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The Crayfish of Nebraska

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by Steven C. Schainost

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Northern crayfish, *Orconectes virilis*

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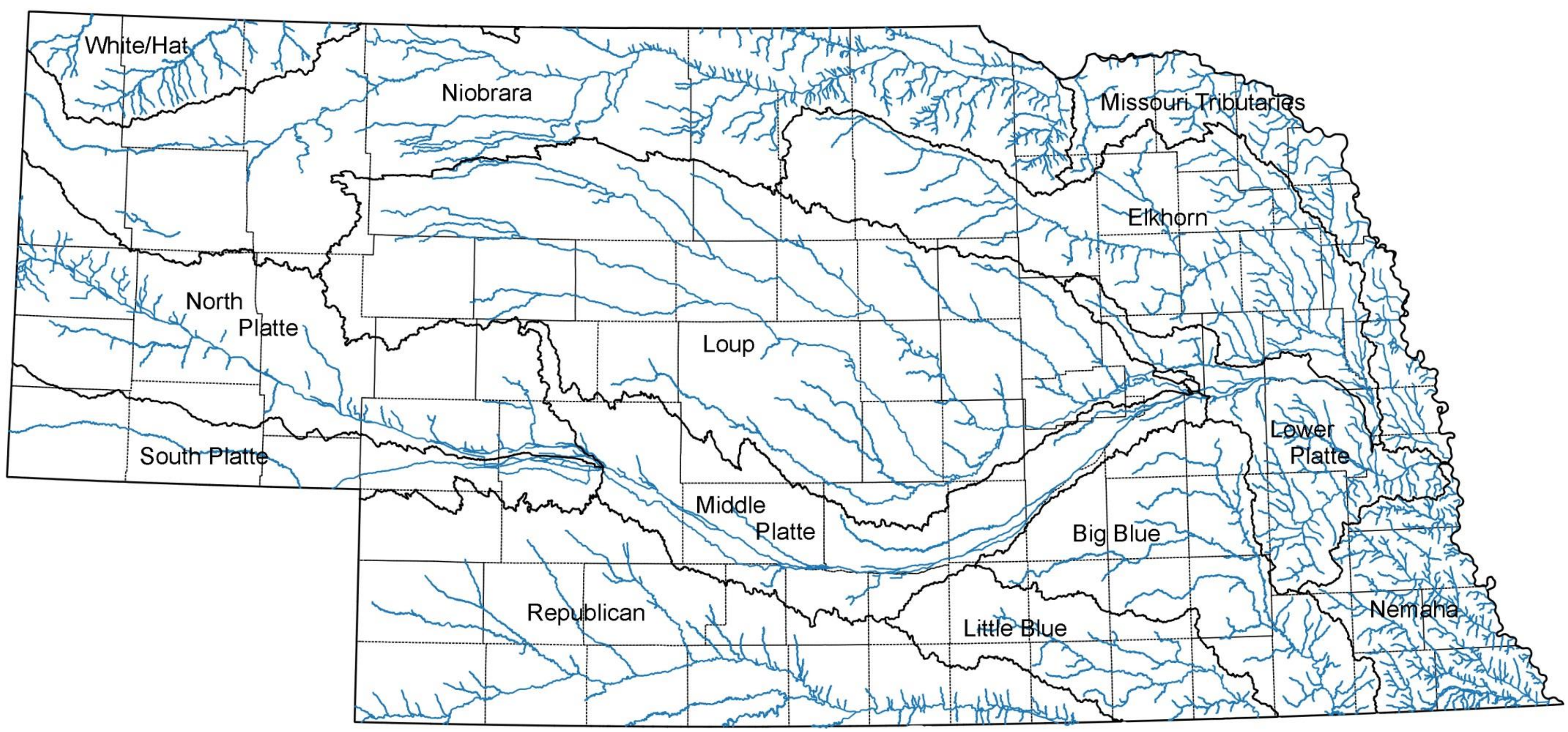

Nebraska River Basins

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PREFACE

Unknown to me at the time, my interest in crayfishes began as a kid in the 1950's. We lived on a farm in Knox County, Nebraska, and my brother and I would go down to the crick to go fishing. The "crick" was a small, unnamed tributary in the headwaters of Little Bazile Creek. Even as kids we could easily hop across it so we fished the pool under the county road bridge. While we did, once, catch a fish (a bullhead), most of our "fishing" was for crawdads. We would put a gob of worms or a piece of liver on a hook which would be lowered to the bottom of the pool. After a bit, we would s.l.o.w.l.y lift the hook out of the water to find a crawdad clinging to the bait. After a bit, it would drop off and we'd do it again. (Must have gotten pinched once because I don't remember handling them.) I would imagine a lot of farm kids had the same experience.

Now let us fast forward to 1995. I was now a fisheries biologist and had spent a couple of decades collecting fishes from the state's streams. In the course of this work, crayfishes were often collected along with the fish, but most were tossed back with hardly a glance. After a while I began to wonder about those crayfish I kept tossing back. So I began checking around only to find that virtually nothing had been done. One paper published in 1926 and then . . . nothing. Well, here we had a whole group of animals was being ignored and this was not acceptable. So I began collecting and saving those crayfishes and taking them back to the office for identification. In my travels around the state, I would often stop at bridges to take a photograph of the stream for my photo library. I would then see if the stream looked "crayfishy". If it did and I had the time, I would grab the dip net to see if I could collect some. Gradually, over the years, I began to get a more complete picture of the crayfishes of Nebraska. Collecting crayfish, identifying what I had found and storing the information in jars on a shelf and pieces of paper in a file were accomplishing little. These were neat critters and, perhaps, others might be interested in what was here. The result is the book you hold in your hands.

ACKNOWLEDGEMENTS

I was able to locate specimens of Nebraska crayfishes in two museums; The National Museum of Natural History and the Illinois Natural History Survey. Access to their online catalogs was much appreciated.

Over the years, I received crayfish specimens from a number of Game and Parks personnel including Andy Glidden, Al Hanson, Joe Rydell, Tony Munter, Jeff Blaser, Gerry Coates, Darrel Hartman, Dean Rosenthal, Jay Francis, Gerald Mestl, Monte Madsen, Randy Winter and Scott Wessel. Summer aides have assisted in the collection of crayfishes when we were sampling streams for fishes. These have included: Baxter Poe, Josh Cloeter, Ryan McMahon, Kyle Charron, Dave Adams, Josh Kreitman, Larry Pape, Mike Wall, Cecilia King and Christopher Dietrich. I thank Jamie Kelley of the Spring Creek Prairie Audubon Center for the report and photos of a Prairie crayfish.

The 2003-2005 statewide stream fishery survey was conducted by students of the University of Nebraska at Lincoln under the guidance of Dr. Edward Peters. They preserved the crayfishes that they collected which they allowed me to examine and identify. The team leaders were Tony Barada, Jesse Fischer and Dane Schuman and I thank them. Other university personnel who provided crayfishes included Dr. Richard Stasiak (University of Nebraska at Omaha), Chelsea Pasbrig (University of Nebraska at Kearney) and Kelly Turek (University of Nebraska at Lincoln).

Thank you all. I may have missed someone who provided specimens to me. If so, I apologize.

INTRODUCTION

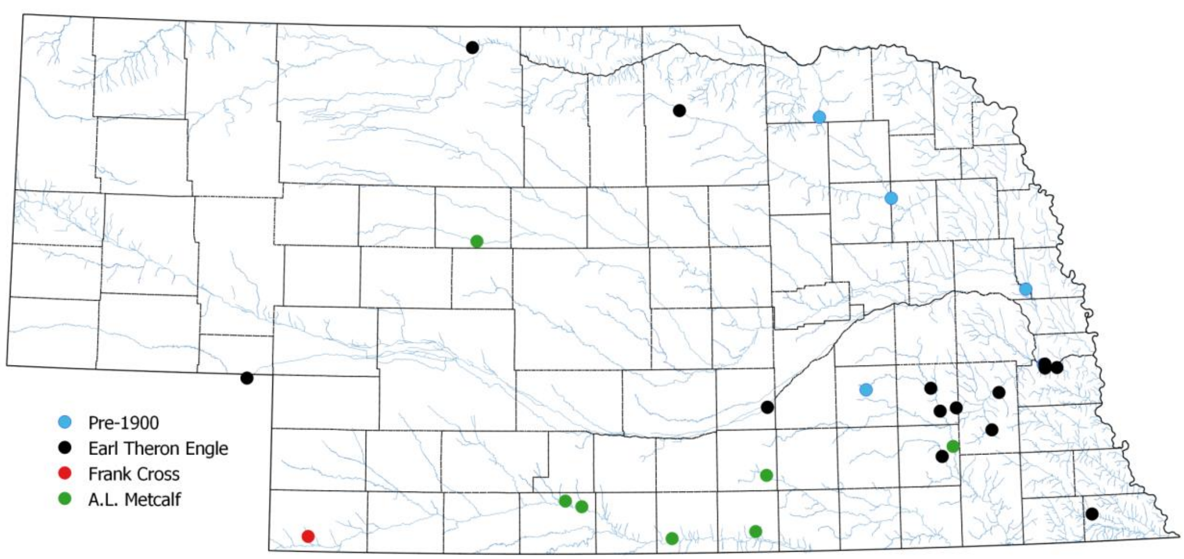
HISTORY OF CRAYFISH COLLECTING IN NEBRASKA

The “history” of crayfish collecting in Nebraska is a short one. The earliest known collections are to be found in the Smithsonian’s National Museum of Natural History. The museum has specimens from the 1890’s (five), 1920’s (two), 1940’s (one), 1950’s (one) and the 1960’s (three). These were of two species, the Calico Crayfish (*Orconectes immunis*) and the Northern Crayfish (*Orconectes virilis*).

The first <u>published</u> account on Nebraska’s crayfishes was done in 1926 by a fellow named Earl Theron Engle[54]. Earl T. Engle, born in Iowa, went to college at Nebraska Wesleyan in Lincoln. He must have shown some interest as he stated that he was encouraged to do a study of Nebraska’s crayfish by Dr. Wolcott of the Zoology Department at the University of Nebraska. Later extended to include Colorado, his Nebraska collections were not terribly extensive. In his paper, he wasn’t very clear as to where he collected but it looks like he visited between 15 and 20 sites statewide. He was a little hazy on some of his identifications but it appears he found four species, the Calico Crayfish, the Northern Crayfish, the Ringed Crayfish (*Orconectes neglectus neglectus*), and the Devil Crayfish (*Cambarus diogenes*).

Now we skip ahead 28 years to 1954. Austin B. Williams[246] mentions the collection of some Ringed Crayfish from Rock Creek in Dundy County, Nebraska by Dr. Frank Cross (University of Kansas). A little after this, A.L. Metcalf, a student of Dr. Cross, collected fishes (and crayfish) in Kansas and Nebraska and wrote a paper on his collections of Ringed Crayfish in Nebraska [158].

That is it. From 1890 through 1970, a period of 80 years, we have a grand total of less than 35 collections of crayfish of four species from the entire state. This is not a very impressive total and whole sections of the state are missed.

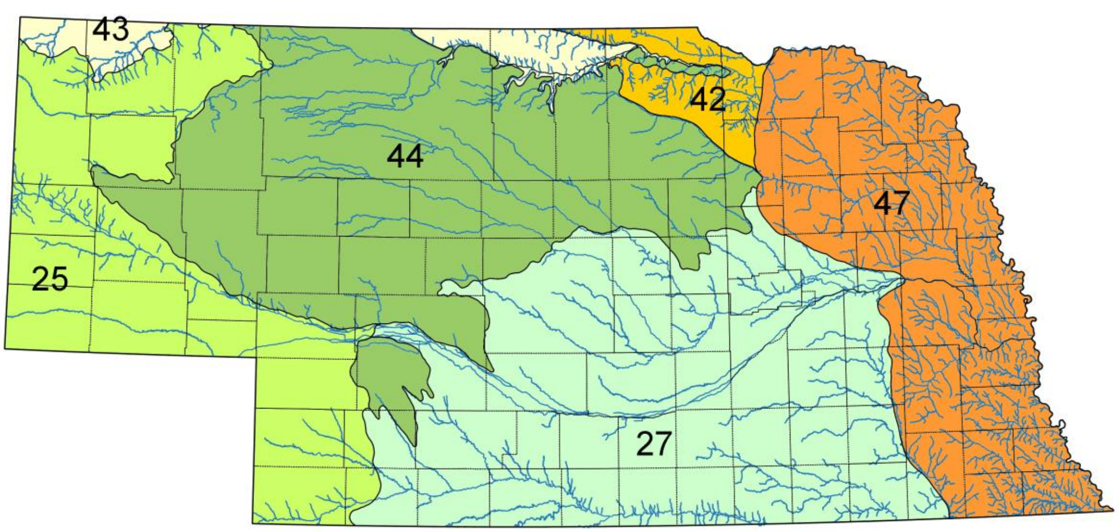


THE NEBRASKA LANDSCAPE

Prior to European settlement, Nebraska was a land of rivers and streams. There were few natural lakes and these were river oxbows or natural lakes in the Sand Hills. It is probable that, historically, the Sand Hills lakes had no fish or crayfish (though we really don't know). Nebraska's streams tend to flow easterly and southeasterly, all draining into the Missouri River. These streams were organized into the 13 river basins that are illustrated in the map at the beginning of this book.

Nebraska is located in the center of the North American continent where climate extremes are the norm. The state is 77,355 square miles and is roughly 200 miles north to south by 400 miles east to west. The highest recorded temperature was 118ºF and the lowest was -47 ºF. The frost-free growing season ranges from 200 days in the southeast to 140 days in the west. Precipitation varies from a high of 34 inches per year in the southeast to 14 inches in the northwest corner of the state. Since 20 inches per year is considered necessary for normal crop production, about one-half of Nebraska may be considered semiarid. As a result, irrigation is prevalent which hass had some important implications for our aquatic wildlife.

The Nebraska landscape has been organized into "ecological regions" or ecoregions. An ecoregion is an area that is similar in geology, soils, landforms, vegetation, climate, water resources, wildlife and human factors. Ecoregions were developed at four levels of detail. For instance, the Great Plains, extending from Canada to Mexico, is a Level I ecoregion. The Level I ecoregions were subdivided into Level II which were subdivided in Level III which were then subdivided again into Level IV ecoregions. The map below shows the Level III ecoregions which may be the most useful in describing Nebraska's landscape. It also may be of use in determining whether differences in the distributions of wildlife species (such as crayfish) might be related to the differences in the landscape.[25, 175]



25. Western High Plains
27. Central Great Plains
42. Northwestern Glaciated Plains
43. Northwestern Great Plains
44. Nebraska Sand Hills
47. Western Corn Belt Plains

THE WESTERN CORN BELT PLAINS

The Western Corn Belt Plains is a region of rolling hills composed of thick deposits of loess over glacial till. Early explorers such as Lewis and Clark traveled up the Missouri River and left many descriptions of this area. It was once a tallgrass prairie of big and little bluestem, switchgrass and Indiangrass with oak-hickory woodlands along some of the streams like the Missouri River. Much of the region has been converted to cropland and, as a consequence, groundwater and surface water contamination by pesticides and fertilizer as well as runoff from feedlots is a significant issue. With the conversion from prairie to crops, streams are much more prone to flooding so many dams have been built causing extensive fragmentation of watersheds.

The streams in this region have been extensively altered. Beginning in the early 1900's, many streams have were straightened in an effort to reduce flooding and to get more land into cultivation. The straightening of stream channels shortens them which increases the stream's gradient. A shorter, steeper stream has more power to erode its bed, especially during floods. As the stream bed erodes, the channel gets deeper (degrades) and the banks become unstable causing them to fail and fall into the channel. At the same time, the stream is trying to re-establish its original gradient by filling its lower end and eroding its headwaters (i.e. lengthening its channel).

Those streams that were not directly straightened but are tributary to a straightened stream are also affected, because, as the main stream's channel cuts downward, the tributaries must follow. This bed degradation and erosion continues until a layer that is resistant to erosion (bedrock or hard clay layers). As a general rule, natural streams have a variety of habitats. Shallow gravel/cobble riffles, deep spools, moderate depth runs along with silty, vegetated oxbows or side channels. Now many, if not most, of the streams in this region have little diversity and minimal habitat for aquatic animals like crayfish.

THE CENTRAL GREAT PLAINS

The Central Great Plains ecoregion is a large section of south-central Nebraska and to discuss this we must break it into four subregions. North of the Platte River are the Dissected Loess Plains, a region of wind-deposited loess that can be over 200 feet thick. The land is hilly with moderate to steep slopes that have been eroded into canyons and deep valleys. Due to the irregular nature of the topography, it is primarily rangeland though increasing irrigation development is bringing more land into cropland. There are only a few perennial streams crossing this area which include the South, Middle and North Loup Rivers as well as Mud Creek, the Cedar River and Beaver Creek.

In the east-central portion and south of the Platte River is the Rainwater Basin. This area is also overlain with a mantle of windborne loess which is a broad, flat area where you can see for miles in every direction. The photo below shows a portion of the Rainwater Basin west of Aurora, Nebraska. The Rainwater Basin has numerous wind-excavated depressions which filled with rainwater, creating thousands of acres of marshes and wetlands that were a major waterfowl production and Perennial streams are found on the southern and eastern edges of this region which stopover area, hence the name "Rainwater Basin". Now most of the wetlands have been drained and the region is almost completely converted to irrigated cropland. include the Little Blue and the Big Blue River watersheds.

The Rainwater Basin near Aurora, Nebraska

To the southwest are the Rolling Plains and Breaks. This is also a loess covered region whose dissected topography is similar to the Dissected Loess Plains except the loess is not as thick. The land has been converted to a mix of rangeland and cropland. There is extensive irrigation development which has markedly changed the hydrology. Several large reservoirs have been built for the dual purpose of irrigation and flood control including Harlan County, Swanson, Enders, Red Willow and Medicine Creek Reservoirs as well as several low-head irrigation diversions. Groundwater pumping has reduced flows or dried several streams such as the upper reaches of the Frenchman and the Republican. The Republican below Harlan County Reservoir functions as an canal with high flows during the irrigation season and low flow at other times.

In the center of the region is the Platte River Valley, a wide, flat valley composed of alluvial silt, sand and gravel deposits. This was the travel corridor for the Oregon Trail so there are numerous historical diary descriptions of the landscape. This area was originally a lowland tallgrass prairie with marshes and wet meadows. Trees were almost totally absent except on the islands. The Platte River was historically wide, shallow and braided. It is now periodically intermittent due to irrigation withdrawals. In the western part, due to the loss of the spring floods which scoured the channel, the channel is now heavily forested and the river has been reduced to small meandering channels. One of the unique features of the Platte River is the nature of its valley. Most rivers erode their own valleys through increasingly older strata. With the Platte River, the valley walls are younger than the river itself. That is because the Platte was a wide, braided stream flowing through a level grassy plain. As the Pleistocene winds deposited thick layers of loess and sand over the area, the Platte was kept busy eroding away that material. Underneath those hills that flank the Platte River to its north and south is its original plain.

NORTHWESTERN GLACIATED PLAINS

In spite of its name, this region, from the South Dakota border to the Elkhorn River and split by the Niobrara River, was not glaciated in its Nebraska segment. North of the Niobrara are the Ponca Plains which are rolling plains that are in a combination of irrigated cropland and rangeland. South of the Niobrara River are the Holt Tablelands. The southern part of the Holt Tablelands is a high, flat tableland that is in irrigated cropland while the northern part is dissected by several stream drainages and is mostly rangeland. In the extreme northeast corner at the mouth of the Niobrara are the Southern River Breaks which are dissected hills and canyons with steep slopes. Major perennial streams include the Niobrara River which has several tributaries on the south side including Verdigre Creek, Eagle Creek and Redbird Creek. To the north of the Niobrara is Ponca Creek. The Elkhorn River, which borders the region on the south, has no tributaries on the north side.

NORTHWESTERN GREAT PLAINS

The Northwestern Great Plains is a large region in Montana, North Dakota, South Dakota and Wyoming with two small widely separated extensions into Nebraska. The easternmost extension is bordered on the south by the Niobrara River and on the north by the Keya Paha River. The northern portion of this area is the Keya Paha Tablelands, an area of rolling hills with some buttes and level plains which is now a mix of rangeland and cropland. To the south, are the Niobrara River Breaks which are dissected canyons with steep slopes and a mix of woodlands that are now mainly used as rangeland. The main perennial streams include the Keya Paha River and its tributaries as well as the Niobrara River and its south-side tributaries, Plum and Long Pine Creeks. Niobrara River tributaries on the north side are very small or intermittent.

In the northwestern corner of the state is the other piece of the Northwestern Great Plains. Between the Pine Ridge and the South Dakota border, this is an area of rolling plains known as the Semiarid Pierre Shale Plains. Primarily used as rangeland there is some dryland and irrigated cropland in this area. Streams are the perennial White River, Hat Creek and Soldier Creek with many small tributaries, some of which are perennial in their headwaters but intermittent lower down. On the southwest and on the east of this ecoregion are the White River Badlands. This is a highly dissected and eroded landscape of buttes, escarpments and badlands with intermittent or ephemeral streams

THE NEBRASKA SAND HILLS

The Nebraska Sand Hills is the largest region of sand dunes in the Western Hemisphere being some three times the area of Massachusetts. Now stabilized with grasses, the dunes vary from gently rolling to massive features that can be several hundred feet high (see photo below). The Sand Hills were formed during the Wisconsin glaciation during an extensive dry period where winds blew the sand that had been deposited by eastward flowing streams. Originally a mixed grass prairie, it is still a mixed grass prairie which is now rangeland. Several streams originate in this region including the Middle Loup, North Loup, Dismal, Calamus, Cedar and Elkhorn Rivers. One major stream, the Niobrara River, crosses the northern edge of the Sand Hills. The Sand Hills sits on top of the thickest part of the Ogallala Aquifer, a huge underground reservoir of water. It is this aquifer that feeds the streams named above which are well-known as having consistent and uniform flows. Between the dunes are marshes, wetlands and lakes that are connected to the groundwater table. In the western part of the Sand Hills is a closed basin area with many alkaline lakes but no streams. These lakes support alkali-tolerant plants as well as invertebrates like brine shrimp (but no crayfish).

Sandhills east of Hyannis, Nebraska

WESTERN HIGH PLAINS

The Western High Plains extends down the western edge of Nebraska from South Dakota to Kansas. This is a diverse area which includes several Level IV ecoregions that are quite different from each other. What they have in common is a short growing season and low precipitation.

Beginning at the north end is the Pine Ridge Escarpment which overlooks the Northwestern Great Plains. It is a steep, rocky area of canyons whose slopes are forested with Ponderosa Pine. Originally a mixed grass prairie, it is mostly used as rangeland as the land is too steep and irregular for much cropland. The Hat Creek and White River drainages originate in the Pine Ridge.

Just to the south of the Pine Ridge are the Tablelands which extend south to the North Platte Valley. The Tablelands are a level, rolling landscape of mixed grass prairie with some canyons along stream courses. The Niobrara River crosses the northern portion of the Tableland while, to the south are several North Platte River tributaries. Sandwiched between the Tablelands on the west and the Sand Hills to the east is an area of level to rolling cropland. The northern portion of this area is crossed by the Niobrara River. To the south is a closed basin, the Snake Creek watershed which crosses the southern edge of Box Butte County. Snake Creek was geologically connected to Blue Creek in Garden County but drifting sand dunes separated them. Over the past few years, groundwater pumping has dried up Snake Creek.

A similar area is found in the southern portion of the Panhandle next to the Colorado border. The only stream her is Lodgepole Creek, much of which has been dried up due to the pumping of groundwater for irrigation. Finally, a third area is found south of the South Platte River. The area south of the South Platte River has few streams, the most notable being Frenchman Creek. Here too, flows have been greatly reduced due to groundwater pumping.

Through the center of the Western High Plains is the North Platte Valley, a flat, alluvial area that is mostly in irrigated cropland and feedlots while the upland areas are in rangeland. Flanking the North Platte Valley on the south are bluffs and the Wildcat Hills which are what remains of the pre-Pleistocene prairies. These are areas of escarpments, rocky outcrops and steep slopes with pine forests. To the north of the river are hills that blend into the Tablelands. The South Platte Valley is also a flat, alluvial area used for irrigated agriculture. The South Platte River has been extensively dewatered by urban water use and irrigation in Colorado.

Finally, in the extreme southeastern corner of the state are the Rolling Sand Plains. These are sandy plains with occasional active sand dunes. Originally a sand sage prairie with few streams, the area was used as rangeland but is now being converted to irrigated agriculture. South and east of these Rolling Sand Plains is rangeland. This area includes the upper end of the Republican River and some of its tributaries. Originally mixed grass and short grass prairie, this area is more irregular than the sand plains to the west. This area has (or had) numerous small spring-fed tributaries that are being dried up by groundwater pumping for agriculture.

CLASSIFICATION AND TAXONOMY OF CRAYFISH

When I was in biology classes in school we learned that all organisms were ranked taxonomically. The ranks were: Kingdom, Phylum, Class, Order, Family, Genus, Species. It was a way to show how everything was related to everything else. These ranks were drummed into our feeble minds to the point that I can cite them in my sleep. But it has now gotten more complicated what with superfamilies and superorders and a mixing up of the interrelationships. So, where do the crayfish fit?

First off, they are in the Kingdom **Animalia**. Within the Animalia are the **Arthropoda** or 'joint-footed' animals. All arthropods have several things in common which include; the body is bilaterally symmetrical, has an exoskeleton, possesses pairs of jointed legs and is divided into two or three sections. Most have a straight-through gut, a nervous system with a brain and ganglia, and an open circulatory system. Within the Arthropoda are the **Crustacea** which have a body with three parts. Within the Crustacea are **Malacostraca** ('soft-shelled') and within that are the **Decapoda** ('ten-footed') which include crabs, lobsters, crayfish and shrimp. Within the Decapoda are the **Astacoidea** which are the crayfishes. These are split into the **Astacidae** and **Cambaridae**. The Astacidae are native to Europe and western North America. Our crayfishes are in the Cambaridae which is the largest group with over 390 species in eastern North America and Asia.

There are 12 genera within the Cambaridae of which only three [**Procambarus**, **Cambarus** and **Orconectes**] are found in Nebraska. These three can be most easily separated by looking at the first pleopod of a male. In Procambarus, the pleopod ends in three or more short extensions. These are often hidden by setae. There are some 160 species in Procambarus of which Nebraska has one native and one (so far) non-native species. In Cambarus, the tip of the pleopod has two short, thick and laterally flattened elements that are sharply curved. There are about 100 species of Cambarus of which one is found in Nebraska. Orconectes has a pleopod with two thin extensions that may be long or short and curved or straight. There are some 85 species of Orconectes of which three native and one non-native species are found in Nebraska.

Procambarus

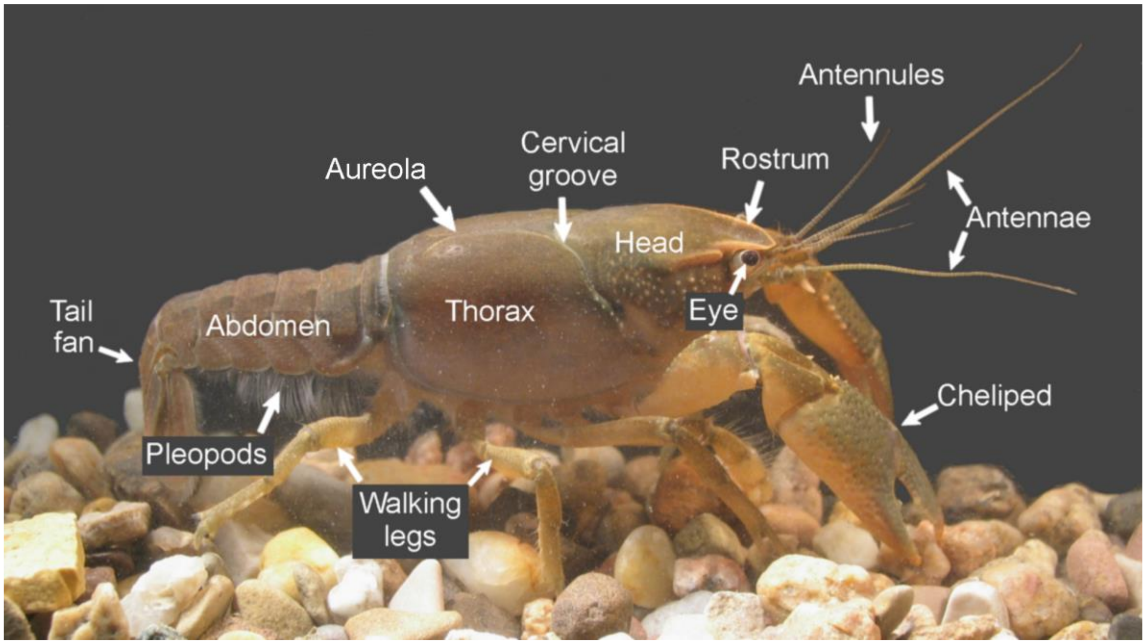
Cambarus

Orconectes

One thing you will soon learn is that most crayfishes have no common names. This is evident in the variety of regional names for crayfish. Names such as crayfish, crawfish, crawdad, crawcrab, crab, stonecrab, creekcrab, mudbug and, in French, ecrevisse. So where did the name "crayfish" come from? The online Free Dictionary (http://thefreedictionary.com/Astacoidea) says it probably came from Old German, *krebiz* ('edible crustacean') which became the French *crevise* or *ecrevisse*. The *crevise* then morphed into the English *crayfish*. These are terms for crayfish in general, not for individual species. Why?

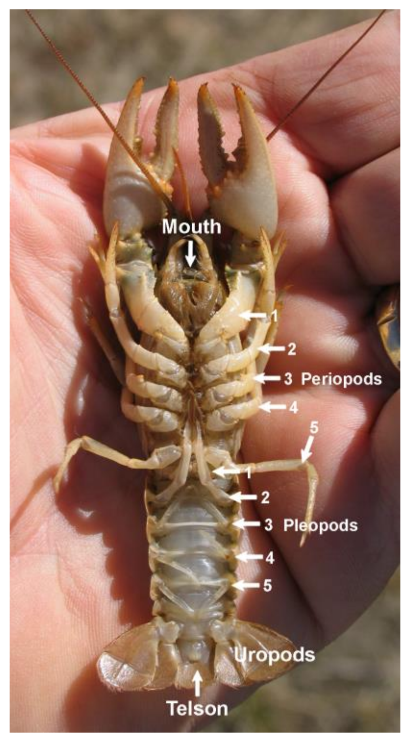
Well, "common" names, as opposed to the Latin binomial or the "scientific" name, is a name that is in "common" use. It is a name that was created by people as a means of communicating information to other people. Let's look at an example; Ole and Lena are out fishing. Ole catches a fish. Lena hollers over, "Whatcha' catch Ole?" Ole hollers back, "Bluegill!" Lena calls back, "OK!" Lena knows exactly what Ole caught. To them, the difference between a bluegill and some other fish is important so they have given it a "common" name. What if Ole had caught a crayfish? Ole might holler back, "Crawdad!" and Lena might respond, "Oh, OK". It doesn't matter to them what species of crayfish Ole caught. To them, a crawdad is a crawdad and all crawdads are the same.

Each species account starts with a section on "Systematics". This begins with the currently accepted scientific name followed by a long list of other names called synonyms. The scientific name is composed of two parts, the genus and the species. The first person to discover and describe a new species gets to give it its species name. But, the scientific name is not fixed, never to be changed. Rather, it is constantly being reviewed and compared to closely related species. If it is determined that the genus is incorrect, it is changed. Also, when papers are published where a species is mentioned, its scientific name is included. Sometimes, this name is misspelled and sometimes the crayfish was misidentified. So, we have a list of synonyms which tries to list all the names that have been used for this crayfish. Most of the names on these lists came from Hobbs[104], Hobbs and Jass[110] and Hobbs[107]. The currently accepted names can be found in "Common and scientific names of aquatic invertebrates from the United States and Canada: Crustaceans".[156]



ANATOMY

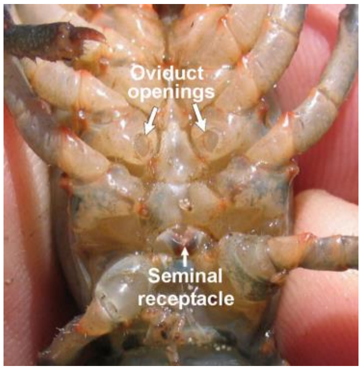
EXTERNAL ANATOMY



The photo above illustrates the major external anatomical features of the crayfish. [Various measurements and ratios of crayfish body parts are contained in Section VI.] The **thorax** and **head** are divided by a **cervical groove** and together are called the **carapace** or **cephalothorax**. In the center of the thorax are two curved edges marking the **aureola.** Protected and hidden by the thorax on the sides are the **gills**. The **rostrum** is the forward extension of the head over the eyes. The **eye** is a compound eye on a movable stalk. There are two long **antennae** and between these are four short **antennules**. Crayfish are members of the **decapoda** which means "ten footed". There are five pair of **walking legs** or **periopods** which are numbered from 1 to 5. Number 1 is the large **cheliped** which is used to gather food, for defense and for mating Legs 2 and 3 have a tiny claw that can be used both for walking and for picking up items of food. Legs 4 and 5 are true walking legs which have a single point. Each of the segments of the **abdomen** has a pair of **pleopods.** The **first pleopod** is used by the male to transfer sperm to the female's seminal receptacle. In the female, the pleopods are where the eggs attach and hatch. The tail consists of a central **telson** which is flanked on either side by a pair of

uropods. The opening to the **mouth** is flanked by several pair of **maxillipeds** which chop their food into small pieces.

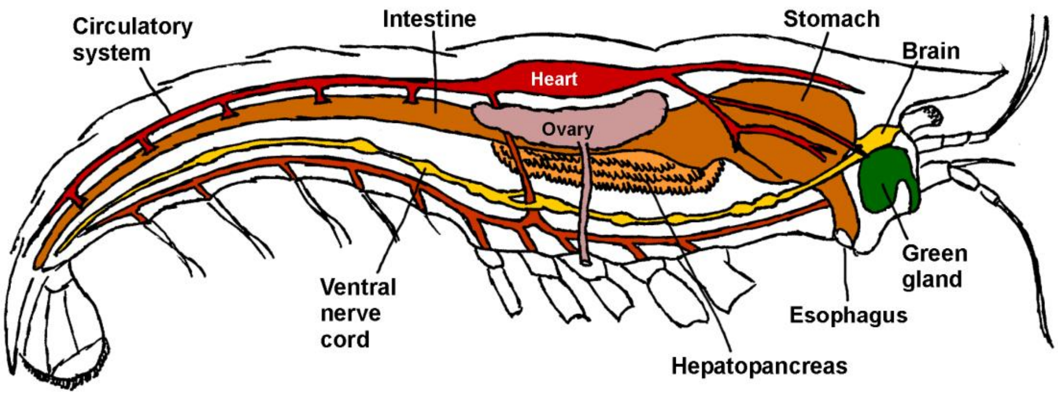
At right is a photo of the underside of a female showing the **seminal receptacle** or **annulus ventralis.** This is a blind pocket that is used to store semen. Ahead of this, at the base of the third pair of walking legs are the **openings** for the **oviducts**.



INTERNAL ANATOMY

Below is a basic illustration of the internal anatomy of a crayfish showing the major organ systems. [For more detailed information, please refer to Felgenhauer[62] or Schramm et.al.[206]]

The **digestive system** consists of a **foregut, midgut** and **hindgut**. The foregut has two parts, the **esophagus** and **stomach**. Digestion begins at the mouth where the mouth parts, the **maxillipeds**, shred the food items and feed them into the esophagus and the stomach. The stomach has two chambers. The larger front chamber is the **cardiac stomach** and the smaller rear chamber is the **pyloric stomach**. On either side of the cardiac stomach are pouches where the **gastroliths** form and are dissolved during a molt. Between the two stomachs is a **gastric mill** consisting of a set of three chitinous teeth that grind the food into mush. Just behind the gastric mill is a filter that stops any food items that are too large to digest (these are reground or spit out). In the pyloric stomach, the food is mixed with digestive enzymes from the **hepatopancreas**. The hepatopancreas is a complex organ that produces digestive enzymes and fat emulsifiers which also absorbs and stores food and minerals. After passing back and forth between the pyloric stomach and the hepatopancreas several



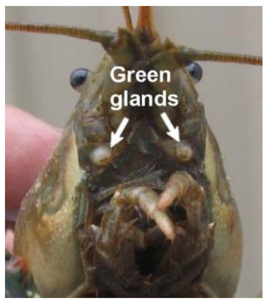
times, what's left passes into the midgut (whose function isn't really understood) then to the hindgut and eventually out the hind end.

The **circulatory system** of the crayfish is an open system where the blood is contained in vessels for only part of the system. The **heart** is located in a **pericardial sinus** located in the upper part of the thorax (a sinus is a sac or cavity). The heart pumps the blood into the arteries. Anteriorly, one pair of arteries, the **ophthalmic**, carries blood forward to the eyes, the brain and the antennae. Another pair of arteries, the **hepatic**, carry blood to the hepatopancreas and the stomach. Posteriorly, the **dorsal abdominal artery**, feeds blood to the abdominal muscles and intestine. Just to the rear end of the heart, the **sternal artery**, drops down and supplies the **ventral abdominal** and **ventral thoracic** arteries which feed blood to the appendages and nerve cord. After leaving the arteries, the blood bathes the cells and organs, eventually collecting in a large **sternal sinus** in the bottom of the thorax. From here it passes through the gills and back to the pericardial sinus and then through three small valves back into the heart to be recycled.

The **nervous system** mainly consists of a **ventral nerve cord** that has numerous swellings or **ganglia**. From the ganglia, nerves branch out laterally leading to the appendages and muscles. In the cephalothorax, the nerve cord leads to an enlarged ganglion that serves as a "**brain**". Nerves lead from the brain to the eyes, antennae and antennules. Their eyes are **compound eyes** on the ends of moveable stalks, each having thousands of facets.

The **reproductive system** consists of pairs of **testes** or **ovaries** located in the upper rear part of the thorax between the hepatopancreas and the heart. In the female, the eggs pass down the **oviduct** to an opening at the base of the third walking legs. In the male, a pair of ducts (**vas deferens**) carry sperm to openings at the base of the rearmost walking legs. The vas deferens also packs the sperm into packets called **spermatophores** for later transfer to the female.

The **excretory system** consists of the two **green glands** or **antennary glands** whose openings are just below the base of each antenna. The green gland filters waste out of the blood and feeds it into a bladder where it then exits through a pore at the base of the antenna. The urine is very dilute as these organs also function to get rid of the excess water that constantly floods the tissues of freshwater animals.



THE BIOLOGY OF CRAYFISHES

Worldwide the freshwater crayfishes (superfamily Astacoidea) are divided into three groups; the Astacidae, Cambaridae, and Parastacidae. The Astacidae are found in Europe and the west coast of North America. The Cambaridae are found in eastern North America and parts of China. The Parastacidae are found in the South Pacific (particularly Australia and New Zealand) as well as Chile and Argentina in South America. Africa and Antarctica have no crayfishes.

The Astacoidea has some 393 species worldwide of which over 340 are restricted to the United States and Canada. Within the Cambaridae of North America, the subfamily Cambarinae includes the three most successful genera, *Cambarus*, *Procambarus*, and *Orconcectes* with 333 species and subspecies[234]. Of these, only five are native to Nebraska including one species of *Cambarus*, one species of *Procambarus*, and three species of *Orconectes*.

HABITATS

At it's very simplest, crayfish need to be wet or, at least, their gills and bodies need to be damp. Like all living organisms, they need to eat and they need refuges from predation, dessication, or freezing. We usually think of crayfishes as living in streams or lakes. But many species will also burrow and a crayfish's propensity to burrow is rated as primary, secondary, and tertiary. We have five native species of crayfish in Nebraska and each of these three burrowing types is represented by one or more of our species.

Primary burrowers spend most of their adult lives living in a burrow. The Grassland crayfish, *Procambarus gracilis*, is a primary burrower and may spend 95% of its life in a burrow. The Devil crayfish, *Cambarus diogenes*, is also a primary burrower spending 80-90% of its life in the burrow though adults or young can occasionally be found in open waters. Burrows don't have to be very near open water, either. While the burrows of the Devil crayfish will often be found on stream banks or in wet meadows, those of the Grassland crayfish can be found in grasslands or road ditches a considerable distance from open water. But, in either case, the burrow has to reach ground water which can be several meters down. Burrow water is often very low in oxygen so these crayfishes tend to live in the damp air just above the water.

Secondary burrowers dig burrows to escape drying waterbodies or freezing weather. The Calico crayfish, *Orconectes immunis*, is a secondary burrower. It spends most of its life in open waters but, in the fall or when a waterbody begins to dry, they dig a deep burrow. These can be a couple of meters deep.

Tertiary burrowers are crayfish that dig a burrow as a last resort and, even then, it is not an extensive or deep burrow. The Northern crayfish, *Orconectes virilis*, is a tertiary burrower which often digs a shallow burrow beneath a rock during winter or during drought. The Ringed crayfish, *Orconectes neglectus*, is also classified as a tertiary burrower but my observations are that it is a non-burrower. I have found them in dry streams under rocks or logs where they had excavated a cavity large enough to fit into but is not really a burrow.

Behavior

A long list of other species will eat a crayfish. As a defense, most crayfishes are nocturnal and secret themselves in refugia during the day to avoid predation, especially when molting. Female crayfish with eggs or young use refuges to seclude themselves. In areas where refuges are in short supply, the species that is more successful at retaining possession of a good refuge will be more likely to survive.

Crayfish have five levels of reaction to a threat from another crayfish which are: no contest, threat posture, restrained physical contact, claw lock, and strike and rip.[95] "No contest" means one or both will retreat and go about their business. With the "threat posture" they assume a "claws-up" position (see photo at right). At the next level, "restrained physical contact" at least one of them touches the other. With the "claw lock", at least one of them grabbed the other with its claw. Finally, with "strike and rip" they actively went after each other.[43]

These reactions can also be seen in fish/crayfish interactions. Crayfish have three responses when approached by a fish including the claws up position, a tailflip retreat and/or no response. Crayfish do not distinguish between a potential predator (rock bass or yellow perch) or a non-predator (darter) as, to them, a fish was a fish and a potential predator. But it was also interesting to note that the crayfish were aware of their relative size. Large crayfishes are less likely to be eaten and usually responded with a claws-up spread. Small crayfishes were more likely to retreat.[131]

Crayfish in "Claws up" posture

Reproduction

As you may have noted in the Anatomy section, the female crayfish is distinguished by the presence of a structure called the annulus ventralis (seminal receptacle) located between the fifth pair of legs. In the male, the first and second pair of pleopods are enlarged and fold up between the legs. The first pleopod is modified to transfer sperm into the female's seminal receptacle

Mature
Form I pleopod

Immature
Form II pleopod

(see photo at right). It is also a key characteristic used to identify the species.

The most significant difference between the Astacidae and Cambaridae is with the variation in the form of adult males. In the Astacidae, the physical appearance of the first pleopod of a male, once it reaches maturity, retains its mature form for life. In the Cambaridae, the structure of the first pleopod alternates between mature (Form I) and immature (Form II) appearance. The Form II pleopod is soft and pale (photo below right). This changes to a mature Form I at the first molt after reaching sexual maturity. The Form I pleopod has a well-defined hardened projection (see photo above). The pleopod will then return to a soft Form II at the first molt after the end of the breeding season. This cycle repeats itself for as long as that male is alive. The presence of Form I and Form II males in the population in any particular season is variable and is related to their growth. Small males grow faster and molt more often so the spring and fall changes are more predictable. Large slow-growing males can retain their Form I pleopods well into the summer.

A change in female form comparable to that seen in males has not been generally recognized but there is a way to differentiate between sexually mature and immature females. Mature females have swollen glair glands (photo below), dependent offspring, or the remains of egg cases attached to the pleopods. The change from mature to immature is also seasonal and only mature females will mate with mature males.[244] It has also been noted that mature females have a broader abdomen than immature females.[79]

Sexual union may happen anytime mature males and females are together. Mating has been observed between June and October though the peak of activity was in late July and early August.[79] (I observed Calico crayfish mating on 9 July 2009 in the Niobrara River.) The process starts with a male approaching and grasping a female with one of his claws. Somewhat dexterously, he turns her over onto her back while holding onto her legs and claws with his claws. She curls her thorax up and he curls his down over hers in a face-to-face "spoon" position. After several minutes, he will rise up and pass one of his fifth legs to the opposite side, hooking his first pleopod which pushes it down. He then presses down forcing the point of the pleopod into the female's seminal receptacle. The hooks on the base of the male's third leg apparently are used to help lock them together at this time.[7, 8, 9]

The transfer of sperm can now begin. The first pleopod has a groove from the base to the tip. The testis has an opening at the base of the male's fifth leg. A thin tube extends from this opening (the vas deferens) and connects to the basal end of the pleopod's groove. Sperm travels from the vas deferens, down the groove and into the seminal receptacle as "long, macaroni-like cords". The process can take several hours and the female barely moves during this time. Then the male rises up and releases the female. After completion, a waxy, white plug blocks the opening until egg laying which may not occur for several weeks or months.[7, 8, 9]

When it comes time to lay her eggs, the female will look for a dark, protected area. At this time she is very excitable and assumes a defensive posture with any disturbance. The process begins with her propping herself up on her claws and tail in a tripod fashion. At this time she is using her fifth legs to clean the underside of her abdomen. The ends of the fifth legs are fitted with picks, hairs and comb-like spines that help in the cleaning process. The second and third legs have miniature claws that also help pluck off debris.[7, 8, 9]

Actual egg-laying occurs at night. The female raises up and waves her pleopods

Glair glands on mature female

back and forth as they became covered with glair. Glair is produced by glands (see photo at right) under the telson and at the bases of the pleopods which, when mature, they take on a milky, white appearance. [The dictionary definition of "glair" is "a viscous substance resembling egg white".] After a bit the female rolled over on her back and curled her abdomen. The glair filled the space from the telson to the second legs. Into this area, the eggs were extruded from the oviduct openings at the bases of the third legs at the rate of 12 to 60 per minute. Apparently, at this same time, sperm was released from the seminal receptacle. The sperm and eggs mixed within the protection of the glair. With the abdomen still flexed and the fertilized eggs protected by the glair, the female began a series of rolling movements from left to right and back numerous times. In one example this process took over four hours. In the process, each egg is encased in a membrane that is connected to a pleopod with a fiber or string that must be formed from the glair. Eventually, the female stands up and, with flexing, the excess glair is washes away.[7, 8, 9]

The female will now retreat to a secluded area while the eggs are developing. Most of the time the abdomen is curled under, protecting the eggs. Occasionally, the abdomen is straightened and the masses of eggs, hanging down like grapes, are waved back and forth to aerate them. The small, clawed legs are used to clean the eggs at this time.[7, 8, 9]

The eggs will begin hatching in five to eight weeks. First, the egg case splits along the embryo's back. The embryo backs out of the egg case, feet last, over a period of about 20 minutes. At this time, the embryo is still attached to the inside of the case at the end of its tail. After straightening its legs, its large claws grab hold of the egg case stalk. It now keeps a firm grasp upon the stalk until its abdomen comes free of the case. This is the first stage and it is now about 4 mm long. About 48 hours later, it molts into a second stage larva.[7, 8, 9]

Eggs attached to female's abdomen

I quote Andrews[7] who said, "As the shed skin still has its claws fast locked to the in the egg stalk the larva though it has drawn its hands out of its gloves, as it were, and come out of its old clothes, still remains indirectly attached to the mother since its telson is fast to its old suit and this is not broken but continuous with the gloves, or claw skins." In this way, they can molt and not loose contact with their mother. Now they are around 4.5 mm long. Through these first two stages, the larva is mostly thorax and head with a tiny tail that ends in a point. After about six days they are ready to molt into their third stage.

The third molt takes only a few minutes and it is at this time that the physical connection to the mother is broken. The antenna and tail fan are now developed and the juvenile now looks like a miniature adult. Now about 8 mm long, they remain with their mother for another week, crawling about on the egg cases and shed skins. They may occasionally leave the mother on short excursions in the outside world but always return. After eight days, most will leave momma and begin their own lives. They will molt into their fourth stage in about 18 days at a size of 12 mm and into their fifth stage in another 17 days at 15 to 18 mm. Females may breed for their first time at the end of their first summer of growth. Mating was seen in October when females were only 4 ½ months old and 50-62 mm long.[7]

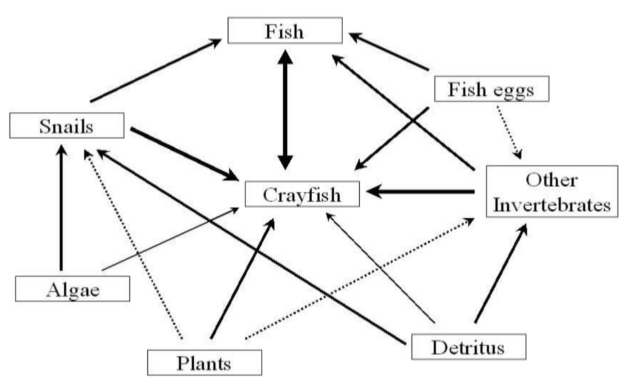
Estimating the fecundity of the female can be done in one of three ways. One is the dissection of the female and counting the number of yolked eggs in the ovaries. This counts every egg that could be laid and is <u>potential</u> fecundity. A second way is by counting the number of eggs that are attached to the pleopods. This deducts eggs that weren't laid and is the <u>realized</u> fecundity. Finally, you can count the number of independent juveniles. This deducts for eggs that didn't hatch or were lost and is <u>actual</u> fecundity. There can be a 58% loss between potential and actual fecundities for Calico crayfish.[220]

One researcher actually counted the ovarian eggs (potential fecundity) in 106 females and egg counts (realized fecundity) on an additional 126. The number of eggs in the ovaries ranged from 76 to 528 and actual egg counts ranged from 11 to 474. The loss of eggs varied widely between the two methods but, overall, averaged 28%.[79]

The number of eggs depends on crayfish size and, as one would expect, larger crayfish produced more eggs. For instance, one study found Calico crayfish had an average of 84 eggs on first spawn and 195 for the second spawn.[79, 210, 226]

FOOD AND FEEDING

Crayfishes have long been considered to be omnivorous opportunists, eating whatever they can find. This idea had its origins in the pioneering work of Huxley[119] where he stated that "few things in the way of food are amiss to the crayfish, living or dead, fresh or carrion, animal or vegetable, it is all one". Crayfishes make their living at several levels including herbivore, scavenger and predator.[109] While they may



be omnivores, they may act mainly as carnivores.[165] For instance, while they eat vegetation, they may be eating it to get at the invertebrates that live on the vegetation. The problem with food habits studies is that the usual procedure is to dissect out the stomach and examine the contents. However, crayfishes grind everything they eat into mush and the stomach contents often cannot be identified.[226] Furthermore, animal protein is more readily digested so it is not at all unexpected that most studies identify their food as "unidentified plant material".

You can find a lot of crayfish food chain charts on the internet but I created my own chart shown here. It is an attempt to illustrate how crayfish may interact with the other organisms with which they live. The arrows show who eats what and the thickness of the arrow shows the strength of the interaction.

In describing crayfish predation, some of the old literature has the most colorful language. In 1873, Abbott[1] observed that crayfish will "seize the minute young Cyprinoids [minnows], that pass up and down . . . peeping into the various little indentation in the banks. Such little fish when once fairly caught by the big. . . "hands" of a Cambarus, have no chance of escape, and are soon torn to pieces and devoured." He went on to note that ". . . darters. . . .will usually take shelter underneath a stone. . . When a crawfish happens to have taken up its abode under such a stone, it is seldom that the frightened darter escapes." Crayfish are also "skilled predators of tadpoles".[76]

Crayfishes are also cannibals. Molting crayfishes, while still soft, can be killed and eaten by other crayfishes.[15] On a personal note, not long ago I had two Northern crayfish in an aquarium with an escape-proof cover. That is, on Friday there were two, on Monday there was one with no evidence that there had ever been a second in the tank.

While all age classes may use plant material, adults do it more extensively. As an herbivore they function as shredders, collectors and grazers.[109] As shredders, they convert leaves, sticks, plants, etc. from coarse organic matter into fine organic matter. In turn, this fine organic matter may be used by smaller macroinvertebrates directly as food or indirectly as a substrate for algae and bacteria which can then be eaten. In a Michigan stream, crayfish (*Orconectes propinquus*) virtually eliminated a filamentous alga (*Cladophora glomerata)* which indirectly benefitted diatoms and grazing insects.[33]

Crayfish, such as the Calico crayfish, can even act as filter feeders but it may be that juveniles <u>must</u> filter feed whereas adults may do so as needed.[16]

MOLTING AND GROWTH

Crayfishes are members of the order Arthropoda along with insects and arachnids. While "Arthropoda" means "jointed foot", their most important characteristic is that they all have an exoskeleton. The success of this group of organisms worldwide shows the advantages of this system. However, periodically, an exoskeleton must be shed and replaced to allow for growth. The technical term for this is "ecdysis" which is the periodic replacement of the external skeleton in arthropods and related groups. The term "molting" for ecdysis is commonly used. ["Molting" occurs throughout the animal kingdom and includes the shedding and replacement of horns, hair, skin, and feathers.]

The frequency of molting depends on the rate of growth and, since juveniles grow more quickly than adults, they molt more often. During their first year of growth, between May and September, a crayfish may molt seven to 13 times and triple in size.[9, 234]

Most of our crayfishes probably live 2 to 3 years. But there has been no way to age a crayfish or know how long they live because they retain no hard structures for their full life span. The only real way to know a crayfish's age is to keep it in captivity for its full life. However, captive animals seldom have the same life span as one in the wild. It is probable that crayfishes in more northern latitudes grow more slowly and mature later but also live longer.[164] One study used growth rates and size classes to estimate that Devil crayfish in Indiana could live 14 years.[232] But growth is so variable that this technique may not be accurate. So, in a nutshell, the larger a crayfish is, the older it is but perhaps with the continued development of micro-tagging technology we can answer some of these questions.

The molt cycle in crayfish has four major phases which are the premolt, the molt, the postmolt, and the intermolt. **Premolt**: the exoskeleton softens as calcium is extracted from it and stored in a pair of gastroliths ("stomach-stone") which are located in the foregut (see photo at right). At the same time that the old exoskeleton is softening, a

new one is forming beneath it. **Molt**: the old exoskeleton splits at the juncture of the thorax and abdomen and the crayfish kicks itself free. It then goes into hiding as it is extremely vulnerable to predation at this time. **Postmolt**: the crayfish has a totally soft exoskeleton which must be hardened with new calcium. Part of this calcium comes by re-absorbing the gastroliths. There isn't enough calcium in the gastrolith to completely recalcify the exoskeleton so much of it probably goes directly to the mouthparts so they can eat.[148] The rest of what they need comes from their food (including the old exoskeleton). **Intermolt**: the period when the exoskeleton is fully re-calcified and the crayfish is free to resume its life. During the premolt, molt, and postmolt periods, the crayfish is soft and vulnerable to cannibalization and predation. As a result, their molt cycle is a dominate factor in their life cycle.

Crayfishes occasionally lose limbs, especially chelipeds, but they also have the ability to regenerate these lost limbs. Termed autonomy, their limbs have a membrane across pre-formed breakage points. No muscle tissue passes through this membrane, only blood vessels and nerves. Thus they are able to regrow a lost limb though the regenerated limb does not exactly match the original. The two photos on the next page illustrate normal and regenerated chelipeds.

Normal Northern crayfish cheliped

Regenerated Northern crayfish cheliped

PRODUCTION

Standing crop and production are two sides of the same coin. For instance, if we put 100 head of cattle, each weighing 500 pounds, into a pasture, we would have a standing crop of 50,000 pounds. Eight months later, we remove the cattle and find they weigh 800 pounds for a total of 80,000 pounds. The production was 30,000 pounds. This concept applies to crayfish but the catch is that this isn't so easy to measure in a stream so there aren't many estimates of annual production out there. One worker estimated that total annual production of crayfishes in an Ozark stream was 20 times that of fish.[195] In Michigan lakes, the mean standing crop of Northern crayfish varied from 9.4 to 30.3 kg/ha while annual production ranged from 71.9 to 169.7 kg/ha.[166]

COMMENSALS, PARASITES AND DISEASES

Commensals, parasites and diseases – Oh My! First, some definitions: a commensalism is where one benefits and other doesn't; mutualism is where both benefit; parasitism is where one benefits and the other is harmed. All of these are forms of symbiosis.

Branchiobdellidans on crayfish

There is a whole group of commensal organisms (some 150 species worldwide) called branchiobdellidans (say that three times fast) that live only on crayfish. In a nutshell, these are small worms (1 to 10mm long) that live on crayfish and cannot reproduce or survive without their crayfish host (obligate ectosymbiotic annelids). What the branchiobdellidans do for the crayfish is to eat the bacteria, algae, diatoms and protozoans that accumulate on their exoskeleton or in the gill chamber. What the crayfish get out of this is a clean exoskeleton and clean gills. Actually, no one is really sure if the relationship is commensal, mutual or parasitic but may be all three, depending on conditions.[214]

Parasites of crayfish include flukes (digeneans), tapeworms (cestods), roundworms (nematodes) and spiny headed worms (acanthocephalans) though these seldom affect the health of a crayfish. There is one fluke (*Paragonimus* sp.) that is of concern to humans as it can cause a serious lung infection (Paragonimiasis) if the crayfish are eaten raw. Though rare in North America, a few cases occur every year.[192]

A number of crayfish diseases have been discovered but there is little known about their effect on our native crayfishes. Crayfish plague is a serious disease caused by a fungus (*Aphanomyces astaci*). Apparently this fungus is native to North America and our native crayfishes are resistant so it doesn't cause problems here. However, heavy mortalities of European crayfishes have occurred as a result of the importation of North American crayfish.[53]

Finally, while not exactly a parasite or a commensal, some aquatic insects such as water boatmen will lay their eggs on crayfish.

"BLUE" CRAYFISH

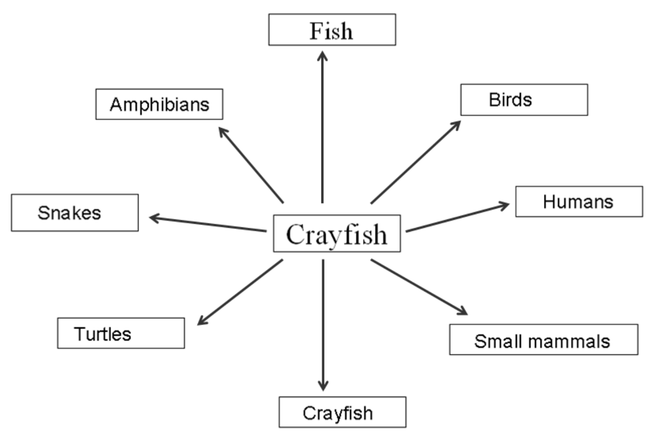
As a rule, our crayfishes tend to be shades of olive-green, brown and red-brown usually in a camouflage pattern. These muted colors and patterns probably help to hide them from predators. But we occasionally see some strikingly different individuals that are a bright blue color. If you did an internet search on "blue crayfish" you would find loads of images of blue crayfish. Apparently, the blue coloration is due to a genetic mutation.

ROLE IN AQUATIC COMMUNITIES

The crayfish is a detritivore, a planktivore, an herbivore, a carnivore, and all of the above (an omnivore). It is a predator and it is prey.

Studies of whether crayfish had an impact on fish populations have had varied results. Some concluded that they did not.[45] Others found that they did. For instance, in a Utah lake, an introduced and rapidly expanding population of Northern crayfish competed directly with Rainbow trout (*Oncorhynchus mykiss*) for the same food source and trout growth declined.[98] Another study found that fathead minnow eggs (*Pimephales promelas*) hatched earlier than normal when crayfish began eating newly hatched embryos.[134]

If you were a crayfish, the image at right wouldn't be very comforting. It shows that everybody likes a crayfish. . . . as a meal. These include birds (herons, cormorants, gulls, terns, pelicans), small mammals (raccoons, otters, muskrats), many fishes, amphibians (mudpuppy, hellbender), turtles (snapping, painted, slider), and snakes as well as other crayfish and humans.[109, 184] A few snakes, such as the Graham's Crayfish Snake (*Regina grahami*), specialize in crayfish as prey.[78, 86]



Crayfish have been described as ecosystem engineers because their actions can alter their environment. The Devil crawfish got that designation through its construction of burrow systems. In the process of burrowing they are moving soil to the surface and mixing the upper soil layers. At the same time, the burrows increase the infiltration of water and nutrients.[190] They can alter the distribution of sand and gravel and, in the process, alter the structure of stream bottoms.[219]

Crayfish burrows are used by many species besides crayfish as refugia. Several species of snakes have been documented to use crayfish burrows for winter hibernation. These include the Common Garter Snake, *Thamnophis sirtalis sirtalis*) and the Northern Water Snake, *Nerodia sipedon sipedon*)[23, 201] , the Massasauga, *Sistrurus catenatus*[152, 154] , the Diamondback Water Snake, *Nerodia rhombifer*[130] and the Copperbelly Water Snake, *Nerodia erythrogaster neglecta*[201]. Frogs like the Striped Chorus Frog, *Pseudacris nigrita triseriata*)[23] and Northern Cricket Frog, *Acris crepitans*[120] used crayfish burrows during winter hibernation. There are instances where the Massasauga, *Sistrurus catenatus*), used crayfish burrows to survive fires.[51, 154] The larvae of the endangered Hines Emerald dragonfly regularly used the burrows of the Devil crawfish as summer refugia.[190] .

AS AN INVASIVE SPECIES

Wildlife species are often being transported and introduced into new areas. The nature of the introduction can range from global to local. Many such introductions don't "take" and the introduced species dies out. Some introductions are relatively benign or even beneficial. A few cause problems and subsequently become a pest. These are the ones we call "invasive". Several crayfishes have fallen into this latter category. Potential sources of introductions include deliberate stockings, the bait trade, aquarium and pet hobbyists, aquaculture and schools.

Impacts can be positive, neutral or negative or a combination of these based on different points of view. A crayfish farmer might consider an alien crayfish as a positive whereas a biologist would consider the same species, after it escapes the farm, a negative. Burrowing crayfishes can cause problems in golf courses, lawns, irrigation canals, flood control levees and earthen dams. Crayfishes feed on snails, insects, fish and fish eggs as well as aquatic plants. Nonnative crayfishes often reach very high densities and this, combined with their food habits, can change the food web of waterbodies. They can compete with native crayfishes directly (predation) or indirectly (competition for hiding spaces) causing the natives to decline. They can also carry diseases into new areas which has been a particular problem in Europe.[113]

A possible positive impact has been seen in Africa where there are no native crayfishes. In this case, the alien Red Swamp Crayfish eats the snails that carry the *Schistosomaisis* parasite. At the same time and in the same areas, the crayfish interfere with fisheries (eating fish eggs) as well as damaging fishing nets. [113]

In Europe, they have been bad news/good news. The North American crayfish imported into Europe brought crayfish plague which has virtually wiped out the natives in many areas. So the commercial fisheries for the native crayfish have been wiped out (negative) only to be replaced by the alien crayfish (positive). [113]

IDENTIFICATION

Crayfish guides often include a key to aid in identification. In this publication, since we only have five species, I did develop a key which is located at the end of the document but you could also use the photographs in the species accounts to help you identify them. Note that if you have a crayfish that just doesn't seem to match the photos, then you may have something new and you should look for an expert to help identify it.

COLLECTING CRAYFISHES

There are quite a few of ways to collect a crayfish. You can roll rocks at the edge of a waterbody and look for crayfishes underneath. You can put a gob of worms on a hook and lower it into the water. After a bit, slowly raise it up and see if a crayfish is holding on. You can use dip nets or seines or traps to collect crayfishes. [The types of nets and traps that are legal are listed in the Fishing Guides published annually by the Nebraska Game and Parks Commission.] We will go though some collection techniques:

Seines: Seines up to 20 feet long and four feet deep with ¼ inch(or larger) mesh are legal. Three people needed. In streams, the best technique is for two people to take the poles on the ends of the seine and anchor t he seine in one place. A third person goes upstream and dislodges crayfish out of their cover and chase them downstream into the seine.

Kicknets: A kicknet is a really short seine about three feet square with poles on two sides. It is usually used to collect bugs but will also catch crayfish. It is sized so that one person can handle it by anchoring it downstream of some promising habitat. A second person works upstream of the net, dislodging (kicking) crayfish down into it.

Seining for crayfish

Dip nets: A dip net has to have a length and width less than 36 inches with ¼ inch (or larger) mesh. One person can anchor this on the bottom and kick crayfish into the net or a person can use it to sweep through promising habitat.

Traps: Any legal minnow trap can be used to catch crayfish. You may have to use bait of some kind. Some of the best baits to use are fresh fish or fish innards. One note on trapping is that crayfish will not go near bait that has gone "bad" or is starting to go bad. They want it to be fresh. Also, in contrast to fishes, if the food runs out, crayfish will find the entrance and leave. So you have to check your traps often and there has to be enough bait to keep them interested.

The collection of burrowing crayfishes is another matter altogether. Burrowing crayfishes live most of their lives in burrows where nets and traps don't work. First, you have to find the burrows and then you have to figure out how to get them out. Not all burrows are occupied but the presence of fresh mud is a sure sign that they are. There are some techniques that can be tried. In the spring, the females will go to a nearby pool or waterbody to release her young and you might be able to catch them then. The young live and grow in the waterbody for several weeks before they dig their own burrow. You might be able to collect these in late summer.

While they spend most of the time in their burrow, they have to come out sometime to feed and mate. Rainy or humid evenings in the spring is the best time to catch them out of their burrows and can be caught by hand or a small net. If they are in the burrow, you can dig them out. But they may be very deep (up to six feet) and this is hard work. I did it once and never again. The final technique is a lot easier than completely digging out the burrow. After you find a burrow, you dig a depression about the size of a large mixing bowl. Pour water into the burrow until there is a small pool in the bottom of the depression. Reach your hand in and agitate the water vigorously. Then sit back and wait. About half the time, if there is a crayfish living in the burrow, it will come up and see what all the commotion was about. You have to watch carefully because you probably will only see the antennae break the surface of the water. If you are quick, you can stab your hand down and pin the crayfish to the side of the burrow. But be warned, they are very wary and very quick to escape back down the burrow. You can find YouTube videos that show how to do this. There is also a burrowing crayfish trap that you can make and I have used with some success. It is a short length of PVC tubing with a trap door built in.[172] I will first try the agitation technique and, if that fails, I screw one of these traps into the burrow entrance and come back the next day. Some of the time this succeeds in capturing a crayfish.

It may be necessary to preserve specimens for accurate identification. For this you will need jars and preservative. Either 8 oz or 16 oz glass jars are adequate for most of your needs and these can be either jars purchased from biological suppliers. On the other hand, the plastic peanut butter jars will work just fine and they can be had for little cost. The usual preservatives used by biologists are 10% formalin and 70% ethanol. Formalin is nasty stuff, hard to get and a known carcinogen. Leave this stuff for professional biologists. 70% ethanol is 200 proof ethyl alcohol diluted with water to 70% (7 parts alcohol and 3 parts water). Full strength ethyl alcohol is expensive and hard to get. The easiest preservative to get is rubbing (isopropyl) alcohol which can be purchased at any drug store. It should also be diluted to 70% for use.

When I preserve crayfish I prefer to euthanize them first. I put the crayfish in a jar almost full of water, then add a small amount of alcohol. After 20 minutes or so, they are knocked out and can then be preserved.

One final and very important point. If you are collecting and preserving specimens, you must document the collection site. You can do this with a collection label similar to that illustrated here. The card should be made from some waterproof paper and they can be printed with a laser printer. If you have contact with a museum, they may have cards available for your use. A special note; be sure record your data with a pencil or waterproof ink. Most preservatives will remove ballpoint or similar inks and you will end up with a blank card.

The collection card lists the waterbody name, location of the site, latitude and longitude, date of collection, county and the collector(s) name. The location is the distance and direction from the nearest major landmark, usually a town. Many GIS mapping programs only work with latitude and longitude in decimal degrees. Nowadays it is common for people to carry a handheld GPS unit with them in the field which makes it easy to record the latitude/longitude. If this is not available, you can get this from online applications such as Google Earth. Be sure to note the datum that the GPS uses to compute the latitude and longitude. This is usually WGS84 but if it is something else, you should note that on the collection card. [WGS84 is the World Geodetic System of 1984].

NEBRASKA GAME AND PARKS COMMISSION – FISHERIES DIVISION
COLLECTION RECORD

WATERBODY ____________________

LOCATION ____________________

____

LAT. __________ LONG. __________

DATE __________ COUNTY __________

Collector

STUDYING CRAYFISHES

The collection and publication of basic life history information used to be a foundation of the study of organisms. Nowadays, research into the life histories is rarely done which is why only 12% of North American crayfishes have published life history information.[169] For many crayfishes, we cannot even define their ranges as there are so many areas that have never been sampled. Collecting life history information is not difficult and students or citizen-scientists at any level can do this. So what is life history information? Such things as:

-What kind of crayfishes live in your local waters?
-When are the females carrying eggs?
-How many eggs do they carry?
-How large are the eggs?
-How long does it take the eggs to hatch?
-When do they release their young?
-How fast do the young grow?
-When do they become mature?
-When do they mate?
-How many young survive to become mature?
-What do they eat?
-How often do they molt?
-Do they move?
-How far do they move?
-How long do they live?
-What habitats are they using?

To be really useful, the information has to be published in some form where others can find it. There are journals that publish this information and this is an option but not the only option. With the advent of the internet, now papers and reports can be "self-published" by posting them on a website. If you are a student, your instructor can help you out with this. But, to be accepted, the work should be carefully thought out, carefully done and, most importantly, accurate and correct. It is disappointing to find, in what appears to be a well-done study, that the crayfish was misidentified. And, please, you should work with crayfish that you have collected locally. Biological supply houses provide common species that are already well known and are often invasive. You learn so much more if you go out and get your hands and feet wet while collecting your own critters.

ECONOMIC IMPORTANCE

Earl Theron Engle, in his 1926 publication on Nebraska crayfishes, stated "Personal inquiry at the office of the game and fish department of Nebraska, at Lincoln, brought the information that crayfishes were worth nothing and could not be considered among the resources of the state."

That is an interesting statement but, given the times, was probably not unexpected. At that time, the Game and Fish Commission consisted of several fish hatcheries and a handful of wardens. There were no biologists and there was no interest in the documenting the state's wildlife resources. Fish and wildlife were valued as to their usefulness to people, usually as food, and studying them was left to people like University students and professors.

On the positive side, in southern states like Louisiana, crayfish growing and harvesting for the food trade is a big business.[118] One Internet site stated that Louisiana crayfish farms produce almost 10 million pounds a year worth some $5 million. The production of crayfish for fish bait and use in laboratories is also fairly important. In Nebraska, aside from a few individuals catching crayfish for their own use, harvest for food appears to be of minor importance. There may be some harvest for resale as fish bait. There are also ecological benefits which are discussed in the later section on Ecology.

On the negative side, crayfish burrowing can be a problem in areas where they develop large populations. As they dig their burrows, these crayfishes create large earthen chimneys. In high numbers, these chimneys can be a problem for farm machinery and lawn mowers. In Nebraska, burrowing crayfishes are relatively uncommon so, here, they are not a problem. Extensive crayfish burrowing has been known to weaken earthen dams and cause canals to leak. Again, this has not been a problem in Nebraska because our populations of burrowers are low. However, if some of the southern burrowing crayfishes that are common in the food and bait trade were to get established here, that situation could change. Nonnative organisms, when introduced into new areas, often have population explosions which could lead to problems, such as in the irrigation canals in the western part of the state and farm ponds in the east.

High numbers of crayfish in fish culture ponds can also be a problem as they will eat young fish and fish eggs as well as competing with the fish for the same food.

HOW THIS BOOK IS ORGANIZED

There are two separate sections with species accounts. The first is for our native crayfishes which are intended to be fairly comprehensive. Each of these will include two maps, one with Nebraska collections and a second illustrating the North American range. The second section if for nonnatives and will be simple overviews of the species and will include only a North American range map.

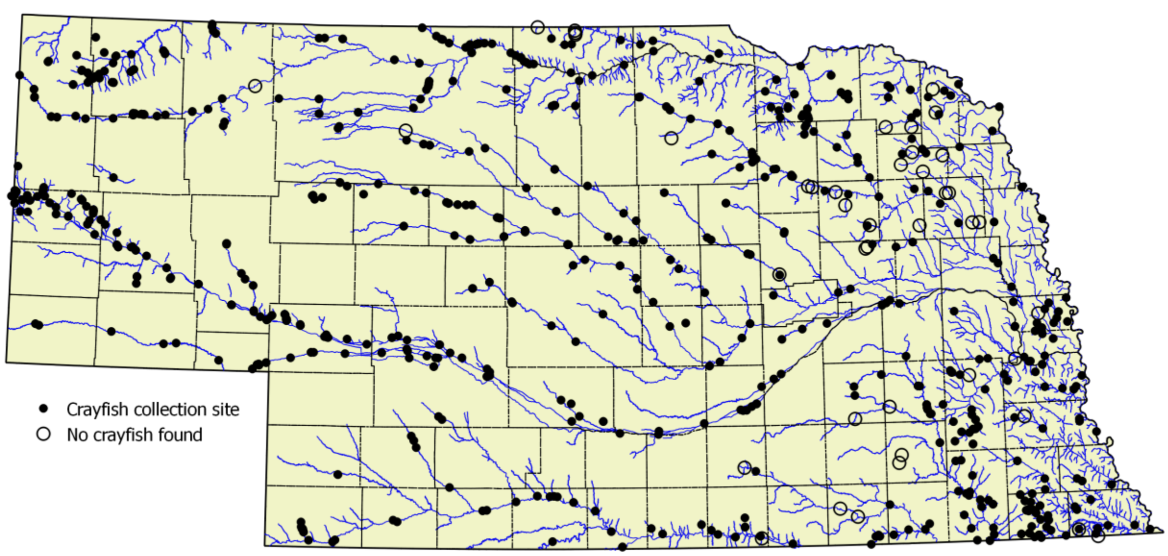
The Nebraska collections map will show all collection locations for that species in Nebraska. On this map, no attempt was made to distinguish between historic and current collection locations for the simple reason that few (< 6%) collections were made before 1993.

The second map is a North American range map. While there are range maps presented in other publications and online, I decided to ignore those and develop my own from published materials and online resources. These include: Aiken[3], Bergey et.al.[10], Bouchard and Robison[14], Campos and Rodriquez-Almaraz[20], Creaser and Ortenberger[32], Crocker[35, 36], Crocker and Barr[37], Daniels[41], Dieter[47], Durbian et.al.[52], Eversole and Jones[57], Francois[70], Ghedotti[75], Hayer et.al.[93], Helgen[97], Hobbs[100, 101, 106], Hobbs and Hart[108], Hobbs and Jass[110], Hovingh[115], Hubert[116, 117], Jass[122], Jezerinac[124, 125, 126], Jezerinac and Thoma[127], Lippson[140], Loughman[146], Minckley and Deacon[162], Morehouse and Tobler[170], Newcombe[171], Ortmann[177], Page[180], Pearse[182], Phillips[189], Pflieger[188], Reimer[198], Schuster et.al.[208], Schuster and Taylor[207], Simon[211], Simon et.al.[212], Sovell and Guralnick[216], Taylor et.al.[231], Taylor and Schuster[228], Thoma and Jezerinac[233], Thoma and Armitage[232], Unger[238], Wagner et.al.[239, 240], Wetzel et.al.[245], Williams and Bivens[249], Williams and Leonard[247], Williams et.al.[248], Ziser[255].

Note that several states and provinces have no published information on their crayfishes though a few have distribution maps available on agency websites. These latter are not listed here as the internet addresses for these frequently change. Also, it is sometimes not known if the range in a particular state is the native range or a combination of native and introduced populations.

NEBRASKA CRAYFISH COLLECTIONS

As of this writing, I have some 915 crayfish collections from 776 sites. Of these, 595 or 65% are my own collections. Of the remainder, 115 were collected during the 2003-2005 statewide stream fishery survey, 98 were collected by my summer aides during stream sampling, 42 were sent to me by other NGPC staff, 31 were found in online museum catalogs, 16 were found in published reports and 10 came from other sources. While there were a few crayfish collections between 1890 and 1980, over 94% were collected after 1993. The map below illustrates the collection locations (black dots) as well as sites that were sampled but no crayfish were found (open circles). I should note that if I found none at a site, I moved on and often failed to fill out a data sheet. Therefore many of the stream sections in the map with no dots or circles actually were places where no crayfish were found.



Nebraska Crayfish collections: 1995-2016

DEVIL CRAYFISH - *Cambarus diogenes diogenes*

SYSTEMATICS

Cambarus diogenes (Girard, 1852)
Type locality:"Vicinity of Washington, D.C."

Synonyms (from Hobbs and Jass 1988, Hobbs 1981, 1989):

Astacus fossor [196]
Cambarus diogenes [69, 77, 180]
Cambarus nebrascensis [77]
Cambarus Nebrascensis [85]
Cambarus obesus [17, 31, 85]
Cambarus Diogenes [59, 85]
Cambarus fossor [77, 85]
Cambarus Diogenes Diogenes [58]
Cambarus diogenes [22, 31, 32, 37, 58, 59, 89, 151, 171, 179, 236, 237]
S.(ambarus) diogenes [221]
Cambarus (Bartonius) diogenes [81, 54, 178, 179]
Bartonius diogenes [250]
Cambarus (Cambarus) diogenes [69].
Cambarus diogenes diogenes [100, 151, 247]
Cambarus diogenes sspp. [184]
Cambarus (Lacunicambarus) diogenes diogenes [102, 103, 104]

DIAGNOSTIC FEATURES AND DESCRIPTION

The Devil Crawfish has a wide range across the country. There are two recognized subspecies, *Cambarus diogenes diogenes* and *Cambarus diogenes ludovicianus*. We probably do not have *Cambarus diogenes ludovicianus* but, as noted by Hobbs[104], this is a "species complex and needs considerable attention". Most crayfish books simply lump them as *Cambarus diogenes*.

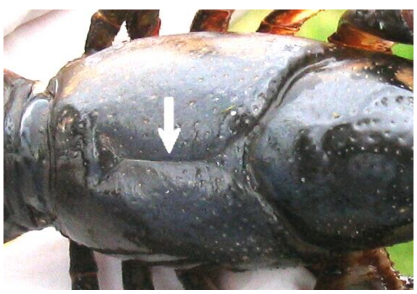
As a primary burrower, the Devil crawfish spends the majority of its life living in a burrow. As such its body form shows adaptations for this lifestyle. The carapace is enlarged to increase gill area for the low oxygen environment of a burrow.[199] There are no spines on the carapace. The rostrum is quite short and turned down over the eyes. The claws, which are used in digging, are large and wide.

If you read the various state crayfish guides you will find that there can be quite a bit of variation in the coloration and markings of this species. The specimen in the photo above was collected from Arkansas Flats in Cherry County. It is very dark but not untypical for the large adults that I have collected. The Minnechaduza Creek specimen at right has a back that is a deep red-brown which grades into a pale underside which can have distinct rosy or reddish tones. The carapace and tail will be about equal length.

This juvenile and the one that opens this chapter show a lighter overall coloration as well as a stripe down the center of the thorax and abdomen. While this stripe is present in adults, it is very hard to see.

One distinctive feature of this species is the large size of the carapace compared to the tail. It is somewhat laterally compressed so this is not very evident from above, but from the side you can see the extra height of the carapace of this crayfish.

The key identification feature for the Devil crawfish is the shape of the terminal elements of the first pleopod of a male. A mature Form I pleopod is shown at left above while an immature Form II pleopod is shown below. You can see that they have the same shape, it just that the Form II doesn't have the yellow tip. .



The two halves of the aureola of the Devil crawfish touch or overlap. There is no gap between the two halves.

The rostrum of the Devil crawfish (and of burrowing crayfish in general) is short, blunt and curves down over the eyes. You can see here that it is deeply dished and smooth.

The edges form a rim around the rostrum. This photo shows how the rostrum curves down over the eyes. This may allow this crayfish to crawl through its burrow more easily.

The chela or claw of the Devil crawfish is short, broad and powerful. Coloration and presence/absence of tubercles will vary. There are never any setae between the fingers. It has been noted that burrowing crayfishes hold their claws vertically while the open-water forms hold them horizontally. Apparently this is to allow them to crawl through their burrow while they carry balls of mud.[199]. I don't know that I have seen this except that they don't seem to hold them as "flat" as the Northern Crayfish.

Female crayfish are identified by their associatio n with and similarity to male crayfish collected from the same area as there are no keys that work with females. But since we have only five species in Nebraska, the secondary characteristics noted above will generally work. At right is the annulus ventralis of a female Devil crawfish. The upper portion of the photo is towards the crayfish's head.

HABITATS

The Devil crawfish is probably more common in the state than collection records indicate due to the burrowing habit of the species. Many species of crayfish will dig burrows for protection from predators and surviving periods of drought. A few, like the Devil crawfish, spend much of their life in a burrow, only occasionally venturing out into open waters. This extends to breeding and rearing their young in the burrow. The result is a relative rarity in collections.

The Devil crawfish digs its burrows in firm or clayey soils which can be on the banks of the stream or some distance away. In an area along the Potomac River, burrows were scattered near the banks of the stream and the adjacent meadow and as far as 10 yards away.[227] In western Pennsylvania, they were commonly found in the bottom lands along rivers but were also found as high as 200 feet above the river.[179] They can inhabit swamps formed "by spring heads, though not in the soft mud, but along the edges of such places".[69]

Burrows near a stream are shallow, not more than six inches deep, but they got progressively deeper as they got further away. Some are as deep at three feet but, however deep they were, they always went down to water. Burrows near the stream have small or no mounds but as they got further away, the mounds get larger and taller, indicating that they are deeper. Burrows vary in their construction but, as a general rule, they have a perpendicular main burrow which may have one or more oblique extra openings. The main burrow ends in a

circular chamber that holds about a pint of muddy, stagnant water. Except when a female was brooding young, individual burrows never contain more than a single crayfish and adjacent burrows do not connect.[227]

The Devil crawfish actually digs it's burrows by moving dirt in two ways: by pushing and by carrying. When beginning a new burrow on bare ground, the third maxillipeds, the claws (the first periopod) and the second periopods are formed into a wedge. With this wedge lowered, they simply push dirt forward like a little bulldozer. They keep doing this until they had a depression large enough for their whole body. Then they switch to carrying soil. Here they use their claws to grab a clump of moist dirt which they raise towards the body and transfer to the third maxillipeds. The clump of dirt is carried to the top of the burrow where it is arranged around the opening of the burrow which forms a chimney. The larger the chimney, the deeper the burrow. The burrow is dug until it reaches water but if the water level drops, the burrow is deepened. Once the main burrow is dug, extra, extra oblique entrances may be added. Sometimes a burrow is abandoned half-way and a new one started a short distance away.[83]

Burrow depths are determined by either the depth to groundwater or the depth at which the ground freezes in winter. This can be as shallow as six inches[227] or more than 12 feet.[17] In Iowa, it was noted that burrows commonly extended straight down for 75 to 100 cm and terminated in a chamber ranging from 8 to 12 cm across. Burrows in small colonies (<10 burrows) or singles were of the single shaft style with only one crayfish per burrow. Occasionally, multi-shaft burrows are found but these still only had one occupant. Occasionally, large colonies may have burrows interconnected and these may be occupied by more than one crayfish.[189]

Devil crawfish are seldom able to build a burrow in coarse-grained substrates like sand. Most of the time they could complete a burrow in fine-grained clayey substrates. Mixed substrates lead to intermediate levels of success. Their preference for clayey soils may be that these soils are easier for them to work with.[84]

Crayfish burrows have a limited exchange of oxygen with the atmosphere. Oxygen levels measured in burrow water was found to average 1.2 mg/l. This was almost the same as the groundwater at the same site (1.3 mg/l) and much lower than that in the adjacent river (8.4 mg/l).[82] How do they survive such low oxygen levels? Burrowing crayfishes like the Devil crawfish have blood with a high oxygen affinity which enables them to extract oxygen from the low-oxygen burrow habitat. In addition, they spend much of their time in the humid air of the burrow rather than in the water.[157]

In Nebraska, they used clay, sandy loam, black loam, gravel, and shaly substrates along clear streams. Near Valentine, their burrows were in the sides of steep banks in sandy loam. The openings were up to three feet above the water and there were no chimneys.[54] I have observed burrows with chimneys like those shown above in eastern Nebraska where heavy clay soils are common. In north-central Nebraska, soils are sandy and I have not seen any burrows with chimneys. Instead I have found simple holes in the stream banks which I have assumed to be crayfish burrows. The photo below shows a pasture in Pawnee County, Nebraska, where burrows were common. The site is on private land a mile west of Burchard Lake and there are no streams flowing through the area. The soils here were very moist which indicates the presence of spring seeps. The darker green grasses in this photo show the area where the burrows are found.

Pasture with many crayfish burrows throughout lower, wetter areas: Pawnee County, Nebraska

BEHAVIOR

Little is known of their behavior outside of their burrowing.

REPRODUCTION

The annual breeding cycle begins in late fall. Mating occurs in the burrow in late fall or winter which may be the only time more than one crayfish will be found in a single burrow. The female lays her eggs in the spring while she is still in the burrow. In late spring (March to May) she leaves the burrow and stays in a nearby stream until her young are released after which she returns to her burrow. The young can be found in open water through the summer and will begin digging their own burrows in late summer.[54, 110]

There are variations on the above scenario. For instance, in Indiana, pairs were found mating in April whereas, in Kansas, a pair were mating in October.[92, 247] Females carrying eggs ("in berry") were collected in April in Kansas and in April and May in Indiana.[180, 247] Eggs varied in diameter from 2.1 to 3.0 mm and larger crayfish had larger eggs.[180]

Females with young were found in June in Michigan and in May and June in Indiana.[32, 180] Free-living juveniles were found in open waters in August near Valentine, Nebraska.[54]

Most of my collections of the Devil crawfish in Nebraska have been of juveniles. To date, only seven adult male Devil crawfish have been collected and, of these, two were Form I males collected in March and the rest were Form II males collected in May (2), July (1) and August (2). Nine adult females were collected in April (1), May (2), July (1), August (3), and October (2). None of these had eggs or young.

PRODUCTION AND GROWTH

Little is known of the food habits, growth or longevity of this species due to the difficulty in collecting adequate numbers of specimens.

FEEDING AND SPECIES INTERACTIONS

The foods of the Devil crawfish are unknown but it is thought that they leave their burrows at night to forage on vegetation.[37, 151] There have been instances of predation on snakes when both were using the same burrow.[23]

On the other hand, crayfishes, including the Devil crawfish, are food to many species. Documented predators of the Devil crawfish include rainbow trout, *Oncorhynchus mykiss*; yellow perch, *Perca flavescens*; pumpkinseed sunfish, *Lepomis gibbosus*; rock bass, *Ambloplites rupestris*; bowfin, *Amia calva*; northern pike, *Esox lucius*; largemouth bass, *Microperus salmoides*; painted turtles, *Chrysemys picta*; snapping turtles, *Chelydra serpentina*; Queen Snake, *Regina septemvittata*; green heron, *Butorides virescens*; American bittern, *Botaurus lentiginosus*; white ibis, *Eudocimus albus*; kingfishers, *Megaceryle sp.*; eastern belted kingfisher, *Megaceryle alcyon alcyon*; foxes, *Lutra sp.*; raccoon, *Procyon lotor*; and otter, *Lutra Canadensis*.[78, 109, 184]

The Devil crawfish (among others) has been called an ecosystem engineer through its construction of burrow systems. Their burrows are used as a summer refuge by an endangered dragonfly during times of stream dewatering. They are also used by reptiles and amphibians for winter hibernation.[190] One burrow had five Common Garter Snakes in addition to the crayfish.[23] Devil crawfish burrows have been used by the endangered Eastern Massasauga Rattlesnake to survive grass fires.[51]

DISTRIBUTION AND ABUNDANCE

The Devil crawfish is one of the most wide-ranging of the North-American crayfishes (Figure 2). The Devil crawfish has been found in southeastern, northeastern and north-central Nebraska. It may be more common in the state than collection records indicate, especially in Sandhills streams.

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

Committee on the Status of Endangered Wildlife in Canada: N3

State Designations: AL (S5), AR (S3?), CO (SNR), DE (S3), District of Columbia (SNR), FL (S3?), GA (S5), IL (S5), IN (S4S5), IA (S3?), KS (S3S4), KY (S4), LA (S5), MD (S4), MI (S4), MN (SNR), MS (S4), MO (S4), NE (S3?), NJ (S3?), NY (S2), NC (S4), ND (SNR), OH (S4), OK (S3?), PA (S4), SC (S3), SD(S3), TN (S5), TX (S4), VA (S3), WV (S3?), WI (S4), WY (SNR)

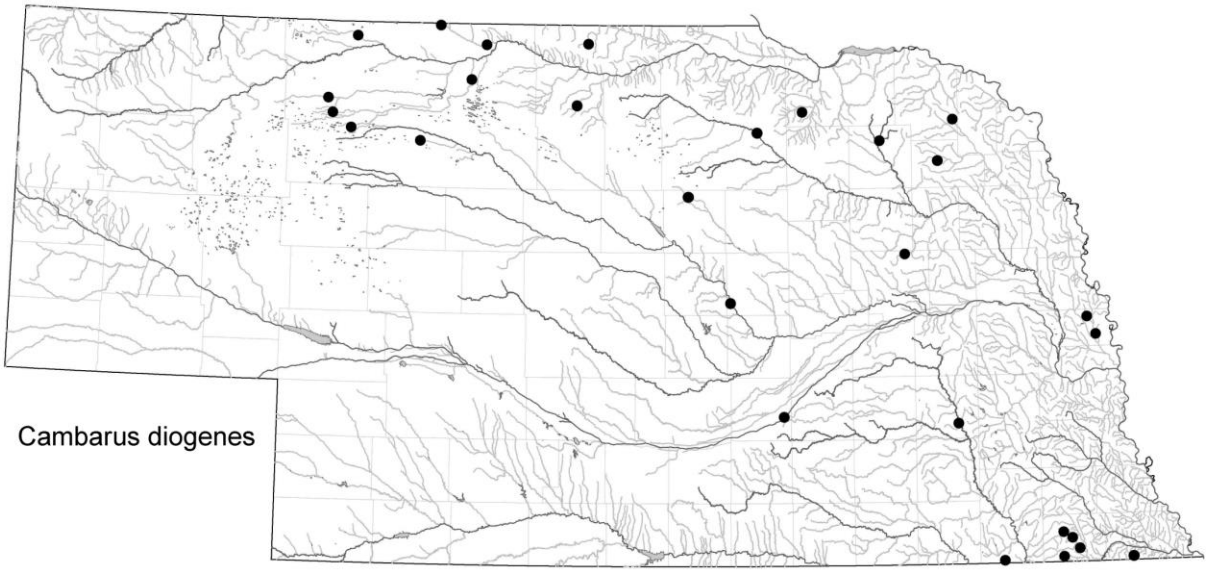
Province Designations: Ontario (S3)

CONSERVATION ISSUES

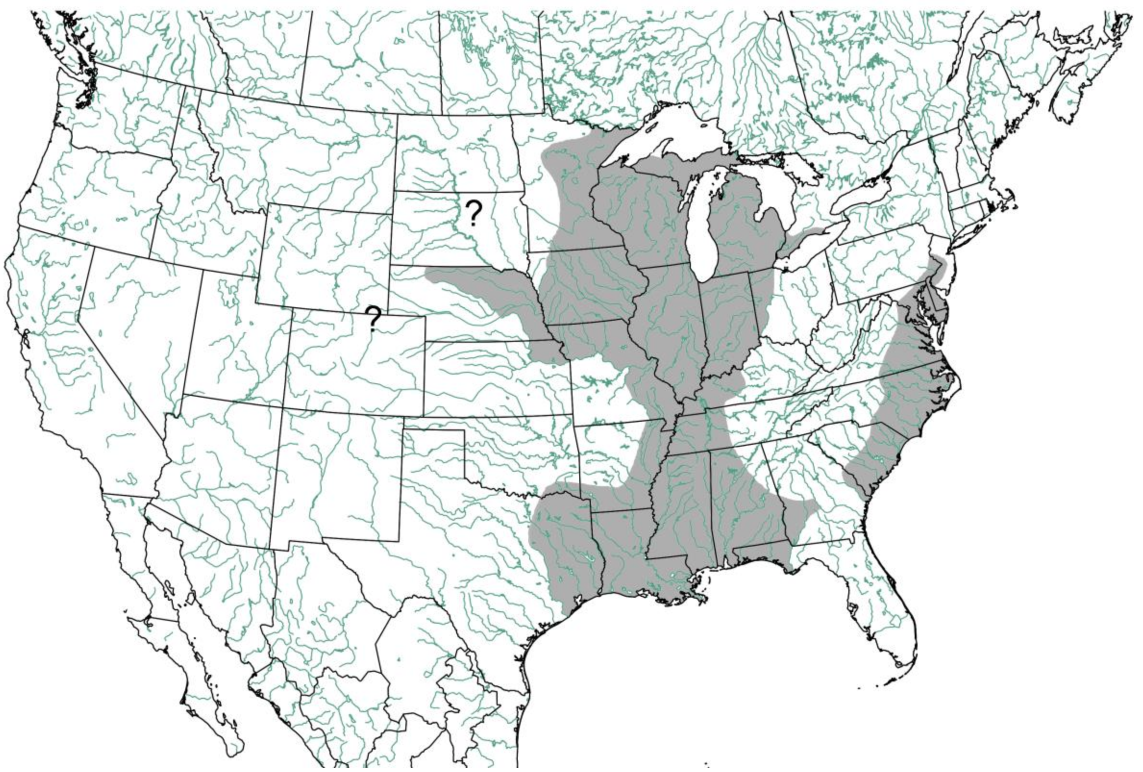
At this time there are few concerns in Nebraska. It appears to be quite widespread but difficulty in collecting them makes them hard to evaluate.

IMPACTS

Impacts on them can include stream dewatering, lowering of the water table due to groundwater pumping, overgrazing with loss of cover on stream margins and pesticide use.



Collection locations for the Devil crawfish, *Cambarus diogenes*, in Nebraska, 1995-2010



Distribution of the Devil crawfish, *Cambarus diogenes*, in North America

CALICO CRAYFISH - *Orconectes immunis*

SYSTEMATICS

Orconectes immunis (Hagen, 1870)
Type locality: Lawn Ridge, Marshall County, Illinois

Synonyms (see Hobbs and Jass 1988, Hobbs 1989):

Cambarus immunis [31, 32, 58, 61, 89, 237]
Cambarus signifer [58, 89]
Cambarus immunis spinirostris [54, 58, 61]
Cambarus (Faxonius) immunis [54, 81, 178]
Orconectes immunis sspp. [184]
Faxonius immunis [250]
Orconectes immunis [36, 37, 104, 180, 184, 187, 243, 246]
Orconectes (Orconectes) immunis [101]
Orconectes (Gremicambarus) immunis [66]

ALSO KNOWN AS:

Papershell crayfish, mud crayfish

DIAGNOSTIC FEATURES AND DESCRIPTION

This crayfish goes under the name of Calico, Papershell or Mud crayfish. Mud crayfish is seen in older literature and this name describes its preferred habitats which are slow moving streams, sloughs, roadside ditches and ponds which are often mud-bottomed.

Irrespective of the name used, its markings are not really distinctive. The adults are often a darker mud brown color like that in the photo above. Juveniles like that in the photograph beginning this section tend to show the best coloration which is a mottled light brown. From above, this color pattern provides good camouflage.

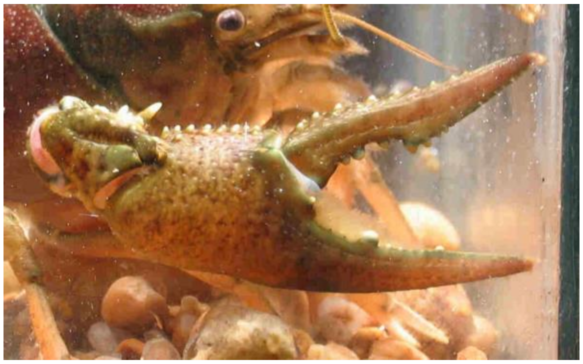
I have noticed that these crayfish often show a purplish tinge on the bottom of the chelae as this photo shows. As with all crayfishes, their color is the lightest and brightest after a molt which steadily gets darker as algae and crud build up on their carapace.

The key identification character of the species is the shape of the first pleopod of a Form I male. This one is quite distinctive from other Nebraska crayfishes in that the corneous tip is short and sharply curved with an almost 90 degree bend. Form II pleopods retain this sharp curve.

The two halves of the aureola of the Calico crayfish come close together but do not touch. There is room for two rows of punctuations in the gap between them.

The rostrum of the Calico crayfish is broad at the base and tapers towards a terminal spine. It is deeply dished and there are no side spines like those on the Northern crayfish.

The chelae or claws of the Calico crayfish are slim with thin, delicate fingers. Just visible in this photo is a row of setae that line the inside edge of the fixed finger. The moveable finger always has an excision or cutout near the base with an opposing tubercle on the fixed finger.



As there are no keys for female crayfish, they are identified by their association with, and similarity to, male crayfish collected from the same area. Since we have only five species in Nebraska, the secondary characteristics noted above will generally work. At right is the annulus ventralis of a female Calico crayfish. The upper portion of the photo is towards the crayfish's head.

HABITATS

Numerous authors have noted that the Calico crayfish is most commonly found in areas with slow or no flow and muddy bottoms.[89, 180, 188, 226] They are tolerant of low oxygen and high turbidity.[15, 226] They are seldom found in streams with coarse bottom substrates and moderate currents.[226] But this may not be an indication of a preference for muddy substrates. Testing Northern crayfish and Calico crayfish separately in a tank with equal amounts of mud, gravel and rock substrates found that both species preferred the rock.[15] In the Lake of the Woods where the Calico crayfish is an introduced species, they preferred areas that with organic and inorganic fines and near beds of vegetation.[121]

It has been long known that the Calico crayfish is a burrowing species. But they tend to burrow only when their ponds are drying or when winter approaches. Burrows usually went straight down anywhere from 15 inches to four feet and ended in a large cavity.[19] In a hatchery, burrows in pond banks went in horizontally and also ended in a cavity. Often the burrows were sealed with clay or mud.[226] In the Maple Creek watershed of Nebraska, Calico crayfish burrowed to avoid summer drying and for overwintering. Two burrows were excavated and found "to be in excess of 1 m deep".[210]

BEHAVIOR

As has been noted for crayfish in general, adult Calico crayfish are mainly nocturnal. Through direct observation in ponds, the number that were visible from any single location increased 10 to 20-fold after dark. Juveniles, on the other hand, were active both day and night until the autumn of their first year. Females with attached eggs or young usually stayed in seclusion, even at night.[226]

Crayfishes are a favorite prey of many species so refuges are important. Calico crayfish avoided overly large refuges but also did not select for the smallest refuge that they could fit in. Actual measurements of chosen refuges showed they picked one between 1.4 and 2.3 times their carapace width. Individuals also tended to select the
It was noted above that the Calico crayfish preferred a rock substrate over mud if they had that choice. But, when both the Northern crayfish and Calico crayfish were in the same tank, the Calico crayfish were on the mud and few on the rock. This was because the Northern crayfish were more aggressive and more successful at evicting Calico crayfish from preferred rock crevices. So, because of this, in streams with rocky, flowing water and stagnant, muddy water, the Calico crayfish will be found in the muddy areas.[15]

same size refuge in successive trials. This says that population sizes could be affected by the availability (or shortage) of refuges.[68]

When temperature preferences were tested, Calico crayfish avoided temperature extremes (6C and 36C) but they wandered freely through the intermediate temperatures. They were most active at night where they tended to select a temperature around 22C while, during the day, they were inactive and selected areas with a temperature around 4 degrees cooler.[34]

In a twist in Germany, one exotic crayfish, the Calico crayfish, was replacing another exotic, the Spinycheek crayfish (*Orconectes limosus*). The Calico was more aggressive and was often successful at displacing the Spiny cheek crayfish from preferred habitat. Here we have one introduced species displacing another.[26]

When the Calico crayfish's ability to maintain itself in a current was tested, they started to slip downstream when it got over 26 cm/sec (0.85 ft/sec). This is quite low and might help to explain why they are mostly found in quiet waters.[153]

REPRODUCTION

Mating in the Calico crayfish can occur whenever the males are in breeding form and runs from mid-June to mid-October with a peak in late summer. In early fall, the females enter their burrows for the winter. The time of egg laying isn't really known but is probably in the spring before they emerge. A few females had laid eggs in the fall, but this was rare.[79, 226]

Egg counts for 37 first spawn females averaged 84 and ranged from 4 to 170.

Second spawn females averaged 195 (range of 38 to 289).[226] In Indiana streams, 15 females collected in early April were carrying from 33 to 367 eggs which ranged

from 1.0 to 2.0 mm in diameter. Three females were carrying from 33 to 333 1st instar young (3mm long). Actual egg counts on the pleopods ranged from 11 to 474. The loss of eggs varied widely but, overall, averaged 28%.[79, 220]

In the Maple Creek watershed of Nebraska, no females in berry were found in the fall but most were carrying eggs in the spring. They averaged 279 eggs per female which ranged from 91 to 468 and this was directly related to crayfish size. The eggs began hatching on 10 May and this continued for two to three weeks. Almost all young had left the female by the end of May.[210]

The female with eggs illustrated here was collected from the upper Niobrara River on 10 May 2011. She is relatively small with a carapace length of 27 mm and was carrying 120 eggs.

PRODUCTION AND GROWTH

There is little variation in the size of juvenile Calico crayfish while still attached to the female through their first three molts. Their growth ceased by early September and when they were 13 to 29 mm and growth resumed about mid-April. While the aging of crayfish has been impossible up to now, it is probable that the fastest growing individuals matured at the end of their first year. Most crayfish probably did not mature until the mid-summer molt of their second year.[226]

Under favorable conditions, the Calico crayfish could mature in four months after hatching, but in temporary ponds, growth would be slow and maturity would be delayed until their second year. It appears that crayfish rarely live more than two years and crayfish that matured early also died early.[19] There is high mortality of males after fall breeding and of females in the spring after their young leave.[79, 226] My collections tend to support these observations. On many occasions I have been able to collect many juveniles in an area where larger adults were almost non-existent.

In Maple Creek in Nebraska, the numbers and biomass of Calico crayfish varied through the year. One site reached its peak numbers on 15 July at 40/m² and 116.4 grams/m² (this is equal to 1,036 lb/ac). Three sites that dried had peak numbers of less than half these numbers at 15 to 19 /m². The biomass figures at these three sites were also lower at 16 to 70 g/m². [15.9 g/m² is equivalent to 142 lb/acre] The early drying sites had slow crayfish growth rates and most did not mature until their second season of growth. At the one site that did not dry, young-of-the-year crayfish matured in their first season.[210]

One study devised a technique to mark crayfish by clipping different sections of the abdomen so that the mark was still visible up to 16 months later. Many of these crayfish died at 12 to 18 months of age. Two years appeared to be the normal life span and only a few managed to live three years. The study sites were three large hatchery ponds which were drained often so it was possible to get direct measurements of total production. In the three years of 1939 to 1941, production in these ponds varied from 1 lb/acre to 692 lb/acre.[79]

FEEDING AND SPECIES INTERACTIONS

One study made direct observations on feeding in ponds. The most common activity was the scraping of algae off rocks. Calico crayfish would also eat the leaves of plants hanging in the water. Aquatic plants were often eaten, (especially by the young crayfish) as was artificial fish feed. One instance of cannibalism was observed (one crayfish eating one recently molted) and one instance of a crayfish eating a fish.[226]

Attempting to analyze stomach contents is difficult because crayfish macerate their food into mush. Plant material is often the dominant food item found. Other foods can include zooplankton (*Daphnia*), insect remains, isopods (*Asellus*), and midge larvae (*Chironomus*). Rotifers and diatoms were commonly seen as they were frequently still attached to plant fragments.[226] Perhaps they were eating the plants to get the rotifers?

Calico crayfish juveniles were found to filter feed whereas adults may do so opportunistically.[16]

Calico crayfish have been tested as a means to control submerged aquatic vegetation. They did so by a combination of eating vegetation and clipping it off. But it would take at least 88 crayfish per square meter to provide adequate vegetation control.[137] Calico crayfish fed on submersed macrophytes in the Lake of the Woods but did litt6le damage.[121]

DISTRIBUTION

The range of the Calico crayfish extends from the Continental Divide in Colorado, Wyoming and Montana eastward to Maine and from Kentucky to Canada. It has been introduced into Europe (Germany) and Canada.[114, 121]

The species is widespread in Nebraska, typically (though not exclusively) found in slower, silt-bed streams. It has not been found in the Little Blue basin, there is only one record for the Republican basin and it is uncommon in the Big Blue basin. In the White River/Hat Creek basin, it is the dominant species.

Its distribution in the upper Niobrara River is interesting. From the Wyoming state line to Agate Fossil Beds National Monument, the Ringed crayfish is the dominant species. At Agate, Ringed crayfish and Calico crayfish can be found together. Between Agate and Box Butte Reservoir, the habitat changes with aquatic vegetation declining markedly and only Calico crayfish are found. Within Box Butte Reservoir we find only Northern crayfish but below Box Butte Reservoir, Northern crayfish and Calico crayfish will both be found for a short distance after which the Calico dominates for several miles.

IMPACTS

The Calico crayfish has been introduced into Europe and into several Canadian lakes.[114, 121]

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

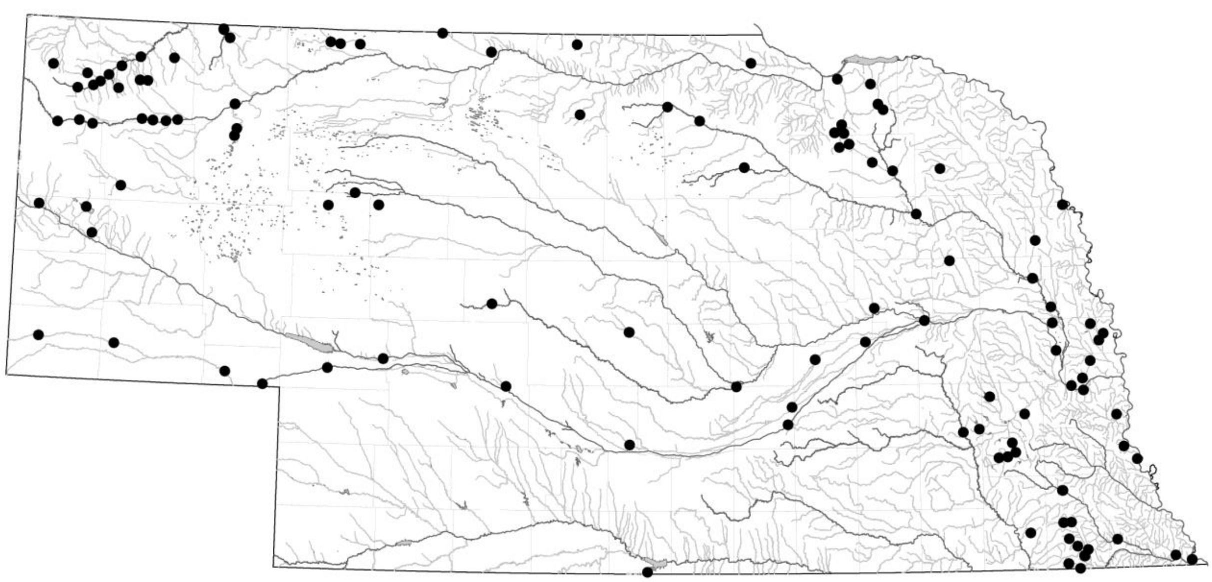
Committee on the Status of Endangered Wildlife in Canada: N4

State Designations: CO (SNA), CT (SNR), IL (S5), IN (S5), IA (S5), KS (S4), KY (SU), ME (SNA), MA (SNA), MI (S4), MN (SNR), MO (SNR), MT (SNR), NE (SNR), NH (SNA), NY (SNR), ND (S3), OH (S4), PA (SNA), RI (SNA), SD(SNR), TN (S5), VT (SNA), WI (S4?), WY (SNR)

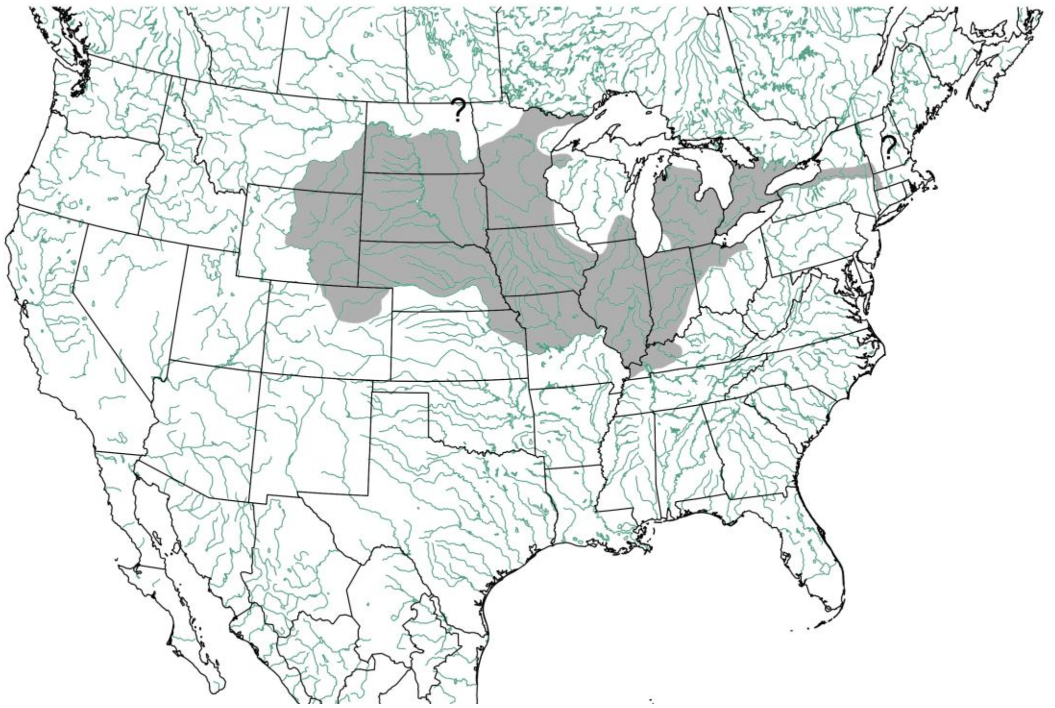
Province Designations: Manitoba (SNR), Ontario (S4), Quebec (S4)

CONSERVATION ISSUES

There are few concerns in Nebraska as it is a widespread, native species. Impacts on them can include loss of cover on stream margins due to overgrazing and pesticide use. On the other hand, it has proven to be an aggressive invasive species where introduced outside of its native range.



Collection locations for the Calico crayfish, *Orconectes immunis*, in Nebraska, 1995-2010.



Distribution of the Calico crayfish, *Orconectes immunis*, in North America

RINGED CRAYFISH - *Orconectes neglectus neglectus*

SYSTEMATICS

Orconectes neglectus neglectus (Faxon, 1885)
Type locality: Mill Creek, Wabaunsee County, Kansas

Synonyms (see Hobbs 1989):

Cambarus neglectus [59]
Cambarus (Faxonius) neglectus [32, 178]
Orconectes neglectus [187, 247]
Orconectes neglectus neglectus [104, 158, 187, 246, 238]
Orconectes (Procericambarus) neglectus neglectus [66]

ALSO KNOWN AS:

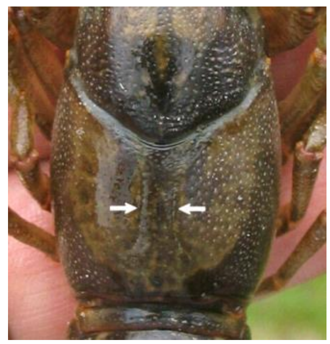
No other names

DIAGNOSTIC FEATURES AND DESCRIPTION

The Ringed crayfish is distinctive in many ways. From the side, this crayfish has a dark back grading into a tan line that abruptly stops. Below this the carapace is transparent, though this appears as a dark band. This can be seen in the photo at right as well as the one opening this section.

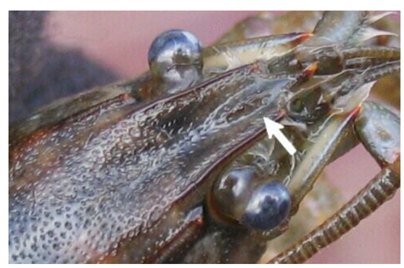
Another color characteristic that is visible in the photo above is the rusty-red tinge on the edges of the telson (tail). Again, this is most visible on freshly molted specimens. If you do an internet search for images of "Ringed crayfish" or "*Orconectes neglectus*", you will often see that this crayfish has a pair of crescent shaped black bars on its carapace which are visible in the photo at left.

One of the key identification characters of many crayfishes is the shape of the first pleopod of a Form I male. The terminal elements of the first pleopod of the Ringed crayfish are straight with the mesial process having a slightly flattened end. [Note that this is quite similar to that of the Rusty crayfish.] In non-breeding season the pleopod reverts to a juvenile form Form II that is of little use for identification.



The aureola in the Ringed crayfish is wide but not well defined. There is room for several rows of punctuations.

The rostrum of the Ringed crayfish is generally similar to that of the Northern and Rusty crayfishes except that it has a bump (median carina) in the center. This is a key characteristic and separates this species from all other Nebraska crayfishes. (Note that on small juveniles this carina is little more than a high spot in the rostrum.)



There are no keys that will work to identify female crayfish. They are identified by their association with and similarity to male crayfish collected from the same location. That is because the main sex characteristic, the annulus ventralis,, is very similar between species. Now, given that, since we only have six species of crayfish in the state of Nebraska, the secondary characteristics noted above will often work with females as will the annulus ventralis. This photo

illustrates the annulus ventralis of a Ringed crayfish female.

The claw of the Ringed crayfish is shorter and stouter than those of the Northern or Calico crayfishes. The movable finger (dactyl) is straight in young specimens but develops a distinctive curve as they get older. The surface of the claw is smooth and there are no setae between the fingers. The size of the gap between the fingers can vary with sex and age. As a rule, larger Ringed crayfish have larger finger gaps. Form I males also develop larger gaps than females or Form II males. As you can see in the photo, the tips of the fingers of the Ringed crayfish usually have a black ring with an

orange/red tip (which Rusty crayfish also have). But, I occasionally find a Ringed crayfish where the black ring is absent or barely visible.

HABITATS

In Oklahoma the species "seemingly prefers streams and rivers with clear water and a rather strong current". They were found living under rocks and boulders and were often abundant.[32] In Kansas they preferred to live under rocks but were also found in burrows of clay-banked streams.[247] In Missouri they preferred clear and rocky streams and rivers where it was found in rocky riffles. They were also found in pools that had enough flow to keep them free of silt.[188]

A detailed study of the habitat use of the Ringed crayfish in an Ozark stream was done in Oklahoma. Here males tended to prefer slighter deeper water than females. Areas with gravel/cobble substrate were dominated by juveniles whereas adults preferred beds of vegetation (*Myriophyllum*). Juveniles inhabited areas of moderate velocity whereas adults occupied low velocity as well as high velocity areas.[80]

The literature above says that the Ringed crayfish prefers clear, fast-flowing streams with rocky substrate. In Nebraska, my experience says otherwise. Streams in seven of the eight river basins where the Ringed crayfish is found (Niobrara, North Platte, South Platte, Middle Platte, Loup, Little Blue, and Republican) have predominately sand-beds with occasional gravels or silt. These streams tend to be clear (less than 300 ntu [nephelometric turbidity units]). Ringed crayfish here most commonly use the cover provided by overhanging grasses (especially exposed grass root mats) and vegetation along the banks. They also use beds of aquatic vegetation or algae that may be found along shorelines or in mid-channel beds, particularly in the Niobrara River, though these are less common than shoreline grasses. While woody debris may be present in theses streams, I seldom find Ringed crayfish here. "Rock" in our streams usually is concrete riprap placed to protect bridge abutments, diversion dams and canal banks, and this is used when present.

They are also found in the Big Blue River basin but habitats here differ from those in the more western streams. Streams here tend to be deeply entrenched. While silts, sands and gravels are the dominant substrates, rock and cobble riffles are often encountered. Measured turbidities were higher and shoreline vegetation and aquatic plants are rare. Here the Ringed crayfish is usually found in rock and cobble riffles. This characterization extends to tributaries where even the smallest riffles will harbor juveniles. On one occasion, adult Ringed crayfish were collected from a silt/sand-bed pool that had no cover whatsoever except that provided by depth and turbidity.

I have not found the Ringed crayfish to burrow in Nebraska. Even in drying streams, dewatered canals, or periods of no flow, they were not found to dig burrows. Instead they were found in small cavities excavated beneath rocks or logs. The cavity is exact size and shape of the crayfish with no room to turn or move around as if they had wiggled their way under the rock.

I have collected Ringed crayfish from pools in streams but have never found them in a lake or reservoir. There are three literature references to their being collected from lakes.[116, 117, 216]

BEHAVIOR

As is typical of crayfishes with limited ranges, there is little information on behavior. One reference noted that juveniles tended to occupy higher-velocity rocky riffles which is similar to what I have found.[80]

REPRODUCTION

For Ringed crayfish in southern Missouri, breeding occurs from October to April. Females were carrying eggs between late March and mid-May and the eggs were hatching by mid-May. Females in a coldwater streams were still carrying eggs and young as late as June 20 when those in other localities had no young anymore.[89, 188]

In Missouri, egg counts on 18 females (41 to 79 mm), found an average of 245 eggs , ranging from 54 to 505). The bright yellow eggs were 1.6 to 2.0 mm in diameter.[188]

Ringed crayfish juveniles (5-10 mm) in Kings Creek, Kansas, did not begin showing up until July and August. This was a month later than those of the Water Nymph crayfish (*Orconectes nais*) in the same stream.[55]

In an Oklahoma stream, adults occupied backwater areas most of the year but, in the spring, egg-bearing females moved to the higher-velocity riffles. Perhaps, as a result, juveniles were more commonly found in high-velocity areas.[80]

FEEDING AND SPECIES INTERACTIONS

One study looked at the gut contents of Ringed and Water Nymph crayfishes in Kings Creek, Kansas. There was little difference between the two and they consumed leaves (42%), animal matter (16%), filamentous algae (13%), detritus (23%), and diatoms (6%). Of these, leaves contributed 46% to annual production while animal matter contributed 29%. The animal matter was mostly other crayfish, dragonflies and mayflies.[55]

A related study compared the stable isotope (^{15}N and ^{13}C) values in crayfish guts with their environmental values in the same stream. The values suggested that, as a whole, crayfish were acting as detrital and algal processors rather than predators. Small crayfish (<20 mm CL) appeared to be more dependent on algae and invertebrates than larger crayfish. The larger crayfish had isotope values that indicated dependence on leaves and FPOM (fine particulate organic matter).[56]

PRODUCTION AND GROWTH

The food habits study mentioned above also computed the biomass, growth and production of the Ringed crayfish in Kings Creek. Densities of Ringed crayfish ranged from 0.23 to 2.68 individuals/m^2 for juveniles (<25 mm) while adults ranged from 0.01 to 0.09/m^2. Most of the production occurred among the smaller crayfishes (<25mm CL) during the late summer and fall (July to October). Mean annual biomass was 244 ± 65 mg/m^2 and the mean annual production was 508 mg/m^2 which was 2.1 times the biomass.[55]

IMPACTS

This species has been introduced into New York and Oregon though impacts there are not known as yet.[42, 135] On the other hand, in Arkansas and Missouri they have been introduced into the Spring River from the White and Spring Rivers in the neighboring drainage. Here they appear to be displacing the native *Cambarus hubbsi* and *Orconectes eupunctus*.[150]

DISTRIBUTION AND ABUNDANCE

Up until now, the primary range of the Ringed crayfish has been described as southwestern Missouri and northwestern Arkansas with extensions into Kansas and Oklahoma. Disjunct populations were also known in north-central Kansas as well as western Kansas, northeast Colorado and southwest Nebraska. My work in Nebraska has shown that this range as shown in the map below is much larger than previously known.[205]

There are two main population centers for the Ringed crayfish, one in the Ozark Interior Highlands and the second in the central Great Plains. A genetic study of the group to which the Ringed crayfish belongs placed the group's center of origin in the

Ozark Highlands.[30] It was thought that the isolated populations in north-central and northwestern Kansas, northeastern Colorado, and southwestern Nebraska represented relict populations. It was felt that these were the remnants of a much larger range that extended through a large drainage system that flowed east and south through central Kansas during the Pleistocene glaciations. Following glacial retreat, the two population centers were disconnected. The hypothesis was that European settlement in the 1800's brought the Great Plains under cultivation which increased the siltation of its streams, making them unsuitable for the Ringed crayfish. As a result, most of the Great Plains populations were presumably lost.[72, 246]

The plowing of the prairies had a negative impact on many species, including the Ringed crayfish, but my Big Blue River collections (where turbidities often exceed 500 ntu) is evidence that this species can tolerate turbid, silty waters. It is possible that this tolerance may represent an adaptation as the Big Blue River has not always been as turbid as we now know it. John Charles Fremont camped on the Big Blue on 20 May 1842 and on page 177 of his report he wrote that "This is a clear and handsome stream, about one hundred and twenty feet wide, running, with a rapid current, through a well-timbered valley".[71] That the Big Blue River was, historically, a clear stream is also noted on page 52 in a history of Gage County published in 1918. Here it was noted that ". . .before the wash from cultivated lands had changed their character its waters were clear, sparkling, beautiful as a mountain stream---in deep places as blue as the overhanging sky".[49]

There are a number of fishes in central North America with disjunct distributions .[38, 39, 159] One of these, the Plains topminnow (*Fundulus sciadicus*), has a distribution that is strikingly similar to the current distribution of the Ringed crayfish.[38, 136] The existence of an "Ancestral Plains Stream" that formed when the Pleistocene glaciations diverted eastward-flowing Great Plains rivers to flow southward has been postulated.[159] Support for this is found in the distribution of the Plains topminnow. "..the modern distribution of *Fundulus sciadicus* suggests southeastward displacement of that species from a place of origin in the central plains into the northern and western parts of the Interior Highlands, where relict populations persist. The Ozarkian populations might have been established as early as the Kansan glaciation via the newly integrated Missouri River Basin or the Ancestral Plains Stream".[39] Further support for this hypothesis is found in a genetic study of the Plains topminnow which found that two widely separated populations (in Nebraska and in the Lamine River of Missouri) were once connected.[138] Given this information, it would seem that, if it was possible for the Plains topminnow to disperse southeast through this Ancestral Plains Stream, then it would seem to be equally possible that the Ringed crayfish could disperse northwest through the same system.

Fish distributional data have been used to describe the hydrographic history of drainage basins.[160, 241] In the same way, the distribution of the Ringed crayfish may show us the nature of the Pleistocene and post-Pleistocene drainages in Nebraska The Ringed crayfish has been collected from the Republican, Big and Little Blue, Platte, Loup, and Niobrara River basins in Nebraska. During Illinoisan times (~200,000 years ago) the Republican River flowed east and southeasterly approximately where it is today. The North and South Platte Rivers also had merged into a southeasterly flowing stream in the early Pleistocene to Illinoisan times (about where the Little Blue River is now).[217] At that time, the Loup River and the Big Blue River appear to have been connected.[28, 149] The location of the upper Niobrara River is not as clear but there was a southeasterly trending paleovalley in that area in the Pliocene which may have connected to the Loup system.[224, 225] Taken together, during the Pleistocene, we have the Loup/Big Blue, Platte, Republican and upper Niobrara basins all trending southeasterly feeding into the Ancestral Plains Stream which could have been the route by which the Ringed crayfish could migrate from the central Ozarks to colonize these same drainages.

These drainages began to separate during the post-Pleistocene formation of the Missouri River. At that time a tributary began to form (the current lower Platte River) which migrated westward where it captured the Loup tributaries, separating them from the Big Blue as well as capturing the pre-Pleistocene Platte River.[149] At the same time, another tributary that was to become the Niobrara River began eroding its way westward, capturing several of the southeast-trending drainages as well as the upper Niobrara River.[215]

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

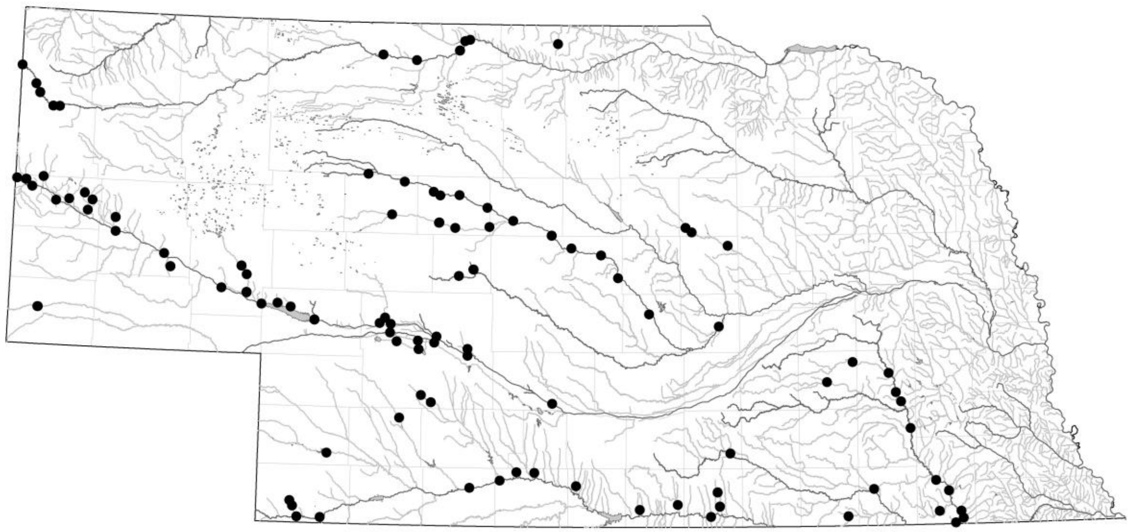
Committee on the Status of Endangered Wildlife in Canada: Not present

State Designations: AR (SNR), CO (S2), KS (S2S3), MO (S3?), NE (SNR), NY (SNA), OK (S4), OR (SNA), WY (SNR)

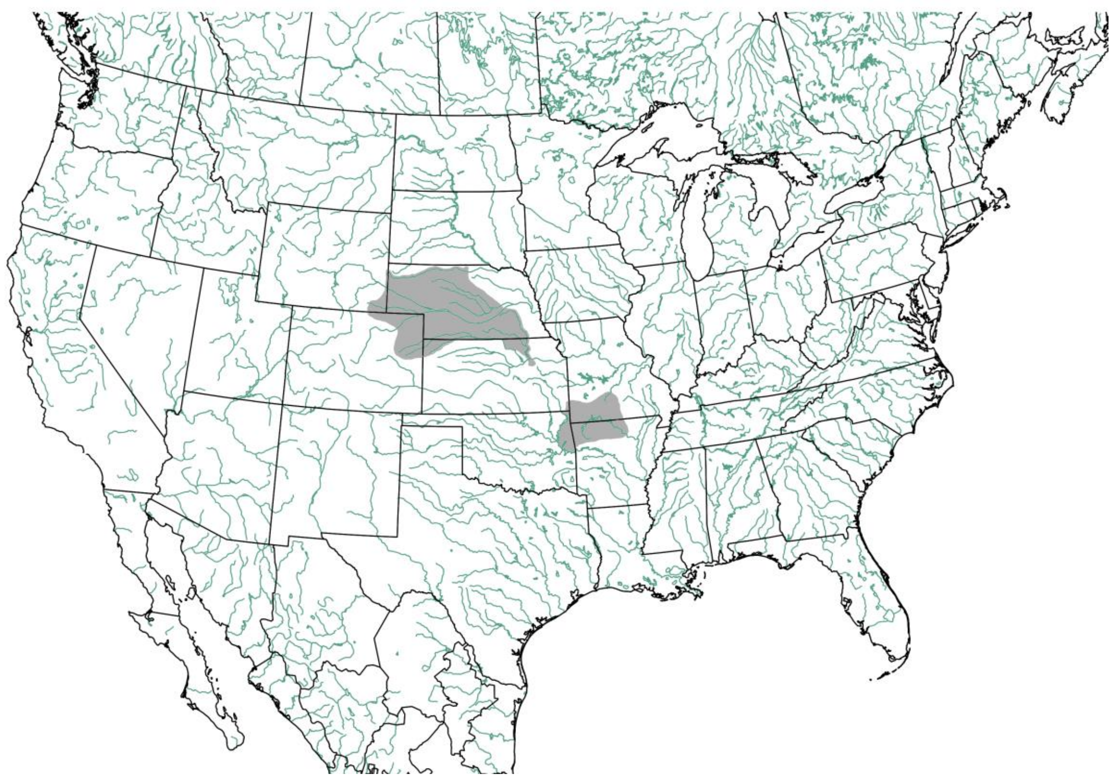
Province Designations: Not found in Canada

CONSERVATION ISSUES

There are few concerns in Nebraska as it is a widespread, native species.



Collection locations for the Ringed crayfish, *Orconectes neglectus neglectus*, in Nebraska, 1995-2010.



Distribution of the Ringed crayfish, *Orconectes neglectus neglectus*, in North America

NORTHERN CRAYFISH - *Orconectes virilis*

SYSTEMATICS

Orconectes virilis (Hagen, 1870)
Type locality: "Lake Superior", restricted by Faxon (1914).

Synonyms (see Hobbs and Jass 1988, Hobbs 1989):

Cambarus virilis [17, 31, 67, 85, 89, 222, 236, 237]
Cambarus viriles [17]
Cambarus debilus [17, 31, 67, 237]
Cambarus wisconsinensis [17, 31, 61, 67, 104, 237]
Cambarus (Faxonius) virilis [81]
Faxonius virillis [183]
Orconnectes virilis [184]

ALSO KNOWN AS:

Virile crayfish, fantail crayfish

DIAGNOSTIC FEATURES AND DESCRIPTION

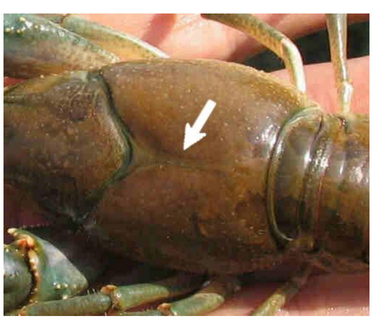
There are two other species of crayfish [the Water Nymph crayfish (*Orconectes nais*) and the Western Plains crayfish (*Orconectes causeyi*) that have been confused with the Northern crayfish for decades. Though the Northern crayfish was described in 1870 [85], the Water Nymph crayfish in 1885 [59] and the Western Plains crayfish in 1967 [123], it is still not clear as to whether these three are separate species. Hobbs[103] considered the Western Plains crayfish to be a synonym for the Northern crayfish and later stated that "This crayfish [*O. causeyi*], insofar as I am able to determine, is indistinguishable from *O. virilis*".[104] Fitzpatrick[66] said that the Northern, Water Nymph and Western Plains crayfishes were "morphologically nearly indistinguishable". In spite of these statements, two old blood serum studies have led to retaining the distinction between the Northern and Water Nymph crayfish.[193, 194]

All three of these species have been reported from Nebraska and are present in museum voucher collections. The characters used to separate these species are the physical proportions of the first pleopod and the relative widths of the aureola. I have done an extensive study of these characteristics for several populations in Nebraska. What I found was that there was greater within-population variability in these characteristics than there was between populations. In a nutshell, I concluded that there was no difference between them and have considered the Water Nymph crayfish and the Western Plains crayfish to be synonymous with the Northern crayfish within Nebraska.

While the Northern crayfish does have markings, they aren't very distinctive and they tend to disappear as they grow. The coloration of adults is an overall tan-brown-olive with blue-green tinges on the claws. The back can be quite dark which grades into a much lighter belly though the coloration can be variable depending on age and water quality. The juveniles like the one in these photos have the best markings and can be quite light colored. Older individuals can become a very dark brown/olive with age. Colors are their brightest immediately after a molt. Algae growth in summer can make them as black as tar.

The key identification character of the species is the shape of the first pleopod of a Form I male. The central projection is corneous, dark yellow and slightly curved (upper photo). The mesial process diverges from the central projection and may be slightly spatulate on the end. In non-breeding season the pleopod reverts to a juvenile form (Form II) that is of little use for identification (lower photo).

The rostrum of the Northern crayfish tapers with a dished center with strong ridges on both sides. There is a fairly sharp tip and no median carina. Juveniles have much more pronounced spines on the tip and on each side. These side spines get very small as they get older.



The aureola in the Northern crayfish is very narrow but the two halves never overlap or touch.

The chelae or claws of the Northern crayfish are large and strong with an olive color though this can vary. The tubercles are light tan and the very tips of the fingers are also light. Dead, dried out chela are often a bright blue. The movable finger (dactyl) has a double curve. Setae are almost always present between the fingers but can vary from a tiny amount in the angle like this specimen to so much that it totally fills the gap.

There are no keys that will work to identify female crayfish. They are identified by their association with and similarity to male crayfish collected from the same location. That is because the main sex characteristic, the annulus ventralis, (the urogenital pore), is very similar between species. Now, given that, since we only have six species of crayfish in the state of Nebraska, the secondary characteristics noted above will often work with females as will the annulus ventralis. These photos illustrate the annulus ventralis of a Northern crayfish female. In my Nebraska specimens, I have found different females from the same location that have an annulus ventralis which are mirror images of each other. This phenomenon was also mentioned as being seen in Minnesota.[97]

HABITATS

The Northern crayfish is generally considered to be a non-burrower but occasionally will dig a short and simple burrow. Burrows in clayey streams were shorter than those in loose soil while young crayfish often dug burrows in sandy areas.[96] Streambank burrows are apparently excavated underwater and then extended with openings just above the waterline. At times of low flow, they will excavate a cavity beneath a rock or log to wait for the water to come back.[102] In aquaria studies burrowing could be induced by lowering the water levels. In undisturbed aquaria, they dug a simple burrow under rocks.[91] Another study attempted to induce burrowing in a controlled laboratory setting. Of 36 trials, one crayfish actually constructed a burrow and only five even attempted to burrow. The other 30 "wedged themselves into the drying substatum".[15]

Burrowing enables crayfish to survive the freezing of winter and desiccation in summer. The Northern crayfish's intolerance of low dissolved oxygen and their non-burrowing nature will exclude them from the intermittent portions of watersheds.[15] The Northern crayfish cannot withstand any degree of freezing and their non-burrowing puts them at risk with high mortality of immature animals. Their survival mechanism in these areas is to migrate to deeper water or areas that do not freeze rather than burrow.[4]

The Northern crayfish is ubiquitous throughout Nebraska and inhabits reservoirs, lakes, ponds, rivers, streams, brooks, and backwaters. In flowing streams it can be found in association with the Calico Crayfish, the Ringed Crayfish and/or the Devil Crayfish. In lakes or reservoirs it is usually the dominant (and only) species. It is almost always associated with some form of cover which can be rock, rock rubble, cobbles, logs or log jams as well as aquatic vegetation. Burrows in stream banks in Nebraska are fairly common in streams with good populations. If these are Northern crayfish "burrows" it is possible that they use these for overwintering as the species virtually disappears from streams when temperatures drop in the fall. Irrigation canals sustain large populations of Northern crayfish and these canals are usually drained in the fall and mortalities are high. Some manage to crawl under riprap and dig holes to survive the winter.

BEHAVIOR

The Northern crayfish apparently does not maintain a "home" but can roam over a home-range that can be up to 300 meters across. These crayfishes were highly individualistic in their behavior and this complexity makes it difficult to make any generalizations. But, during the day, individuals remained in burrows or under rocks. At night they would come out to forage for food, returning to the burrow, especially after a molt. During several nights of movement, they may move 50 to 200 meters. Females tended to remain in one area longer than males but, when they moved, they moved further.[96]

In one neat study, video monitoring was used to observe the movements of marked Northern crayfish individuals in a natural stream. These crayfish were solitary animals and encounters with other crayfishes resulted in a "fight or flight" interaction. Small crayfish used the shallow waters at the stream edge while larger ones used deep water and were more nocturnal. Burrows were used and defended by individual crayfish and, occasionally, a fight for a burrow occurred where the larger crayfish usually won.[43]

One study observed their response to a non-crayfish threat which was usually several quick tail-flips for a quick backwards retreat. Larger crayfish might respond to a fish with the "claws-up" meral spread.[43]

In interactions between the Northern crayfish and the Calico crayfish, the Northern crayfish was the more aggressive species and would displace the Calico crayfish from crevices.[15]

In Ontario, Canada, it was noted that the Northern crayfish was rarely found in swift streams. When tested in the lab, it was found that when the current got over 28 cm/sec (0.92 ft/sec) they started to slip downstream.[153] This is quite low and seems to contradict its frequent presence in Nebraska streams that flow much faster than that. It may be that crayfish may be using the thin boundary layer next to the substrate where velocities are much lower.

REPRODUCTION

In the Northern crayfish, ovarian maturation depends on an extended period of four to five months of darkness and low temperatures. Increased water temperatures in the spring induce egg laying.[5] Females lay their eggs in the spring and the number of eggs produced by a female depends on body size. As females deposit their eggs while in open water, quite a few are lost but they have been found to have an average of 94 though not all will hatch.[163] When hatched, a baby crayfish looks like a tiny adult. They remain attached to the female for their first two molts then leave to make their own lives. While a female is brooding, she moves little and remains in hiding.[181]

In Kings Creek, Kansas, it was noted that the abundance of Water Nymph crayfish began to increase in June and July with the appearance of newly hatched individuals.[55]

PRODUCTION AND GROWTH

In Michigan lakes, the mean standing crop varied from 9.4 to 30.3 kg/ha while annual production ranged from 71.9 to 169.7 kg/ha.[167] In small lakes in Ontario, annual production was 18.9 to 70.4 kg/ha/year.[168]

In Kings Creek, Kansas, the numbers of juvenile Water Nymph crayfish [Note that I consider Water Nymph to be the same as the Northern crayfish] ranged from a low of one per 50 m^2 and up to two per m^2. Adults were less common and ranged from one per 20 to one per 90 m^2. Mean annual standing crop was 296 mg/m^2 while the mean annual production was 719 mg/m^2. In simpler terms, the annual production was 2.4 times the standing crop. Most of the production occurred among the smaller crayfishes during the late summer and fall.[55]

FEEDING AND SPECIES INTERACTIONS

The Northern crayfish, perhaps due to its extensive range within North America, has a large body of literature on its feeding and species interactions.

In Kings Creek, Kansas, they consumed leaves (42%), animal matter (16%), filamentous green algae (13%), detritus (23%), and diatoms (6%). Of these, leaves contributed 46% to annual production while animal matter contributed 29%. The animal matter was mostly other crayfish, dragonflies and mayflies.[55]

Numerous animals feed on Northern crayfish, so many that a literature review might be several pages long. Suffice it to say that virtually any predator will eat and relish a crayfish. From fishes (bass, trout, etc.) to wading birds (herons) to mammals (raccoons and otters) to reptiles (alligators) up to and including humans. On the other hand, the food of crayfish is almost as extensive.

Northern crayfish will eat fish eggs and sac-fry. One study tested the impact of egg predation of Northern crayfish on pumpkinseed (*Lepomis gibbosus*) and bluegill (*Lepomis macrochirus*) in ponds. In densely vegetated ponds, pumpkinseed had delayed reproduction and lower young-of-year biomass due to crayfish predation. In less vegetated ponds, crayfish prevented bluegill reproduction except in crayfish-proof exclosures.[50] Another study looked at their impact on lake trout and rainbow trout. While Northern crayfish fed on eggs and sac fry but the overall impact was low in most instances.[204]

Northern crayfish can compete directly with adult fishes. In the 1970's, the Northern crayfish appeared in Newcastle Reservoir, Utah, which is a put, grow and take rainbow trout fishery. While the rainbow trout did consume the crayfish, the overall impact was negative as the crayfish competed with the trout for the same food supply. Stocking rates of rainbow trout had to be cut in half to compensate for the reduced food supply and lowered growth rates.[98]

The Northern crayfish can alter macroinvertebrate assemblages. In a study where known densities of crayfish and macroinvertebrates were stocking in plastic pools, Northern crayfish greatly reduced the abundance of snails after which the other invertebrates were eaten. This showed that crayfish could substantially impact the macroinvertebrate community and, by extension, the fish community.[87]

Northern crayfish can alter plant growth and density. In one study known densities of crayfish were stocked in plastic pools containing four species of aquatic plant (*Potamogeton rechardsonii, Myriophyllum exalbescens, Nuphar variegatum* and

Spargenium eurycarpum). In this study, the female crayfish, by eating the grazing snails, improved plant growth while the male crayfish grazed on the plants and reduced their growth.[24]

The Northern crayfish will compete with other crayfishes. Northern crayfish introduced into the Patapsco River drainage in Maryland displaced the native Spinycheek crayfish to the extent that Northern crayfish became the dominant species.[209] Two surveys of Wyoming crayfishes documented the total replacement of the native Pilose crayfish (*Pacifasticus gambelii*) in the Bear Creek drainage by the Northern crayfish.[116, 117] On the other hand, in some Wisconsin lakes, Rusty crayfish are indirectly replacing Northern crayfish by taking the best cover so that fish can eat more Northern crayfish.[46]

One positive impact of this species was noted by in aquaria studies where Northern crayfish were offered zebra mussels and rainbow trout eggs singly and together. When offered only zebra mussels, they ate zebra mussels. When offered both, they preferred the eggs but they did not stop eating zebra mussels. The net food value of mussels was 1/3 that of eggs.[147] Another study used enclosures and exclosures to find that female Northern crayfish ate zebra mussels up to 15 mm and the sizes eaten were directly related to the size of the crayfish. The presence of zebra mussels also reduced predation on snails in the same areas.[186]

IMPACTS

The Northern crayfish have been introduced into a number of states including Utah[128], Alabama[228], Maryland[209], Arizona[63, 202], California[200], Washington[135], Idaho[27], New Mexico, Texas, North Carolina, Virginia, Pennsylvania, New York, New Jersey, and West Virginia[253]. In addition, it has been introduced into New Brunswick in Canada[155], Mexico[21] and Europe[2]. The Spinycheek crayfish, *Orconectes limnosus*, is native to the eastern seaboard from Maine to Virginia. Within this range, it is rapidly disappearing due to competition with introduced Rusty and Northern crayfish.[139]

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DISTRIBUTION AND ABUNDANCE

The distribution map shows that this species is widespread throughout the northern U.S. and southern Canada from the Rocky Mountains eastward.

In Nebraska it is widespread and common, found in all drainages. It is native to the state with the possible exception of the White River and Hat Creek watersheds in the extreme northwest corner of the state. Streams that have been totally or periodically dewatered, such as Lodgepole Creek, Pumpkin Creek, and Snake Creek in the Panhandle or the Little Blue River have few or no crayfishes anymore. Streams in the south-central and northeast have not been sampled adequately so the Northern crayfish may be more common in these areas than the map indicates.

To date, they have not been collected from the Hat Creek drainage. In the White River drainage they are limited to Whitney Lake, Carter P. Johnson Lake and Soldier Creek which suggests that they were introduced to these waterbodies as bait.

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

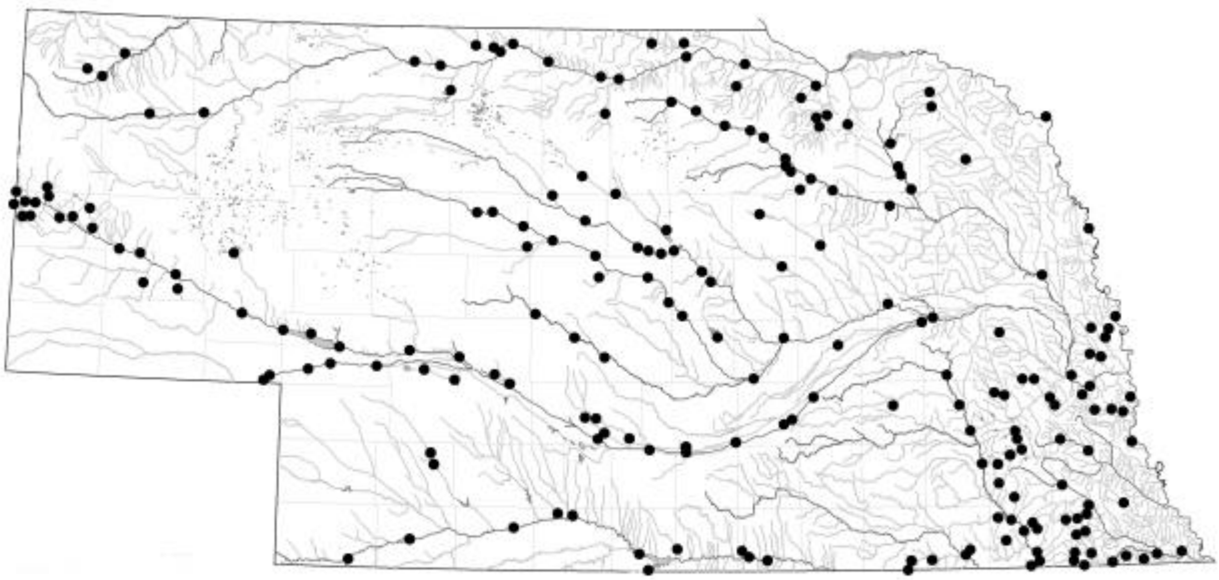
Committee on the Status of Endangered Wildlife in Canada: N5

State Designations: AL (SNA), AZ (SNA), AR (SNR), CA (SNA), CO (S4?), CT (SNA), ID (SNA), IL (S5), IN (S5), IA (S5), KS (S5), ME (SNA), MD (SNA), MA (SNA), MI (S4), MN (SNR), MO (SNR), MT (S4), Navajo Nation (S3?), NE (SNR), NH (SNA), NJ (SNA), NM (SNA), NY (SNA), NC (SNA), ND (S3), OH (S3), OK (SNR), PA (SNA), RI (SNA), SD(SNR), TN (S5), TX (SNA), UT (SNA), VT (SNA), VA (SNA), WA (SNA), WV (SNA), WI (S5), WY (SNR)

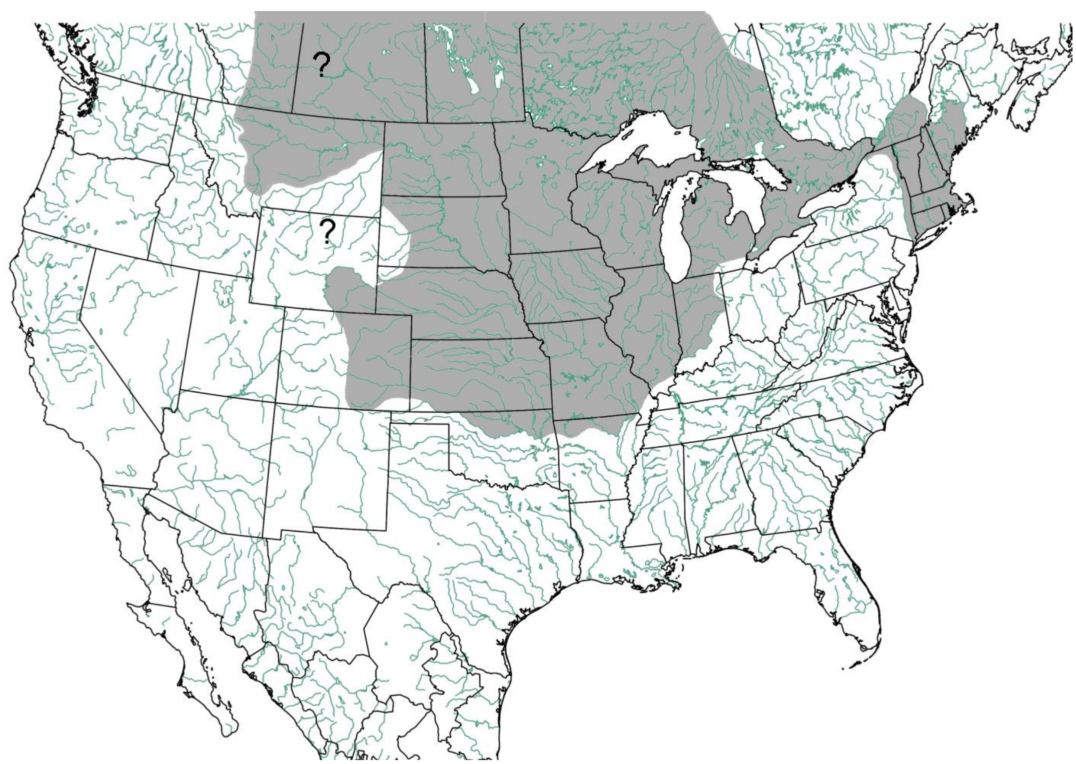
Province Designations: Alberta (S4), Manitoba (SNR), New Brunswick (SNA), Ontario (S5), Quebec (S4), Saskatchewan (S5)

CONSERVATION ISSUES

There are few concerns in Nebraska as it is a widespread, native species. Impacts can include loss of cover on stream margins due to overgrazing and pesticide use. On the other hand, it has proven to be an aggressive invasive species where introduced outside of it’s native range.



Collection locations for the Northern Crayfish, *Orconectes virilis*, in Nebraska, 1995-2010.



Native distribution of the Northern crayfish, *Orconectes virilis*, in North America

PRAIRIE CRAYFISH - *Procambarus gracilis*

SYSTEMATICS

Procambarus gracilis (Bundy1876)
Type locality: Normal, McLean County Illinois

Synonyms (see Hobbs and Jass 1988, Hobbs 1989):

Cambarus gracilis [17, 31, 32, 58, 61, 67, 81, 89, 178, 237]
Cambarus gracillis [17]
Cambarus (Cambarus) gracilis [178]
Procambarus gracilis [13, 22, 95, 101, 103, 180, 185, 188, 189, 198, 246, 247]
Procambarus (Girardiella) gracilis [104, 112]

OTHER COMMON NAMES

Grassland crayfish

DIAGNOSTIC FEATURES AND DESCRIPTION

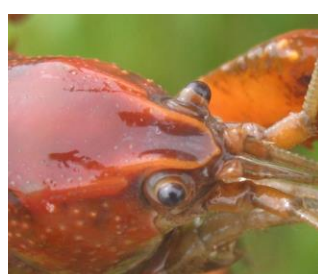
As you can see in these photographs, there are few distinctive markings other than color. Even then, their coloration can vary from red, reddish-brown to olive-brown. One author stated that females are olive-green while males were “almost a salmon red”.[89] I have not been able to examine enough specimens to confirm this but the specimen in the photo below is a female which is an olive-brown. The crayfish in the photo

above-right is a bright reddish-brown and it is a male so there might be something to the sex-related coloration. As with all crayfishes, their color is the lightest and brightest after a molt which steadily gets darker as algae and crud build up on their carapace.

The key identification character of the species is the shape of the first pleopod of a Form I male. This one is quite distinctive

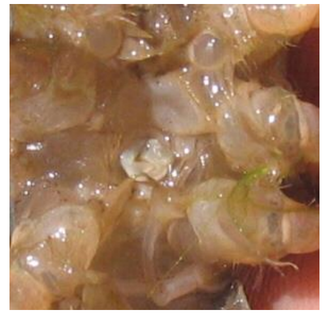
from the other Nebraska crayfishes in that the pleopod is tipped with a series of four short terminal elements. This general shape is typical of *Procambarus* of which this is the only native species in Nebraska.

The two halves of the aureola of the Prairie crayfish touch each other and almost overlap.



The rostrum of the Prairie crayfish is typical of burrowing crayfishes in that it is short, blunt and curves down between the eyes. It is dished and there are no side spines. Most Prairie crayfish that I have seen have the rostrum outlined in a lighter shade of color.

The chela or claw of the Prairie crayfish is a relatively short and wide. The moveable finger is about half the length of the chela and the palm is large. There are no setae between the fingers.



As there are no keys for female crayfish, they are identified by their association with, and similarity to, male crayfish collected from the same area. But, since we have only six species in Nebraska, the secondary characteristics noted above may generally work. Here is the annulus ventralis of a female Prairie crayfish. The upper portion of the photo is towards the crayfish's head.

HABITATS

This is a primary burrowing crayfish which means that they spend the majority of their lives in a burrow. These are dug down to ground water which might be 2 meters down. At the bottom of the burrow it constructs a large pocket where it lives, only coming out at night to feed, mate and maintain its burrow.

As its name suggests, the Prairie crayfish was assumed to be restricted to grasslands or prairies where burrows might be a long distance from surface water.[17, 31, 32, 180, 188, 221] However, others have found them in many other locations including ponds, vernal pools, roadside ditches, wet meadows, small creeks, marshes, and the banks of creeks and ponds.[110, 189, 199, 247] Collections in southeast Wisconsin and Illinois expand the suitable habitat to include oak savanna and sedge meadows.[112]

In Iowa, of three excavated burrows, the deepest was 1.2 m. The tunnels were vertical, 2 to 3 cm in diameter and ended in a flask-shaped cavity some 10 cm across.[189]

In Wisconsin, while they were collected from a creek, "ditches, temporary pools and ponds, wet meadows, and a mowed hayfield", the majority of specimens were collected by excavating burrows. These burrows typically had a vertical shaft going down some 1.5 to 2 meters. Most of these burrows had a single opening though a few had two and, often, one (or both) openings were plugged with mud at the time of collection. In this area, the water table was fairly close to the surface, averaging 46 cm below the surface of the ground. Oxygen levels in the burrow water were quite high, averaging 8.6 mg/l.[112]

In Nebraska, I have had considerable difficulty in locating areas with Prairie Crayfish having only been able to make four collections.

1) The first was a female from a pasture in the Big Blue River basin in northwest Gage County on 1 August 2002. The particular site was in an unmowed section of ground that was a hundred yards from an intermittent drainage in the Clatonia Creek watershed.

2) The second was from a pasture one mile west of Burchard Lake in Pawnee County. The pasture was lightly grazed at the time and the burrows were in a low

area with moist soils. Many juveniles were collected from a small vernal pool on 16 May 2012. By September, that pool was almost dry. Devil crayfish were also found in this area.

3) The third collection was at the Mayberry State Wildlife Management Area in Pawnee County on 1 May 2013. This area includes a small reservoir and the grassland upstream. A mature Form I male was collected from a burrow in a heavily vegetated wet meadow. Devil crayfish was also found in this area. Burrows were numerous though difficult to find in the dense vegetation.

4) The fourth and most recent collections were in a road ditch along Hiway 77 just south of Princeton in Gage County on 5

May 2014. This is in the headwaters of the Big Nemaha River but only 8 miles northeast from the first collection in the Clatonia Creek watershed. The road ditch is perennially wet and is visibly wet because of the wetland plants growing here. In the photo, we are looking south and the burrows tend to be near the bottom of the ditch. Burrows appear to be shallow as they are only a few inches above the level of the water in the ditch. There was also a culvert at this site with a small pool of water. A female and four mature Form I males were collected. A few juveniles were collected from this pool on 5 June 2014.

A fifth site was reported to me via an email that included several photos and a short video on 8 June 2014. It was received from Jamie Kelley, the Community Education Director of the Spring Creek Prairie Audubon Center near Denton, Nebraska. The Center is in the Salt Creek watershed and the site is 11 miles northwest of Princeton site.

So, to date, we have two centers of distribution in Nebraska, both of which are in the southeast corner of the state. One is in Pawnee County in the South Fork Big Nemaha watershed. The other is in the northwest corner of Gage County and southwest corner of Lancaster Counties where three watersheds meet. These are Clatonia Creek (Big Blue River basin), Salt Creek (Lower Platte River basin) and North Fork Big Nemaha River (Nemaha River basin).

BEHAVIOR

Numerous authors have noted that crayfishes are primarily nocturnal. The Prairie crayfish was studied in eastern Oklahoma several things were learned about their nighttime behavior.[94] These include:

-the greatest social activity occurs from late April through early July.

-crayfish usually leave the burrow during nights when it is rainy or warm and humid.

-they leave their burrows soon after sunset to roam around the area.

-aggressive and sexual encounters are common at this time and result in the occupation of burrows by breeding pairs (one adult female and one Form I male).

-they were most active from just before sunset to one hour after sunset.

In a Wisconsin study, only one crayfish was found per burrow with one exception. Three (two males, one female) were taken from a single burrow and this was described as being very unusual. Contrasted with the comments about breeding pairs using burrows.[94], it is clear that additional field work will be needed to find out how often this occurs.[112]

There are eight types of social interaction when outside the burrow which are identified by the posture the crayfish assumes. These include: alert, approach, threat, combat, submission, avoidance, escape and courtship. Within the burrow, the defense posture is to block the tunnel with the claws.[94]

REPRODUCTION

Little is known about the reproduction of the Prairie crayfish. We have to rely on the collections of various life stages for clues. One study found young-of-the-year in pools away from burrows in April. In July they noted burrowing next to ponds and streams with juveniles present through August. A female with eggs was collected on 17 July while Form I males were seen from July through October.[112]

In the courtship of the Prairie crayfish, the male approaches a female and assumes a threat posture. If the female becomes submissive or avoids him, he assumes a courtship posture. In this posture, his body and tail are held up and horizontal, the fingers are spread and the claws are flexed and held vertically so the female can see the tops of the chelae. He then approaches the female from the side, turns her over and mounts her.[94]

In Missouri, females leave their burrows in February and March to release their young into nearby creeks and ponds. Juveniles could be collected in April and May.[221] Form I males were collected in traps set at burrow entrances in June suggesting increased breeding activity. Juveniles were collected in late October, March, April, May and June which indicates an extended reproductive period.[188]

In Kansas, females had young attached in early spring but none were found with eggs.[247]

The proportion of Form I males in collections is usually very low. In Illinois, 101 collections had only five Form I males while there were no females with eggs or young. The Form I males were found in June, July and October. Juveniles (<10 mm CL) were collected as early as late February and as late as early October.[180]

In Iowa, juveniles were most often found in May and June but in one year numerous small specimens (<10 cm carapace length) were seen in late September. This suggested that they had hatched in August at the beginning of an unusual rainy period.[189]

As noted earlier, I have collected juveniles on 16 May and 5 June. Mature males were collected on 1 May and 5 May.

PRODUCTION AND GROWTH

There is nothing in the literature on growth rates or production of the Prairie crayfish other than the Prairie crayfish tends to be smaller than other crayfish with the largest being 82 mm total length.[221]

In Illinois, length frequency graphs were used to estimate that males could live into their third year and females might live one year longer. The same data showed that males might grow to 38 mm carapace length (CL) while females might reach 47 mm CL. These were maximum lengths as the vast majority didn't live past their second year and 20-25 mm CL.[180]

FEEDING AND SPECIES INTERACTIONS

There is nothing in the literature on the feeding habits of this species. We are left with making some inferences (guesses) based on what we do know about them. First off, they are terrestrial, building burrows in grasslands, wet meadows and mesic (moist) forests. We also know that they come out of their burrows in the early evening. Therefore, they must be foraging for food at this time. It is possible that they could be clipping and eating vegetation. It is also possible that they are catching and eating insects or earthworms. This is another one of those questions that may remain unanswered.

DISTRIBUTION

The range of the Prairie crayfish fits within the central portion of the eastern tallgrass prairie. It runs from southeastern Wisconsin through Illinois, Iowa and Missouri to southeast Nebraska, eastern Kansas and Oklahoma and into northeastern Texas.[230]

In Nebraska, they are found only in the southeastern corner of the state. To date, I have found them five times, three in southwest Lancaster and northwest Gage Counties and twice in Pawnee County. They are probably more common in the southeastern corner of the state than these collections indicate.

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

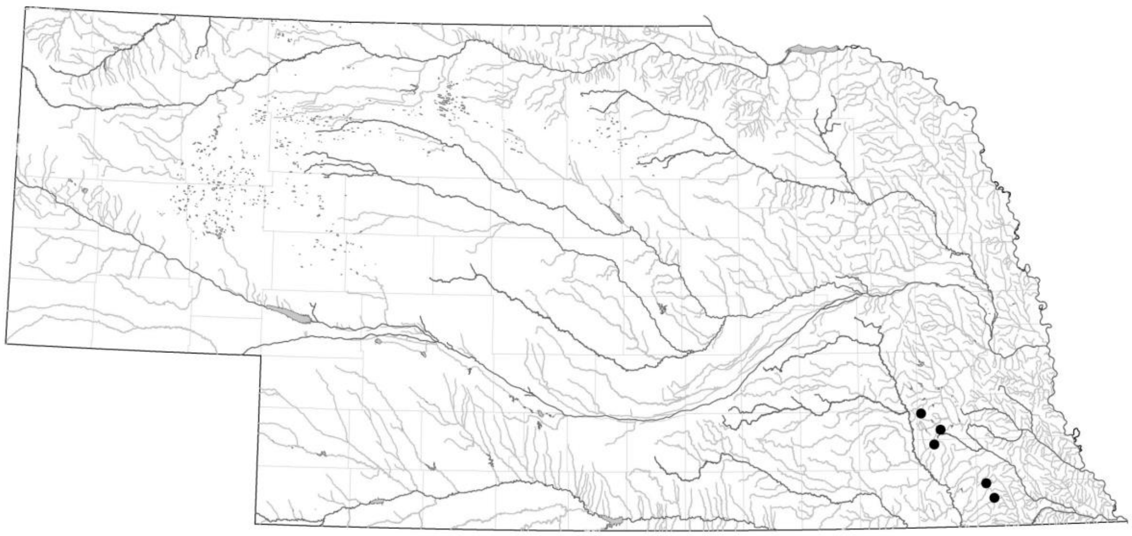
Committee on the Status of Endangered Wildlife in Canada: Not present

State Designations: IL (S4), IN (S1S2), IA (S4S5), KS (S5), MO (SNR), NE (SNR), OK (SNR), TX (SNR), WI (S2?)

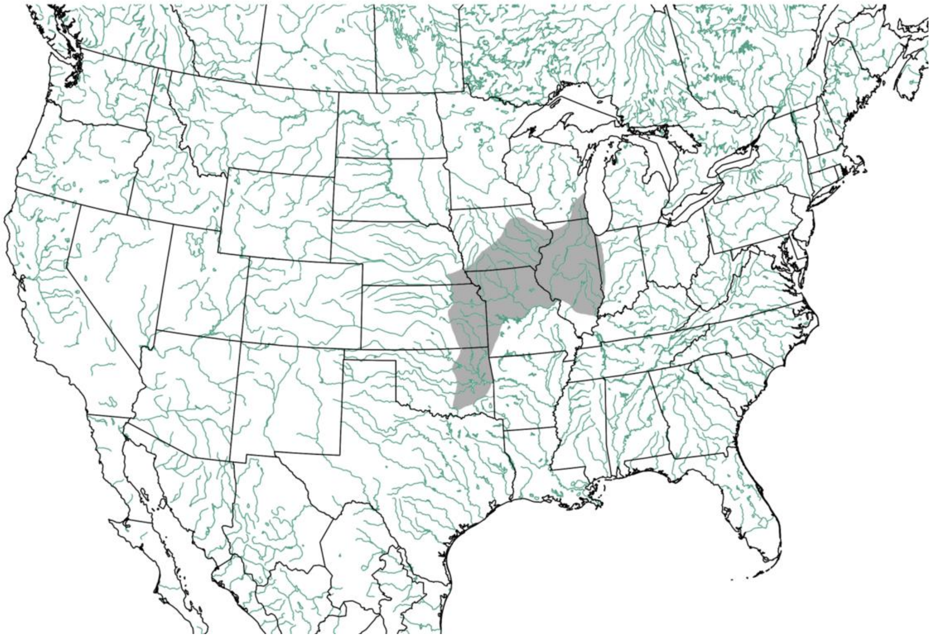
Province Designations: Not found in Canada

CONSERVATION ISSUES

Little known as to their status in Nebraska. It is a primary burrower found in undisturbed grasslands and wet meadows. Impacts can include conversion of grassland to cropland, overgrazing and pesticide use.



Collection locations for the Prairie crayfish, *Procambarus gracilis*, in Nebraska, 1995-2010



Native distribution of the Prairie crayfish, *Procambarus gracilis*, in North America

INTRODUCED CRAYFISHES

Introduced crayfishes are those that are not native but have been found in the state. Nonnative crayfishes are native to some portion of North America but not to Nebraska. Exotic crayfishes are not native to North America. To date, no exotic crayfishes have been found in Nebraska. Three nonnative crayfishes have been found in the state. These are the Rusty crayfish (*Orconectes rusticus*), the Red Swamp crayfish (*Procambarus clarkii*) and the White River crayfish (*Procambarus acutus*).

The White River crayfish were found in a bait dealer's tanks in North Platte in 1995(?). It has not been found since then and it has not been found in the wild. At this time it is presumed to have been in isolated bait importation that did not get established in the wild.

The Red Swamp crayfish was also found in a bait dealer's tanks, this time on the Missouri River near Gavins Point Dam in 2014. In this case it is known that some were released into the Missouri River in that area. As of 2016, they have been confirmed to be in the Missouri River and Lake Yankton below Gavins Point Dam.

The Rusty crayfish was found in a bait dealer's tanks in Omaha in 2006. Subsequently, established populations have been found in two Omaha area lakes and the Missouri River. One was Benson Park Lagoon in 2007 and the second was in the Lakeside Association Lake in 2010. A healthy (?) population is now also found in the Missouri River below Gavins Point Dam.

In 2015, a survey of the bait vendors of the state was conducted but the results have not been reported as yet.

I have produced species accounts for each of the three crayfishes named above. The White River crayfish does not have a distribution map as this is the only one that is not known to be established. The purpose of the accounts is to acquaint you, the reader, with what these crayfishes look like. I should note also that there are over 400 species of crayfish in North America and any of these could be imported. So, if you have a crayfish in hand and it just doesn't quite fit any of the descriptions in this guide, it could be something totally new. In any case, you can be prepared when you report these to your local Game Warden, the nearest office of the Game and Parks Commission or the Nebraska Invasive Species Program website.

White River crayfish – *Procambarus acutus acutus*

SYSTEMATICS

Procambarus acutus (Girard. 1852)
Type locality: tributary to Tombigbee River of Mobile River, Kemper Co., MS

ALSO KNOWN AS

No other names

DIAGNOSTIC FEATURES AND DESCRIPTION

The White River Crayfish looks a lot like the Red Swamp Crayfish. The thorax of both is covered with tubercles, which makes it look and feel like coarse sandpaper. The coloration of adult White River Crayfish can vary from dark red to a light brown/tan.

Young White River Crayfish are generally brown or yellowish. One thing that it does have is a wide dark stripe down the top of the abdomen, something that the Red Swamp Crayfish lacks. One feature that differentiates these two species is that the halves of the aureola of the White River Crayfish has a small gap where the two halves in the Red Swamp Crayfish touch.

One of the key identification characters of many crayfishes is the shape of the first pleopod of a Form I male. The first pleopod of the White River Crayfish terminates in four short elements with some setae. In non-breeding season the pleopod reverts to a juvenile form (Form II) that may still be of use for identification.

The rostrum of the White River Crayfish is triangular with a wide base tapering to a fairly blunt tip with a terminal spine. It has a deeply dished center with strong ridges on both sides. There is no median carina. It is almost identical to that of the Red Swamp Crayfish and similar to that of the Calico Crayfish.

The chelae or claws of the White River Crayfish are long and narrow with long skinny fingers. Again, these are almost identical to those of the Red Swamp Crayfish (among others).

Here is the annulus ventralis of a female Prairie crayfish. The upper portion of the photo is towards the crayfish's head.

Note: Most of the information in the following sections was compiled from information found in the literature.[110, 180, 188, 228]

HABITATS

The White River Crayfish appears to prefer quieter waters with abundant vegetation and is seldom collected from streams with strong flow. It is most often found in sloughs, swamps, ponds and seasonally flooded ditches but will also use creeks and smaller rivers. Substrates include silt, muck, packed mud, sand and gravel. It will dig a simple burrow if a waterbody dries up or for the winter.

BEHAVIOR

They have been found to be tolerant of a wide range of pH, pollution, temperature, turbidity as well as a variety of bottom types and vegetation.[70]

REPRODUCTION

Not too much is known about the reproduction in the White River Crayfish. It is possible that females mate in the fall before entering their wintering burrows, then lay and fertilize their eggs in the burrow in the spring. But they must have an extended breeding season as females with eggs have been found from March to December and mature males from April to November. Females carrying eggs and young tend to hide in a burrow so they are seldom collected. One female collected in March in Missouri was carrying 303 young. In Illinois, one female collected in December had 30 young.

FEEDING AND SPECIES INTERACTIONS

In Kentucky, they are often collected along with Devil Crayfish, Calico Crayfish and Red Swamp Crayfish (among others).[228] In Wisconsin, they have been found with Devil Crayfish, Prairie Crayfish and Northern Crayfish.[110]

IMPACTS

The White River Crayfish is widely grown for food and the bait trade.

DISTRIBUTION AND ABUNDANCE

The White River Crayfish is widely distributed in two separate ranges. One is down the Atlantic coast of the U.S. from Massachusetts to Georgia. The larger extends along the Gulf coast of Mexico to Georgia then northward through the Mississippi basin to the Great Lakes states of Wisconsin to Ohio. There is some question as to whether these are all the same species.

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

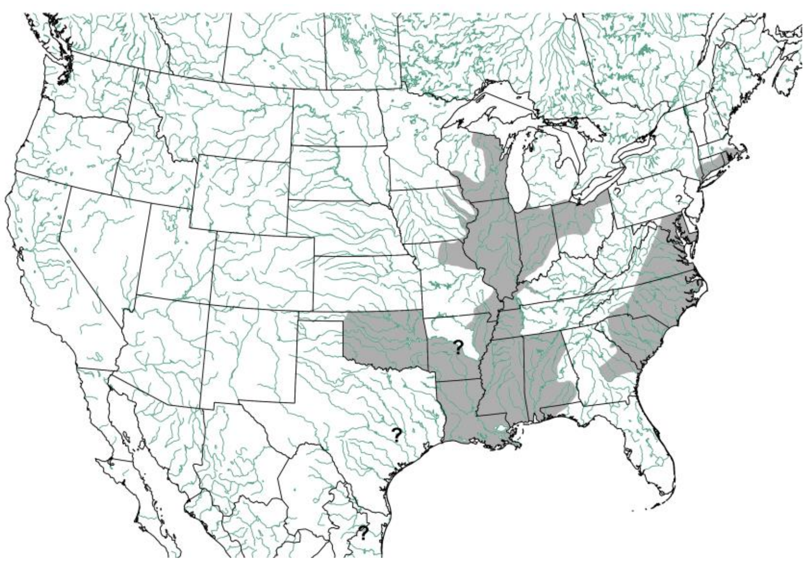
Committee on the Status of Endangered Wildlife in Canada: NNA

State Designations: CT (SNA), IL (SNA) IA (SNA), KY (SU), ME (SNA), MD (SNA), MA (SNA), MI (S2), MN (SNA), NH (SNA), NJ (SNA), NM (SNA), NY (SNA), NC (SNA), OH (S5), PA (SNA), TN (S5), VT (SNA), VA (SNA), WV (SNA), WI (S5)

Province Designations: Manitoba (SNA), Ontario (SNA), Quebec (SNA)

CONSERVATION ISSUES

None.



Distributional range of the White River crayfish, *Procambarus acutus acutus*, in North America.

RED SWAMP CRAYFISH – *Procambarus clarkii*

SYSTEMATICS

Procambarus clarkii (Girard, 1852)
Type locality: between San Antonio and El Paso del Norte, Texas

ALSO KNOWN AS

No other names

DIAGNOSTIC FEATURES AND DESCRIPTION

The Red Swamp Crayfish is a very distinctive crayfish. Most notably, they are red, dark on the top and light on the bottom, but definitely red. Another distinguishing feature are the tubercles ("bumps") all over the carapace. These make the carapace look and feel like coarse sandpaper.

The two sides of the aureola in the Red Swamp Crayfish touch each other. The rostrum of the Red Swamp Crayfish is triangular with a wide base tapering to a fairly blunt tip with a terminal spine. It has a deeply dished center with strong ridges on both sides. There is no median carina.

One of the key identification characters of many crayfishes is the shape of the first pleopod of a Form I male. The terminal elements of the first pleopod of the Red Swamp Crayfish have been described as "four short, bladelike terminal processes"[188]. This may be accurate; if you have enough magnification. To the naked eye, the end appears rounded with a notch in the middle.

The annulus ventralis of the female is pictured here.

The chelae or claws of the Red Swamp Crayfish are long and narrow with long skinny fingers. The specimen photographed here had red tubercles on a dark red-black background. The undersides are a uniform red.

Note: The information in the following sections was compiled from the literature.[180, 183, 188, 228]

HABITATS

The Red Swamp Crayfish, as its name implies, likes the quiet waters of ponds, swamps, sloughs and slow moving streams. They like waters with abundant vegetation and muddy bottoms. On the other hand, in Missouri, they were most often collected from streams with a noticeable current. They will burrow to escape drying habitats and to overwinter.

REPRODUCTION

In Illinois, mature males were found in the spring and late summer/fall. One female collected in February had 43 young. Females with eggs or young tend stay in burrows so are seldom collected. The exception to this is after heavy rains when they may come out to feed. In Kentucky, mature males in the spring (May, June) and fall (September, October). No females with eggs or young were found here.

Large female Red Swamp Crayfish can produce upwards of 600 young.[111]

FEEDING AND SPECIES INTERACTIONS

The Red Swamp Crayfish is an omnivore and generalist meaning what they eat depends on what is available. In studies in Spain and Portugal, they ate aquatic vegetation, detritus, insect larvae, snails and other crayfish.[6, 29] Other European studies found that Red Swamp Crayfish had reduced or eliminated aquatic vegetation in many areas. They may have been responsible for converting lakes from clear, vegetation dominated areas to turbid, eutrophic states dominated by phytoplankton.[74]

In Missouri, Red Swamp Crayfish are often collected along with White River Crayfish (among others). In Kentucky, they have been collected with Devil Crayfish.

PRODUCTION AND GROWTH

[Because of their importance in the food trade, there is an extensive literature available on production that is not presented here.]

IMPACTS

The Red Swamp Crayfish is the foundation of a major industry in the South (e.g. Louisiana) where they are harvested from the wild or cultured in ponds for sale as food or bait. Because of its popularity in the food trade, it has been widely introduced outside of its native range in North America and other countries. In Europe, it is now found in Spain, Portugal, France, England, Germany, Switzerland, Cyprus, Italy and the Netherlands.[142] The consequences of these introductions are usually negative.[111]

Their introduction into European waters has resulted in numerous studies of their impacts.[113] The Red Swamp Crayfish is a carrier of the crayfish plague fungus that has been decimating the native crayfishes of Europe. Their burrowing has damaged earthen canals, levees, dams and irrigation water control structures. It is also noted that importation for aquaculture in earthen ponds is the same as transplanting them into new streams and lakes as it is impossible to keep them contained.[111]

There has been one positive impact as a result of their introduction into Africa (which has no native crayfishes). Here, the Red Swamp Crayfish are eating the snails that host the Schistosomaisis parasite. But this has to be balanced against the negative effects. They have been found to eat fish eggs; they compete with native food fishes for the same foods; they damage fishing nets; they destroy beds of aquatic vegetation; and they burrow into irrigation dams.[113]

In Portugal, the Red Swamp Crayfish has caused the decline (six species) or extinction (seven species) of amphibians in a 554 ha marsh.[40] In California, they reduced the abundance of invertebrates in two streams by direct predation or, indirectly, by competing for food.[133]

DISTRIBUTION AND ABUNDANCE

The native range of the Red Swamp crayfish is the Gulf Coast from northeastern Mexico to Florida then northward up the Mississippi to the southern tip of Illinois. It has been widely introduced outside of its native range.

These are not native to Nebraska but were found in a bait dealer's tank in the summer of 2014. The dealer was located on the Missouri River downstream of Gavins Point Dam and it was reported that some had been released into the Missouri River. As of 2016, they have been confirmed as being present in the Missouri River and Lake Yankton, downstream of Gavins Point Dam.

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

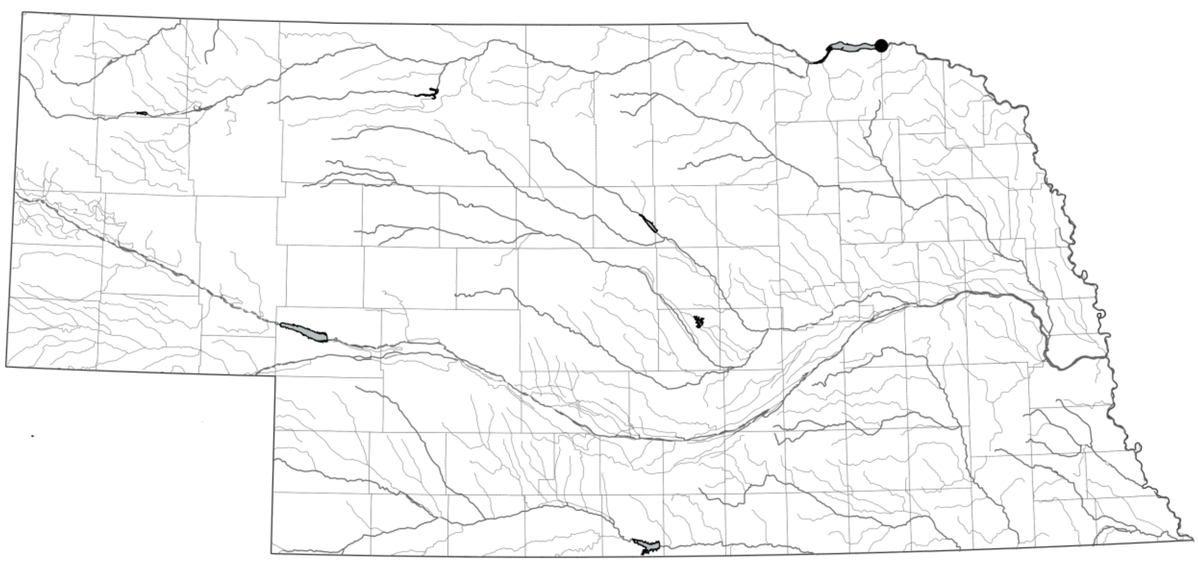
Committee on the Status of Endangered Wildlife in Canada: NNA

State Designations: CT (SNA), IL (SNA) IA (SNA), KY (SU), ME (SNA), MD (SNA), MA (SNA), MI (S2), MN (SNA), NH (SNA), NJ (SNA), NM (SNA), NY (SNA), NC (SNA), OH (S5), PA (SNA), TN (S5), VT (SNA), VA (SNA), WV (SNA), WI (S5)

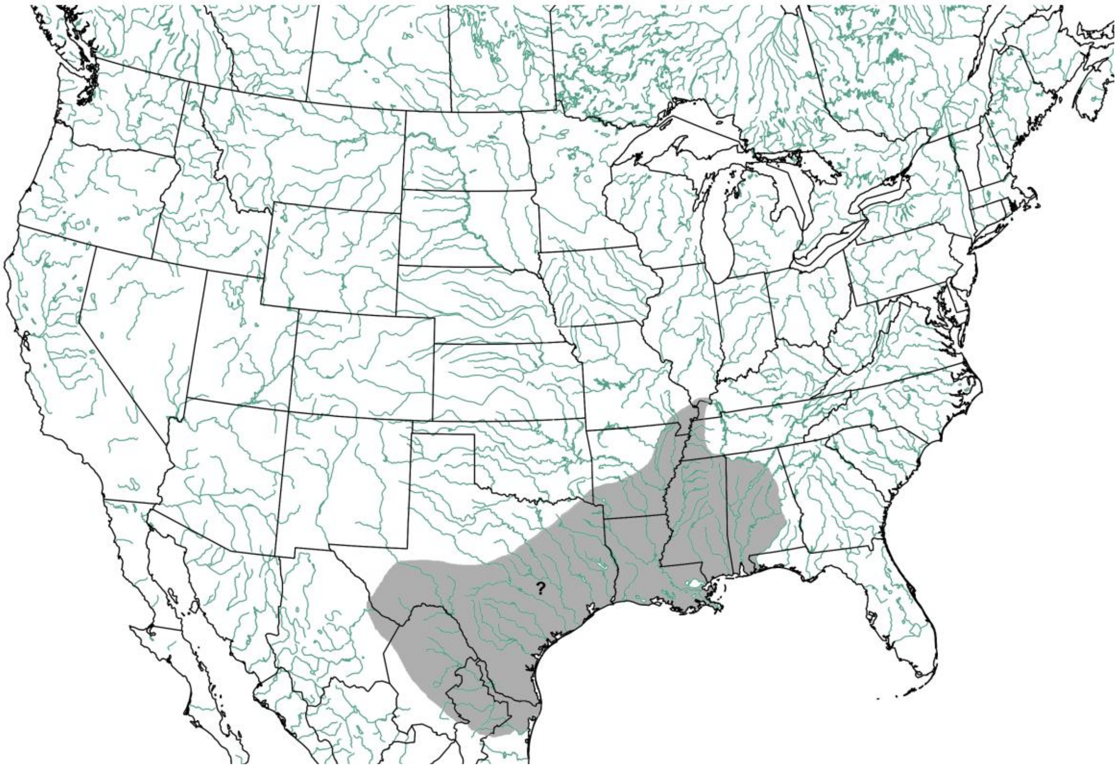
Province Designations: Manitoba (SNA), Ontario (SNA), Quebec (SNA)

CONSERVATION ISSUES

None in Nebraska.



Collection locations of the Red Swamp crayfish, *Procambarus clarkia*, in Nebraska, 2015-2016.



Native distribution of the Red Swamp crayfish, *Procambarus clarkia*, in North America

Rusty Crayfish - *Orconectes rusticus*

SYSTEMATICS

Orconectes rusticus (Girard, 1852)
Type locality: Ohio River at Cincinnati, Hamilton County, Ohio

Synonyms (see Hobbs and Jass 1988, Hobbs 1989):

Cambarus rusticus [77, 58]
Cambarus juvenilis [85]
Cambarus (Faxonius) rusticus [178]
Faxonius rusticus [250]
Orconectes rusticus [22, 103, 125, 141, 144, 145, 153, 164, 180, 181, 185, 235]
Orconectes (Procericambarus) rusticus [66]

ALSO KNOWN AS

No other names

DIAGNOSTIC FEATURES AND DESCRIPTION

In contrast to most of our native crayfishes, the Rusty crayfish does have some rather distinctive markings. Overall they are a gray-green with a darker rusty red coloration on the dorsal surfaces. Underneath they are a grayish color as can be seen below. The distinctive markings are the rust-red spots on the rear of the carapace seen in the photo above. Older individuals can become a very dark brown/olive with age. Colors are their brightest immediately after a molt. Algae growth in summer can make them as black as tar.

One of the key identification characters of many crayfishes is the shape of the first pleopod of a Form I male. The terminal elements of the first pleopod of the Rusty crayfish are straight with the mesial process having a slightly flattened end. In non-breeding season the pleopod reverts to a juvenile form (Form II) that is of limited use for identification. Note that this is very similar to the first pleopod of the Ringed crayfish. .

The aureola in the Rusty crayfish is quite wide with room for several rows of punctuations.

The rostrum of the Rusty crayfish is similar to that of the Northern crayfish. It has a dished center with strong ridges on both sides. There is a fairly sharp tip and no median carina. Juveniles have much more pronounced spines on the tip and on each side which get smaller as they get older.

The chela or claw of the Rusty crayfish look like a cross between those of the Northern and Ringed crayfishes. The movable finger (dactyl) has a double curve like that of the Northern crayfish. They are similar to those of the Ringed crayfish in that they are smooth with few tubercles, have a large gap and there are no setae between the fingers. Also, the tips of the fingers have a black ring at the tip similar to that of the Ringed crayfish.

There are no keys that will work to identify female crayfish. They are identified by their association with and similarity to male crayfish collected from the same location. That is because the main sex characteristic, the annulus ventralis, is very similar between species. Now, given that, since we only have six species in the state of Nebraska, the secondary characteristics noted above will often work with females as will the annulus ventralis.. This photo illustrates the annulus ventralis of a Rusty crayfish female. Note also the genital pores at the bases of the third periopods just above.

HABITATS

The Rusty crayfish is found in a wide variety of habitats including creeks, rivers, reservoirs and lakes of all sizes and on all types of substrates. They are often found under rip rap, rocks, woody debris, logs or rooted vegetation. They can be found in waters varying from a few centimeters in stream riffles to 15 m in large lakes.

The Rusty crayfish is considered to be a tertiary burrower that burrows only when necessary, if then. In aquarium tests, where water levels were gradually lowered to simulate natural drying, only 45% of the adult and 76% of juvenile Rusty crayfish dug a burrow.[12]

Rusty crayfish are habitat generalists meaning they will do fine in most any waters. In Wisconsin, the nonnative Rusty crayfish successfully colonized a wide variety of habitats. These included: soft bottomed lakes and pools, rubble bottomed lakes, and swift streams with and without weed beds. They were collected from quiet waters and moderately fast streams that were clear or turbid.[110] In Iowa, typical habitats for Rusty crayfish were rocky pools and riffles in small, clear streams as well as in medium and large warmwater streams. They were not observed to burrow in Iowa but they did excavate cavities under flat stones.[189] Larger Rusty crayfish were found in the deepest parts of pools among cobbles whereas small specimens used the shallows that had gravel bottoms.[124]

They are not native to Nebraska but are now found in two lakes in Omaha. Benson Park Lagoon is a fairly turbid, mud-bottomed pond. During my last visit in the late summer of 2015, I had little difficulty collecting several with a dip net. The second lake, at Lakeside Hills, is clearer, also with a mud-bottom, has extensive shoreline rock riprapping. The Rusty crayfish in this lake are using the riprap along with the native Northern crayfish.

BEHAVIOR

Laboratory studies found that the Rusty crayfish was able to dominate over the Spinycheek crayfish and got the best shelters.[132]

In an intensely studied lake in Wisconsin, Rusty crayfish were able to disperse around the lake at the rate of 0.68 km/year.[251]

REPRODUCTION

The mating season of the Rusty crayfish is early fall (September/October) when temperatures begin to drop.[124,189] The majority of females lay their eggs at one year old in April or May though a few did so in October.[189] Eggs take some 20 days to hatch and the young are released about five days after this. Egg counts increase as the female gets larger so can range from 54 (34 mm CL) to 357 (70 mm CL).[191]

Males typically molt from mature Form I to immature Form II in late spring then back to Form I in late summer though Form I males have been collected in every month except May.[189, 228] In one study, of 1,188 Rusty crayfish collected, almost 57% were males.[124]

The Rusty crayfish does have a reproductive advantage over many other crayfishes in that it can begin breeding earlier in the spring when temperatures rise above 4°C.[11]

FEEDING AND SPECIES INTERACTIONS

It has been noted that several crayfishes, including the Rusty crayfish, will reduce or eliminate aquatic vegetation in lakes.[44, 141, 203, 251]

However, aquatic vegetation is a poor food for crayfish as it is low in nutrients.[164] It may be that Rusty crayfish are clipping off the plants to look for macroinvertebrates on those plants or just to get the plants out of their way. This is supported by the observation that they take no further interest in the plants after they cut them off.[143] They may eat some because there is nothing else to eat or as incidental ingestion while eating the attached organisms.[165] .

Aside from aquatic plants, foods eaten include snails.[141, 143, 186, 251], freshwater mussels and fingernail clams[132], aquatic insects[251], other aquatic crustaceans[251] and fish eggs.[129]

Information on the ability of Rusty crayfish to consume Zebra mussels (*Dreissena polymorpha*) is mixed. In one study, they were tested in cages and there was a 31% reduction in Zebra mussel density.[186] However, a similar study contradicted this finding where they found little or no reduction. It is possible that the lack of alternative foods in the former study may have forced the crayfish to eat the Zebra mussels.[223]

PRODUCTION AND GROWTH

Aging crayfish is almost impossible but it is estimated that, on average, they live 2 ½ years.[191]

In Illinois, the largest male collected was 40.5 mm CL while the largest female was 41.5 mm CL.[180]

IMPACTS

The Rusty crayfish has been widely introduced outside of its native range. There have been many impacts noted, mostly negative.

Nonnative Rusty crayfish have been displacing or had other impacts on native crayfishes in many areas.[22, 144, 174] The Rusty crayfish was introduced into Wisconsin waters in 1965. Prior to that, the native Northern crayfish was present in 62% of collections whereas, since 1985, they have dropped to 34%.[173] When tested together, the Northern crayfish had poorer growth and higher predation by Largemouth bass than Rusty crayfish.[73, 99] All crayfishes use shelter to avoid predators and, where shelter is in short supply, the Rusty crayfish is better at displacing other crayfishes. The result is that the other crayfishes are forced to use poor shelter which leads to higher predation.[73, 132] The Spinycheek crayfish is native to the eastern seaboard from Maine to Virginia. Within this range, it is rapidly disappearing due to competition with introduced Rusty and Northern crayfish.[139]

Rusty crayfish at moderate densities can reduce aquatic plant densities while high densities can totally eliminate plants.[141, 203]

Snail numbers declined drastically (from >10,000 to <5 per square meter) in a Wisconsin lake after a Rusty crayfish invasion.[251] In the same lake, the numbers of dragonflies, damselflies, caddis flies and amphipods also declined. A similar impact was observed in Lake Erie with a 33% reduction in macroinvertebrate biomass.[223] The Bluegill and Pumpkinseed, fishes that shared prey with Rusty crayfish, declined over time while piscivorous fishes showed no change.[251]

On potential positive impact was noted were Rusty crayfish reduced Zebra mussels though a similar study found no impact.[186, 223]

DISTRIBUTION AND ABUNDANCE

The original native range of the Rusty crayfish is considered to be an area comprising eastern Indiana, western Ohio, and central Kentucky in the Ohio drainage as well as southeast Michigan and northwest Ohio in the Lake Erie drainage.

The species is often sold as bait so has been widely introduced in many areas around North America. Another source of introductions was deliberate stocking as, in the 1930's, the Ohio Division of Conservation reared crayfish in their hatcheries and provided them to private parties around the state. Most of these were probably Rusty crayfish.[233]

To date, the rusty crayfish has been found four times in Nebraska. The first three were all in Douglas County.

1) The first were discovered in a bait dealer's tank in August 2005.

2) The second was in Benson Park Lagoon in 2007.

3) The third was in 2010 in the lake owned by the Lakeside Hills Association just north of 175th and West Center Road. Based on aerial photos, this lake was built sometime between 1993 and 1999. In 1993, this area was an undeveloped pasture with a small stream and a couple of ponds. By 1999, the lake had been constructed while housing and a shopping center were under construction. By 2003 the area was pretty much as it appears now. The Rusty crayfish was first found in this lake in the spring of 2010 along with the Northern crayfish. The Northern crayfish was historically present in the drainage and mght have been present at this location. The Rusty crayfish had to have been stocked but the source is unknown.

The newest find was in 2015. A South Dakota Conservation Officer found Rusty Crayfish in the possession of an angler who had collected them from the Missouri River below Gavins Point Dam (west of Yankton, South Dakota). Their presence in the Missouri River was subsequently confirmed and, as they seem to be well-established here, they must have been introduced several years earlier. The source was probably a bait dump.

CONSERVATION STATUS (NatureServe)

Global rank: G5

US Fish and Wildlife Service: N5

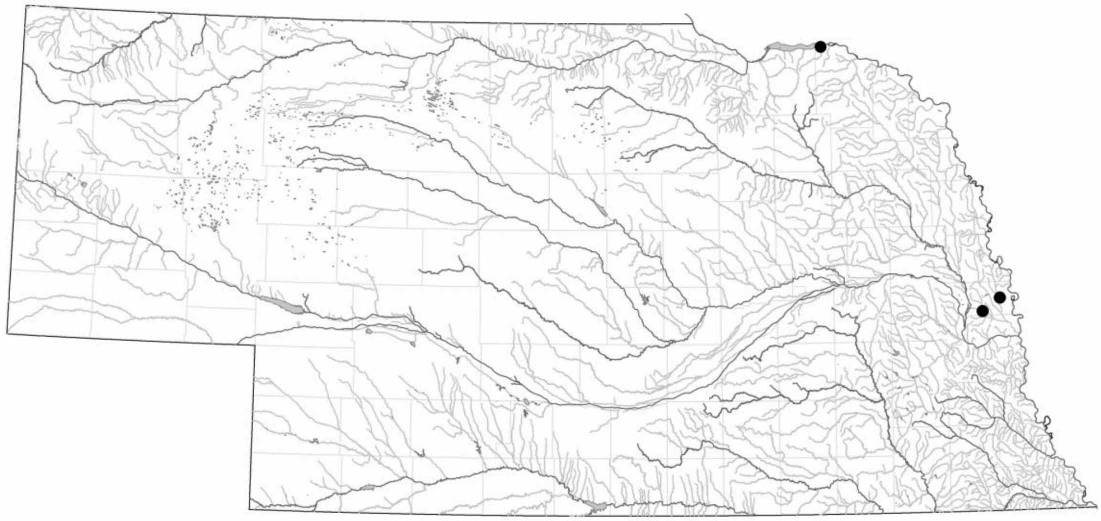
Committee on the Status of Endangered Wildlife in Canada: NNA

State Designations: CT (SNA), IL (SNA) IA (SNA), KY (SU), ME (SNA), MD (SNA), MA (SNA), MI (S2), MN (SNA), NH (SNA), NJ (SNA), NM (SNA), NY (SNA), NC (SNA), OH (S5), PA (SNA), TN (S5), VT (SNA), VA (SNA), WV (SNA), WI (S5)

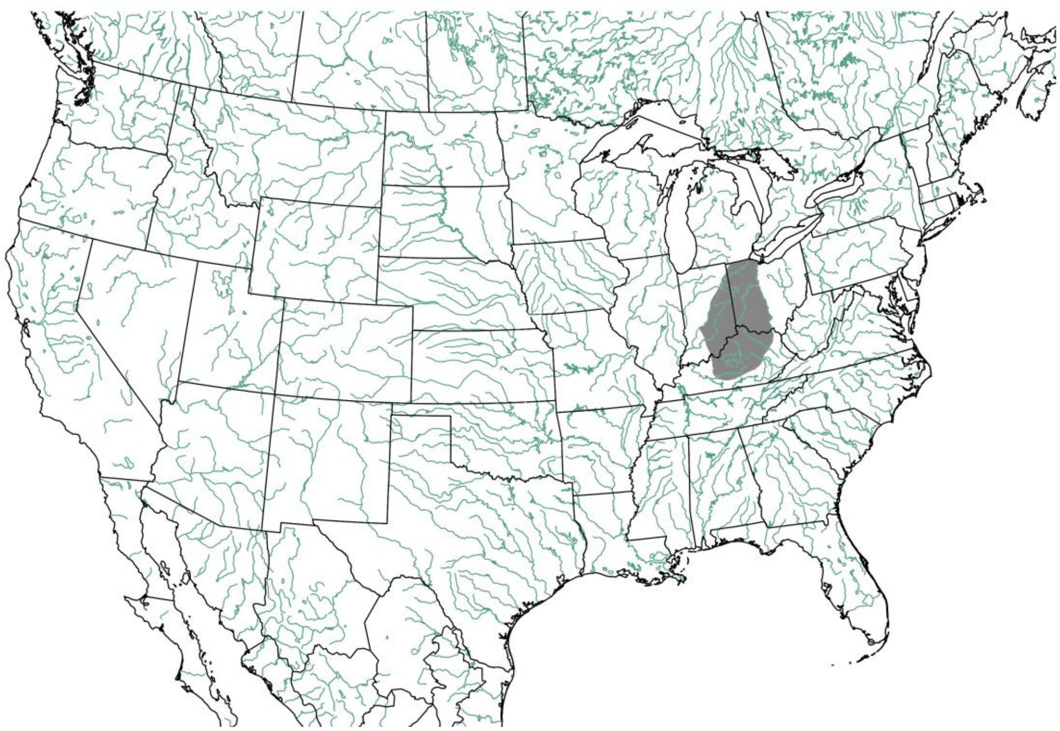
Province Designations: Manitoba (SNA), Ontario (SNA), Quebec (SNA)

CONSERVATION ISSUES

The rusty crayfish has proven to be an aggressive invasive species where introduced outside of it's native range. It has recently been discovered in two lakes in Omaha; Benson Park Lagoon, a private housing development lake (Lakeside) and the Missouri River at Gavins Point Dam. These populations will be watched to see how they develop.



Collection locations for the Rusty crayfish, *Orconectes rusticus*, in Nebraska



Native range of Rusty crayfish, *Orconectes rusticus*, in North America

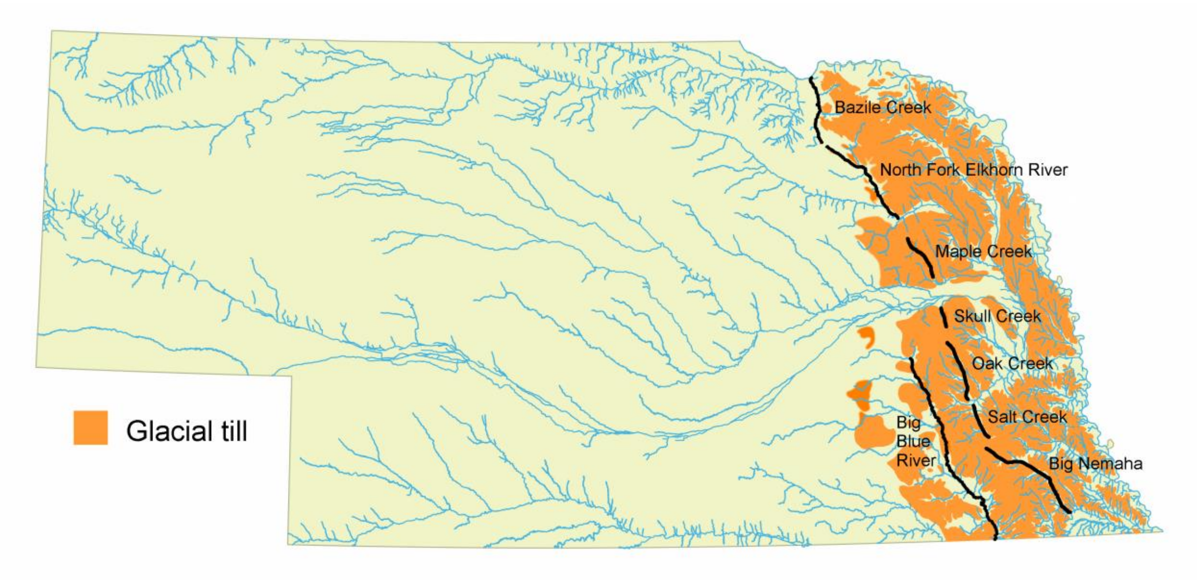
GEOLOGY AND GLACIATIONS

Five million years ago, in the center of the North American continent, an immense grass-covered and treeless plain sloped eastward from the mountains. Across this plain flowed large, broad, shallow and braided rivers carrying the sands and gravels that had eroded from the mountains. These streams were carrying so much sand and gravel that these often choked the river's own channel causing it to spill over its banks and move sideways into a new channel. These rivers created what we now call the Great Plains, extending from Canada to Mexico. Over these Great Plains roamed herds of grazers like horses, camels, mastodons and bison which were stalked by predators like saber-toothed cats. Then this plain gradually lifted while its western (next to the mountains) and its eastern edges were eroded away. A large section of the center of this plain is still present as the High Plains stretching from the Nebraska/South Dakota border south to Texas.

Some 2.5 million years ago, the Pleistocene epoch began. During the Pleistocene, the planet had cooled to the point that the polar ice caps had formed and wobbling of the planet's axis caused the climate to alternately warm and cool. During the cool periods, massive, continent-wide ice sheets formed and ground their way south. But there wasn't just one Pleistocene glaciation; there may have been as many as 20 in North America over that 2.5 million year period. [That may sound like a long time (well, actually, it is) but, if we compress the age of the earth into a 60 minute basketball game, the Pleistocene began in the last 2 seconds of the game]. Traditionally, these glaciations were lumped into four main periods. The oldest was the Nebraskan (2.5 to 0.5 million years ago), followed by the Kansan, the Illinoian and, finally, the Wisconsin, ending some 10,000 years ago. Currently the geology literature doesn't recognize most of these as separate, well-defined periods. But, I don't really care if there were two or 22. The point is that there were major, early glacial periods that had a hand in forming Nebraska's watersheds.

Well before the Pleistocene began, the ancestral North Platte River, heading in the Laramie Range of Wyoming, flowed northeast to the Red River of the North. The ancestral South Platte was a tributary of the North Platte and, of course, it too, flowed northeast. The ancestral Republican River was about where it is now, flowing southeast. Only one million years later, the North/South Platte Rivers were now flowing southeast into Kansas.[218] This may have been the major drainage flowing southeasterly from southern Nebraska/northern Kansas and through central Missouri (called the Grand or Old Grand-Missouri).[30, 39]

During the Pleistocene glaciations, the whole region became wetter and colder, with a treeless tundra nearest the glacial ice giving way to spruce forests growing as far south as Kansas. With the coming of the ice, the rivers that had been flowing to the northeast and to the east were now blocked by the ice sheet. That must have been something to see. The rivers flowing northeast and mixing with meltwater off the ice with nowhere to go. The river valleys would have filled creating huge lakes. Then the lakes would have overtopped the divides between watersheds cutting new channels to the south and southeast. Only the first two (Nebraskan and Kansan) ice sheets reached into Nebraska and the location of the edges of those glaciers can be seen in the glacial till deposits shown in the map below. When the ice reached its maximum southerly extent, parts of the Grand River drainage were cut off and a new drainage (the Ancestral Plains Stream) formed flowing south through Kansas.[39, 159]

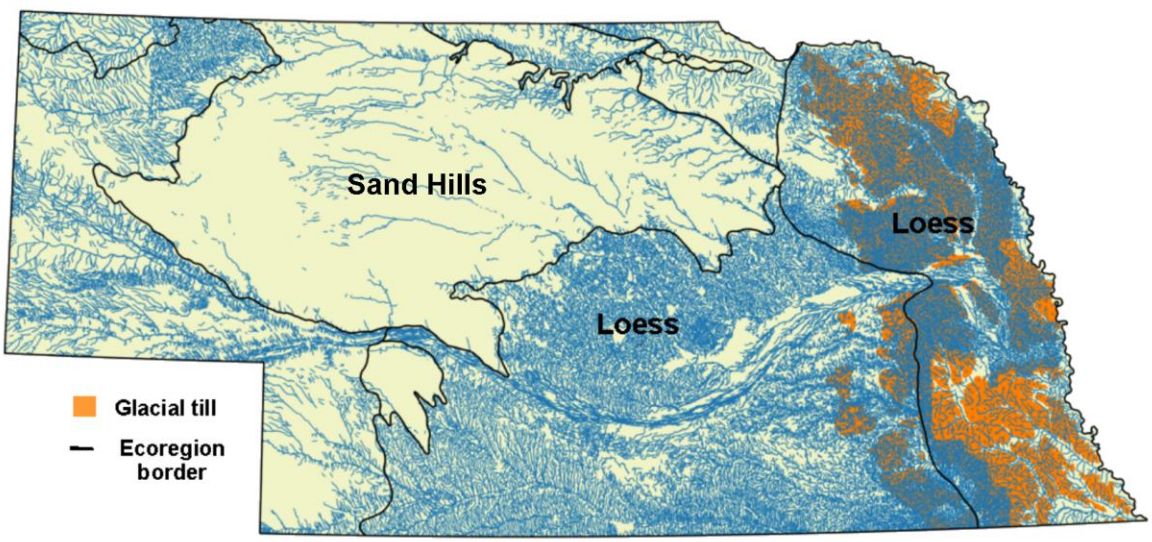


Glacial till map of Nebraska illustrating how existing stream courses may show the edges of a Pleistocene ice sheet.

When the last Kansan ice sheet began to melt, new rivers and watersheds began forming as the ice retreated northward. The ice melt must have started and stopped and restarted numerous times. Whenever it stopped, a new stream drainage formed. If you look at the glacial till area in the map below, you will see a number of streams that line up and follow a north/south path. These must mark where the ice stopped long enough for new drainages to form.[242] For instance, the western edge of the glacial till lines up with Bazile Creek, the North Fork Elkhorn River, Maple Creek, Skull Creek, Oak Creek, Salt Creek and the Big Nemaha River as well as the Big Blue River. If you look closely at a map of eastern Nebraska, you can see a number of streams or portions of streams (such as Logan Creek, Bell Creek and the lower Elkhorn River) that have this same alignment. Is this a coincidence? Perhaps not.

Notice in the map above that many of the streams in the state have a generally northwest/southeast alignment. These include the Elkhorn, the Loup basin streams and the Blue Rivers. Then right through the middle is the Platte River flowing northeast, exactly opposite of these other rivers. I noted earlier that the Platte River was one of those large, broad, braided prairie rivers that was constantly moving back and forth across the plains. 2.5 million years ago it was flowing northeast. One million years ago it was flowing southeast. Apparently, it began settling into its present course some 30,000 years ago.[218] It is thought that the rivers in the Loup River basin were originally the headwaters of the Big Blue River basin.[149] At this same time, the lower end of the Platte River was probably the lower Elkhorn River. Then a tributary of the Elkhorn, by working its way west, captured several

streams, diverting them east. Some 10,000 years ago, another tributary, working its way southwest, capturing the southeasterly flowing Platte River near Elm Creek.[28]
So, during the Pleistocene, the climate periodically got colder and the ice sheets built up and moved south. Then the climate warmed and the ice sheets melted and retreated back north. As they were retreating, the land got very dry and high winds (paleowinds) deposited thick layers of loess over eastern and southeastern Nebraska. The map below uses the National Hydrography Dataset laid over the glacial till map with the Level III Ecoregions outlined. The National Hydrography Dataset shows all drainages that have been carved into the landscape, many of which are dry drainages. Loess is a highly erodible soil and the areas marked "Loess" in the map show where these deep loess deposits are located. Note that the "Sand Hills" shows only a few drainages. This is because, while sand is very erodible, it is also highly permeable. So rain doesn't run off and erode the Sand Hills landscape, it simply soaks in.

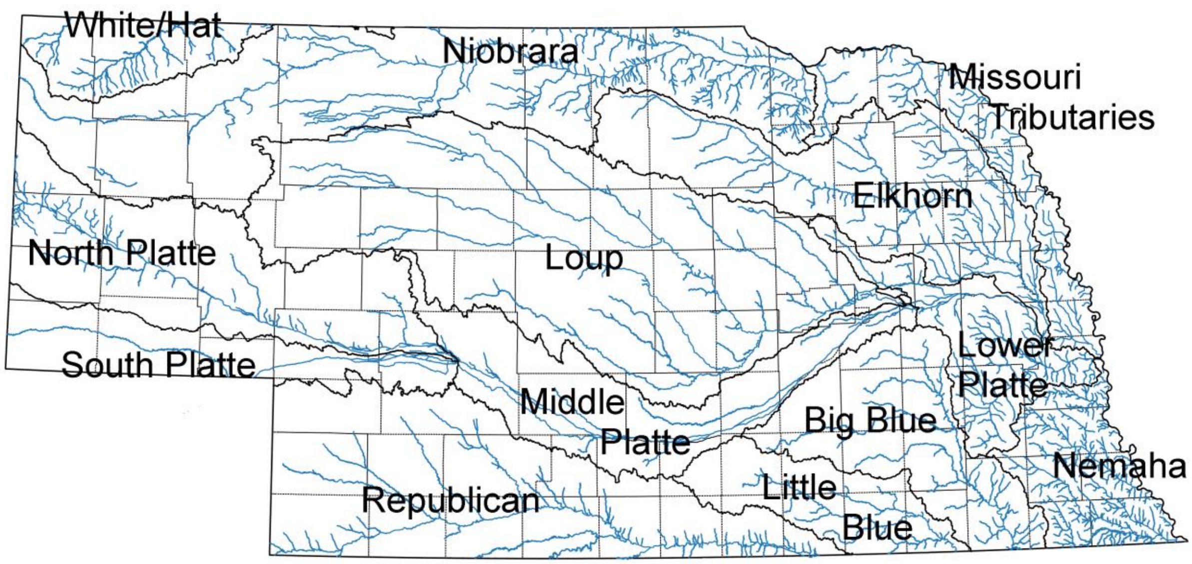


Nebraska drainages as shown by the National Hydrography Dataset overlaying a glacial till map with the Level III Ecoregions outlined.

What possible relevance could this long-winded discussion have to the crayfish of Nebraska? Crayfishes have been with us for a very long time. Fossil crayfishes (the ancestors of our modern crayfishes) have been found that date back to the Triassic (more than 216,000,000 years).[161] These fossil crayfish, while of long extinct species, are clearly related to those we have now. The crayfishes we find in eastern North America are thought to have originated in the area called the Eastern Highlands, an area centered on the Appalachian Mountains extending from Alabama to Pennsylvania. From here they extended their ranges west to the mountains, south into Mexico and north into Canada. By the time the Pleistocene began, streams and lakes throughout eastern North America were well populated with crayfishes.

Every time the glaciers ground their way south, any critters living in the path of the ice would have been wiped out. Then, as the glaciers melted and retreated back north, new streams and watersheds formed and crayfishes could follow along and colonize these new waters. But, to be able to colonize the new streams, wildlife including crayfish, had to survive in places of refuge (called refugia) away from the ice and the harsh conditions near the ice. Several authors have already looked at where these refugia may have been located.[18, 110, 180, 213, 233] These authors suggest that the refugia of the Northern crayfish, the Calico crayfish and the Prairie crayfish were in the Missouri River basin to the west. The refuge of the Devil crayfish must have been to the south of the ice margin.

The point is that if we plotted the ranges of these species on a national map and then marked where the margin of the ice had been, we might be able to trace these refugia. We could also plot the current Nebraska crayfish distributions on top of the state glacial till/loess map. This may help us trace how they could have colonized the new drainages and, perhaps, there are also clues as to the landforms that produce the habitats they prefer.



Nebraska river basins

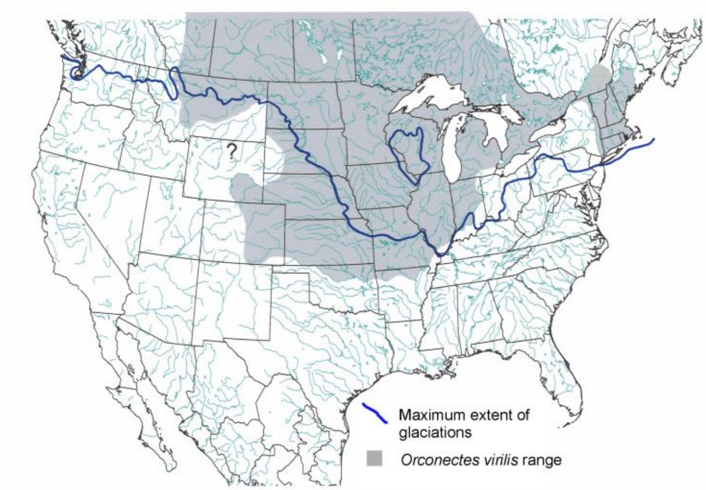
It might be helpful to review the timeline of the formation of some of the major rivers of the state shown in the map above. The Platte and Republican Rivers are the oldest streams in the state and existed before the Pleistocene began. The Republican River flowed southeast in the same general area where it is now. The Platte was flowing northeast then migrated into a southeasterly course as part of the ancestral Grand watershed flowing through central Missouri. After the Platte had moved to the southeast, the Loup, Elkhorn and Blue River basins must have begun forming. In the late Pleistocene, the Platte was diverted into its present course. At the end of the

Pleistocene, about 10,000 years ago, the Niobrara River began to form, capturing headwater streams in the Elkhorn and Loup basins. About 8,000 years ago, during arid periods, the Sand Hills and its streams began forming with the youngest river in the state being the Dismal River which may be less than 1,500 years old.[225]

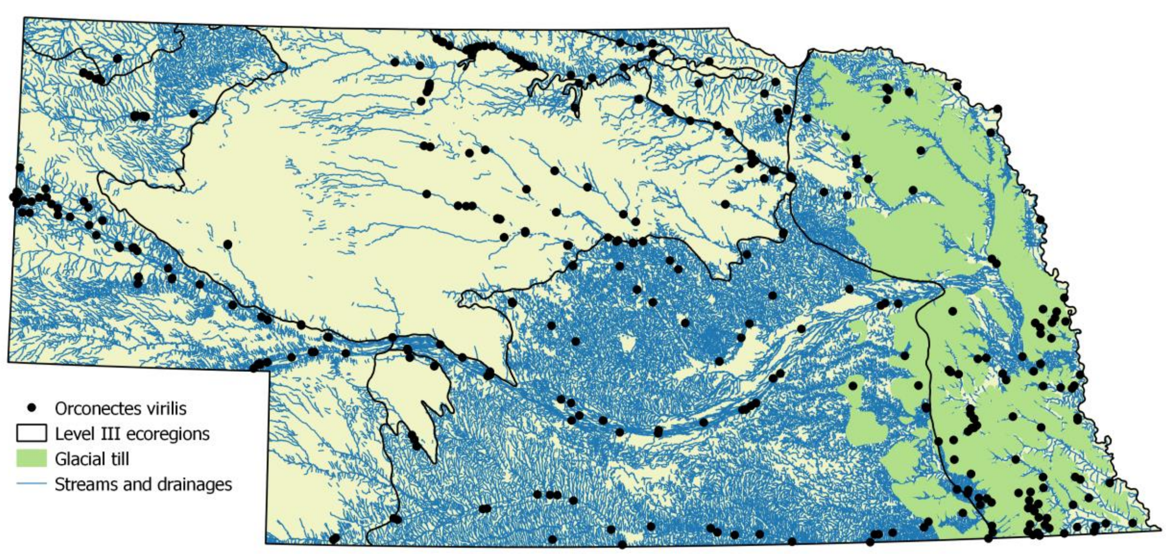
In attempting to see how the glaciations would have affected crayfishes, we are comparing the current ranges with information on the maximum extent of the glaciations. We do not know and will never know what the ranges would have been like before the Pleistocene. All we can do is look at the current information and make our best guess as to what happened.

Northern crayfish, *Orconectes virilis*

This map shows that the Northern crayfish, *Orconcectes virilis*, is truly a northern species, with a range extending from the Continental Divide to the Atlantic Ocean and from the south-central U.S. well into central Canada. The blue line denoting the maximum extent of the ice shows that most of this range would have been under the ice during the Pleistocene. It also shows what other authors suggested; that the refugia for this species was the western portion of the Missouri River basin.



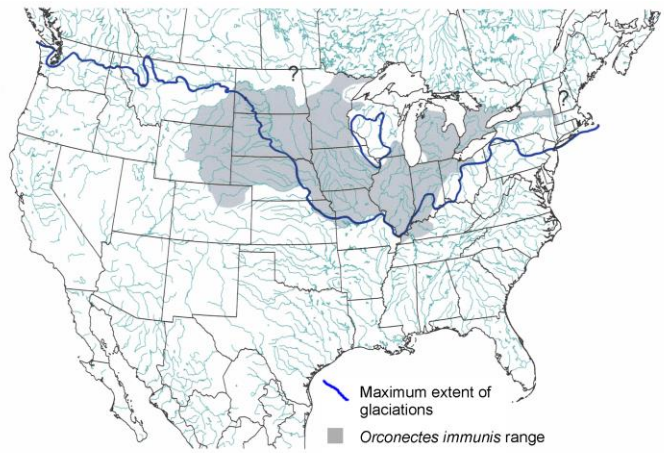
The Nebraska collections of the Northern crayfish are plotted on the map shown below. In the Northern crayfish species account I mentioned that it is likely that those in the White River basin and the upper Niobrara River are likely to be recent introductions. So what does this map say about their presence in the rest of the state and possible glacial refugia?



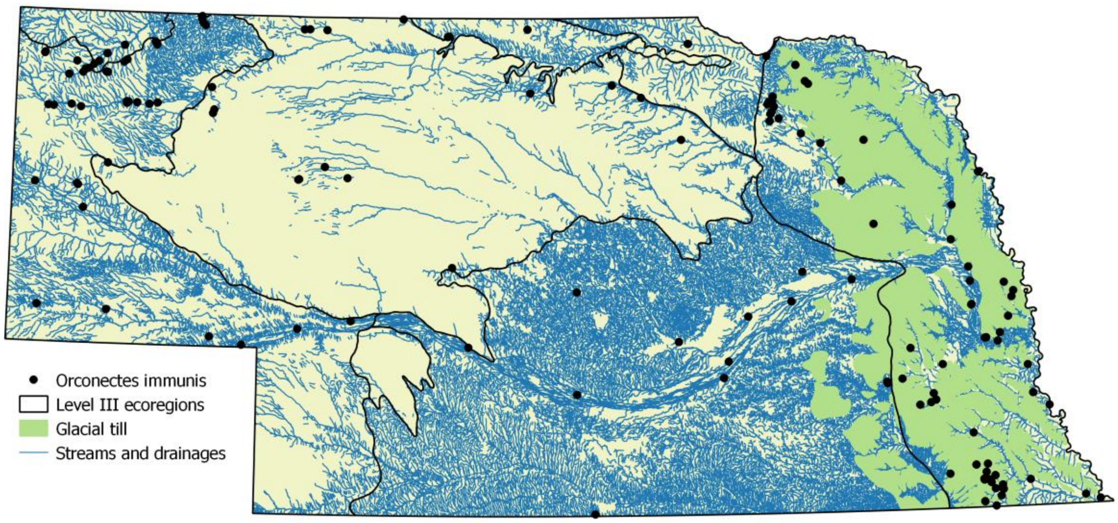
The Northern crayfish is found in most all of the state so it doesn't seem to be picky about the type of streams or landforms it inhabits. It is common in the two oldest watersheds, the Platte and Republican, so it is a good probability that these served as glacial refugia. The other watersheds are all younger than these so had to have been occupied later. The Glacial Till area dates from the end of the Kansan glacial period which ended some 500,000 years ago. At that time, the Platte and Republican were both flowing to the southeast into the Old Grand-Missouri watershed. If so, was this the route the crayfishes used to move into new watersheds? It would be interesting to conduct a detailed genetic study of this species. Would it tell us if the Big Blue and Loup basins were really connected at some distant time in the past? Would it give us a timeline as to when watersheds were occupied? Would it tell us how watersheds were connected?

Calico crayfish, *Orconectes immunis*

This map shows that the Calico crayfish, *Orconcectes immunis*, is widespread in the north-central U.S. As with the Northern crayfish, the blue line denoting the maximum extent of the ice shows that most of this range would have been under the ice during the Pleistocene. It also shows what other authors have suggested; that the refugia for this species was the western portion of the Missouri River basin. The map shows that they seem to prefer the glaciated portions of the upper Midwest. The southern limit of their range closely follows the southern limit of the glaciation and they are absent from the unglaciated region in southwest Wisconsin.

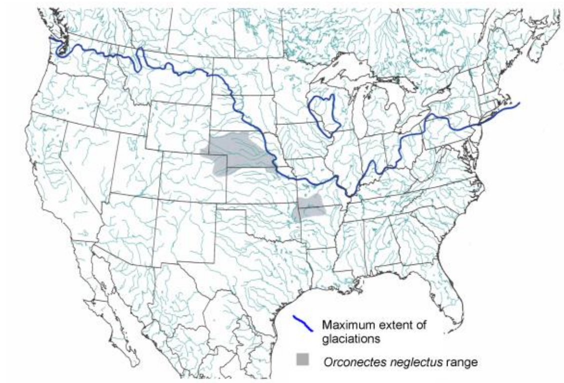


In contrast to the Northern crayfish, the Calico crayfish is absent (or nearly so) from several ecoregions in the center part of the state. It most common in the eastern glaciated region as well as the western un-glaciated areas. It is virtually absent from the Republican basin and is present but uncommon in the Platte. Similarly, it is uncommon in the Loup, Elkhorn and lower Niobrara basins. The small pocket of collections in the central Sand Hills might represent a recent introduction as there are several fishing lakes in that area. The Platte River could have been a possible glacial refugia but the map suggests that it might have been further north also. The frequency of collection in the White River basin in the extreme northwest suggests this. This cannot be resolved here as there is a lack of crayfish distributional data out of South Dakota. The frequency of collection in the upper Niobrara suggests a geological connection between that basin and those to the north. If this is so, then their presence in the eastern glaciated region would argue that they came down from the northwest to occupy this area. Again, a detailed genetic study might give us some clues as to what happened.

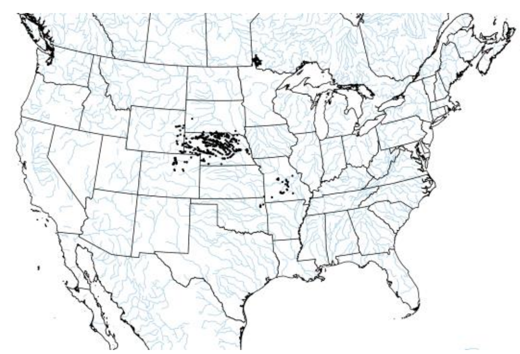


Ringed Crayfish, *Orconectes neglectus neglectus*

The Ringed crayfish has a limited distribution as can be seen in this map. None of this range was directly impacted by the glaciations. This map does argue in favor of the ancestral Grand watershed. The center of origin of the species has been postulated to be in the Ozark Highlands of southern Missouri.[30]



Ringed Crayfish range map



Plains topminnow range map

The range of the Ringed crayfish is strikingly similar to that of the Plains topminnow (*Fundulus sciadicus*), a fish that is endemic to the central Great Plains. The two maps at the right show how similar they are. It has been suggested that the Plains topminnow originated in the central plains and moved downstream into the Ozark Highlands. A genetic study of the Plains topminnow.[138] found that the two population centers were related and that they split some 622,000 years ago. Since this is during the Nebraskan glaciation, it is possible that the changing climate and changes in the drainages caused the split between the two.

So, if the ancestral Grand watershed connected these two regions and the Plains topminnow used it to expand its range south and east into the Ozark Highlands, is it not equally possible that the Ringed crayfish used the same drainage to move west and north? Subsequently they could have used the Ancestral Plains Stream to populate the several Nebraska drainages.

In any case, the map above shows that the Ringed crayfish does not appear to like the streams in the glaciated areas. The only exception to this is their presence in the Big Blue River basin. It is possible that the Big Blue is a remnant of the Ancestral Plains Stream. The map shows that this species is common in the North Platte and Republican River basins which suggests that these were glacial refugia for the Ringed crayfish. Though, perhaps, "glacial refugia" is a poor term as they were not directly impacted by the ice. The map also shows that they are common in the Loup and Big Blue River basins which might indicate that these two basins were once connected. The two isolated population centers in the Niobrara River are interesting. The Niobrara began forming some 20,000 years ago and captured streams from the Elkhorn and Loup basins as it migrated west.[215, 225] Is it possible that the population center in the middle Niobrara River had its origin in a stream captured from the Loup? Also, there is a second population center in the extreme western Niobrara River. Might the upper Niobrara have been a part of the North Platte River in the distant past? Of course, one cannot rule out that these are recent introductions but bait bucket introductions are usually found near a reservoir or fishing lake. There are none in these areas. Again, a genetic study might help us resolve these questions.

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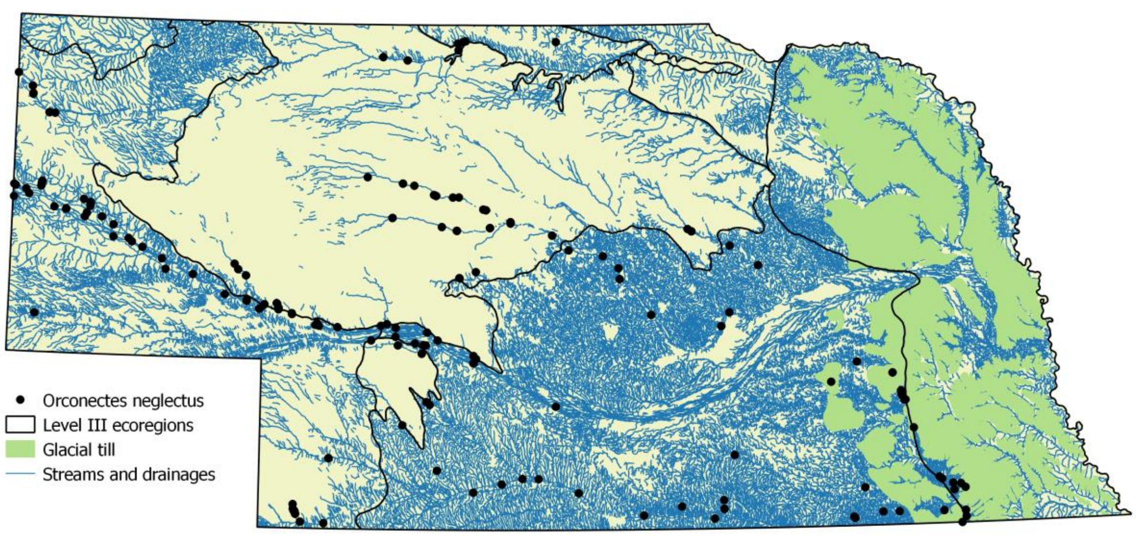
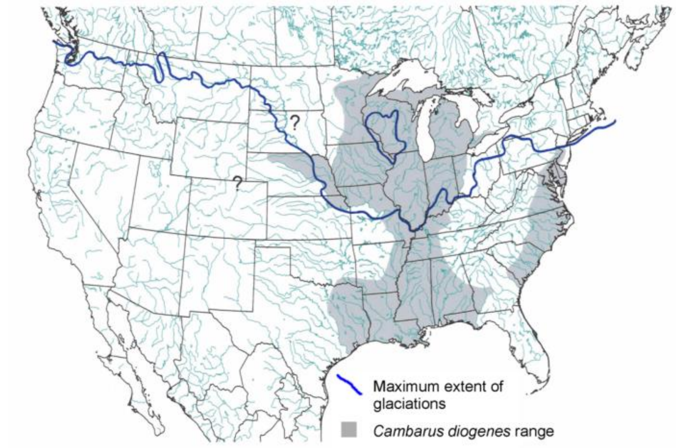
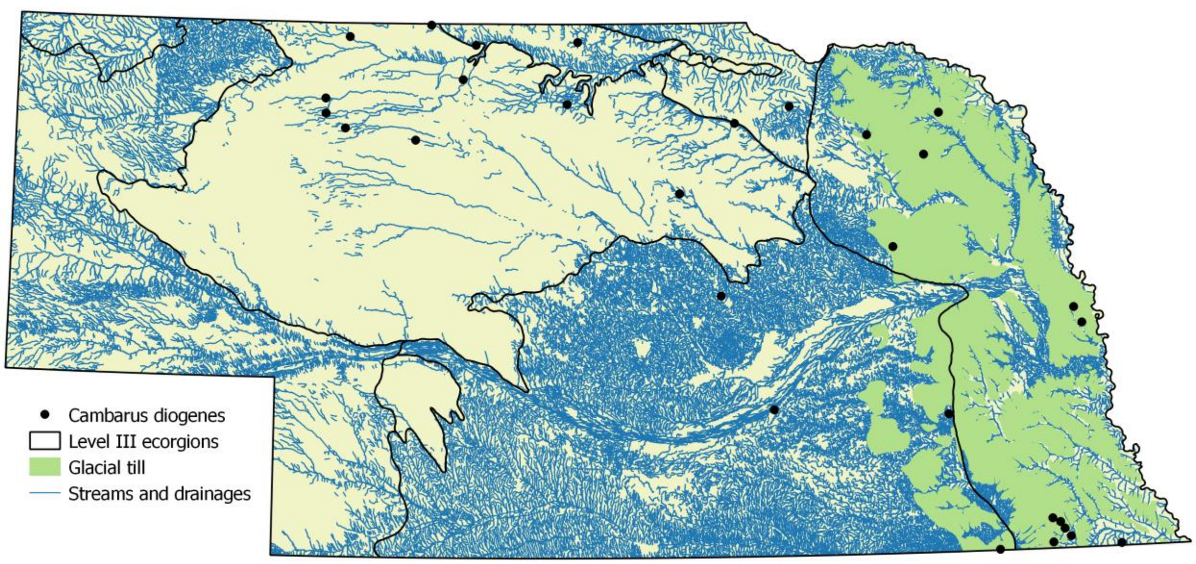


Devil crayfish, *Cambarus diogenes*

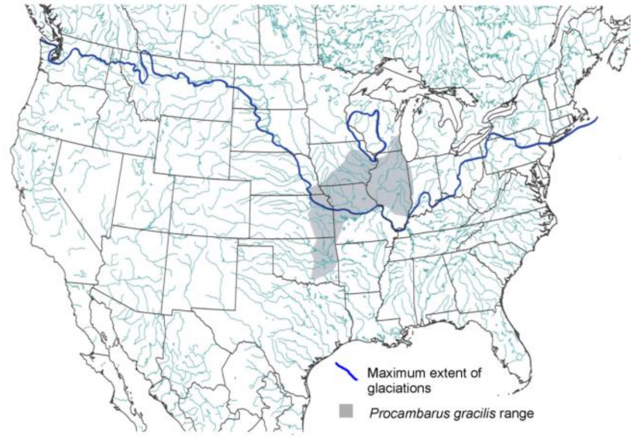


This map shows that the Devil crayfish, *Cambarus diogenes*, is widespread in the central and eastern U.S. In contrast with the previous species, only the northern half of its range would have been affected by the ice during the Pleistocene. It also shows what other authors have suggested; that the glacial refugia for this species was in the southern portion of the Mississippi River basin.

The map above shows the collection locations for the Devil crayfish in Nebraska. This is a burrowing species and are difficult to find so this may not fully represent their range here. Comparing the two maps above, it would seem that they prefer the glaciated areas. It also looks like they have followed the Missouri River upstream into Nebraska. Beyond that it is difficult to get a good picture of their path into the state as there is not enough information.

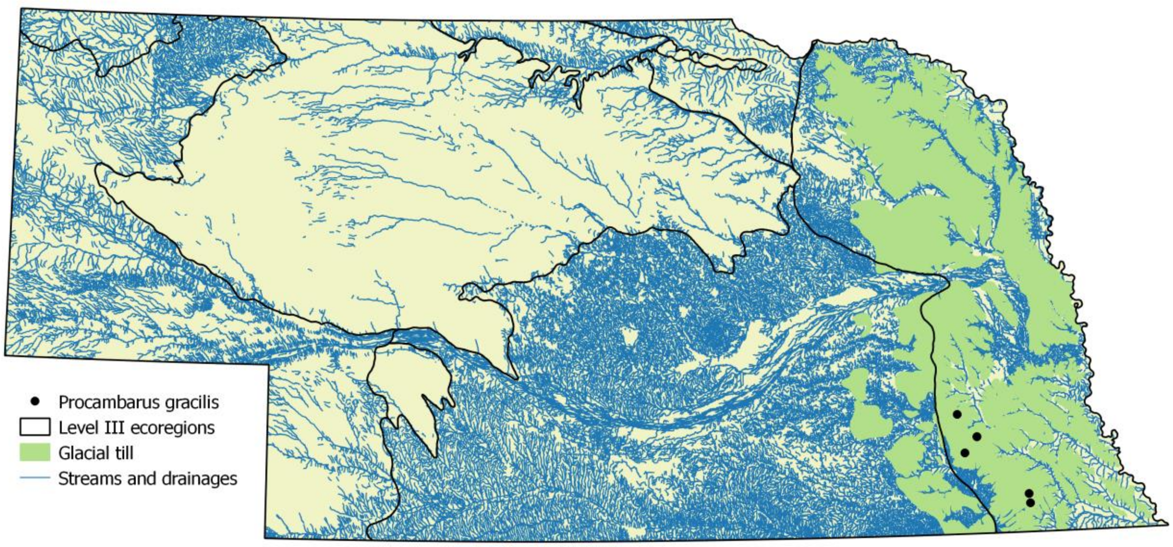


Prairie crayfish, *Procambarus gracilis*



This map shows that the Prairie crayfish, *Procambarus gracilis*, has a small range in the central and eastern U.S. As with the Devil crayfish, only the northern portion of its range would have been affected by the ice during the Pleistocene. It also shows that the glacial refugia for this species was south of the ice. In its migration north and east, it seems to be favoring the glaciated areas since it has not moved into the non-glaciated area in southwest Wisconsin.

If a burrowing species like the Devil crayfish is hard to sample, the Prairie crayfish is doubly so. To date, I have only five records for the species in Nebraska. All of these are in a small area in the glaciated area of southeast Nebraska. At this time, my best estimate is that this species will only be found in the southeastern corner of the state, east of the Big Blue River and south of the Platte. This species prefers undisturbed grassland with moist soils. Much of the grassland in southeast Nebraska has been drained and converted to row crops which has probably affected their presence in the state.



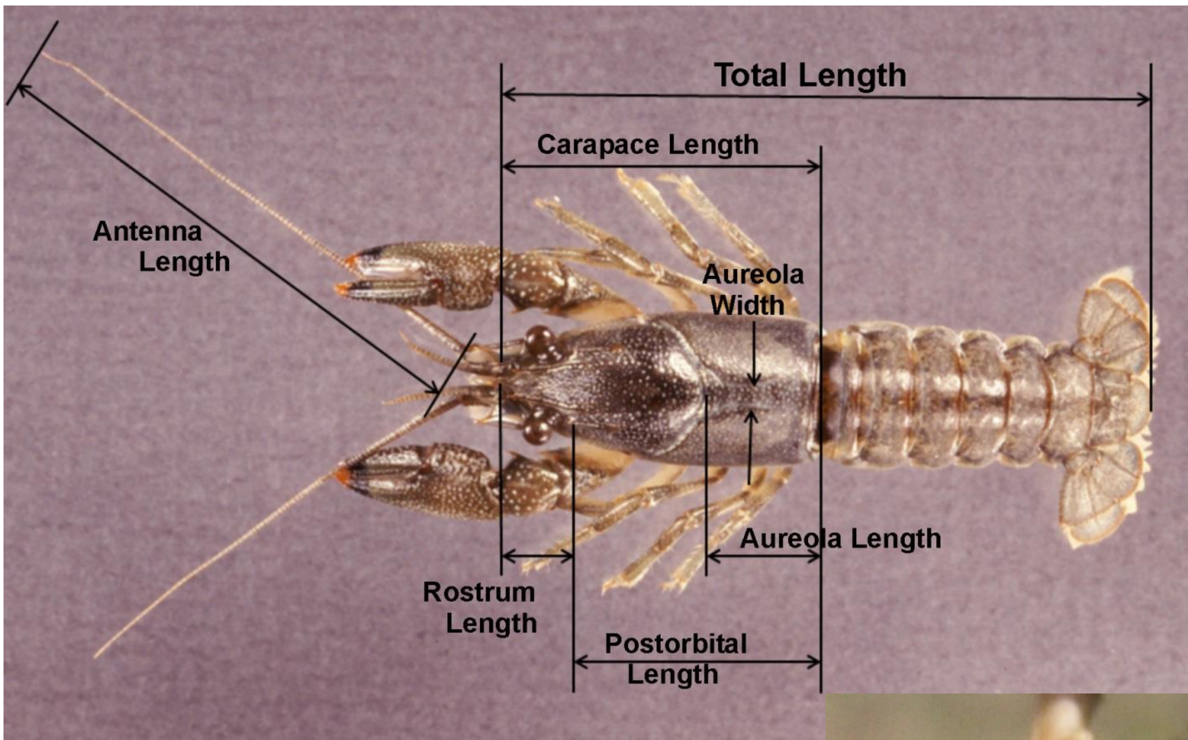
Discussion

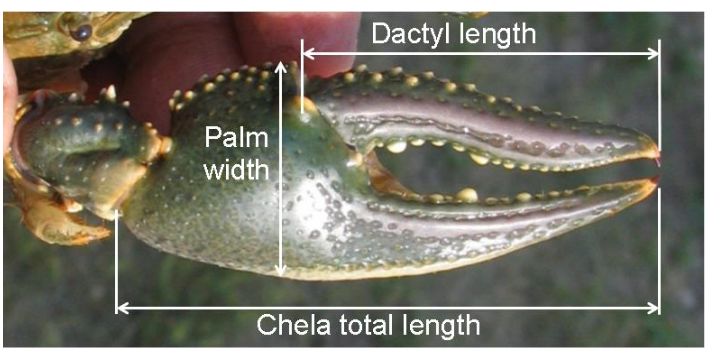
This has been an interesting exercise but don't know if it proved anything. Perhaps someone reading this can address some of these questions in the future.

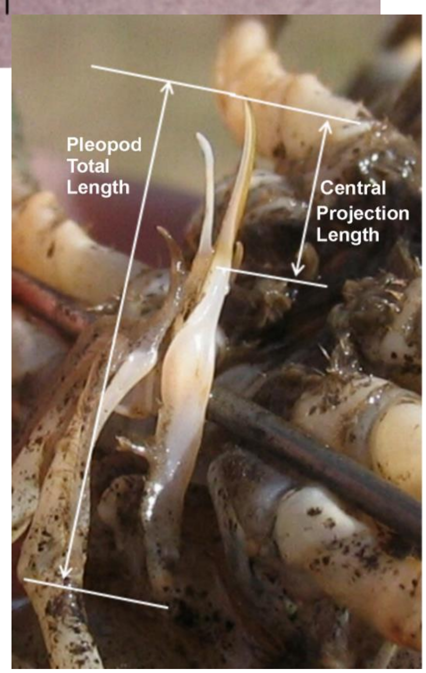
BODY MEASUREMENTS AND RATIOS

These crayfishes have extensive ranges across North America. It is often of interest to workers in different areas to be able to compare the crayfishes that they see with those found elsewhere. This section contains measurements of the five native crayfishes of Nebraska. The measurements taken are illustrated in the images below.

Separate tables are provided for Form I males, Form II males and females.
The ratios of one body dimension versus another is sometimes useful in identification. These can also vary in different parts of the species' range. A range of ratios is provided in the tables.







Devil Crayfish, *Cambarus diogenes*: Measurements and Ratios: Form I Male

		Number	Minimum	Maximum	Mean
	Total length	4	26.8	83.6	65.7
Carapace					
	Total length	4	36.9	55.4	45.6
	Postorbital length	4	31.3	48.3	39.4
Aureola					
	Length	4	14.4	23.2	18.5
	Width	4	0.0	0.0	0.0
Chela					
	Total length	3	26.1	35.8	32.1
	Dactyl length	3	17.5	25.0	21.9
	Palm length	3	7.9	10.4	9.1
	Palm width	3	12.0	15.6	13.9
	Finger gap	3	2.3	3.0	2.5
Antenna					
	Total length	4	53.3	81.3	63.4
Pleopod					
	Total length	3	8.6	11.4	10.2

Ratios		Number	Minimum	Maximum	Mean
	Carapace length / Total length	4	0.53	0.54	0.54
	Aureola length / Carapace length	4	0.39	0.42	0.41
	Chela length / Carapace length	3	0.71	0.80	0.76
	Dactyl length / Chela length	3	0.64	0.73	0.68
	Palm width / Chela length	3	0.41	0.46	0.44
	Pleopod length / Carapace length	3	0.23	0.25	0.24

Devil Crayfish, *Cambarus diogenes*: Measurements and Ratios: Form II Male

		Number	Minimum	Maximum	Mean
	Total length	11	43.7	93.6	63.8
Carapace					
	Total length	11	22.5	51.5	35.1
	Postorbital length	11	19.8	262.6	51.8
Aureola					
	Length	11	8.8	21.7	14.1
	Width	11	0.0	0.0	0.0
Chela					
	Total length	11	13.8	43.7	24.4
	Dactyl length	11	8.8	28.3	15.8
	Palm length	11	3.8	12.7	7.3
	Palm width	11	6.2	18.7	10.9
	Finger gap	11	0.3	3.7	1.7
Antenna					
	Total length	10	30.5	60.2	42.9
Pleopod					
	Total length	8	4.7	12.0	8.4

Ratios		Number	Minimum	Maximum	Mean
	Carapace length / Total length	11	0.51	0.83	0.56
	Aureola length / Carapace length	11	0.39	0.42	0.40
	Chela length / Carapace length	11	0.55	0.85	0.68
	Dactyl length / Chela length	11	0.60	0.69	0.65
	Palm width / Chela length	11	0.41	0.48	0.45
	Pleopod length / Carapace length	8	0.20	0.26	0.23

Devil Crayfish, *Cambarus diogenes*: Measurements and Ratios: Female

		Number	Minimum	Maximum	Mean
	Total length	13	39.2	106.0	66.9
Carapace					
	Total length	13	20.3	54.0	34.6
	Postorbital length	13	17.2	46.9	29.8
Aureola					
	Length	13	7.7	22.6	13.8
	Width	13	0.0	0.0	0.0
Chela					
	Total length	11	11.5	38.3	21.4
	Dactyl length	11	7.1	26.6	14.0
	Palm length	11	3.3	9.5	6.3
	Palm width	11	5.0	15.6	9.7
	Finger gap	11	0.0	2.5	1.0
Antenna					
	Total length	12	25.4	69.1	38.2

Ratios		Number	Minimum	Maximum	Mean
	Carapace length / Total length	13	0.50	0.54	0.52
	Aureola length / Carapace length	13	0.38	0.42	0.39
	Chela length / Carapace length	12	0.55	0.71	0.63
	Dactyl length / Chela length	12	0.62	0.69	0.65
	Palm width / Chela length	12	0.41	0.48	0.46

Northern Crayfish, *Orconectes virilis*: Measurements and Ratios: Form I Male

	Number	Minimum	Maximum	Mean
Total length	357	45.4	116.1	81.7
Carapace				
Total length	357	22.6	61.2	41.4
Postorbital length	356	17.3	48.7	32.4
Aureola				
Length	357	8.0	23.4	15.1
Width	357	0.1	1.8	0.8
Chela				
Total length	354	16.8	70.1	39.3
Dactyl length	354	9.0	49.1	27.5
Palm length	354	4.5	16.8	9.7
Palm width	354	1.3	28.3	15.6
Finger gap	354	0.0	8.9	3.2
Antenna				
Total length	344	30.5	115.6	72.3
Pleopod				
Total length	357	9.4	24.2	16.7
Central projection	357	2.9	8.1	5.6

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	357	0.48	0.57	0.51
Aureola length / Carapace length	357	0.31	0.39	0.37
Aureola length / Aureola width	357	8.3	43.1	19.0
Chela length / Carapace length	353	0.68	1.17	0.94
Dactyl length / Chela length	353	0.52	0.78	0.70
Palm width / Chela length	353	0.29	0.47	0.40
Pleopod length / Carapace length	357	0.34	0.49	0.40
Central Projection length / Pleopod length	357	0.26	0.44	0.34

Northern Crayfish, *Orconectes virilis*: Measurements and Ratios: Form II Male

	Number	Minimum	Maximum	Mean
Total length	43	37.5	101.0	66.2
Carapace				
Total length	43	19.6	51.7	33.4
Postorbital length	43	14.8	40.2	25.6
Aureola				
Length	43	6.4	18.4	11.9
Width	43	0.3	1.0	0.6
Chela				
Total length	42	11.2	49.0	24.9
Dactyl length	42	7.2	35.4	17.0
Palm length	42	2.6	12.1	6.1
Palm width	42	4.2	18.9	9.3
Finger gap	42	0.0	4.7	1.4
Antenna				
Total length	42	31.2	87.9	61.2

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	43	0.42	0.87	0.51
Aureola length / Carapace length	43	0.33	0.42	0.36
Aureola length / Aureola width	43	10.6	43.3	22.0
Chela length / Carapace length	41	0.51	1.03	0.73
Dactyl length / Chela length	41	0.63	0.73	0.68
Palm width / Chela length	41	0.26	0.41	0.37

. **Northern Crayfish, *Orconectes virilis*: Measurements and Ratios: Female**

	Number	Minimum	Maximum	Mean
Total length	61	52.9	121.2	77.7
Carapace				
Total length	61	25.9	59.3	38.4
Postorbital length	61	19.9	47.7	29.9
Aureola				
Length	61	9.3	22.4	13.8
Width	61	0.4	1.5	0.9
Chela				
Total length	61	14.1	53.0	29.0
Dactyl length	61	10.4	35.8	19.9
Palm length	61	3.4	13.5	7.3
Palm width	61	5.4	21.5	11.5
Finger gap	53	0.0	5.3	1.7
Antenna				
Total length	56	38.1	109.5	62.5

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	61	0.47	0.53	0.49
Aureola length / Carapace length	61	0.34	0.38	0.36
Aureola length / Aureola width	61	10.8	39.5	17.9
Chela length / Carapace length	61	0.55	0.93	0.74
Dactyl length / Chela length	61	0.61	0.76	0.69
Palm width / Chela length	61	0.34	0.46	0.40

Calico Crayfish, *Orconectes immunis*: Measurements and Ratios: Form I Male

	Number	Minimum	Maximum	Mean
Total length	33	55.3	91.9	72.0
Carapace				
Total length	33	27.9	47.5	35.7
Postorbital length	33	20.7	37.1	25.9
Aureola				
Total length	32	322.5	0.0	0.0
Width	33	21.5	0.0	0.0
Chela				
Total length	30	18.8	48.3	31.4
Dactyl length	30	12.7	31.9	21.1
Palm length	30	5.4	12.5	8.3
Palm width	30	6.7	15.2	10.7
Finger gap	29	0.0	13.2	2.6
Antenna				
Total length	29	27.9	72.9	49.1
Pleopod				
Total length	33	8.8	18.8	11.7

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	33	0.48	0.52	0.50
Aureola length / Carapace length	31	0.32	0.38	0.35
Aureola length / Aureola width	31	11.0	24.1	15.2
Chela length / Carapace length	28	0.67	1.11	0.87
Dactyl length / Chela length	28	0.61	0.71	0.67
Palm width / Chela length	28	0.31	0.38	0.34
Pleopod length/Carapace length	29	0.36	0.96	0.44

Calico Crayfish, *Orconectes immunis*: Measurements and Ratios: Form II Male

	Number	Minimum	Maximum	Mean
Total length	10	56.3	84.4	72.7
Carapace				
Total length	11	28.1	42.4	36.0
Postorbital length	11	20.4	33.6	27.5
Aureola				
Total length	11	9.7	16.3	13.0
Width	11	0.5	1.0	0.8
Chela				
Total length	11	16.5	50.8	30.0
Dactyl length	11	10.4	33.8	19.6
Palm length	11	4.1	13.7	8.0
Palm width	11	5.7	16.0	9.8
Finger gap	9	0.8	3.6	2.0
Antenna				
Total length	10	32.3	86.4	53.0

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	10	0.47	0.51	0.49
Aureola length / Carapace length	11	0.34	0.44	0.36
Aureola length / Aureola width	11	12.9	25.4	16.6
Chela length / Carapace length	11	0.59	1.38	0.82
Dactyl length / Chela length	11	0.61	0.68	0.65
Palm width / Chela length	11	0.30	0.35	0.33
Pleopod length/Carapace length	5	0.32	0.42	0.35

Calico Crayfish, *Orconectes immunis*: Measurements and Ratios: Female

	Number	Minimum	Maximum	Mean
Total length	19	54.9	94.8	74.3
Carapace				
Total length	19	26.6	45.4	35.8
Postorbital length	19	19.5	34.4	25.9
Aureola				
Total length	19	9.1	16.1	12.5
Width	19	0.5	1.3	0.8
Chela				
Total length	19	14.2	32.2	23.4
Dactyl length	19	9.2	21.4	15.6
Palm length	19	3.6	8.9	6.3
Palm width	19	4.8	11.8	8.6
Finger gap	18	0.5	2.5	1.6
Antenna				
Total length	17	29.2	53.3	44.6

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	20	0.47	0.50	0.48
Aureola length / Carapace length	20	0.33	0.37	0.35
Aureola length / Aureola width	31	11.0	24.1	15.2
Chela length / Carapace length	20	0.51	0.75	0.64
Dactyl length / Chela length	20	0.61	0.74	0.66
Palm width / Chela length	20	0.32	0.41	0.37

Ringed Crayfish, *Orconectes neglectus*: Measurements and Ratios: Form I Male

		Number	Minimum	Maximum	Mean
	Total length	28	44.1	91.1	70.6
Carapace					
	Total length	28	21.4	46.0	35.1
	Postorbital length	28	16.9	37.6	25.9
Aureola					
	Length	28	7.6	16.9	12.5
	Width	28	1.3	3.8	2.3
Chela					
	Total length	27	17.8	53.6	34.9
	Dactyl length	27	11.4	34.5	22.6
	Palm length	28	5.5	17.3	10.7
	Palm width	28	8.0	24.6	15.6
	Finger gap	28	0.8	6.6	3.1
Antenna					
	Total length	24	25.4	74.9	56.0
Pleopod					
	Total length	27	9.1	18.2	14.3
	Central projection	25	2.9	6.5	5.0

Ratios		Number	Minimum	Maximum	Mean
	Carapace length / Total length	28.00	0.47	0.52	0.50
	Aureola length / Carapace length	28.00	0.34	0.37	0.36
	Aureola length / Aureola width	28.00	3.9	7.9	5.5
	Chela length / Carapace length	27.00	0.65	1.17	0.97
	Dactyl length / Chela length	26.00	0.61	0.73	0.65
	Palm width / Chela length	27.00	0.41	0.52	0.45
	Pleopod length / Carapace length	27.00	0.36	0.45	0.41
	Central Projection length / Pleopod length	25.00	0.27	0.41	0.35

Ringed Crayfish, *Orconectes neglectus*: Measurements and Ratios: Form II Male

		Number	Minimum	Maximum	Mean
	Total length	27	41.7	80.9	69.8
Carapace					
	Total length	27	20.4	41.0	34.5
	Postorbital length	27	15.5	33.2	27.5
Aureola					
	Length	27	6.7	15.0	12.1
	Width	27	1.0	2.8	2.4
Chela					
	Total length	25	11.3	35.5	26.4
	Dactyl length	25	7.5	23.4	17.0
	Palm length	25	0.3	10.7	7.8
	Palm width	25	4.2	15.0	11.3
	Finger gap	17	0.8	3.6	2.0
Antenna					
	Total length	26	24.6	66.0	51.7
Pleopod					
	Total length	5	12.1	15.2	13.8

Ratios		Number	Minimum	Maximum	Mean
	Carapace length / Total length	27.00	0.48	0.52	0.49
	Aureola length / Carapace length	27.00	0.33	0.38	0.35
	Aureola length / Aureola width	27.00	4.2	6.7	5.1
	Chela length / Carapace length	25.00	0.55	0.90	0.76
	Dactyl length / Chela length	25.00	0.60	0.68	0.64
	Palm width / Chela length	25.00	0.37	0.54	0.43
	Pleopod length / Carapace length	5.00	0.38	0.41	0.40

Ringed Crayfish, *Orconectes neglectus*: Measurements and Ratios: Female

		Number	Minimum	Maximum	Mean
	Total length	17	62.2	76.0	68.9
Carapace					
	Total length	17	28.7	36.2	32.8
	Postorbital length	17	22.6	28.4	26.1
Aureola					
	Length	17	10.0	12.7	11.4
	Width	17	0.8	3.4	2.3
Chela					
	Total length	17	19.6	28.1	23.8
	Dactyl length	17	11.9	18.5	15.5
	Palm length	17	6.0	8.5	7.5
	Palm width	17	8.8	16.0	11.2
	Finger gap	16	0.5	2.0	1.2
Antenna					
	Total length	15	38.1	71.9	51.6

Ratios		Number	Minimum	Maximum	Mean
	Carapace length / Total length	17.00	0.46	0.50	0.47
	Aureola length / Carapace length	17.00	0.33	0.37	0.35
	Aureola length / Aureola width	17.00	3.3	16.7	5.9
	Chela length / Carapace length	17.00	0.63	0.82	0.72
	Dactyl length / Chela length	17.00	0.61	0.70	0.65
	Palm width / Chela length	17.00	0.44	0.75	0.47

Prairie Crayfish, *Procambarus gracilis*: Measurements and Ratios: Form I Male

	Number	Minimum	Maximum	Mean
Total length	6	53.8	73.4	66.0
Carapace				
Total length	6	29.3	39.7	36.0
Postorbital length	6	25.0	34.9	31.3
Aureola				
Length	6	12.2	17.1	15.2
Width	6	0.0	1.0	0.3
Chela				
Total length	6	21.3	35.5	29.1
Dactyl length	6	13.3	21.4	18.0
Palm length	6	8.0	12.8	10.5
Palm width	6	10.1	14.6	12.6
Finger gap	6	0.0	2.7	1.5
Antenna				
Total length	6	31.5	49.0	39.8
Pleopod				
Total length	6	9.0	12.2	10.8

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	6	0.51	0.56	0.55
Aureola length / Carapace length	6	0.41	0.44	0.42
Chela length / Carapace length	6	0.67	0.89	0.80
Dactyl length / Chela length	6	0.60	0.65	0.62
Palm width / Chela length	6	0.40	0.48	0.44
Pleopod length / Carapace length	6	0.28	0.31	0.30

Prairie Crayfish, *Procambarus gracilis*: Measurements and Ratios: Form II Male

	Number	Minimum	Maximum	Mean
Total length	2	60.6	62.7	61.7
Carapace				
Total length	2	32.4	32.7	32.6
Postorbital length	2	27.6	28.2	27.9
Aureola				
Length	2	13.2	13.7	13.4
Width	2	0.4	0.4	0.4
Chela				
Total length	2	22.4	22.6	22.5
Dactyl length	1	15.1	15.1	15.1
Palm length	2	8.1	8.3	8.2
Palm width	2	10.0	10.4	10.2
Finger gap	1	1.0	1.0	1.0
Antenna				
Total length	1	37.3	37.3	37.3

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	2	0.52	0.53	0.53
Aureola length / Carapace length	2	0.41	0.42	0.41
Chela length / Carapace length	2	0.69	0.69	0.69
Dactyl length / Chela length	1	0.67	0.67	0.67
Palm width / Chela length	2	0.45	0.46	0.46
Pleopod length / Carapace length	2	0.27	0.29	0.28

Prairie Crayfish, *Procambarus gracilis*: Measurements and Ratios: Female

	Number	Minimum	Maximum	Mean
Total length	4	62.3	80.6	69.7
Carapace				
Total length	4	31.4	41.5	36.0
Postorbital length	4	27.5	36.7	31.3
Aureola				
Length	4	13.1	18.3	15.2
Width	4	0.0	0.3	0.1
Chela				
Total length	4	20.7	28.9	23.1
Dactyl length	4	12.8	15.1	15.1
Palm length	4	6.6	10.4	8.7
Palm width	4	8.9	12.7	10.3
Finger gap	4	0.0	1.9	0.8
Antenna				
Total length	2	32.5	48.0	40.3

Ratios	Number	Minimum	Maximum	Mean
Carapace length / Total length	4.00	0.50	0.53	0.52
Aureola length / Carapace length	4.00	0.41	0.44	0.42
Chela length / Carapace length	4.00	0.64	0.70	0.66
Dactyl length / Chela length	4.00	0.62	0.63	0.62
Palm width / Chela length	4.00	0.43	0.45	0.44

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GLOSSARY

ABDOMEN – the flexible 'tail' of the crayfish

ACUMEN – the pointy tip of the rostrum.

ANNULUS VENTRALIS – the blind pocket on the underside and between the hind legs of the female that is used to store sperm. Also known as "seminal receptacle".

ANTENNAE – the two long sensory filaments or 'feelers'.

ANTENNULES – the two pair of short sensory filaments between the antennae.

AUREOLA – the area on the top rear half of the thorax (the rear half of the carapace) that looks like a pair of curved grooves

AUTONOMY – where a crayfish sheds or self-amputates a limb. This can be a survival strategy to escape a predator or can happen during a molt.

CARAPACE – the hard covering of the head and thorax.

CENTRAL PROJECTION – one of the terminal elements of the first pleopod or gonopod of the male. In mature males, this is hardened and a yellow color.

CEPHALOTHORAX – see "carapace".

CERVICAL GROOVE – the angled groove wrapping around the carapace which marks the separation between the thorax and the head.

CHELA – the pincer or claw (plural = CHELAE). The chela consists of the base (palm) and fixed finger with a separate moveable finger (dactyl).

CHELIPED – the first periopod which has the chela, used in mating, defense and feeding.

DACTYL – the moveable finger of the chela.

EYE STALK – the moveable stalk that supports the compound eye.

FIXED FINGER – the finger on the chela that is fixed to the base or palm

FORM I – the mature, breeding form of the male; identified by the tips of the gonopod being hardened and yellowish color. In females, where the glair glands under the tail are visible, full and white.

FORM II – the immature, non-breeding form the male; identified by the tips of the gonopod being soft and white. In females, where the glair glands under the tail are not visible.

GILLS – located under the carapace on either side of the thorax.

GLAIR – the 'glue' that connects the eggs to the female's swimmerets. Glair is produced in glands under the tail which are visible and white color when mature.

GONOPOD –the first pleopod of the male crayfish that has been modified to transfer sperm to the female. See "pleopod".

GREEN GLANDS – the 'kidneys' of the crayfish which filter waste out of the blood as well as pump excess water via pores located at the base of the antennae.

HEAD – the front portion of the carapace.

MAXILLIPEDS – the "jaw-feet". The three pair of appendages at the mouth that shred food and feed it into the mouth and esophagus.

MEDIAN CARINA – "middle ridge"; the 'bump' in the center of the rostrum of certain crayfish species.

PALM – the base of the chela from which projects the fixed and moveable fingers (dactyl).

PERIOPOD – the first five pairs of legs. The first pair of periopods carries the chelae. The next two pair are dual purpose limbs which can be used as walking legs while the tiny pincers on the end are searching for and picking up food items. The fourth and fifth pairs are true walking legs.

PLEOPOD – one of the five paired appendages on the bottom of the abdomen (the 'tail'). The first pleopod is modified to transfer sperm to the female. The rear four pair are also known as swimmerets. see "gonopod".

ROSTRUM – the portion of the carapace that extends out over the eyes.

SEMINAL RECEPTACLE – see "annulus ventralis".

SETAE – the thin hairlike filaments between the fingers of the chelae or on the tip of the first pleopod of some crayfishes

SWIMMERETS – see "pleopod".

TAIL FAN – the flattened rearmost section of the crayfish's abdomen or 'tail' composed of the telson and uropods. Used to rapidly retreat from danger ("to crawfish").

TELSON – the center scale of the tail fan.

THORAX – the rear portion of the carapace.

UROPODS – the paired scales on either side of the telson which make up the tail fan.

IDENTIFICATION KEY TO NEBRASKA'S CRAYFISHES

1A. Carapace covered with small tubercles giving it the appearance and feel of coarse sandpaper

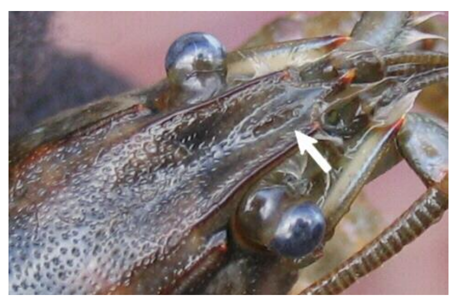
Go to 6

1B. Carapace relatively smooth with many small pits but few or no tubercles.

Go to 2

2A. Rostrum with median carina or "bump" in groove (see arrow)

Ringed crayfish, *Orconectes neglectus*



2B. Rostrum without median carina

Go to 3

3A. Rostrum short, blunt and curves down

Go to 4

3B. Rostrum does not curve down but is quite straight with terminal spine

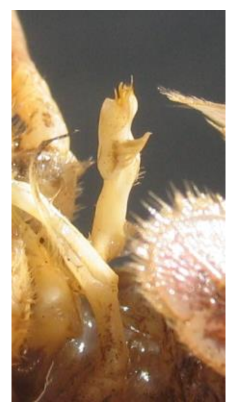
Go to 5

4A. Terminal elements of first pleopod with sharp curve and club shaped

Devil crawfish, *Cambarus diogenes*

4B. Terminal elements of first pleopod are a cluster of several small projections.

Grassland crayfish, *Procambarus gracilis*



5A. The two terminal elements of first pleopod of Form I male are long, gently curved and diverge from each other

Northern crayfish, *Orconectes virilis*

5B. The two terminal elements of first pleopod of Form I male are straight and parallel to each other

Rusty crayfish, *Orconectes rusticus*

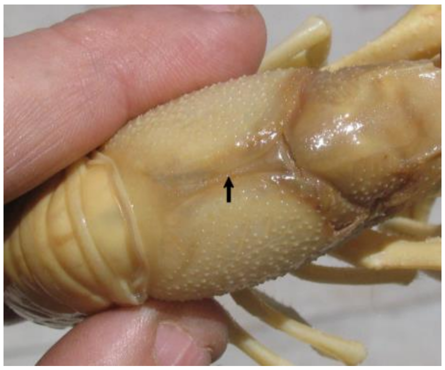
5C. The two terminal elements of first pleopod of Form I male are short and have 90 degree curve

Papershell crayfish, *Orconectes immunis*

6A. There is no gap between the curved edges of the aureola.

Red swamp crayfish, *Procambarus clarkii*

6B. There is a small gap between the curved edges of the aureola.



White River crayfish, *Procambarus acutus acutus*