NCRAC Technical Bulletins | North Central Regional Aquaculture Center

5-1997

Culture Potential of Selected Crayfishes in the North Central Region

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Abstract
The first topic that must be considered is the name. Crayfish is the term most often used in technical literature and the name used in this document. However, these same animals are also known as crawfish, crawdads, and mudbugs. Rest assured, regardless of the name, they all refer to the same broad category of animals. Specifically, they are freshwater decapod crustaceans, the freshwater equivalent of shrimp and lobsters. In most years, production of crayfish in the United States is the second largest aquacultural industry. This fact surprises most people in the North Central Region (NCR) because the availability of crayfish outside the traditional production area is minimal. Most of the crayfish are produced in the southern United States (Louisiana, Arkansas, Texas and Mississippi) and most of that production is consumed in the same area. Two species comprise the majority of production—the red swamp crayfish (Procambarus clarkii) and the white river crayfish (P. zonangulus). Crayfish culture in those areas is seasonal, available as a fresh product from November through June. Thus, the crayfish aquaculture industry is interesting because of it's size and the fact that it violates conventional wisdom in several ways.

Disciplines
Aquaculture and Fisheries | Zoology

Comments
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Culture Potential of Selected Crayfishes in the North Central Region

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Technical Bulletin Series #112

In cooperation with USDA's Cooperative State Research,
Education and Extension Service

USDA Grant #93-38500-8392
Purdue University 1993 Crossroads Initiative
May 1997

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Printed on Recycled Paper

Preface

In 1992, the Industry Advisory Committee of the USDA North Central Regional Aquaculture Center (NCRAC) asked for a research and extension project on native species of crayfish (Grant #92-38500-6916). This report represents completion of Objective 2 from that project, which was development of a report on indigenous species of crayfish.

There are many species of crayfish native to the region and this report does not include information on all of them. Most of the aquacultural information in the North Central Region has been developed for the orconectid crayfishes, certainly one of the dominant taxonomic groups. In the Southern portion of the region, there is geographic overlap with several of the southern species, particularly the procambarid crayfishes, which are the dominant culture species in the southern US. Our choice of species in this document is a reflection of the research that has been conducted within our individual programs. You will find a section at the end of each chapter that suggests needed research activities for each species; those lists are typically long. Research on culture of native species is a new topic with few published reports. Even with the sparse amount of information, we can conclude from this synopsis that crayfish culture is feasible, but can be significantly improved by additional research studies and extension activities.

The authors of the respective chapters are recognized experts in their field and the ones conducting a large portion of the research on native midwestern species. Additional references and sources of information can be found at the end of this document including detailed descriptions of native species and taxonomic keys for differentiating species. We hope this report will be useful to those seeking information on crayfish culture in the North Central Region.

Culture of Crayfish in the North Central Region

Paul Brown and Jeff Gunderson

Introduction

The first topic that must be considered is the name. Crayfish is the term most often used in technical literature and the name used in this document. However, these same animals are also known as crawfish, crawdads, and mudbugs. Rest assured, regardless of the name, they all refer to the same broad category of animals. Specifically, they are freshwater decapod crustaceans, the freshwater equivalent of shrimp and lobsters.

In most years, production of crayfish in the United States is the second largest aquacultural industry. This fact surprises most people in the North Central Region (NCR) because the availability of crayfish outside the traditional production area is minimal. Most of the crayfish are produced in the southern United States (Louisiana, Arkansas, Texas and Mississippi) and most of that production is consumed in the same area. Two species comprise the majority of production—the red swamp crayfish (*Procambarus clarkii*) and the white river crayfish (*P. zonangulus*). Crayfish culture in those areas is seasonal, available as a fresh product from November through June. Thus, the crayfish aquaculture industry is interesting because of it's size and the fact that it violates conventional wisdom in several ways.

Fish and shellfish wholesalers in the NCR consistently tell aquaculturists they want a product on a regular basis, preferably available each week. However, these same wholesalers are buying and distributing crayfish, a seasonal commodity. They overcame the seasonality problem by acquiring crayfish from the west coast (*Pacifastacus leniusculus*, the signal crayfish) during the nonproducing season in the South. Availability of the signal crayfish is offset from the red swamp and white river crayfish from the South. The same opportunity may exist for other aquaculture species in the NCR. This situation serves as an example of how initial comments from a wholesaler may be misleading to the new aquaculturist exploring market potential of new products.

Biology

Crayfish are ectothermic. That is, their body temperature is the same as the environmental temperature, the same as in fish. Thus, aquatic invertebrates respond to seasons, much the same way fish do, particularly in the temperate climate of the NCR. Reproduction is cued by seasonal changes (particularly temperature) and growth of juveniles tends to be during the period of maximum availability of food and optimum temperature. Most orconectid females expel eggs during late winter or early spring, and juveniles hatch a few weeks to a few months later. The juveniles hatch with an attached yolk sac and utilize that food source for the first few days. At first feeding, zooplankton seems to be an important food item. Zooplankton are also aquatic invertebrates and are responding to the same environmental cues as crayfish. Thus, zooplankton populations are also increasing during the same period juvenile crayfish are hatching and seeking their first food source. A similar situation exists in the southern US, but it occurs in October or November.

Procambarid crayfishes in the South expel eggs in late fall or early winter and the juveniles hatch and grow through the winter. This is in response to seasonal changes, also. Optimum temperature for crayfish, regardless of species, is generally thought to be in the range of 68-79° F (20-26° C). Fall and winter are the times when water temperatures are in that range in the South and spring is the time when water temperatures in the NCR reach the desired range.

Many years ago, a small population of red swamp crayfish from the South were transplanted to Lake Erie. Those crayfish survived and adapted to their new environment. They now reproduce in the spring; direct response to environmental cues. Procambarid crayfishes in the southern portion of the NCR seem to expel eggs throughout the year, probably in response to annual temperature variations. The chapter on *P. acutus* discusses this as a possible advantage.

The average monthly temperatures during the production period in Louisiana are not that different than summer temperatures in the NCR (Table 1). Therefore, the difference between northern and southern culture of crayfish is not as dramatic, climatically, as is the difference between raising catfish in the NCR and in the south. The primary difference is that crayfish farmers in Louisiana are able to raise a forage crop during the non-producing season, which is not possible in the NCR. Just because average temperatures are similar between the NCR and Louisiana does not necessarily mean that NCR crayfish farmers will be as successful as Louisiana producers. Our species generally grow slower and are less fecund than the red swamp crayfish, but at least it does not appear that the NCR climate should necessarily be a limiting factor.

Crayfish adhere to many basic biological principles. One of the more interesting, and one discussed by the authors of the respective chapters, is symmetry. Each of the authors presented a length-weight mathematical relationship for their respective species. Thus, given some length or weight of a crayfish you can calculate the other factor. This becomes important in size grading. The cephalothorax, or carapace, of the crayfish is essentially the front end of the animal, from the junction with the tail (abdomen) to the tip of the rostrum, which is between the eyes. A common physical relationship among crayfish is that the length of the carapace is approximately 50% of total length. Several of the authors discuss their respective crayfish in terms of length of carapace, so simply double that number for total length.

Another important crayfish term is Form. Orconectid crayfishes in wild settings are thought to molt only twice per year, once in the

Table 1. Comparison of growing season temperatures for two locations in Louisiana and the North Central Region*.

	Average monthly temperatures (Degrees F)							
	April	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Ave**
Indianapolis	47.5	56.9	65.8	69.5	67.3	60.6	49.7	59.6
Minneapolis	42.6	54.6	63.8	68.8	66.5	57.0	46.3	57.1
	Nov	**Dec**	**Jan**	**Feb**	**March**	**April**	**May**	**Ave**
Baton Rouge	54.5	49.4	47.6	50.2	56.2	62.7	69.1	55.7
New Orleans	57.0	51.3	48.4	50.9	57.2	63.7	69.8	56.9

* Data from the National Weather Service

spring and once in the fall. After the spring molt, male crayfish are considered Form II, or sexually inactive. After the fall molt, they are considered Form I, or sexually active. The difference is subtle to most people, but important to crayfish. According to Hobbs and Jass (1988), cited in Additional Reading section, the Form I male has "well developed hooks on the ischiopodites of one or more of the third and fourth periopods and often bosses from the bases of the coxopodites of the fourth and / or fifth periopods". This means that the male crayfish has hooks on the third and / or fourth walking legs and often expanded segments on the fourth and / or fifth walking legs near where the leg is attached to the thorax. The simplest method of determining Form of your crayfish is the hooks on the legs. They are distinctive. Form is important because a Form II male is not ready to reproduce, while a Form I male is ready.

One of the more common questions we receive is "If we know how to grow red swamp crayfish from the South and that is an acceptable product in the market, then why are we not transplanting southern crayfish to the NCR for culture?"

Legalities

Movement of animals outside their native ranges can exert three possible effects on native populations; good, bad or indifferent. Predicting effects of introduced organisms is difficult, and some people would argue it is impossible. We have numerous examples of relocating animals outside their native ranges and those transplants reeking havoc with native animals. Thus, movement of animals is generally discouraged and several states in the NCR have specifically outlawed movement of crayfish into their state. The restrictions on movement of crayfish across state boundaries is a direct response to displacement of native species by introduced crayfish. Some states even declared some of their native species illegal for culture. Check with your state extension contact for laws pertinent to your area.

Perhaps more importantly, each state in the NCR has native populations of crayfish that attain "jumbo" size. Size grading is a relatively new concept in the crayfish aquacultural industry, but jumbo generally refers to crayfish over 15 crayfish per pound (30 g) or over 3.5 inches (9.0 cm) measured from head to tail, not including the chelae or claws. The native species that attain jumbo size are generally considered safe for culture by the respective regulatory agencies. Thus, with native populations that reach marketable sizes, we have to turn the question around and ask why not grow native species that are already adapted to your growing conditions?

Economics

The economic viability of tail meat production from species native to the NCR is another common question, but one that is difficult to answer. The price of the final product is greatly dependent on three primary factors; initial cost of the crayfish, percent meat yield of the crayfish, and size of the crayfish. The simple break even cost of producing crayfish tail meat can range from $3.44 / lb to $10.16 / lb depending on these variables (Table 2). Processor and retailer mark-up would significantly increase the price of the final product. Consumer willingness to pay will ultimately dictate whether peeled crayfish tail meat can be successfully marketed in the NCR. The Rough-Cut Economic Analysis presented in Table 2 was designed to demonstrate the large variation in the cost of the final product that must be considered when contemplating tail meat production. Another consideration is that increasing amounts of crayfish tail meat are being imported from China at prices that even the established Louisiana crayfish industry has difficulty competing with. Because crayfish production is low and price for live crayfish is high, crayfish tail meat production from NCR crayfish does not appear to be a viable option.

Table 2. Rough-cut economic analysis of production of crayfish tail meat in the North Central Region.

Cost of live crayfish	**$0.50/lb**						**$1.00/lb**					
Percent meat yield	**12%**		**16%**		**20%**		**12%**		**16%**		**20%**	
Pounds of crayfish needed for one pound of peeled meat	8.33		6.25		5.00		8.33		6.25		5.00	
Cost of tail meat Based on yield only	**$4.17**		**$3.13**		**$2.50**		**$8.33**		**$6.25**		**$5.00**	
Size of crayfish	**25/lb**	**35/lb**	**25/lb**	**35/lb**	**25/lb**	**35/lb**	**25/lb**	**35/lb**	**25/lb**	**35/lb**	**25/lb**	**35/lb**
Number of crayfish needed for one pound of peeled meat	208	292	156	219	125	175	208	292	156	219	125	175
Labor costs[1]	$1.11	$1.55	$0.83	$1.16	$0.66	$0.93	$1.11	$1.55	$0.83	$1.16	$0.66	$0.93
Processing costs[1]	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28	$0.28
Break even cost[2]	**$5.56**	**$6.00**	**$4.24**	**$4.57**	**$3.44**	**$3.71**	**$9.72**	**$10.16**	**$7.36**	**$7.69**	**$5.94**	**$6.21**

[1] Labor was determined using an estimate that Louisiana crayfish peelers can produce six pounds of meat per hour. A salary of $6.00/hr means that it costs $1.00/lb of meat. It was assumed that laborers can peel large crayfish as quickly as small crayfish. Peeler size crayfish in Louisiana are 24 to 35 per pound. Thirty crayfish per pound and 16% yield was used as the average. Labor costs for other sized crayfish and yields were adjusted accordingly. The processing cost is the cost to cook the crayfish prior to hand peeling.

[2] This is not a true break even cost because many of the business expenses, equipment depreciation costs, etc. are not included.

Crawfish boil

Crayfish, as a human food source, also violates conventional wisdom. The most common method of consuming crayfish is to boil them with potatoes, carrots, garlic, onions (and any other vegetable you desire), lots of salt and red pepper, and serve them from a strainer in front of the consumer directly on paper placed on the table. No plates or silverware, but plenty of napkins and cold beverages. The vegetables will retain the hot pepper, so be careful, but the crayfish tail meat is protected by the external shell and is not as spicy. Crayfish tail meat is then acquired by the consumer by breaking the crayfish into two pieces and peeling the meat from the tail section, much like peeling shrimp or cracking lobsters or crabs. Dressout percentage (the percentage of meat relative to the total weight of the animal) is lower than in shrimp or lobsters, so it takes a little while to consume a sufficient quantity to constitute a meal. This is not a sit-down meal. It is an event, more like a picnic. As more people from the NCR visit the southern US during the crayfish production season, they are finding that they enjoy the camaraderie and novelty of a true “crawfish boil”. Crayfish have also found their way into numerous sit-down types of recipes. Tail meat from crayfish substitutes for shrimp tail meat nicely and the Creole chefs in Louisiana have developed several recipes specifically for crayfish (for example, etouffe). The availability of crayfish is increasing in the NCR; live crayfish are available in at least three grocery stores in Lafayette, Indiana.

The basic argument for culture of crayfish in the NCR is that we have the opportunity to fill a market niche in the second largest aquacultural industry in the United States with a native species. Further, there will not be competition from the traditional suppliers. The fundamental problem in taking advantage of this opportunity is that we have very little information on culturing our native species. The goal of this document was to summarize the available data on selected native species of crayfish and their culture potential.

Papershell Crayfish, *Orconectes immunis*

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Introduction

Orconectes immunis are widely dispersed throughout the North Central Region of the United States. Hobbs and Jass (1988) describe the range as extending from Colorado and Wyoming in the west to the New England states in the east. *O. immunis* are found north to Ontario and Manitoba, Canada, and south to Mississippi and Alabama. They primarily inhabit ponds, backwaters, and slow moving streams. They can tolerate lower dissolved oxygen levels than other species (Bovbjerg 1970) and can sometimes be found in temporary pools. They have been known to walk considerable distances overland (Crocker and Barr 1968), then burrow when ponds dry or with the approach of autumn (Gunderson and Kapuscinski 1992). In many permanent waters, the papershell crayfish does not burrow (Hobbs and Jass 1988). They are frequently found in muddy, soft-bottomed lakes which support vegetation (Tack 1941). *O. immunis* can become locally abundant in some human-modified environments such as wild rice paddies and fish production ponds.

Bovbjerg (1970) demonstrated that *O. immunis* prefer rocky bottomed habitat, but are competitively displaced to soft-bottomed habitat by *Orconectes virilis*. Caldwell and Bovbjerg (1960) indicated that *O. virilis* in Iowa eliminates *O. immunis* from rivers and streams and restricts them to temporary or permanent ponds. Since *O. virilis* are usually displaced by *O. propinquus* and *O. rusticus* (Capelli 1982; Capelli and Munjal 1982; Olsen et al. 1991), it is likely that in permanent lakes or streams with good water quality *O. immunis* would also be displaced by invading populations of these other orconectid species.

Aquaculture

O. immunis are generally smaller than the other orconectid species considered for commercial production and are thought of primarily as a bait species, although there may be some exceptions (Gunderson and Kapuscinski 1992; Huner 1994). Wetzel and Brown (1993) found that third instar *O. immunis* were larger than *O. virilis* and they gained weight more rapidly through the first 21 days. Hobbs and Jass (1988) reported that *O. immunis* reach maturity at a length of 0.6-0.9 inches (16-23 mm) carapace length (CL). The mean and maximum size of *O. immunis* in their collections was about 1.2 and 1.9 inches (30 and 48 mm) CL, respectively.

Size and growth

Cultured Louisiana crayfish are frequently harvested at a size of 30 per pound (15.1 gm each) (Seafood Leader 1989). This translates to a size of about 1.5 inches (38 mm) CL. Crayfish grown at low density in central Minnesota grew to 1.3 inches (34 mm) CL in one growing season and approached a food market size. The following year, however, when densities were much higher, crayfish only grew to 1.1 inches (28 mm) CL or 62 per pound (7.3 gm each) (Gunderson and Kapuscinski 1992). These were still larger than *O. immunis* reported in other studies. Crayfish from the four New York ponds described by Tack (1941) averaged smaller than 230 per pound (1.9 gm each). *O. immunis* from a Michigan pond (Lydell, 1938) were nearly as small, averaging 195 per pound (2.3 gm each) over three years, and *O. immunis* from a study in New York (Forney, 1957) ranged from 99 to 253 per pound (4.6 to 1.8 gm each). It appears that *O. immunis* is not likely to obtain food size in one growing season, at least not in the northern parts of its range and at commercially viable densities. They can, however, be used for fish bait as young-of-the-year, and may reach food size by the end of their second year of growth.

Yields

The harvest of crayfish from Louisiana ponds averaged 506 pounds per acre in 1990 (Lorio et al. 1991). The harvest potential of *O. immunis* in the northern US seems good by comparison. New York ponds studied by Tack (1941) and Forney (1957) produced only 46 to 352 lbs per acre, but the crayfish in these ponds may have been harvested only at the end of the season when the ponds were drained. This may have resulted in an estimate of standing stock rather than true seasonal harvest potential. Harvest of crayfish throughout the growing season would result in total pound per acre production which would be greater than a one-time end of season harvest. Not only would fishing mortality replace some natural mortality, but thinning the population throughout the growing season would increase food resources (and growth) for remaining crayfish. *O. immunis* harvested throughout the summer in a Michigan pond produced 689 to 810 pounds per acre, over three years (Lydell, 1938). The harvest potential from Minnesota wild rice paddies was estimated at 562 to 675 pounds per acre (Gunderson and Kapuscinski, 1992).

Fecundity

O. immunis usually carry from 30 to 300 eggs (Forney 1957). Crayfish from Minnesota wild rice paddies carried from 50 to 500 eggs and averaged 290 eggs per female (Gunderson and Kapuscinski 1992).

Dressout

McDonald et al. (1992) found that *O. immunis* had higher tailmeat yield than *O. propinquus* or *O. virilis*. Tailmeat yield for *O. immunis* averaged 19.8% for females (range of 15-26.7%) and 18.4% for males (range of 14.7-22.6%). They also showed that percent tailmeat yield decreased as crayfish size increased. Small *O. immunis* (CL = 0.6-1.0 inches or 15-25 mm) generally had tailmeat yields of 24-27%, while larger *O. immunis* (CL = 1.2-1.6 inches or 30-40 mm) had yields of 16-23%.

Physical relationships

Average length of crayfish from wild rice paddies can be converted to weight by using the following relationships for males and females, respectively:

$Wt = 9.44 \times Lt - 19.95$; and,

$Wt = 7.73 \times Lt - 14.34$

with weight (Wt) in grams and length (Lt, measured as carapace length) in cm (Frank Kutka, personal comm.).

Soft shell

Soft shell crayfish are an important fishing bait in some areas of the NCR. Crayfish must shed their hard exoskeleton, or molt, to grow . Immediately after crayfish molt, the new exoskeleton is soft permitting an increase in body size and volume. Until the new exoskeleton hardens, they are called soft shell crayfish. *O. immunis* were selected by McDonald et al. (1992) as the species with the greatest soft shell culture potential because they molted well in the lab, were readily available, and were tolerant of a wider range of water quality than the other orconectid species examined. Adapting the methods for soft shell crayfish production developed in Louisiana (Culley and Duobinis-Gray 1990; Malone and Burden 1988), McDonald et al. (1992) examined four orconectid species *(O. immunis, O. propinquus, O. virilis* and *O. rusticus*) to assess commercial soft shell production potential. The orconectid crayfish studied tended to have synchronous molts in the wild. McDonald et al.

(1992) showed that by bringing large numbers of crayfish into a culture facility just prior to this molting period, they could produce soft crayfish in a reasonable period of time, resulting in an economically viable operation.

Crayfish can also be induced to molt by eyestalk ablation, limb removal, or hormone injection (Aikin and Waddy 1987). Following the techniques for eyestalk ablation developed by Chen et al. (1993) for commercial production of soft shell *P. clarkii*, Richards et al. (1995) examined the molting and mortality of three orconectid species subjected to eyestalk ablation. Results of molting trials incorporated into an economic assessment showed that commercial soft shell crayfish production using eyestalk ablation could be economically viable for *O. immunis, O. virilis,* and *O. rusticus.*

Culture systems

Two production systems for *O. immunis* are described below. The first, is a small pond production described by Forney (1957) and Nolfi (1980). The second is production in wild rice paddies (Gunderson and Kapuscinski 1992; Richards et al. 1995).

Ponds

Forney indicated that *O. immunis* have been raised in ponds ranging in size from 1/30th to 5 acres (0.015 to 2.27 hectares). He suggested ponds under 1/2 acre (0.23 hectares) are easier to manage and seine. Depth of the ponds in New York was typically 6 to 10 feet (1.8 to 3.1 meters) to allow overwinter survival, but ponds of only 2 ft (0.34 m) produced excellent crops. Ponds should be stocked in the fall with 600 to 1000 mature crayfish per acre or in the spring with 300 to 500 berried (egg carrying) females per acre. Young crayfish reach bait size by July and are removed by seining. Fertilization of ponds is recommended to improve growth and survival.

Minnows can be raised together with the crayfish, but they are injured and suffer high mortality when seined together with the crayfish. Crayfish are generally considered a nuisance in bait fish ponds. Game fish and pan fish, if present, significantly reduce crayfish yields.

Rice paddies

Behavior of *O. immunis* in Minnesota's wild rice paddies is similar to the behavior of *P. clarkii*, which annually accounts for a commercial harvest of around 100 million pounds (45.4 million kilograms) from aquaculture and wild harvest in Louisiana each year. Both species burrow to escape harsh environmental conditions. In Louisiana, red swamp crayfish burrow when water quality declines due to summer's heat, whereas *O. immunis* in wild rice paddies burrow in late summer to escape declining water levels and the onset of winter.

O. immunis have been observed burrowing from the beginning of July until freeze-up. The majority of mature crayfish appear to burrow during the last two weeks of August even though water quality and level were maintained (Gunderson and Kapuscinski 1992). Essentially, mature crayfish become unavailable after September 1. Young-of-the-year crayfish seem to delay burrowing longer than adults and can frequently be found through the month of September, concentrated in paddy ditches that have not completely dried and in water supply ditches.

Crayfish emerge from burrows shortly after paddies are flooded each spring. Mature females appear to emerge from the burrow in berry (carrying fertilized eggs), but some do not lay their eggs until sometime after emergence. Crayfish trappers in natural lakes indicate that berried females of other orconectid species do not readily enter traps (Capelli 1975; McDonald et al. 1992; Threinen 1958). *O. immunis* berried females do, however, appear to trap as well as males (Richards et al. 1995).

Eggs hatch in late May. Juveniles remain with the female for two to three molts after the eggs hatch and usually leave the female by the end of May. Females undergo a molt following the dispersal of their young. It is thought that many of the larger, older females die during this molt, because they are not taken in traps after about the first of June. Young-of-the-year crayfish seem to grow at different rates depending on food availability, their own density and the size of the adult population.

Crayfish typically retreat during the day to the deeper water (3 to 6 feet or 0.9 to 1.8 meters) of the ditches that ring the paddies and forage in the shallower water (6 to 18 inches or 15.2 to 45.7 centimeters) of the paddy at night (Richards et al. 1995). Therefore, crayfish can be trapped or seined from the ditches and there is no need to attempt harvest from the whole paddy. Intensive trapping proved not to be an effective method for rapid crayfish removal. Catch rates increased or remained stable through the summer rather than declining as seen in studies with *O. virilis* (Brown et al. 1989) and *O. nais* (Klaassen unpublished data). Water temperature and molting cycles appear to be important determinants in crayfish trapping success. Seining may be a better option for crayfish harvest from wild rice paddies; however, modification of ditches, such as vegetation control, may be needed to allow effective seining.

Enclosure studies (McDonald et al. 1993) demonstrated that crayfish have strong negative impacts on paddy wild rice survival prior to the stage when the wild rice becomes aerial. After wild rice becomes aerial, however, *O. immunis* does not appear to affect rice production. Production strategies for polyculture of paddy wild rice and crayfish must incorporate this relationship. One approach is to stock berried females in the spring. Young-of-the-year *O. immunis* do not affect wild rice; therefore, crops of both crayfish and wild rice are possible. Significant carryover of crayfish to the next spring could negatively impact rice production the following year.

Wild rice paddies offer a potential production system for *O. immunis*, either alone or in polyculture with wild rice. Should *O. immunis* culture and marketing prove feasible, the approximately 25,000 acres (1,136 hectares) of wild rice paddies in Minnesota offer the potential for quick development of commercial scale production.

A study of the bait industry in the NCR estimated that approximately 42,000 dozen crayfish were sold in the region (Meronek 1994). The survey also found that bait dealers in many states reported shortages of crayfish throughout the season. Advances in the culture of both hard and soft shell crayfish would help meet this existing market demand.

Critical information gaps — *Orconectes immunis*

1. An examination of the factors that determine second year growth of *O. immunis* to determine if they can reach food market size by the end of the second growing season. It is frequently assumed that orconectid crayfish only molt once (females) or twice (males) per year after they reach maturity, but immature crayfish entering their second growing season might molt more frequently and eventually surpass crayfish that matured during their first year. Growth of young-of-the-year crayfish could be controlled by food availability, stocking density or water level manipulation to produce only immature crayfish during the first growing season.
2. Economic assessment of growing *O. immunis* for two seasons to attain food market size.
3. Assessment of the use of supplemental feeding to increase growth and / or production.

4. Examination of the genetic differences in stocks of *O. immunis* throughout the region to determine the most suitable choices for aquaculture production.

Literature cited

Aiken, D.E. and S.L. Waddy. 1987. Molting and growth in crayfish: a review. Canadian Technical Report in Fisheries and Aquatic Sciences 1587:1-34.

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

Brown, P.B., M.L. Hooe, and D.H. Buck. 1989. Preliminary evaluation of baits and traps for harvesting orconectid crayfish from earthen ponds. Journal of the World Aquaculture Society 20:208-213.

Caldwell, M.J. and R.V. Bovbjerg. 1969 Natural history of the two crayfish of northwestern Iowa, *Orconectes virilis* and *Orconectes immunis*. Proceedings of the Iowa Academy of Sciences 76:463-472.

Capelli, G.M. 1975. Distribution, life history, and ecology of crayfish in northern Wisconsin, with emphasis on *Orconectes propinquus*. Ph.D. Dissertation, University of Wisconsin-Madison, 215 pp.

Capelli, G.M. 1982. Displacement of northern Wisconsin crayfish by *Orconectes rusticus*. Limnology and Oceanography 27:741-745.

Capelli, G.M., and B.J. Munjal. 1982. Aggressive interactions and resource competition in relation to species displacement among crayfish of the genus *Orconectes*. Journal of Crustacean Biology 2: 486-492.

Chen, S., J.V Huner, and R.F Malone. 1992. Molting and mortality of red swamp and white river crawfish subject to eyestalk ablation: A preliminary study for commercial soft-shell production. Journal of the World Aquaculture Society 24:48-57.

Creaser, E.P. 1932. The decapod crustaceans of Wisconsin. Transactions of the Wisconsin Academy of Science, Arts, and Letters 27:321-338.

Crocker, D.W. and D.W. Bar. 1968. Handbook of the crayfishes of Ontario. University of Ontario Press, Toronto, 158 pp.

Culley, D.D., and L. Duobinis-Gray. 1990. Culture of the Louisiana soft crawfish: a production manual. Louisiana Sea Grant College Program, Baton Rouge, Louisiana.

Forney, J.L. 1957. Raising bait fish and crayfish in New York ponds. Cornell Extension Bulletin 986:3-30.

Goellner, K.E. 1943. The life cycle and productivity of the crayfish *Cambarus immunis*. Ph.D. Dissertation, University of Michigan, Ann Arbor, 160 pp.

Gunderson, J. L. and A. Kapuscinski. 1992. Crayfish Aquaculture Demonstration in Minnesota Rice Paddies. Legislative Commission on Minnesota Resources Report, 4 pp.

Helgen, J.C. 1987. The distribution of crayfishes (Decopoda, Cambaridae) in Minnesota. Report the Nongame Wildlife Program of the Minnesota Department of Natural Resources, 128 pp.

Hobbs, H.H., and J.P. Jass. 1988. The crayfishes and shrimp of Wisconsin. Milwaukee Public Museum, Milwaukee, Wisconsin, 177 pp.

Huner, J.V. 1990. Biology, fisheries, and cultivation of freshwater crawfishes in the U.S. Reviews in Aquatic Sciences 2:229-254.

Huner, J.V., and J.E. Barr. 1991. Red Swamp Crawfish: Biology and Exploitation. Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, Louisiana, 128 pp.

Huner, J.V. Ed. 1994. Freshwater crayfish aquaculture in North America, Europe and Australia. Haworth Press, Binghampton, New York, 312 pp.

Lorio, W., J. Avery, and G. Lutz. 1992. Louisiana aquaculture as of 1990. Aquaculture Fact sheet, Louisiana Cooperative Extension Service, Baton Rouge, Louisiana, 2 pp.

Lydell, Claude. 1938. Crayfish affects fish production. Progressive Fish-Culturist 41:22-23

Malone, R.F., and D. Burden. 1988. Design manual for intensive softshell crawfish production. Louisiana Sea Grant College Program, Louisiana State University, Baton Rouge, Louisiana.

Maronek, T.G. 1994. Status of the bait industry in the north central region of the United States. M.S. Thesis. University of Wisconsin-Stevens Point, Stevens Point, Wisconsin, 250 pp.

McDonald, M., P. DeVore, C. Richards, J. Skurla, J. Gunderson. 1992. Economic and Technologic Development for the Crayfish Industry in Minnesota: Final Report. Natural Resources Research Institute, Technical Report NRRI / TR-92 / 15, 74 pp.

McDonald, M., C. Richards, and J. Gunderson. 1993 Crayfish in Minnesota wild rice paddies. *in*: Minnesota Wild Rice Research 1992, Miscellaneous Publication 78-1993, Minnesota Agricultural Experiment Station, pp 67-76.

Nolfi, J.R. 1980. Commercial aquaculture systems for crawfish in the northeastern United States. Proceedings of the World Mariculture Society 11:151-162.

Olsen, T.M., D.M. Lodge, G.M. Capelli, and R.J. Houolihan. 1991. Mechanisms of impact of an introduced crayfish *Orconectes rusticus* on littoral congeners, snails, and macrophytes. Canadian Journal of Fisheries and Aquatic Sciences 48:1853-1861.

Richards, C., J. Gunderson, P. Tucker and M. McDonald. 1995. Crayfish and baitfish culture in wild rice paddies. Technical Report No. NRRI / TR-95 / 39. 35 pp.

St. John, F.L. 1982. Crayfish and bivalve distribution in a valley in southwestern Ohio. Ohio Journal of Science 82:242-246.

Stein, R.A. 1975. Selective predation, optimal foraging, and resource depression within the predator-prey interaction between fish and crayfish. Ph.D Dissertation, University of Wisconsin-Madison, 196 pp.

Tack, P.I. 1941. The life history and ecology of the crayfish *Cambarus immunis.* American Midland Naturalist 25:420-446.

Threinen, C.W. 1958. A summary of observations on the commercial harvest of crayfish in northwestern Wisconsin, with notes on the life history of *Orconectes virilis.* Wisconsin Conservation Department, Fish Management Division, Miscellaneous Report, 2:1-15.

The Kansas pond crayfish, *Orconectes nais* (Faxon)

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Introduction

Williams and Leonard (1952) describe *Orconectes nais* as follows. The color is green to dull rusty reddish brown dorsally. The chelae are green, blue or bluish green dorsally with scattered bright yellow to orange tubercles especially on cutting edges of fingers. The immovable finger of chelae are bearded within near base. The areola width is very narrow with the lines almost touching at the narrowest point. The gonopods of a Form I male end in two elongated processes, both processes gently curved caudad at tips to angle considerable less than 90^0. Both processes are bladelike at the tips. The third ischius of males have hooks.

Additional characteristics given by Hobbs (1972) help in distinguishing this species from similar species. The chelae are broad with dactyl less than three times the length of the mesial margin of the palm. On the first gonopods of a Form I male the central projection is less than ⅓ of the total length of the appendages.

Morphologically, *Orconectes nais* is very similar to *O. virilis.* According to Hobbs (1972) the main characteristic separating these two species is the relative length of the central projection of the Form I male gonopod. In *O. nais*, it is less than ⅓ the total length and in *O. virilis* it is over ⅓ the total length. Of those examined in Kansas (Klaassen, unpublished data), only about 75% were less than ⅓ the total length. Hobbs (1972) also states that the relationship between these two specimens is far from clear. Page (1985) states that even though these two species are very similar morphologically, they are distinct serologically. These two species have overlapping ranges so subspecies status may be possible

The range of occurrence of *Orconectes nais* is primarily the central part of the United States. The range is not clear cut and presumably overlaps with *O. virilis.* Williams and Leonard (1952) show the range to extend from northern Texas and Arkansas northward through all of Oklahoma, Kansas, Missouri, Nebraska, Iowa, South Dakota, North Dakota, and part of Minnesota to the Canadian border. Hobbs (1972) states that *O. nais* is found in Kansas and Texas eastward to Arkansas, but the range is not clearly defined since it is often confused with *O. virilis.* Pflieger (1987) does not recognize *O. nais* as occurring in Missouri. Page (1985) states that *O. nais* occurs in Missouri and may extend to Illinois. Both Page (1985) and Hobbs and Jass (1988) show *O. virilis* extending over much of Kansas confirming the confusion of the distribution.

The species is definitely the common large species of crayfish throughout Kansas. Klaassen (unpublished data) examined large crayfish from numerous farm ponds, private aquaculture ponds, and state fish hatchery ponds and they all appear to be the same species that Williams and Leonard (1952) and Hobbs (1972) call *Orconectes nais.*

O. nais is found in a range of aquatic areas. It is found in both slowly moving to swiftly moving streams. It is also found in ponds and ditches which are free of vegetation and also choked with vegetation (Williams and Leonard 1952).

O. nais is not a primary burrowing species, but lives in open water and under rocks. At times it will make shallow burrows under grass tussocks at the edge of the water and in muddy or clayey banks (Williams and Leonard 1952).

Aquaculture

Reproduction

The typical reproductive pattern for *O. nais* is to lay eggs during the spring. The earliest that Jackson (1973) found egg carrying females in Kansas was February, but he found most egg carrying to be from late April through May. Money (1988) conducted an extensive reproductive study on *O. nais* in Kansas. He found that the gonodosomatic index (GSI) in females began to increase in August and kept increasing through fall and into winter, and peaked in February. It dropped rapidly during March and April indicating egg laying. The GSI reached a very low level by the end of April implying that most of the egg laying was complete. Money (1988) found that the percentages of females bearing eggs were 0% in February, 24% in March, 81% in April, and 8% in May.

The male reproductive readiness corresponds to the developing female. Jackson (1973) found in Kansas that all males over 0.9 inches (23 mm) carapace length (CL) were Form I during October and a high percentage were Form I the following spring. Money (1988) found that the young-of-the-year (YOY) males in Kansas began to turn into Form I toward end of August and by late September 96% were Form I. The following year the number of Form I started to decrease in March and was down to 4% in April. He also found that by mid summer, 60-72% of these adults were again Form I. Money (1988) determined the GSI of the maturing YOY males. He noted that the GSI increased rapidly in mid summer and reached a peak by the beginning of September, then remained at a high level during winter and dropped off in March and April. This pattern was determined only with the testes and not the vas deferens. If the latter had been included, the GSI pattern may have been more similar to the females.

Fecundity

The fecundity of *O. nais* has been determined. Jackson (1973) determined that the number of eggs carried and carapace length were curvilinear. The equation describing this was

$$\text{Log } N = -0.06 + 1.42 \text{ Log } CL \text{ (mm)},$$

where N equals the number of eggs and CL equals carapace length in mm. This amounted to about 60 to 250 eggs for females with a CL of 0.8-2.0 inches (20 to 50 mm), respectively. Money (1988) found that fecundity and CL to be a straight line relationship of

$$N = -434.9 + 20.663 \text{ CL (mm)}.$$

This amounted to 67 to 671 eggs carried by females of 0.9-2.0 inches (22 to 52 mm) CL, respectively.

The length of the incubation period is a function of temperature. Money (1988) determined hatching time at different temperatures in the laboratory. At 46° F (8° C), none hatched, at 54° F (12° C), the eggs hatched in 62 days, and at 61° F (16° C), the eggs hatched in 34 days. So depending on when in the spring the eggs are laid, hatching time can be expected to be between 1 and 2 months.

The age to maturity is variable for *O. nais*. Momot (1966) reported that *O. nais* in Oklahoma generally lived for two years and reproduced during the second spring. At Lawrence, Kansas, Armitage et al. (1972) determined that this species did not reproduce until the third spring at 22 to 24 months of age. Jackson (1973) who also worked in the Lawrence, Kansas area observed rather slow growth in his crayfish, therefore many did reach a size large enough to reproduce the second spring. The smallest Form I male he observed was 0.8 inches (19 mm) CL and the smallest female carrying eggs was also 0.8 inches (20 mm) CL. Based on the observations in Kansas by Money (1988) and Klaassen (unpublished data), if the YOY *O. nais* would grow fast enough during the first summer to get beyond the minimum maturity size of about 0.8 inches (20 mm) CL, and especially greater than 1.2 inches (30 mm) CL, they would reproduce the following spring. Slower growing populations would not mature that first winter but wait until the next year.

Physical relationships

The length-weight relationship of *O. nais* was determined by Jackson (1973) to be

$$\text{Log W} = -4.36 + 3.50 \text{ Log L.}$$

Ingelin (1984) determined the length and weight relationship to be

$$\text{Log W} = -4.149 + 3.372 \text{ Log L.}$$

In both cases W is wet weight in grams and L is the carapace length in mm.

Growth

One of the primary factors affecting crayfish growth is the population density in relation to the food supply. Populations that are relatively dense exhibit slow growth and tend to stunt. Ingelin (1984) followed the growth of YOY *O. nais* in two farm ponds, one with a moderate density and one with a very high density. Both populations grew at similar rates until August when the high density crayfish leveled off for the year at about 0.8 inches (20 mm) CL. The moderate density crayfish kept on growing and reached an average of about 1.2 inches (30 mm) CL by fall. The high density pond peaked with a crayfish density of 4.2 / ft^2 (45 / m^2) over the whole pond while the moderate density pond peaked at 0.7 / ft^2 (7.5 / m^2). The maximum biomass standing crop in the high density pond reached 1052 pounds / acre (1180 kg / ha).

Klaassen (unpublished data) attempted to manipulate the growth of *O. nais* through heavy density reduction with trapping and seining. Four Kansas farm ponds were used in this study and it was conducted for three years. The total amount of crayfish harvested per year from each pond ranged from 119 to 942 pounds / acre (134 to 1,056 kg / ha). The individual growth rate during this study was rapid. The YOY grew rapidly during their first summer typically reaching 1.2 inches (30 mm) CL or 67 / lb (30 / kg). The following spring they would go through a growth spurt and usually top out in June at about 1.6-1.8 inches (40-45 mm) CL or 25-17 / lb (11-7 / kg). These adults generally would not grow any more during the summer.

World record

The largest *O. nais* observed by Jackson (1973) was 2.4 inches (60 mm) CL. The largest observed by Klaassen (unpublished data) was 2.5 inches (63 mm) CL. According to the length-weight relationship, this crayfish should have weighed almost 3 oz or 5.5 / lb (83 grams).

Oxygen tolerance

Ingelin (1984) found that the summer distribution of *O. nais* in farm ponds was greatly affected by the dissolved oxygen content of the bottom water. He found that crayfish avoided areas with oxygen content of less than 2 mg / L. This generally limited their summer distribution to water that was less than 3 ft (1 m) deep.

Winter survival is an important problem in crayfish culture. Kichler (1987) evaluated simulated winter conditions with *O. nais*. He showed that at 39° F (4° C) and 0.04 mg / L dissolved oxygen over 50% of the crayfish survived for 3 days and almost none survived for 12 days.

Dressout percentage

Klaassen (unpublished data) determined the tail meat dressout for *O. nais*. The percentage of tail meat recovered from cooked crayfish ranged from 13 to 16%. The higher amount coming from small individuals and females and the lower amount from mature males.

The nutrient composition of *O. nais* tail meat was also determined. On a dry matter basis, raw meat contained 0.417% fat and 100.3% crude protein, while cooked meat contained 0.54% fat and 101.9% crude protein. Crayfish meat is obviously low in fat and very high in protein.

Critical information gaps — *Orconectes nais*

1. Winter survival: over winter mortality often is a major problem. Information is needed on what are the critical conditions and how they can be improved.
2. Egg survival: many of the early eggs carried by the females have been observed to be dead. This reduces the early part of the reproduction which is necessary for a longer growth period.
3. Growth manipulation: more information is needed on how to speed up or slow down growth so bait size individuals can be available at the peak demand times of the year.
4. Systematics and genetics: modern taxonomic techniques need to be employed to better define species and genetic strains so undesirable introductions and mixing will not occur.
5. Feeds: feeds and food bases need to be evaluated so economical feeding programs can be developed to increase production.
6. Water quality: the necessary water quality parameters for good crayfish growth need to be defined. Methods need to be developed to maintain these especially during feeding programs.
7. Marketing: more extensive marketing, especially for food size crayfish needs to be developed.

Literature cited

Armitage, K.B., A.L. Buikema, Jr. and N.J. Willems. 1972. Organic constituents in the annual cycle of the crayfish *Orconectes nais* (Faxon). Comparative Biochemistry and Physiology 41A:825-842.

Hobbs, H.H., Jr. 1972. Crayfish (Astacidae) of North and Middle America. Biota of Freshwater Ecosystem Identification Manual No. 9., Water Pollution Control Research Series. U.S. Environmental Protection Agency, Washington, D.C. 173 pp.

Hobbs, H.H., III and J.P. Jass. 1988. The crayfishes and shrimp of Wisconsin (Cambaridae and Palaemonidae). Milwaukee Public Museum, Milwaukee, WI. 177 pp.

Ingelin, M.E. 1984. Growth and distribution of the crayfish *Orconectes nais* in Kansas farm ponds. Master of Science Thesis, Kansas State University, Manhattan, KS, 89 pp.

Jackson, H.P. 1973. Observations on the crayfish *Orconectes nais* (Faxon) in two Kansas ponds. Master of Art Thesis, The University of Kansas, Lawrence, KS, 35 pp.

Kichler, C.E. 1987. Evaluating survival of the crayfish *Orconectes nais* exposed to hypoxic winter conditions. Master of Science Thesis, Kansas State University, Manhattan, KS, 44 pp.

Momot, W.T. 1966. Upstream movement of crayfish in an intermittent Oklahoma stream. American Midland Naturalist 75: 150-159.

Money, J.H. 1988. Aspects of reproduction for the crayfish *Orconectes nais*. Master of Science Thesis, Kansas State University, Manhattan, KS, 56 pp.

Page, L.M. 1985. The crayfishes and shrimps (Decopoda) of Illinois. Illinois Natural History Survey Bulletin 33:335-448.

Pflieger, W.L. 1987. An introduction to the crayfish of Missouri. Missouri Conservationist, Missouri Department of Conservation, Jefferson City, MO, 16 pp.

Williams, A.B. and A.B. Leonard. 1952. The crayfish of Kansas. The University of Kansas Science Bulletin 34:961-1012.

The Northern or Fantail Crayfish, *Orconectes virilis*

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Introduction

The northern or fantail crayfish, *Orconectes virilis*, is a relatively large crayfish common to many bodies of water in the North Central Region (NCR). The dorsal surface (back of the thorax) ranges from brown to greenish brown (Page, 1985). Most individuals from culture ponds tend to be more greenish. Several other colors have been found, including blue and white. Blue is an uncommon color in nature, and uncommon among crayfish, but there are numerous reports of individual blue-pigmented crayfish. Based on studies with southern crayfishes, the blue pigmentation is a simple genetic mutation (Black and Huner 1980). Blue parents tend to have blue offspring. The blue pigmentation can also be developed by feeding certain feeds in laboratory conditions (Brown et al. 1989), but this should be rare in pond culture conditions. While still debated among scientists, the white color does not appear to be true albinism, because the eyes are black. Thus, color of crayfish should not be the determining factor when identifying species of crayfish. A formal description of this species is presented by Page (1985).

The range of the northern crayfish extends from New England into Canada, to the Hudson Bay and west to Montana. The southern extent of the range is northern Kentucky and west through central Missouri and Kansas ending in Colorado. Thus, the northern crayfish is native to all states in the NCR. This species inhabits both streams and static bodies of water (lakes, ponds, and wetlands) and has been called one the "pond craws" by producers in Indiana.

Aquaculture

Because of its size, *O. virilis* has been the focus of several pond production studies in Illinois and Indiana. In general, those studies used southern pond production practices modified for a temperate climate.

Pond production studies

Culture potential of the northern crayfish has been explored in several experimental situations. Brown et al. (1990) reported harvest yields of 357 to 714 pounds / acre (400-800 kg / ha) in two types of aquaculture production settings. Further, most crayfish, regardless of production system, attained marketable size during their first growing season. The two production systems used in that study were shallow ponds stocked with known numbers of juveniles or deep ponds (typical fish culture ponds with a maximum depth of 6 feet or 2 meters). The deep ponds were stocked with adults in the fall prior to the production season. The stocked individuals then reproduced in early spring. Harvest yields were higher in the shallow ponds stocked with juveniles, probably the result of diminished predation by adults in the deeper ponds. Crayfish in both culture systems were restocked for evaluation of overwinter survival and growth. Even in shallow ponds (18 inches or 0.5 meters deep), survival was greater then 75% by the next spring and both males and females gained weight (approximately 15%) during that period. Over 95% of the females were carrying eggs when harvested in the spring. Thus, the northern crayfish becomes sexually mature after one growing season.

Harvesting

Harvesting crayfish has been one of the most expensive and inefficient parts of crayfish culture in the southern US. Brown et al. (1989) evaluated the susceptibility of the northern crayfish to common crayfish traps and baits. Crayfish readily entered both pillow and pyramid traps when those traps contained commercial baits and cut fish. Those are two of the more common types of traps used in the southern US. Most of the commercial baits attracted more crayfish than cut shad in that study. Sex ratios of trapped crayfish were close to 1:1 (males to females) regardless of bait. The northern crayfish is susceptible to crayfish traps and baits commonly used in the southern US.

Physical relationships

Brown and Konoval (1993) described various physical relationships of the northern crayfish. Carapace length (CL, length from the tip of the head to the end of the thorax or the beginning of the tail) is ½ of total length and width of the carapace is about ½ of CL, or ¼ of total length. The relationship between length and weight for males was best described as

$$TL = 35.39 \times WT^{0.28} \; (r = 0.97),$$

where TL was total length in mm and WT was wet weight in g. The relationship for females was similar. Crayfish used to develop that relationship ranged from approximately 0.01 to 0.16 lb (6 to 73 g). This is important information for grading purposes and grader sizes were recommended by the authors for retaining jumbo crayfish.

World record

Over the past seven years, several large *O. virilis* have been collected from ponds in Indiana. Individual male crayfish of 0.19 to 0.20 lb (90-94 g), or 5 / pound, were routinely collected from fish rearing ponds in central Indiana. One female weighing 0.23 lb (104 g) was collected from the same series of ponds (unpublished data).

Foods

The types of food for crayfish culture has varied through the course of the early studies with the northern crayfish. The first studies used selected agricultural products. Throughout all studies, wheat straw and alfalfa hay have consistently been the best products to use (Brown et al. 1990; 1995). This is similar to findings from the southern US. Agricultural forages have been recommended as forages for crayfish reared in ponds for many years (Huner 1991). An important question has been why this is successful. Direct consumption of aquatic plants by crayfish appears to be minimal (Brown et al. 1990; McClain et al. 1992). Bacteria growing on decomposing forages was thought to be a significant source of food, but has been difficult to demonstrate in controlled experiments (Brown et al. 1992). More recent ideas have been focused on zooplankton communities in ponds and the effect of agricultural products simply serving as fertilizer that stimulates production of normal pond organisms that serve as the food supply. Use of relatively expensive formulated feeds has not resulted in increased yields of crayfish from ponds (Brown et al. 1995). However, nutritional research is continuing and may be result in benefits in the future (Brown 1995).

Diseases

There are very few diseases of North American crayfish when reared in freshwater (Huner 1991). Most of those diseases are parasites that tend to be commensalistic, causing no real harm to the host crayfish, but providing no real benefit either. An outbreak of one of the parasites occurred recently in a group of *O. rusticus* (the rusty crayfish). Brown et al. (1993) were able to experimentally infect *O. virilis* in the same ponds. The primary cause of the parasitic outbreak appeared to be poor water quality. Thus, parasitic and other disease problems are possible, although crayfish tend to be relatively free of these maladies.

Dressout

Wetzel (1993) examined dressout percentages of male and female *O. virilis* of varying weights. Overall average dressout percentage was 18.8% for males and 17.7% for females. There was a clear relationship between tail meat weight and carapace length. The relationship for males was best described by the equation

$$DO = 0.165 \times CL^{1.07},\ r = 0.92$$

where DO was dressout percentage and CL was carapace length in mm. The relationship for females was similar.

Economics of crayfish culture

There are no known economic evaluations of culturing the northern crayfish; however, the production methods that would be the simplest to adopt would be slight modifications of those from the southern US. For example, even in shallow ponds, native species of crayfish reach marketable size in 1 year in the southern portion of the NCR, and survive and grow through the winter. Shallow ponds cost less to construct than "normal" fish culture ponds because there is less dirt to move. These are similar to crayfish culture ponds in the southern US. Feed is usually one of the most expensive costs in aquaculture, but agricultural forages seem to suffice with native species raised in ponds. Thus, feed cost is minimal. The other expense in aquaculture is usually juvenile animals for stocking. Crayfish reproduce on their own if given a body of water and some minimal forage input to the pond, so juvenile cost is low. The most expensive cost seems to be the initial cost of acquiring adult animals for stocking a new pond. Recommended initial stocking rates are 36 pounds / acre (40 kg / ha) at a cost of $3.00 / pound. Therefore, you must build a pond ($2-3,000 / surface acre) and buy the initial adults for stocking (40 pounds / acre at $3.00 / pound = $120 / acre). Based on early production studies, you should be able to harvest approximately 400 pounds / acre / year at $3.00 / pound = $1,200 / acre / year. The market price of $3.00 / pound is reasonable in the NCR, but is much lower in the primary producing states in the southern US. Thus, a 1.0 acre pond should pay for itself within 3 years.

The above example should be viewed with caution. The idea of culturing crayfish for human food consumption in the NCR is a relatively new idea. The economic projections above are a biologists view of economics, not to be construed with true economic assessment that would include opportunity costs, depreciation, etc. However, it does seem to support the idea that culture of crayfish in the NCR has a high probability of success.

Critical information gaps — *Orconectes virilis*

1. Biological and environmental limitations to increased density. Crayfish, like most other crustaceans, exhibit density dependent growth and survival. That is, when densities exceed approximately 5 / yd^2 (approximately 5 / m^2) growth and survival decrease.
2. Critical nutritional requirements. Crustaceans require several atypical nutrients in their diets (for example, cholesterol, lecithin, and asparagine). Lack of those factors may be inhibiting our ability to increase densities when provided food.
3. Factors impacting rapid and consistent molting for soft-shell production. Current practices require handling all crayfish each day and identifying premolt animals by the gap that develops between the new and old exoskeleton. This is labor intensive. Changing environmental conditions and eyestalk ablation seem to have the most potential.

4. Lack of market awareness in the NCR. We all must educate the market and expose them to our native species.

Literature cited

Brown, P.B. 1995. A review of nutritional research with crayfish. Journal of Shellfish Research 14:20-28.

Brown, P.B., M.L. Hooe, and D.H. Buck. 1989. Preliminary evaluation of baits and traps for harvesting orconectid crayfish from earthen ponds. Journal of the World Aquaculture Society 20:208-213.

Brown, P. B., M. L. Hooe, S. Noblitt, and P. Harrison. 1989. Diet-induced blue pigmentation in crayfish and hypotheses testing regarding the change in pigmentation. 20th Annual Meeting of the World Aquaculture Society, Los Angeles, California.

Brown, P.B., M.L. Hooe, and W.G. Blythe. 1990. Preliminary evaluation of production systems and forages for culture of *Orconectes virilis*, the northern or fantail crayfish. Journal of the World Aquaculture Society 21:53-58.

Brown, P.B., M.L. Hooe, P. Tazik, and W.G. Blythe. 1990. Consumption and apparent dry matter digestibility of aquatic macrophytes by male and female crayfish (*Orconectes virilis*). Aquaculture 89:55-64.

Brown, P.B., M.R. White, D.L. Swann and M.S. Fuller. 1993. A severe case of ectoparasitism due to *Epistylis* sp. in pond-reared orconectid crayfish. Journal of the World Aquaculture Society 24:116-120.

Brown, P.B. and G.K. Konoval. 1993. Length, weight, and width relationships of form 1 *Orconectes virilis*. Journal of the World Aquaculture Society 24:112-115.

Brown, P.B., K.A. Wilson, J.E. Wetzel, II, and B. Hoene. 1995. Increased densities result in reduced weight gain of crayfish *Orconectes virilis*. Journal of the World Aquaculture Society 26:165-171.

Black, J.B. and J.V. Huner. 1980. Genetics of the red swamp crawfish, *Procambarus clarkii* (Girard): state of the art. Proceedings of the World Mariculture Society, Volume 11.

Huner, J.V. 1991. Red swamp crawfish: biology and exploitation. Louisiana Sea Grant College Program, Baton Rouge, LA.

McClain, W. R., W. H. Neill and D. M. Gatlin. 1992. Partitioning the contributions of forage-based production system components to weight gain of juvenile crayfish (*Procambarus clarkii*). Aquaculture 101:267-281.

Wetzel, J.E., II. 1993. Morphological and physiological characteristics of orconectid crayfishes important to aquaculture. M.S Thesis, Purdue University, West Lafayette, IN, 166 pp.

Wetzel, J.E., II and P.B. Brown. 1993. Growth and survival of juvenile *Orconectes virilis* and *O. immunis* at different temperatures. Journal of the World Aquaculture Society 24:339-343.

The White River Crayfish, *Procambarus acutus*

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Introduction

The geographic range of *P. acutus* is unclear at this time, because of taxonomic uncertainties within *Procambarus*. We believe that, unless more taxonomic information becomes available regarding *P. acutus* and *P. zonangulus*, the species in our region should be considered *P. acutus*. Hobbs (1991) suggested that the range of *P. zonangulus* includes southeastern Texas and southern Louisiana. Additionally, he pointed out that beginning in northern Louisiana, *P. zonangulus* is replaced by a different "species" which is lumped together with *P. acutus*. This "species", he asserted, has a larger range. It is not known at this time if *P. acutus* or the species referred to by Hobbs that is currently lumped together with *P. acutus* is the species we see in this area. However, *P. acutus* appears to be the most appropriate designation for this species in our region at this time, because the Midwest is clearly not within the range for *P. zonangulus* that was proposed by Hobbs and the type specimen for *P. acutus* came from Mississippi.

The historical range of *P. acutus* (including *P. zonangulus* and other closely related forms) was described by Page (1985) as a disjunct distribution with one portion of the range on the east coast extending south into Georgia from Maine. The other portion of the range extends from Wisconsin south into Mexico. In the U.S., the range extends east to west from eastern Iowa to western Ohio in the north and from Oklahoma / Texas to Alabama in the south. In addition to Page's description of the range, Hobbs and Jass (1988) provided information on introductions and range expansions. An introduction into San Diego County, California was attributed to shipments from a biological supply house during the 1920's (Gander 1927). Crocker (1979) attributed collections in Massachusetts and Rhode Island to natural range expansion facilitated by marginal glacial lakes. Hobbs and Jass (1988) also listed reports on translocations within Massachusetts and Georgia.

Aquaculture

Reproduction

Procambarus acutus apparently mates in spring and summer in the North Central Region. However, it has been difficult to define a specific period for egg laying and recruitment. Hobbs and Jass (1988) collected females with eggs attached during July in Wisconsin. Payne (1986) identified the period of recruitment in Shelby County, Tennessee, as being between late August to early November. In Illinois, Page (1985) found females with eggs in April, July, August, and December. Egg laying and hatching occurred primarily in September (Wills 1991) in southern Illinois. This fall recruitment of juveniles into the pond population is consistent with the peak in catch of harvestable size *P. acutus* early in the production season in Illinois (Heidinger et al. 1992).

Growth rate and dressout

Procambarus acutus grows rapidly (mean growth = 0.42 g / day, or 0.0009 lb / day during July to September in southern Illinois) (Sheehan et al. 1991), and its dressout surpasses that of the red swamp crayfish by about 27% on average.

Table 1. Percent yield of tail meat from four species of crayfish by weight (g) groups (N in parentheses).

Weight group (g)	no. per lb.	*Procambarus acutus*	*P. clarkii*	*Orconectes virilis*	*O. immunis*
5-10	60/lb.	20.7 (3)	——	23 (10)	23.8 (64)
10-15	36/lb.	22.3 (18)	17.1 (15)	21.4 (32)	21.2 (136)
15-20	26/lb.	20 (24)	14.5 (7)	20 (35)	21.2 (36)
20-25	20/lb.	19 (19)	——	17.4 (23)	——
25-30	16/lb.	17.5 (14)	12.2 (3)	17.5 (17)	——
30-35	14/lb.	15.9 (8)	——	16.2 (3)	——
> 35	13/lb.	14.7 (4)	——	15 (8)	——
Mean		19.3 (90)	16.1 (25)	19.6 (129)	21.9 (236)

Dressouts for *O. virilis* and *O. immunis* also appear to be better than the red swamp crayfish (Table 1) (Heidinger et al. 1992).

Culture systems

The culture systems for *P. acutus* in all likelihood will be very similar to those used to produce the other species of interest in the NCR. The primary difference and production advantage for this species can be found in its life cycle. Abundance of *P. acutus*, and thus production, is not synchronized with that of the orconectid species, since they can release young during the fall months when reared in the southern portion of the region. A polyculture scheme involving both *P. acutus* and orconectid species, with proper management, could provide for an increase in the length of the production season.

Another approach for lengthening the production season might be for farmers to produce *P. acutus* in some ponds, which could be harvested earlier in the summer, and orconectids in others, which would become harvestable and peak in production later. However, the polyculture system appears to be more promising at this time. The southern crayfish culture industry benefits from the multiple waves of recruitment and production provided by the red swamp crayfish. Each cohort is cropped off throughout the production season as it reaches harvestable size. Cropping is known to enhance overall production in other aquaculture species, but it would be a much less effective technique for midwestern crayfish species which reproduce only once per year. Thus, using *P. acutus* and an orconectid species in the same pond would provide two waves of recruitment and more closely simulate population dynamics found in southern crayfish aquaculture.

Critical information gaps — *Procambarus acutus*

1. Production methods in the NCR will probably differ from those in the South, owing to the substantially shorter growing season. The shorter growing season would preclude the use of cover crop production in much of the NCR. Thus, another energy source (i.e., food) is needed for crayfish production. Also, many native species are tertiary burrowers which would not respond well to pond draining.
2. Production in the NCR may well involve the use of deeper ponds to prevent winter kill, water quality enhancement to overcome potential dissolved oxygen problems during the summer, continuously filled ponds to

better fit the biology of native species, and additions of allochthonous organic matter to replace cover crop production.

Literature cited

Brown, P.B., C.D. Williams, E.H. Robinson, D.M. Akiyama, and A.L. Lawrence. 1986. Evaluation of methods for determining in vivo digestion coefficients for adult red swamp crayfish *Procambarus clarkii* Journal of the World Aquaculture Society 17:19-24.

Crocker, D.W. 1979. The crayfishes of New England. Proceedings of the Biological Society of Washington 92:225-252.

D'Abramo, L.R., and D.J. Niquette. 1991. Seine harvesting and feeding of formulated feeds as new management practices for pond culture of red swamp crawfish, *Procambarus clarkii* (Girard, 1852), and white river crawfish, *P. acutus acutus* (Girard, 1852). Journal of Shellfish Research 10:169-177.

de la Brettone, L., Jr. 1987. Crawfish season summary (1986-1987) and update. Crawfish Tales 6:10-11.

Gander, F.F. 1927. Eastern crayfish in San Diego County. California Fish and Game 13:221-222.

Goyert, J.C., and J.W. Avault, Jr. 1977. Agricultural by-products as supplemental feed for crayfish, *Procambarus clarkii*. Transactions of the American Fisheries Society 106:629-633.

Heidinger, R.C., R.J. Sheehan, C.C. Kohler, D.A. Selock, and W.T. Davin. 1992. Aquaculture Development in Illinois. Progress Report to the Illinois Department of Commerce and Community Affairs.

Hobbs, H.H., Jr. 1991. Taxonomy of *Procambarus* spp. International Association of Astacologists Newsletter 13:4.

Hobbs, H.H., III, and J.P. Jass. 1988. The crayfishes & shrimp of Wisconsin. Milwaukee Public Museum, Milwaukee, Wisconsin.

Huner, J.V., and J.E. Barr. 1984. Red Swamp Crawfish: Biology and Exploitation. Louisiana Sea Grant College Program, Center for Wetland Resources, Baton Rouge, Louisiana.

Nolfi, J.R. 1979. Prospects for commercial aquaculture of crayfish in Vermont. 35th Annual Fisheries and Wildlife Conference, Rhode Island, 35 pp.

Page, L.M. 1985. The crayfishes and shrimp (Decapoda) of Illinois. Illinois Natural History Survey Bulletin 33:335-448.

Payne, J.F. 1986. Factors influencing patterns of crayfish distribution. Freshwater Crayfish 6:100-110.

Sheehan, R.J., P.S. Wills, and W.T. Davin. 1991. Crayfish production: a promising enterprise for the midwest. Proceedings of the North Central Aquaculture Conference 1991:219-225.

Wills, P.S. 1991. Evaluation of a crayfish polyculture system for the midwest using young-of-the-year stocking and pond circulation. Masters Thesis, Southern Illinois University, Carbondale, Illinois.

General recommendations

Based on the chapters presented in this report, we feel that we can make several general recommendations regarding culture of crayfish in the North Central Region.

1. Several species exhibit characteristics that suggest they are suitable for culture. We recommend using a species that is locally available. There are several species of crayfish endemic within each of the states in the NCR and they have adapted to the environmental conditions in that area.
2. Maximum size of crayfish should be a consideration. Make sure the species you choose attains the desired market size.
3. If you culture crayfish in ponds, depth of new ponds is an important consideration. We recommend that ponds should be deep enough to ensure they never freeze completely. That is, there should always be a nonfrozen layer under the ice even in the most severe winter conditions. Thus, depth of ponds would vary from north to south within the NCR.
4. We recommend a source of water, preferably ground water, for your pond. This allows filling the pond as necessary, replacement of evaporative losses, and addition of good quality water when the quality of water in the pond degrades.
5. For maximum production, we recommend aeration capability for your pond. Crayfish are benthic organisms (i.e., they live on the bottom) and the bottom of the pond is the area most susceptible to oxygen depletion.
6. Feed input into the pond should be in the form of inexpensive agricultural forages, such as wheat straw or alfalfa hay. Forage addition should be in the range of 40-80 pounds / surface acre (18-36 kg / ha) as needed, usually every 1-2 weeks.
7. Host a crayfish boil in your area. You will be surprised how many people attend, then want to you to do it again!

Additional sources of information

Culley, D.D., and L. Duobinis-Gray. 1990. Culture of the Louisiana soft crawfish: a production manual. Louisiana Sea Grant College Program. Available from the Louisiana Sea Grant College Program, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA 70803-7507.

Hobbs, H.H., Jr. 1972. Crayfish (Astacidae) of North and Middle America. Biota of Freshwater Ecosystem Identification Manual No. 9., Water Pollution Control Research Series. Available from the U.S. Environmental Protection Agency, Washington, D.C.

Hobbs, H.H., III and J.P. Jass. 1988. The crayfishes and shrimp of Wisconsin (Cambaridae, Palaemonidae). Milwaukee Public Museum, Special Publication in Biology and Geology no. 5. Available from the Milwaukee Public Museum, Milwaukee, WI 53204.

Huner, J.V. 1990. Biology, fisheries, and cultivation of freshwater crawfishes in the U.S. Reviews in Aquatic Sciences 2:229-254. Available from most university libraries.

Huner, J.V. 1991. Red swamp crawfish: biology and exploitation. Louisiana Sea Grant College Program. Available from the Louisiana Sea Grant College Program, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA 70803-7507.

Huner, J.V. (editor). 1994. Freshwater crayfish aquaculture in North America, Europe and Australia. Food Products Press. Available from The Haworth Press, Inc., 10 Alice Street, Binghamton, NY 13904-1580.

Malone, R.F., and D. Burden. 1988. Design manual for intensive softshell crawfish production. Louisiana Sea Grant College Program. Available from the Louisiana Sea Grant College Program, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA 70803-7507.

Page, L.M. 1985. The crayfishes and shrimps (Decapoda) of Illinois. Illinois Natural History Survey Bulletin, volume 33, article 4. Available from the Illinois Natural History Survey, Natural Resources Building, 607 East Peabody Drive, Champaign, IL 61820.

Series Editor: Joseph E. Morris, Associate Director,
North Central Regional Aquaculture Center.

Design by Dennis Melchert, Ames Best Communications

Originally published by Iowa State University, Ames, Iowa