at least two separate peaks of hatching separated by a period in which few or no new larvae appeared.

Two factors controlled the appearance of multiple hatches; one was the flooding of additional areas of soil containing pre-hatched cysts and the second was the length of time which the pre-hatched cysts could survive in the soil in the spring. Flooding of additional soil in turn was governed by two factors: first, precipitation, and the second, the morphometry of the ponds. Comparing the hatching record with the precipitation record indicates that peak periods of hatching occurred soon after a heavy rain or melting of snow.

The 1961 winter had been relatively dry. All snow in open areas had evaporated by the end of February, but about seven inches of snow fell during the first week in March. Some of this evaporated, but some melted and caused a slight filling of the ponds during the middle of the month. Newly hatched larvae were collected 19 March in three ponds. Daytime temperatures rose to 60º F (15.5º C) for several days toward the end of the month without additional moisture. Almost an inch of rain fell on 27 March, providing the initial filling of Carl's Pond (#1) and John's Pond (#2) and a reappearance of water in the main East Isanti pond (#3). On 30 March, newly hatched shrimp were evident in four ponds. A small amount of rain the first week in April had no visible effect on hatching, but an inch and a half of mixed rain and snow from 11-16 April caused the appearance of newly hatched larvae in two and possibly three of the ponds by 19 April. Three inches of rain from 13-17 May raised three of the pond levels to new heights and a few new larvae appeared 19 May in the main East Isanti pond (#3).

Though successive rainfalls were general over the entire test area, not all ponds had multiple hatches. The differences in multiple hatches between the ponds were the result in part of the differences in the morphometry of the ponds. John's Pond (#2) and the main East Isanti pond (#3) both had obvious multiple hatches. They also had two morphometric features in common. Their basins were large enough to contain all the runoff which collected. They also had flat, gradually sloping bottom profiles which provided for a considerable increase in surface area with each small rise in water level. Consequently, each successive increase in precipitation inundated a new area of the pond basin. Carl's Pond (#1) and the north East Isanti pond (#4) on the other hand had basins which held only a limited amount of water as they had outlets which overflowed when a certain level was reached. The slope of the bottom along the margins was also steep enough so that any increase in water depth subsequent to the first hatching period did not greatly increase the surface area, nor inundate a significant amount of new soil. W&W Pond (#5) enlarged considerably with each rain and should have produced additional separate hatches but did not, possibly due to extensive collecting of adults along the pond's periphery in the previous season that may have reduced the number of eggs laid in those areas. The population during the 1961 season was rather small.

This comparative five pond example shows well the differences between ephemeral wetlands within even a fairly circumscribed area. These pond differences did result in different fairy shrimp hatching patterns and thus provided insights into the complexity of meteorological and physiographic factors which determine the ability of fairy shrimp to survive at a particular site in a particular season.

Discussion of Predators and Conservation

Pearse (1913a) published in the Wisconsin Natural History Society Bulletin one of the earliest studies of fairy shrimp behavior. It included his hypothesis regarding sex-specific differences in behavior and their possible effect on differing predation rates on each sex. Pearse hypothesized about differences between males and females in their orientation toward light, his observations suggesting that females had a stronger orientation towards the substrate and that males showed a comparatively stronger orientation towards light, resulting in differences in the micro-habitats occupied by each. In their active search for mates, males would spend more time in the open water. But females would be more likely to be hidden among debris at the bottom and thus, Pearse assumed, perhaps receive more protection from potential predators, such as the aquatic immatures of various beetles, a situation depicted in the illustration accompanying Pearse's article.

Many aquatic insects are known fairy shrimp predators, including adults, such as diving beetles (Dytiscidae) and water scorpions (Nepidae), as well as immatures. Larval dipterans were cited by Graham (1994). Although observations of predation in the wild are rare, a number of laboratory studies have documented the ease with which certain predatory species, for example backswimmers (Notonectidae) (Clark 1928), prey on fairy shrimp. Woodward and Kiesecker (1994) found that the clarity of the water affected the ability of notonectids to prey on fairy shrimp, thus pointing to a complex picture of biotic and abiotic factors governing the vulnerability of anostracans to predation in a particular site.

The puzzling occurrence of seemingly similar ponds (for example, Pfennig et al. 1991), some with fairy shrimp and others without, has led certain researchers to explore hypotheses regarding the potential for predators to cause the complete eradication of the shrimp from the sites in question. Assuming that the likelihood for fairy shrimp to be introduced to all ponds was equal, some studies have focused on differences in predators between sites, the expected result being that fairy shrimp populations would be able to become established only in those where predation did not exclude them. Aspects of this predator/prey relationship have been explored by Dodson and Dodson (1971), Sprules (1972), and Pfennig et al. (1991).

Especially important as potential predators are the larvae of those amphibians, such as the mole salamander family Ambystomidae, that breed in temporary ponds in early spring. In Minnesota and Wisconsin, one of the most common members of this family is *Ambystoma tigrinum* (Green). This widespread salamander was the subject of the Dodson and Dodson (1971) and Sprules (1972) predator/prey research. Farrar and Hey (1997) demonstrated the dependence of certain amphibian tadpoles on a diet of fairy shrimp, a prey item which may be uniquely able to share habitat with spadefoot toads (*Spea bombifrons* Cope) in short-lived rain ponds in Iowa.

In some studies where a large number of predatory species have been observed to inhabit temporary ponds, this factor has been used to lend support to the assumption that predation is the obvious factor causing the absence of fairy shrimp from certain sites (for example, Ardo 1948). However, McCarraher (1970) found fairy shrimp coexisting with fish under specialized circumstances in certain alkaline lakes in the sandhills region of Nebraska. Some authors (for example, Morgan 1930) have hypothesized that the ability of fairy shrimp to coexist with aquatic predators in certain situations is due to the very early spring timing of their mating and reproduction, which are largely completed before cold-blooded carnivores sharing their habitat have begun to feed at their maximum rate.

Among the vertebrate predators of fairy shrimp are several duck species, including the longtailed duck, *Clangula hymenalis* (Linneaus) (Cottam 1939), blue-winged teal, *Anas discors* Linnaeus (Swanson et al. 1974) and northern pintail, *Anas acuta* Linneaus (Krapu 1974). In certain habitats where other prey are not present, fairy shrimp have been reported as the chief diet item, as in one study of longtailed duck ducklings in fishless Swedish lakes (Pehrsson and Nystrom 1988).

However, even when they are a lesser part of the diets of these ducks, the contribution of anostracans may be nutritionally significant. For example, the pintail is generally thought of as a vegetarian. However, this idea is based primarily on food habit studies of non-breeders (for example, Anderson 1959). When breeding birds were studied, animals were found to comprise about 80 percent of the diet, especially for females. Fairy shrimp were 13-17 percent of that nonvegetarian portion (Krapu 1974). Waterfowl biologists have concluded that the animal content of the diet of breeding females may contribute significantly to their reproductive success by providing certain nutrients required for the production of viable eggs.

As waterfowl and shorebirds migrate north in the spring, some recent research has linked their survival during migration to the fauna of temporary ponds as a food source. The flocks follow defined flight paths, such as the Mississippi flyway. This route takes them over a series of impermanent and often small wetland pools dotting the landscape, which have been formed by spring thaws and rains. In contrast to coastal migrants who make the entire trip with few stops (perhaps aided by stronger air currents along the coasts), research with several sandpiper species has shown that birds following inland routes seem to need a number of refueling stops, in order to maintain the high energy level necessary to complete the long journey (Skagen and Knopf 1994, Anonymous 1995).

Because the timing of this migration coincides with the early spring appearance of fairy shrimp in ephemeral ponds and wetlands along the way, these early springtime crustaceans are hypothesized to have a major role in making small aquatic stop spots rich and concentrated sources of food for the returning flocks (Saunders et al. 1993). The Nature Conservancy (Gutin 1993) and the Ducks Unlimited organization (Beno 1991) have taken the lead in the call for conservation of sufficient numbers of these small wetlands, because of the key role they play in maintaining populations of waterfowl for the future.

Migrating waterbirds also play a role in dispersing fairy shrimps to isolated sites. Viable encysted eggs may be carried in mud on the feet or wings or even pass unharmed through the bird's gut (Proctor 1964, Proctor et al. 1967). Donald (1983) hypothesized that the seemingly puzzling, abrupt appearance and disappearance of fairy shrimp in certain sites over the years may be due to a series of introductions and subsequent colonizations initiated by migrating birds. If a formerly thriving fairy shrimp population undergoes extinction as the result of unfavorable pond conditions, the use of the pond by a new season's migrants may result in a chance reintroduction and possible reestablishment of fairy shrimp again at that site.

Map 6 gives all known county records (solid=present) for the distribution of *Eubranchipus* in the U.S. (Jass and Klausmeier 2000) and shows some correlation with the four major flyways used by migrating waterfowl. Especially in the eastern U.S., fairy shrimps whose seasonal cycles most closely synchronize the annual return of migrant birds from the south with the appearance of matures in vernal ponds do belong to this genus. A similar connection for western U.S. fairy shrimps was highlighted by Saunders et al. (1993).

Factors of concern for conservation of fairy shrimp species in the U.S. are off-road vehicle traffic (Hathaway et al. 1996), precipitation and runoff waters that have been contaminated by pesticides (Lawrenz 1985, Batzer and Sjogren 1986), and most especially agricultural and urban developments which destroy habitats (Eng et al. 1990).

Krapu (1974) has detailed how the habitat destroyed by agricultural development has affected pintail ducks and their use of various wetlands. In agricultural situations, studies of breeding pintails showed a significant difference between springtime wetlands that were tilled during the summer months and those that were left untilled, in terms of the kind of food they provided for the ducks. Aquatic plants which were eliminated by tilling the land had been the ones providing the best niches for those invertebrates which as food items resulted in good egg production by the pintails. Springtime wet spots in fields that had been cultivated in summer were more silty too, and that factor also decreased the numbers of important food item invertebrates. Tradeoffs which propose to exchange these small scattered wet spots for equal acreage of permanent, deeper wetlands unfortunately are thus not equivalent in their ability to maintain an adequate food base for breeding waterfowl.

In some ways, the small size of these sites is their unique advantage in terms of suitability for anostracans. In small ephemeral wet spots, many aquatic predators (such as fish) are unable to survive, thus allowing fairy shrimp populations to thrive. Also, for surface-feeding waterfowl such as the pintail, it was the shallowness of very small wetlands which gave them access to the invertebrates which thrived there during the ducks' breeding season.

Initial steps in the conservation process for these wetlands include the location and identification of them within the landscape and the scientific assessment of differences in the types of habitat they provide. Naugle et al. (2001) used a geographic information systems (GIS) approach to evaluate the landscape of eastern South Dakota as wetland bird habitat and emphasized the importance of small shallow wetlands to the conservation of breeding waterfowl such as the northern pintail. Small (<0.5 ha) wetlands were the most abundant wetlands, especially in the unprotected category. Also, the suitability of larger wetlands as bird habitat declined when the smaller ones were removed from the study. The cause of such decline was due to the birds' behavior of moving between large and small wetlands to procure food and breeding sites. In Wisconsin, Dodson and Lillie (2001) examined the effectiveness of restoration measures on various types of wetlands, focusing specifically on the impact of wetland differences on their zooplankton communities including fairy shrimp.

In a unique move aimed at incorporating volunteer assistance in the process of taking an initial step toward protection of such sites, the state of Massachusetts in 1987 instituted a program of certification for vernal pools through their Wetlands Protection Act. Certification involves the maintenance of records giving a detailed locality description and data regarding the presence of key species for each site (Colburn 1995). Certifying pools affords no legal protection but does provide official documentation upon which protection might be based and can be used with already in-place conservation measures. Certification is a means of addressing the conservation of ephemeral wetlands and their inhabitants which could well be explored by states in the Midwest.

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MAP 2 Wisconsin counties.

MAP 3 Minnesota and Wisconsin county records for *Eubranchipus bundyi.*

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MAP 6. U.S. county-level records for the genus *Eubranchipus.*

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PICTURE KEY FIGURE 2 Features of male heads in *Branchinecta*, *Eubranchipus*, and *Streptocephalus*.

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PICTURE KEY FIGURE 4 Four male *Eubranchipus* spp. heads with frontal appendages lifted to show claspers and accessory structures.

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Appendix V: Plates

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PLATE II Anatomical terms labeled on ventral view, male genital segments and head of adult *Eubranchipus bundyi.*

PLATE III Apparatus for measuring and recording live fairy shrimp.

PLATE IV Photographs of live, unhatched, "fully-developed" larvae.

PLATE V Minnesota fairy shrimp ponds, 1961.

Appendix I: Midwestern Families and Species

Class Crustacea

Subclass Branchiopoda

Superorder Sarostraca

Order Anostraca (11 species)

Family Branchinectidae (2 species)

Branchinecta lindahli Packard 1883
Type locality: Wallace County, Kansas

Branchinecta readingi Belk 2000
Type locality: Fleeinghorse Lake, Alberta

Family Chirocephalidae (6 species)

Eubranchipus bundyi Forbes 1876
Type locality: Jefferson, Wisconsin

Eubranchipus holmanii (Ryder 1879)
Type locality: ditches near Woodbury, New Jersey

Eubranchipus intricatus Hartland-Rowe 1967
Type locality: about 26 km west of Calgary, Alberta

Eubranchipus neglectus (Garman 1926)
Type locality: bluegrass region of Kentucky

Eubranchipus ornatus Holmes 1910
Type locality: near Madison, Wisconsin

Eubranchipus serratus Forbes 1876
Type locality: near Normal, Illinois

Family Streptocephalidae (2 species)

Streptocephalus sealii Ryder 1879
Type locality: Woodbury, New Jersey

Streptocephalus texanus Packard 1871
Type locality: Clifton, Bosque County, Texas

Family Thamnocephalidae (1 species)

Thamnocephalus platyurus Packard 1877
Type locality: Ellis, Kansas

Appendix II: State Species Lists

The following state species lists were compiled mainly from the literature and the MPM and SMM collections. Sources and institutions contributing additional records are cited in the Acknowledgments and under each of the species treatments.

Illinois (4)
- *Eubranchipus bundyi*
- *Eubranchipus neglectus*
- *Eubranchipus serratus*
- *Streptocephalus sealii*

Indiana (3)
- *Eubranchipus bundyi*
- *Eubranchipus neglectus*
- *Eubranchipus serratus*

Iowa (3)
- *Branchinecta lindahli*
- *Streptocephalus texanus*
- *Thamnocephalus platyurus*

Michigan (2)
- *Eubranchipus bundyi*
- *Eubranchipus neglectus*

Minnesota (6)
- *Branchinecta readingi*
- *Eubranchipus bundyi*
- *Eubranchipus holmanii*
- *Eubranchipus intricatus*
- *Eubranchipus ornatus*
- *Streptocephalus sealii*

Missouri (4)
- *Eubranchipus serratus*
- *Streptocephalus sealii*
- *Streptocephalus texanus*
- *Thamnocephalus platyurus*

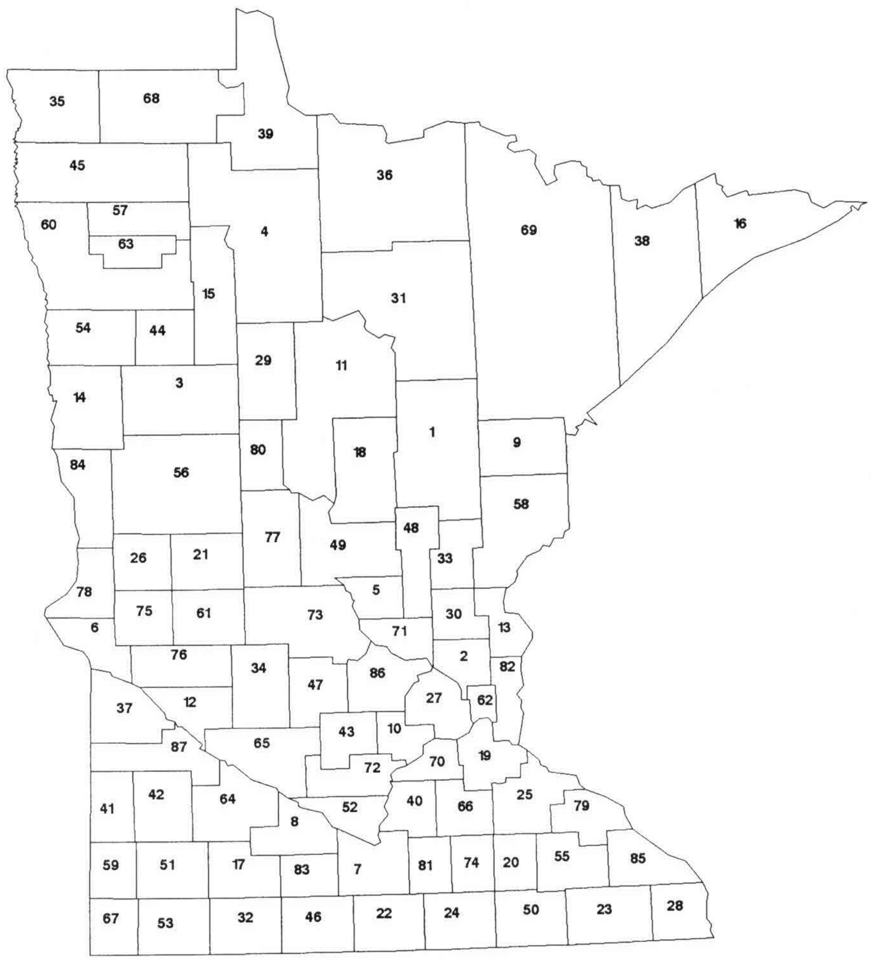
Ohio (4)
- *Eubranchipus bundyi*
- *Eubranchipus holmanii*
- *Eubranchipus neglectus*
- *Eubranchipus serratus*

Wisconsin (3)
- *Eubranchipus bundyi*
- *Eubranchipus ornatus*
- *Eubranchipus serratus*

Appendix III: Maps

Counties of Minnesota

1. Aitkin
2. Anoka
3. Becker
4. Beltrami
5. Benton
6. Big Stone
7. Blue Earth
8. Brown
9. Carlton
10. Carver
11. Cass
12. Chippewa
13. Chisago
14. Clay
15. Clearwater
16. Cook
17. Cottonwood
18. Crow Wing
19. Dakota
20. Dodge
21. Douglas
22. Faribault
23. Fillmore
24. Freeborn
25. Goodhue
26. Grant
27. Hennepin
28. Houston
29. Hubbard
30. Isanti
31. Itasca
32. Jackson
33. Kanabec
34. Kandiyohi
35. Kittson
36. Koochiching
37. Lac qui Parle
38. Lake
39. Lake of the Woods
40. Le Sueur
41. Lincoln
42. Lyon
43. McLeod
44. Mahnomen
45. Marshall
46. Martin
47. Meeker
48. Mille Lacs
49. Morrison
50. Mower
51. Murray
52. Nicollet
53. Nobles
54. Norman
55. Olmsted
56. Otter Tail
57. Pennington
58. Pine
59. Pipestone
60. Polk
61. Pope
62. Ramsey
63. Red Lake
64. Redwood
65. Renville
66. Rice
67. Rock
68. Roseau
69. Saint Louis
70. Scott
71. Sherburne
72. Sibley
73. Stearns
74. Steele
75. Stevens
76. Swift
77. Todd
78. Traverse
79. Wabasha
80. Wadena
81. Waseca
82. Washington
83. Watonwan
84. Wilkin
85. Winona
86. Wright
87. Yellow Medicine

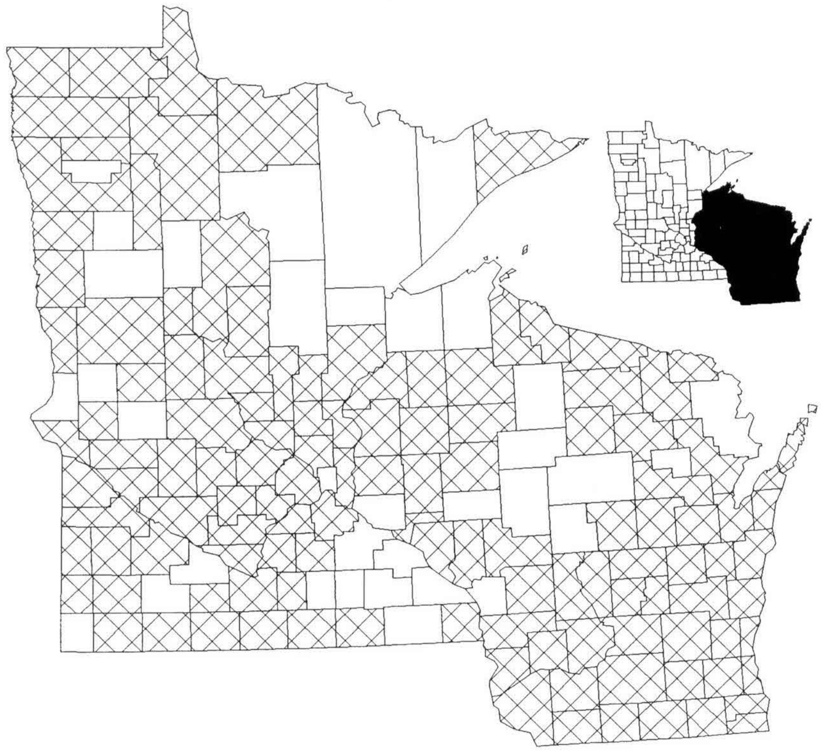


Map 1 Minnesota counties.

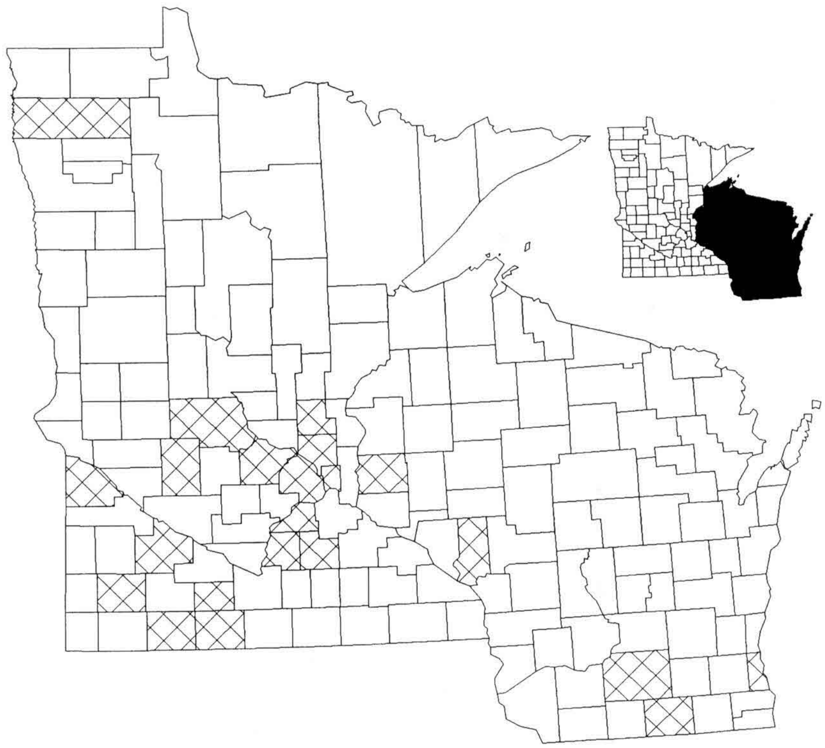
Counties of Wisconsin

1. Adams
2. Ashland
3. Barron
4. Bayfield
5. Brown
6. Buffalo
7. Burnett
8. Calumet
9. Chippewa
10. Clark
11. Columbia
12. Crawford
13. Dane
14. Dodge
15. Door
16. Douglas
17. Dunn
18. Eau Claire
19. Florence
20. Fond du Lac
21. Forest
22. Grant
23. Green
24. Green Lake
25. Iowa
26. Iron
27. Jackson
28. Jefferson
29. Juneau
30. Kenosha
31. Kewaunee
32. La Crosse
33. Lafayette
34. Langlade
35. Lincoln
36. Manitowoc
37. Marathon
38. Marinette
39. Marquette
40. Menominee
41. Milwaukee
42. Monroe
43. Oconto
44. Oneida
45. Outagamie
46. Ozaukee
47. Pepin
48. Pierce
49. Polk
50. Portage
51. Price
52. Racine
53. Richland
54. Rock
55. Rusk
56. St.Croix
57. Sauk
58. Sawyer
59. Shawano
60. Sheboygan
61. Taylor
62. Trempealeau
63. Vernon
64. Vilas
65. Walworth
66. Washburn
67. Washington
68. Waukesha
69. Waupaca
70. Waushara
71. Winnebago
72. Wood

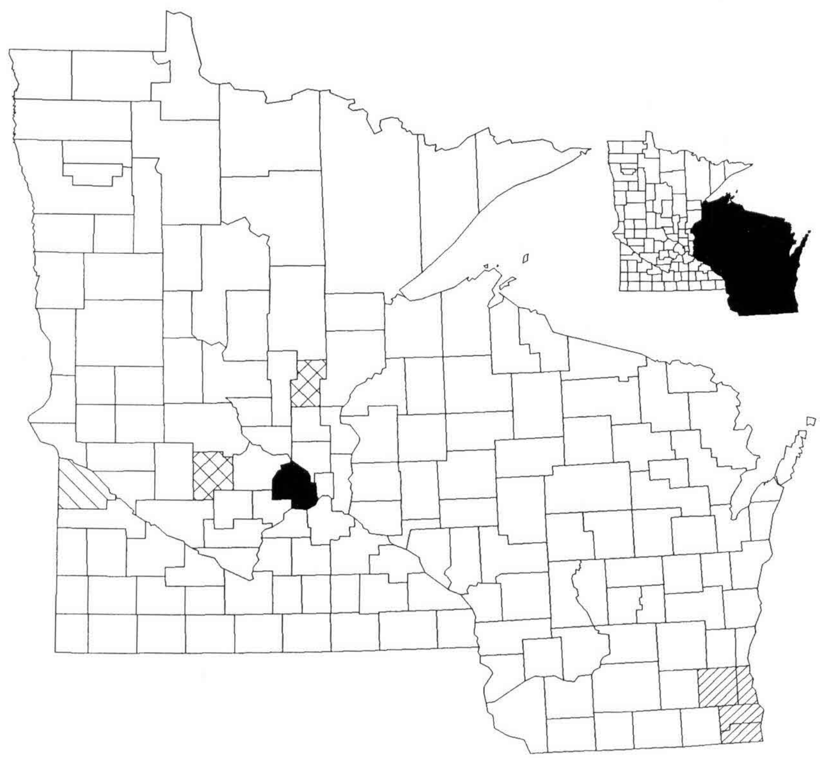
MAP 2 Wisconsin counties.



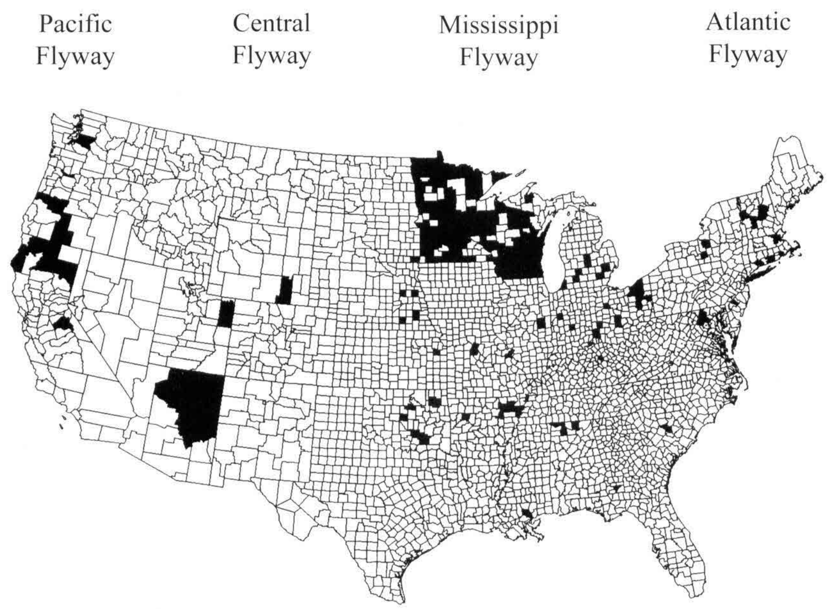
Map 3 Minnesota and Wisconsin county records for *Eubranchipus bundyi.* Inset shows Minnesota and Wisconsin boundary.



MAP 4 Minnesota and Wisconsin county records for *Eubranchipus ornatus*. Inset shows Minnesota and Wisconsin boundary.



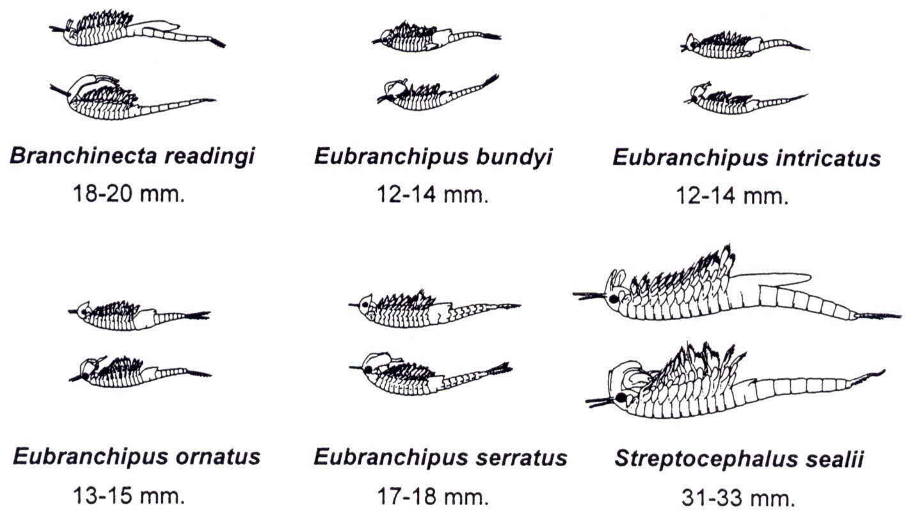
Map 5 Minnesota and Wisconsin county records for *Branchinecta readingi* (slant), *Eubranchipus intricatus* (cross), *E. serratus* (fine slant), and *Streptocephalus sealii* (solid). Inset shows Minnesota and Wisconsin boundary.



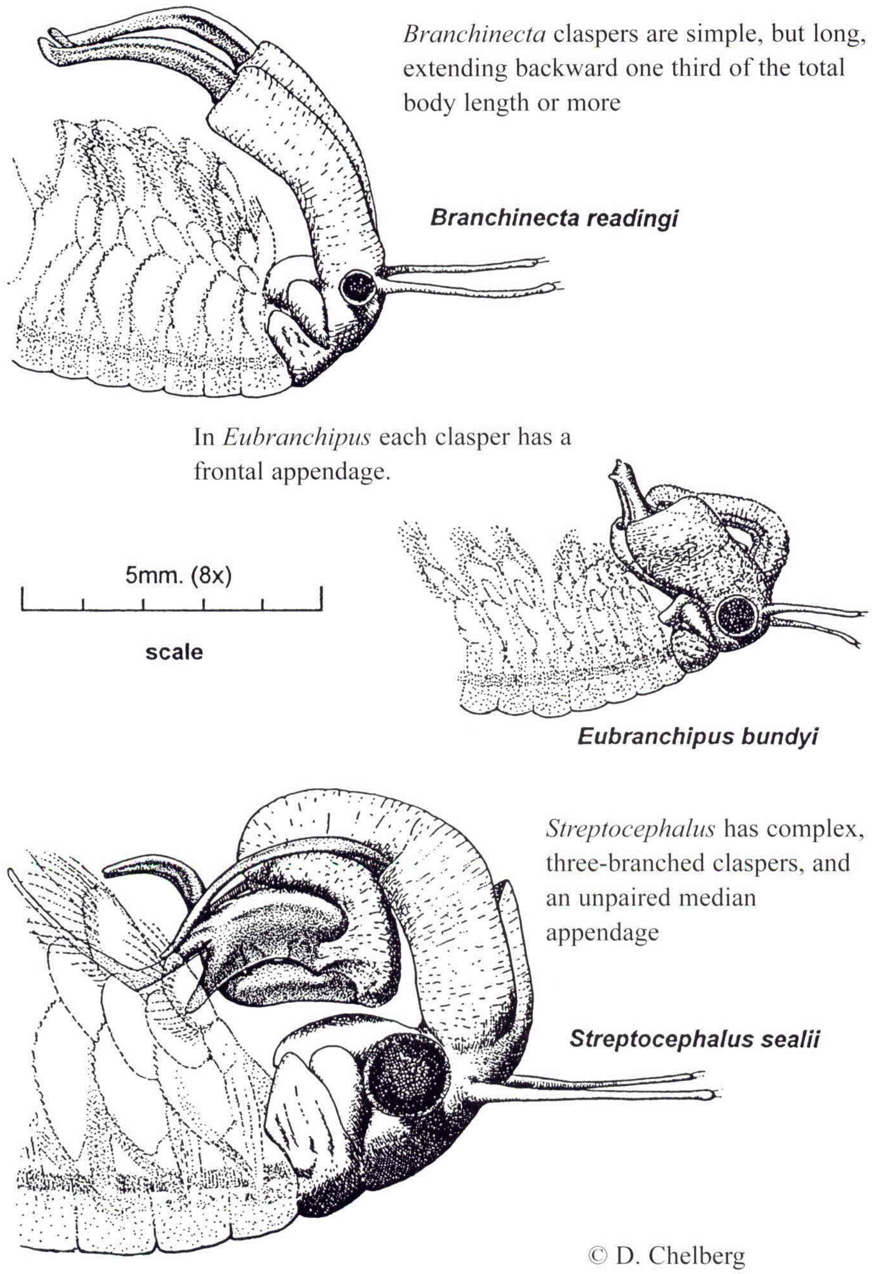
Map 6 U.S. county-level records for the genus *Eubranchipus*.

Appendix IV. Picture Key

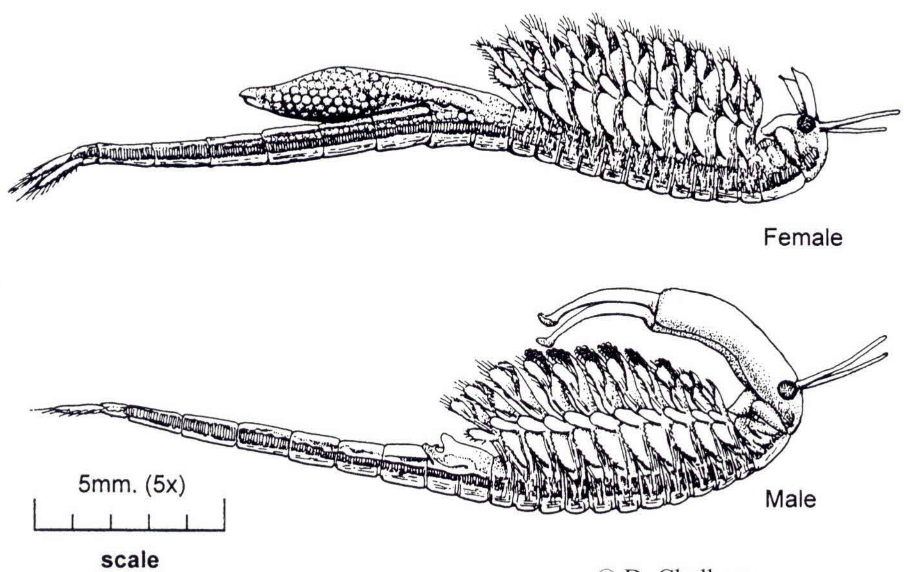
Total length is measured from ocellus to anus



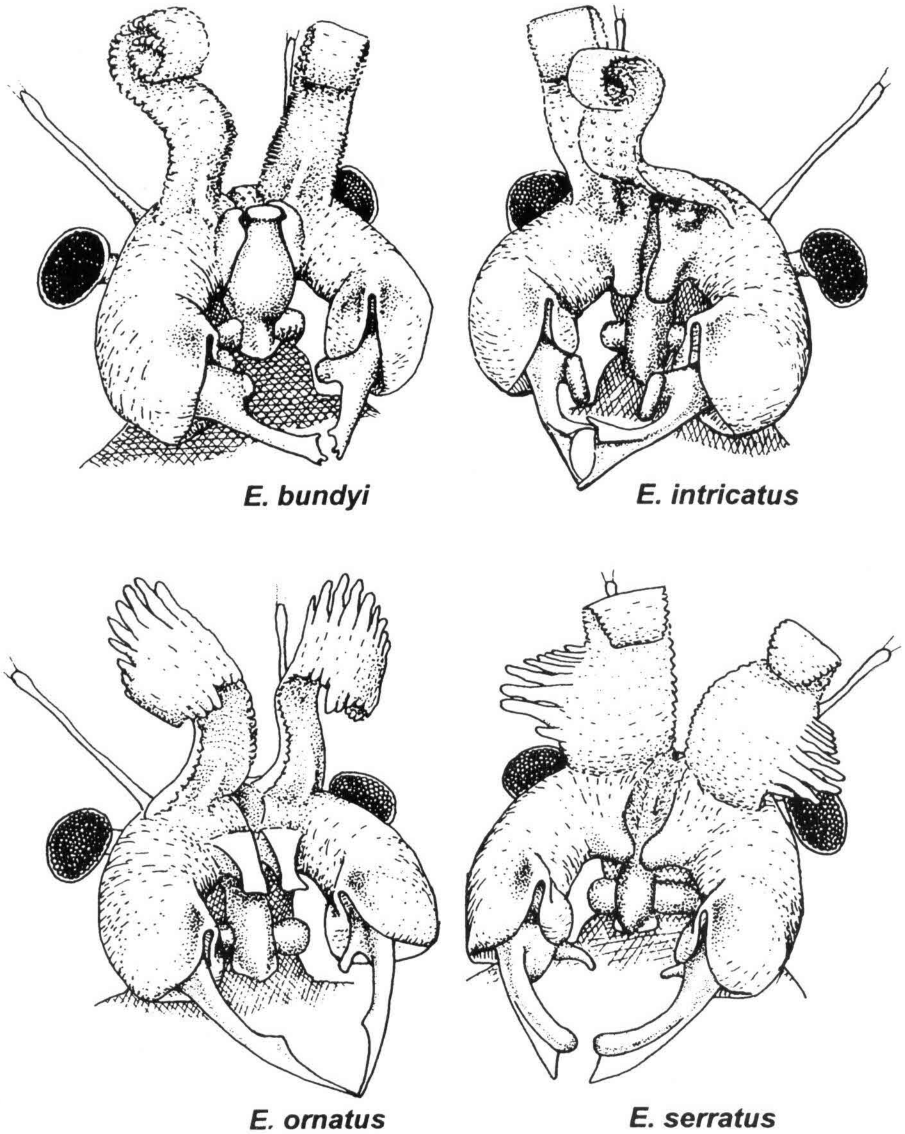
Picture Key Figure 1 Typical sizes of Upper Midwest fairy shrimp.



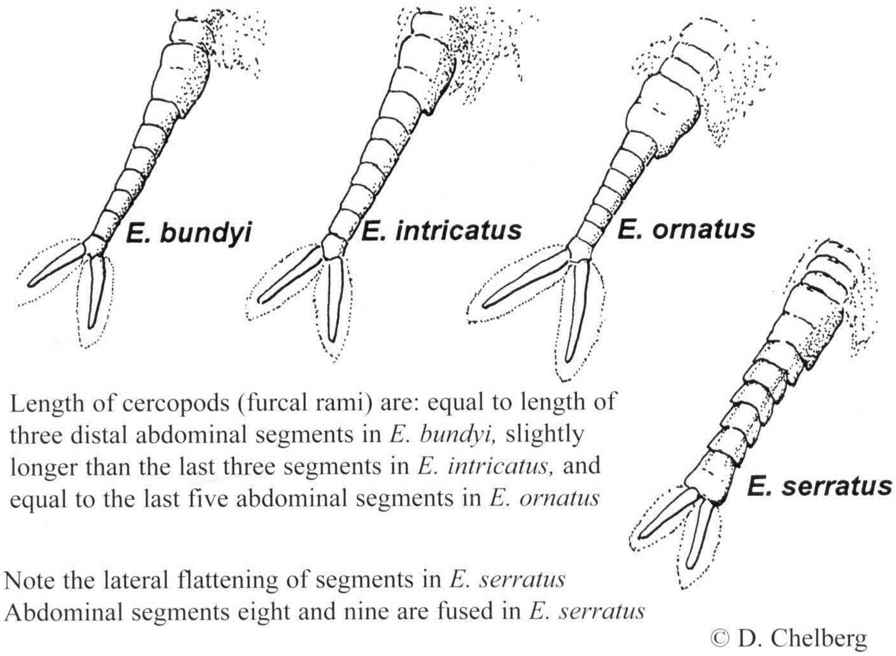
Picture Key Figure 2 Features of male heads in *Branchinecta*, *Eubranchipus*, and *Streptocephalus*.



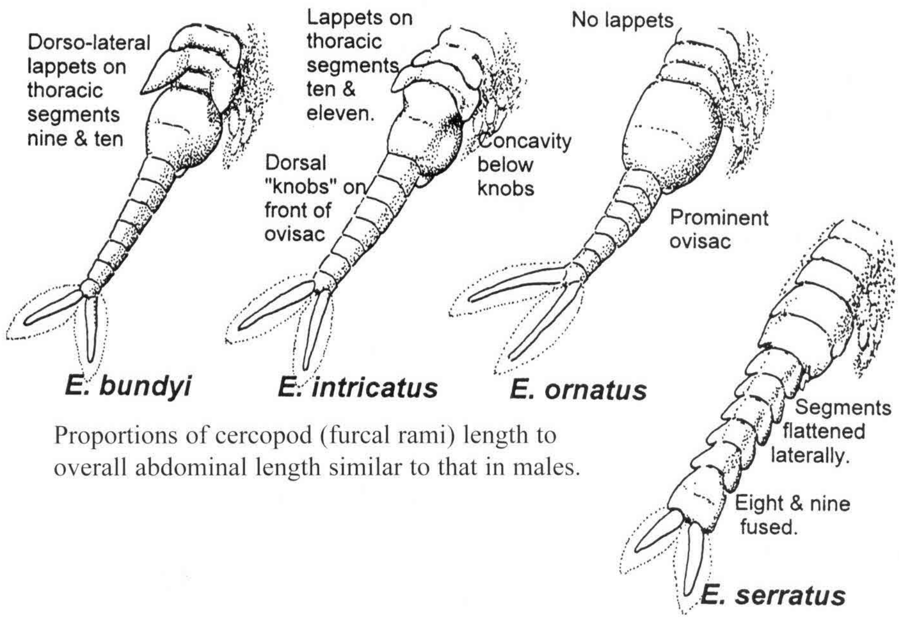
Picture Key Figure 3 Lateral view of female and male *Branchinecta readingi*.



Picture Key Figure 4 Four male *Eubranchipus* spp. heads with frontal appendages lifted to show claspers and accessory structures.

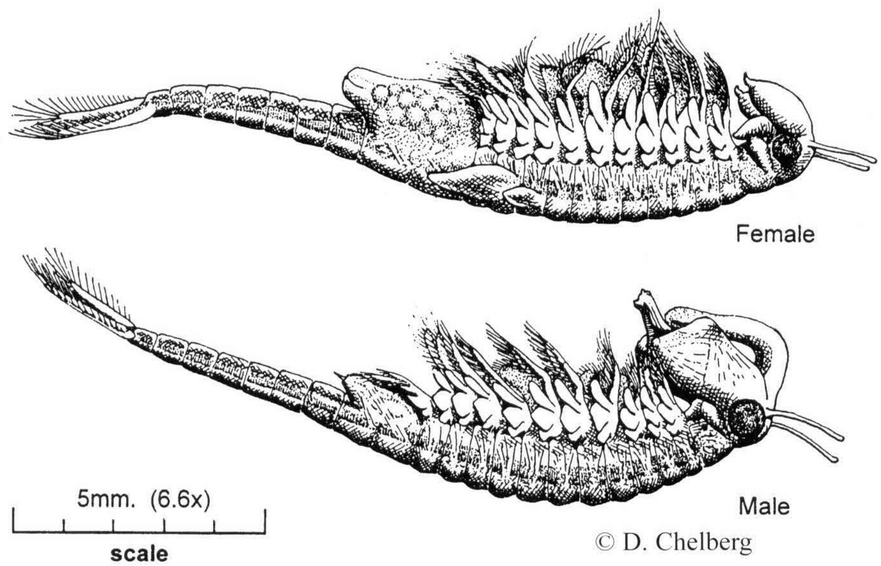


Picture Key Figure 5 Dorso-lateral views of posterior segments of four male *Eubranchipus* spp.

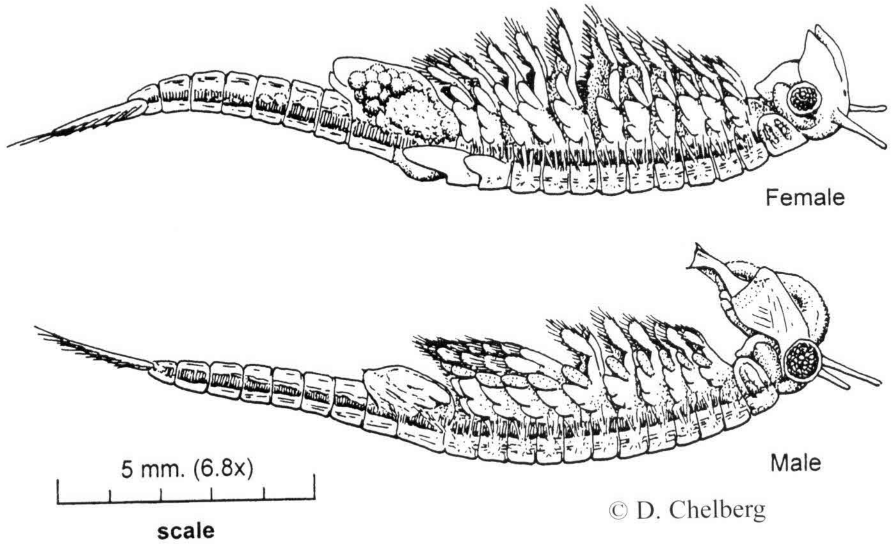


Proportions of cercopod (furcal rami) length to overall abdominal length similar to that in males.

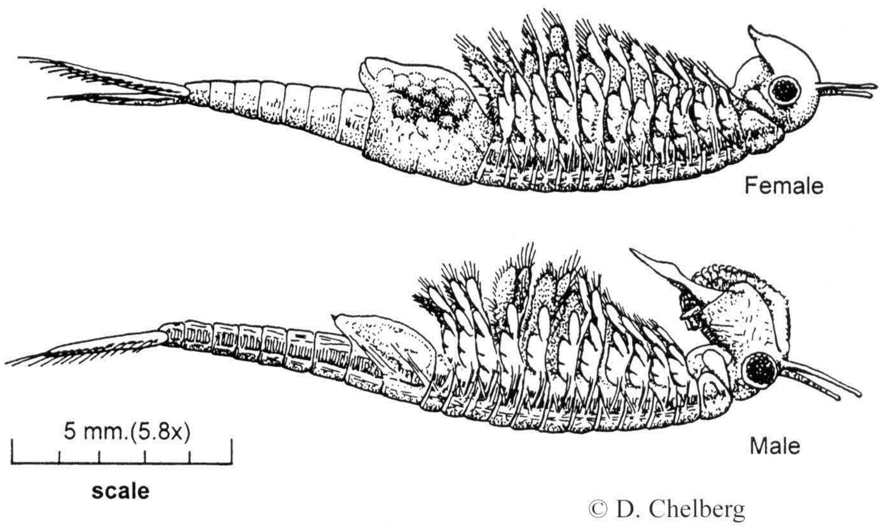
Picture Key Figure 6 Dorso-lateral views of posterior segments of four female *Eubranchipus* spp.



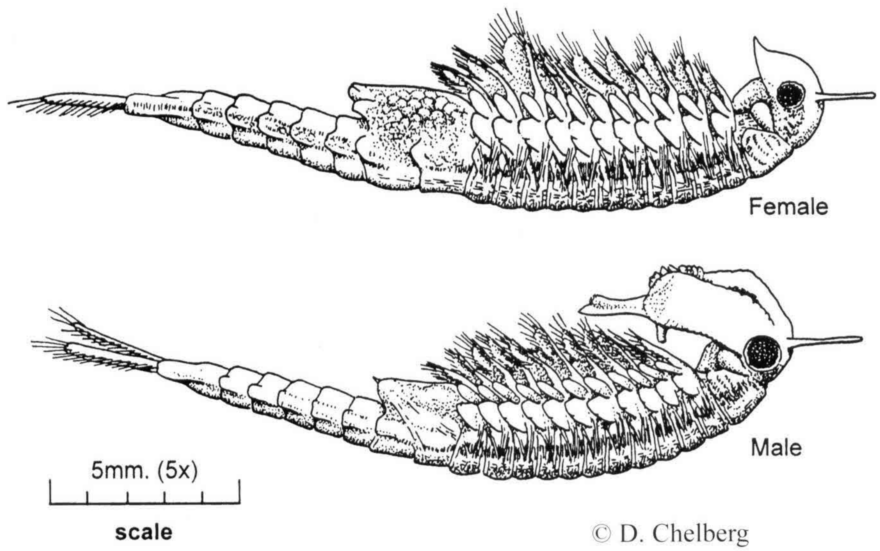
Picture Key Figure 7 Lateral view of female and male *Eubranchipus bundyi*.



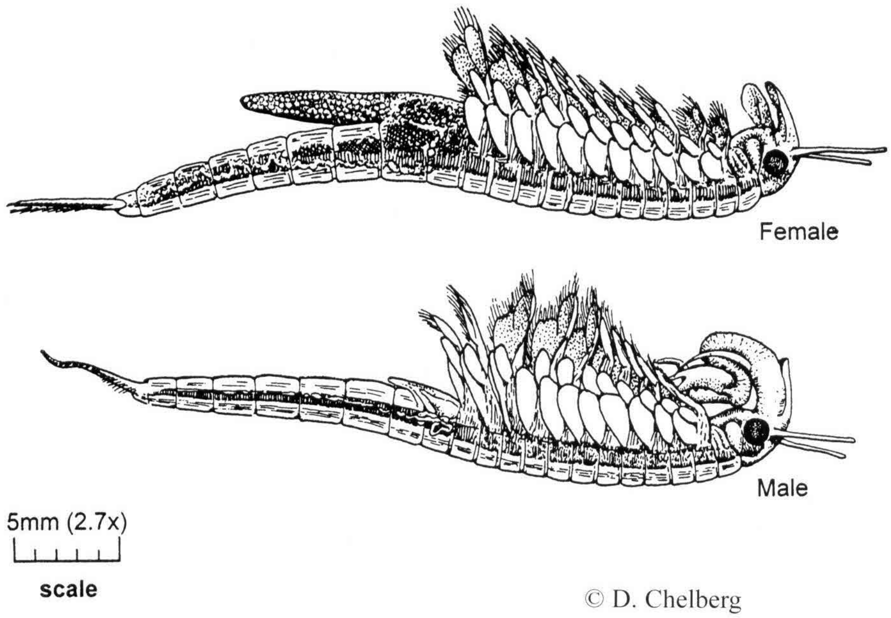
Picture Key Figure 8 Lateral view of female and male *Eubranchipus intricatus*.



Picture Key Figure 9 Lateral view of female and male *Eubranchipus ornatus*.



Picture Key Figure 10 Lateral view of female and male *Eubranchipus serratus*.



Picture Key Figure 11 Lateral view of female and male *Streptocephalus sealii*.

Appendix V. Plates

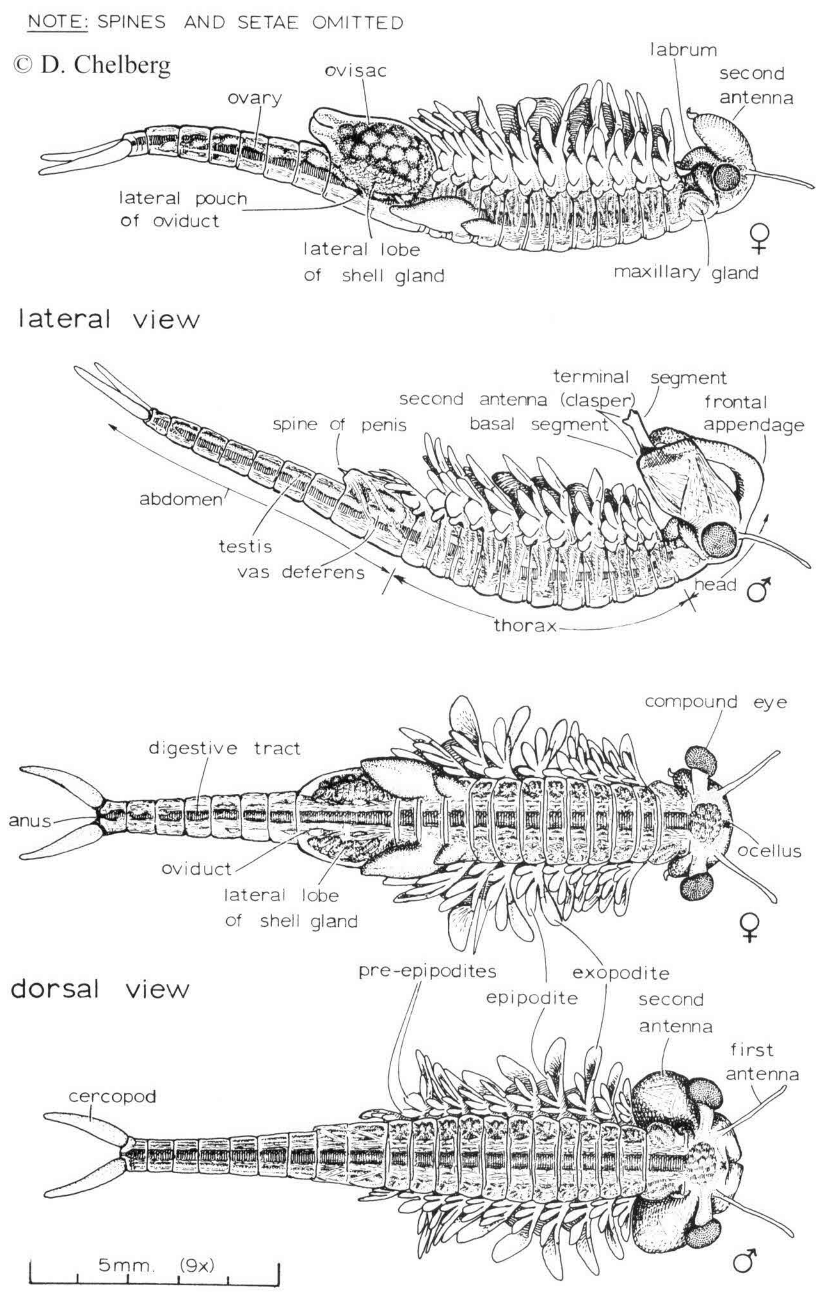


Plate I Example of anatomical terms labeled on lateral and dorsal views of adult *Eubranchipus bundyi*.

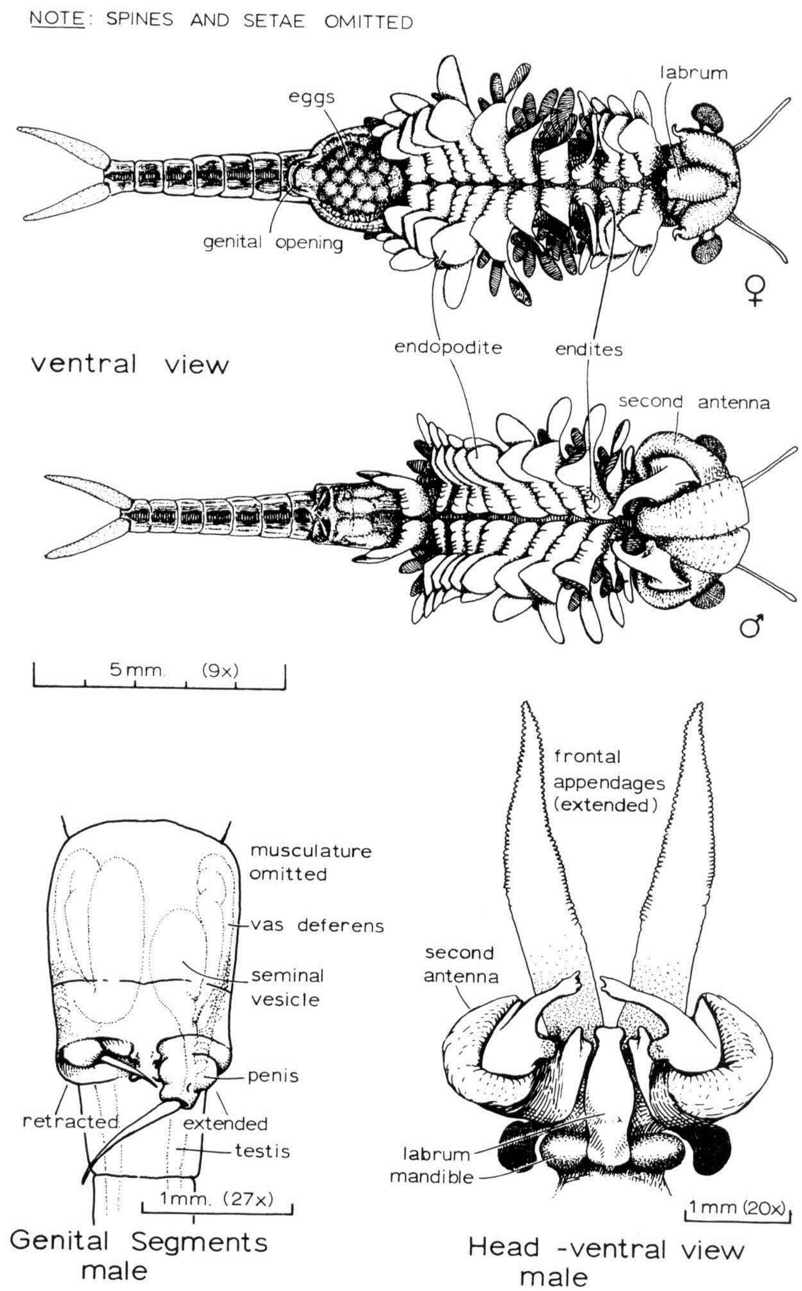


Plate II Example of anatomical terms labeled on ventral view, male genital segments, and head of adult *Eubranchipus bundyi*.

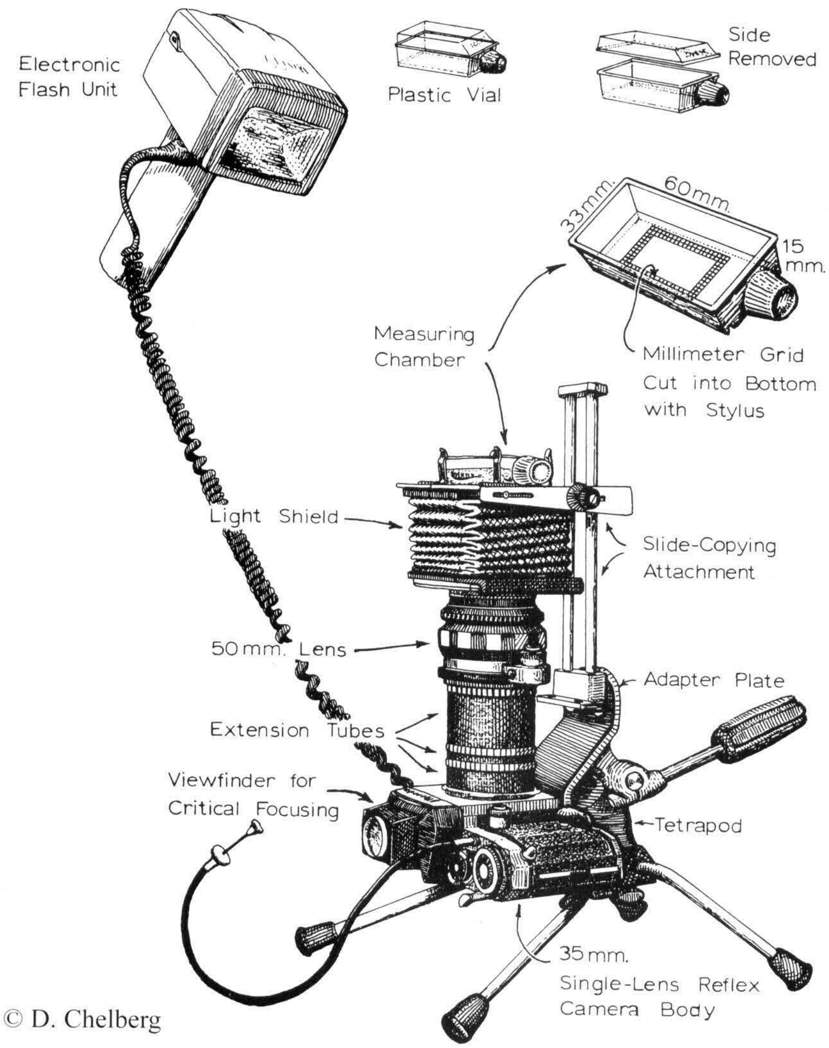


Plate III Apparatus for measuring and recording live fairy shrimp.

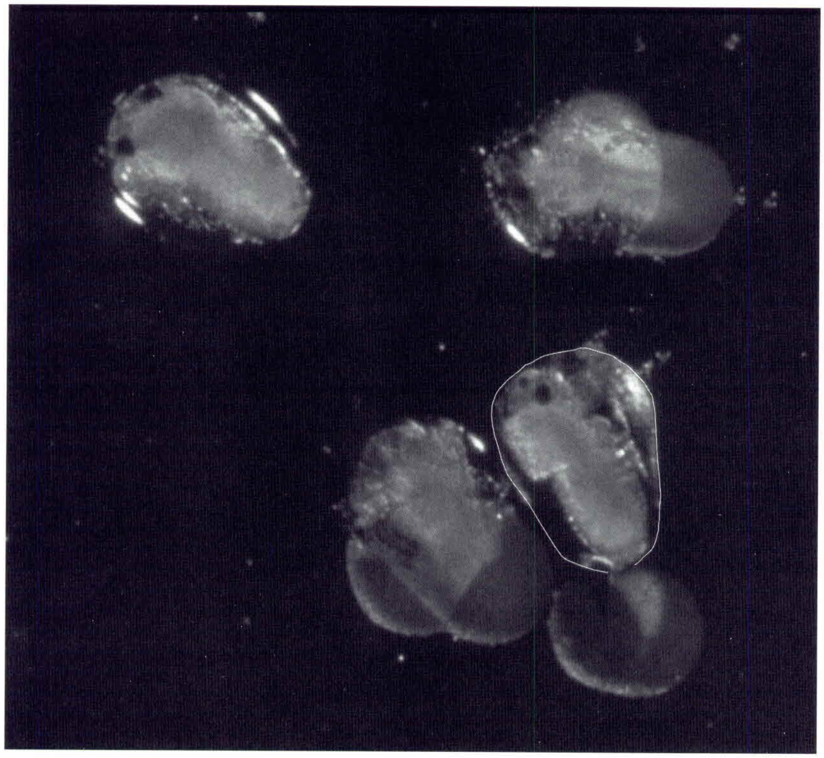


Plate IV Photograph of live, unhatched, "fully-developed" larvae.

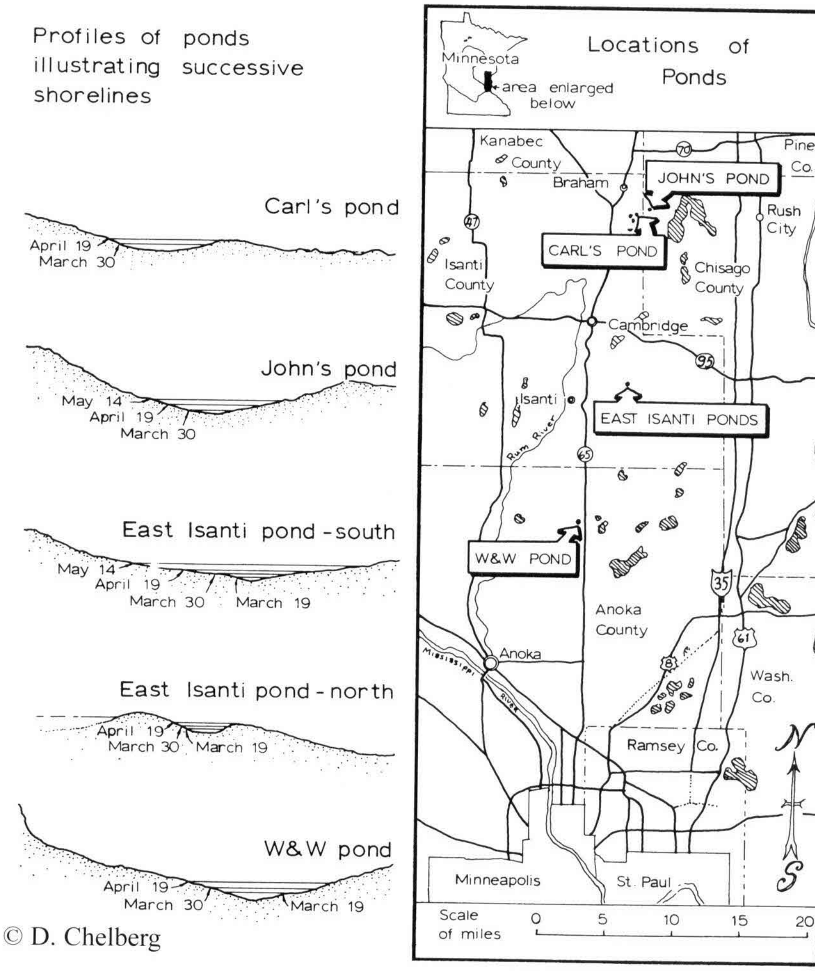


PLATE V Minnesota fairy shrimp ponds, 1961.

Also Available by these Authors:

Jass, J. and Klausmeier, B. 2000. Atlas and bibliography of the first state and county records for anostracans (Crustacea: Branchiopoda) of the contiguous United States. Milwaukee Public Museum Contributions in Biology and Geology, v. 94, p. 1-158.

Jass, J. and Klausmeier, B. 2001.Terrestrial isopod (Crustacea:Isopoda) atlas for Canada, Alaska, and the contiguous United States. Milwaukee Public Museum Contributions in Biology and Geology, v. 95, p. 1-105.

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