Crawfish culture: A Louisiana aquaculture success story

W. RAY MCCLAIN[1] AND ROBERT P. ROMAIRE[2]

Development and growth of commercially viable aquaculture industries in the United States have been slow and precarious. While the catfish industry, North America's flagship aquaculture industry, is a model of success, other aquaculture industries and many individual operations have failed or are struggling.

One smaller industry that has remained viable and resilient, even under some considerable constraints as of late, is the crawfish aquaculture industry in the southern United States. This industry is located predominately in Louisiana where total annual yields during the last decade ranged from 10,000 to 27,000 tons. Crawfish aquaculture in this region is based on the production of animals for the table, though a few are also sold as fish bait. Currently, Louisiana's 1,100 crawfish farmers cultivate crawfish on about 43,000 ha (LCES 2002). It is estimated that fewer than 3,000 ha are devoted to crawfish production in the United States outside of Louisiana, though other areas may be suited for production.

Success of the crawfish culture industry in Louisiana can be attributed to several factors. Established markets and infrastructure were in place from the beginning due to the large commercial fishery based, in part, on the state's large segment of French ancestral population with a heritage for consuming crawfish. The non-technical nature of crawfish farming practices and, subsequently, its integration with other farming operations, most notably rice culture, aided in its economic success.

Red swamp crawfish, Procambarus clarkii, from a Louisiana pond. (photo by Randy McClain)

Development of Crawfish Aquaculture in Louisiana

Louisiana was first known for its crawfish thriving capture fishery, where recreational and commercial fishermen harvested crawfish from the extensive wetlands of the lower Mississippi River floodplain. The red swamp (*Procambarus clarkii*) and white river (*P. zonangulus*) crawfishes flourish in these rich riparian habitats that experience seasonal flooding and drying. However, crawfish abundance is seasonal and depends primarily on overflow patterns from the Mississippi River, which is largely related to precipitation patterns in the upper and middle Mississippi River Valley watershed. The short seasons of the capture fishery of 1 - 4 months of the year, unpredictable harvests, and increasing consumer demand provided much of the impetus for development of crawfish aquaculture.

Crawfish culture is thought to have existed in Louisiana in the 18th century, and methods for crawfish aquaculture were reported by Viosca (1937). Current farming practices, however, began modestly in the 1950s (Avery and Lorio 1996), becoming more commercialized in the 1960s and 1970s. Land area devoted to crawfish farming doubled in Louisiana from 1980 until its peak at 52,000 ha in 1987.

Crawfish aquaculture is dominated by the same two species found in the capture fishery, mainly because these crawfish are native, large, hardy, prolific, adaptable to farming conditions and are readily recognized and accepted in the marketplace. The development of crawfish aquaculture as a successful commercial endeavor can be partially attributed to the fact that no highly technical cultivation practices are required to rear the animals. Unlike the culture of many aquatic species that require hatcheries and formulated feeds, crawfish culture is based on extensive methods of production using earthen ponds, while relying on self-propagating populations and a vegetal-based food web system. In fact, current farming practices are based on annual hydrological cycles and conditions similar to those to which the crawfish have become adapted, with little additional input. Flooding and draining of culture ponds mimic, to some degree, inundation and drying cycles in riparian habitats, albeit the control achieved with aquaculture provides for greater control of timing and length of flooded periods, food resources, and, to some degree, water quality and predator control.

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Crawfish Life Cycle

The life cycle of crawfish is well suited to fluctuating periods of flooding and dewatering. Sustained periods of river overflow, or flooded impoundments in aquaculture, permit crawfish to feed, grow and mature. Temporary dewatering, in nature and aquaculture, promote oxidation of the bottom sediments, reduce abundance of aquatic predators and allow for the establishment of vegetation, which serves as cover for crawfish and food resources when flooded. Crawfish survive the dry intervals by digging or retreating to burrows where they can avoid predators and acquire the moisture necessary for survival. Crawfish have also adapted to reproduce within the protection of the burrow. In essence, the burrow is a crawfish hatchery.

Crawfish burrow in progress. (photo by Randy McClain)

Mating occurs in open water and the sperm is stored in a protective receptacle on the female, usually until she retreats to the protection of the burrow to spawn weeks or months later. Burrows of procambarid crawfish are simple, nearly vertical tunnels that typically are 40 to 90 cm deep. Burrow entrances are often marked by the characteristic chimney and are found slightly above the water on pond levees or associated with puddles under drying conditions. Burrows usually contain a single female, or male and female, but occasionally contain additional crawfish. Burrowing activity can occur at any time of the year but is most prevalent in Louisiana beginning in late spring as crawfish mature and ponds are drained.

Harvesting crawfish with an aluminum boat equipped with a rear wheel hydraulic unit and foot operated steering controls. (photo by

Successful survival during burrow occupation depends primarily on the moisture content in the burrow and health of the animal. Immature crawfish and crawfish forced to burrow by rapidly dropping water levels may construct shallow burrows that are ineffective at maintaining sufficient moisture for survival during drought. Soil types with limited clay content or soil with very high clay content that cracks during severe drought may also limit crawfish survival during their stay in the burrow.

Although crawfish can survive in high humidity environments within the burrow, free water is necessary for successful reproduction. While ovarian and embryo development are temperature dependent, the incubation period is about three weeks at 23ºC (Huner 1994). Crawfish have direct embryonic development and the fecundity is not particularly high. The number of offspring produced varies with female size and condition, but a large crawfish can have more than 500 young. Hatchlings are physically attached to the female through two instar molts and then instinctively remain with her for several weeks. It is critical that the female and her young leave the burrow within a reasonable time because little food is available in burrows and females are known to cannibalize their young.

Crawfish are confined to the burrow until the hard plug that seals the burrow is sufficiently softened by external moisture. Pond flooding, especially when associated with heavy rainfall, facilitates and encourages the emergence of crawfish from burrows. Brood females emerge with young, or sometimes eggs, attached to the abdomen. Hatchlings are quickly separated from the females and become independent. Because reproduction is somewhat synchronized in pond-reared crawfish, ponds are routinely flooded in autumn to coincide with the main period of hatching. *P. zonangulus* are seasonal spawners and usually spawn only in early autumn in the southern region of the United States. Reproduction of *P. clarkia*, however, may occur at any time, but peak recruitment usually occurs in autumn and subsequent, but minor, waves of young-of-the-year recruits are common. Continuous recruitment and differential growth result in a population of mixed sizes.

As with all crustaceans, crawfish must molt or shed the hard exoskeleton to increase in size. Hence, the process of growth involves periodic episodes of molting with an intermolt period between each shedding incident. Molting is hormonally controlled and occurs more frequently in younger animals than older ones. Frequent molting and rapid growth occur in production ponds when temperatures are optimum, food resources are adequate, and crawfish are not overly crowded. Typically, harvest size is reached 3-5 months after hatching. After a period of growth, both males and females molt to a sexually active stage and growth ceases. Sexually mature individuals exhibit distinct secondary sexual characteristics, including darker coloration, enlarged chelae (claws), and

Typical style "pyramid" crawfish trap. (photo by Ray McClain)

Day's catch from single crawfish trap during peak harvest season. (photo by Randy McClain)

In a typical rice-crawfish rotational strategy, the recently planted rice field (in background) will serve as a crawfish pond in a subsequent season following harvest of the grain crop, and the crawfish pond (foreground) will be planted in rice the following year. (photo by John Sonnier)

cornified sexual structures. Mature males also develop prominent hooks at the base of the third and fourth pair of walking legs or pereiopods. The appearance of mature crawfish in the population typically increases as the temperatures of late spring rise. Females will mate, often several times, after their maturity molt and begin the process of constructing burrows at the water's edge.

The red swamp and white river crawfishes have similar ecological and cultural requirements and are frequently found in the same pond or habitat. Though the abundance of one species may vary among and within culture ponds over years, red swamp crawfish most often dominate and are the desired species in the marketplace and the preferred species for culture.

Overview of Aquaculture Practices

Production of the procambarid crawfishes requires little more than 1) understanding of the natural life cycle processes, 2) providing the proper accommodations and environmental conditions for reproduction and growth and 3) harvesting. Crawfish are prolific and can provide sufficient recruitment under natural conditions without the need for hatcheries. Although many areas have indigenous crawfish, normally crawfish broodstock are introduced into new ponds or ponds that have been out of production for a year or more. Permanent ponds usually require no further stocking inasmuch as the populations are self-sustaining. Stocking of broodstock usually occurs from late spring to early summer prior to the summer drawdown.

Ponds are drained during the summer to establish a forage crop that serves as the foundation of a detritus-based food web when the pond is reflooded. Crawfish production in the southern United States currently does not rely on the feeding of pelleted or supplemental feeds, nor has supplemental feeding been shown in limited research to reliably increase yield or harvest size under current production practices. Crawfish receive their sustenance from sources within the pond, based largely on a detrital food chain. Therefore, establishment of a forage crop that adequately provides vegetal material to the detrital pool throughout the season is an important aspect of food resource management. Voluntary vegetation can sometimes be an effective resource, but a planted agronomic crop, namely rice, routinely has been the most effective forage crop. Sorghum-sudangrass, commonly used by cattlemen for grazing and hay, has also proved to be a suitable crawfish forage crop if properly managed.

Intact vegetative matter contributes little to the direct nourishment of crawfish, short of providing some limited nutrients, and is mostly eaten when other food sources are in short supply. Decomposing plant material and associated microorganisms, collectively referred to as detritus, and certain seeds are consumed to a much greater degree by crawfish and have higher food values. The optimum food resource in the pond, however, is the collection of aquatic invertebrates that, in turn, depend on detritus for their nourishment. Thus, the main role of forage crops in crawfish aquaculture is not to provide direct nutrition; rather, it is to provide the fuel that powers the food web, with crawfish at the top of that web.

Ponds are reflooded in autumn to coincide with the major period of young-of-the-year recruitment. Water depths are typically maintained at 20 - 60 cm to facilitate water and forage management and because current harvesting practices require shallow water levels. Inundation of the forage crop begins the food web processes, and pond flooding creates an environment that allows hatchlings to thrive, provided good water quality is maintained.

Water requirements for crawfish production are similar to those for other aquaculture species with the exception of the quantity of water needed. With the entire pond area covered with substantial amounts of vegetation, the biological oxygen demand can be high and its effects must be overcome with timely water exchanges. Mechanical aeration is not widely practiced.

The heavy vegetation cover, encompassing virtually the entire pond area, also limits the harvesting options. Seine harvesting, a common method for many aquaculture species, is ineffective. Additionally, since crawfish recruitment to the harvestable population is continual over much of the season, regular and frequent harvests are necessary, as opposed to the more common infrequent batch harvests. Furthermore, presence of soft, newly molted crawfish precludes most active harvest methods. Therefore, the industry relies on the passive technique of baited traps – another similarity to the capture fishery.

The shallow nature of farm ponds allows for a different and more effective trap configuration than those used in the commercial fishery. The wire-mesh pyramid trap, designed for use in shallow water, has emerged as the industry standard and is effective in capturing crawfish and efficient to operate. The trap is positioned upright in the pond with the top extending above water. The top is open to facilitate rapid removal of crawfish and rebaiting, and contains a retainer collar that minimizes crawfish escape and serves as a handle. The size and shape of the mesh wire used to construct the trap govern the size of crawfish retained after capture. Most traps are currently made of 1.9-cm plastic-coated square mesh that retains crawfish 12g (about 70mm total length) and larger; however, consumer preferences are for crawfish larger than 20g. Two categories of bait are used to attract crawfish to the trap: natural baits of fish and manufactured baits of proprietary formulations. Although more expensive, fish is the preferred and most effective bait at water temperatures below 20°C. Manufactured baits are most effective at temperatures above 20°C. Most baiting regimes are based on a 24 hr trap-set, but 12 and 48 hr or longer sets are sometimes used.

Crawfish grown in different physical locations each year under a rotational cropping strategy requires annual stockings of broodstock directly into the young rice crop. (photo by Randy McClain)

Traps are used most effectively when distributed throughout the pond and are normally set in rows to accommodate harvest by boat. Most commercial ponds larger than 2 - 3 ha are harvested with the aid of a motorized, flat-bottom boat designed for shallow-water propulsion. Several boat types and propulsion designs are available, but the most widely used apparatus consists of an aluminum boat equipped with a hydraulically driven metal wheel that extends beyond the boat and either pushes or pulls it through the pond. A gasoline engine inside the boat powers a hydraulic system for propelling and steering the boat. Commonly, the boat travels down the lanes of traps and a fisherman, sometimes two, will empty and rebait each trap from one side of the boat, often without stopping at the traps.

Producers use approximately 30 traps/ha, but trap density can range from 20 - 60/ha, depending on intensity of the operation. Harvesting begins as soon as catch per unit effort (CPUE) is justifiable – usually 2 - 4 months after flooding. Trapping frequency and duration also vary. Traps are emptied 2 - 7 day/week, often intermittently for 3 - 8 months. Frequency and duration of the harvest are influenced largely by cost of harvesting, CPUE, and marketing price. The CPUE is determined by crawfish population density and structure, trapping effort, indigenous food resources, bait quantity and quality, along with environmental conditions, but rarely exceeds 1.0 kg/trap/day on a sustained basis.

Harvesting is the most labor intensive component of crawfish farming and, typically, 50 - 70 percent of total direct expenses are associated with the harvest. Bait and the labor required for trapping are the greatest expenses (Romaire 1995). It is not uncommon for some producers to lease the harvest rights to fishermen who receive a percentage of the daily revenue from the sale of crawfish.

Culture Methodology

Methods of farming crawfish can best be described by two major approaches – crawfish monocropping systems, whereby crawfish is the sole crop harvested and multi-crop rotational systems, whereby rice and sometimes an additional agronomic crop is harvested in addition to crawfish (Eversole and McClain 2000). There are several variations within each of these major cropping approaches, but basic culture requirements and practices for producing crawfish are similar (Table 1). However, different production goals and constraints dictate different management concerns and outcomes with regard to the different systems.

In crawfish monocropping systems, a rice crop may be planted as a crawfish food resource, but grain is either not harvested or not produced. Crawfish monoculture is the production method of choice for many small farms or where marginal lands are available and unsuited for other crops. Permanent ponds, or sites devoted to at least several consecutive production cycles are typically are used for this strategy. The main advantage of the monocropping strategy is that producers can manage for maximum crawfish production without the various concerns associated with other crops, such as pesticide exposure, seasonal limitations and other constraints. Crawfish yields typically range from less than 225 kg/ha in large, low input systems to over 1,120 kg/ha in intensely managed ponds, though some ponds have yielded in excess of 3,000 kg/ha. Disadvantages of the monoculture approach often include: 1) the need to construct ponds, whereas with rice/crawfish multicropping, the established rice field serves the purpose, 2) cost must be amortized over one crop only and 3) crawfish overcrowding frequently occurs after several annual cycles, particularly in the smaller ponds; therefore, yields become composed of small or stunted, low-priced crawfish that are difficult to market.

Crop rotational systems that include crawfish involve a rice-harvesting component and may sometime include soybean or another commodity in sequence. In one rotational approach, crawfish and rice are rotated in the same physical location within a year, and this practice is conducted for several consecutive years. In another rotational strategy, the rice crop is planted in

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Table 1. Summary of Different Typical Crawfish Culture Techniques.

Months	Crawfish Monocropping	Rice-Crawfish-Rice	Rice-Crawfish-Soybean or (Rice-Crawfish-Fallow)
Jul – Aug	Forage crop is planted or natural vegetation is allowed to grow	Rice crop is harvested in August and stubble managed for regrowth	Rice crop is harvested and stubble managed for regrowth
Sep – Oct	Pond is flooded and water quality is monitored and managed	Ponds is flooded in October and water quality is monitored and managed	Pond is flooded in October and water quality is monitored and managed
Nov – Dec	Harvesting begins when CPUE[a] can be justified	Harvesting begins when CPUE can be justified	Water quality is monitored and managed
Jan – Feb	Crawfish are harvested 2-4 days per week according to CPUE and markets	Crawfish are harvested 2-4 days per week according to CPUE and markets	Crawfish are harvested 2-4 days per week according to CPUE and markets
Mar – Apr	Crawfish are harvested 3-5 days per week according to CPUE and markets	Crawfish are harvested 3-5 days per week until April, then pond is drained and readied for planting	Crawfish are harvested 3-5 days per week according to CPUE and markets
May – Jun	Crawfish are harvested until CPUE is no longer justified then pond is drained	Rice is planted in May and rice crop is managed for grain production	Pond is drained and soybeans are planted (or harvest proceeds as long as CPUE is feasible, pond is then drained and left fallow)
July – . . .	Repeat cycle	Repeat cycle	Harvest soybeans in October, plant rice in March/April, stock crawfish in May, then repeat cycle

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alternate locations annually; therefore, crawfish culture occurs in different fields each year to conform to typical field rotations of the agronomic crops. In both strategies, crawfish culture follows the rice harvest, and the forage crop used for growing crawfish is derived from crop residue and re-growth of the rice stubble after grain harvest. Advantages of these multicropping strategies include efficient use of land, labor and farm equipment. Moreover, some fixed costs and the cost of rice establishment can be amortized over two crops instead of just one.

The first rotational approach, referred to as rice-crawfish-rice rotation, takes advantage of the seasonality of each crop to obtain two crops in one year. Rice is grown and harvested during the summer while crawfish are grown during autumn, winter and early spring in the same field each year. As with monocropping systems, crawfish are only stocked initially – they are introduced directly into the rice crop at 30 - 60 days post-planting. Following grain harvest, the residual rice crop is usually fertilized with a nitrogen-based fertilizer and irrigated to promote re-growth of forage. Management practices after fall flooding are similar to those of a monocropping system with the exception of a shortened season to accommodate the establishment of the next rice crop. A major disadvantage with this rotational strategy is that usually neither crop can be managed to yield maximum production. Those systems managed mainly for crawfish can expect crawfish yields similar to well managed monocropping systems, but at the expense of rice yield and vice versa.

Rice-crawfish-soybean, or rice-crawfish-fallow are the other major rotational strategies that use a field rotational approach. The major difference in the rotation strategy is that the agronomic crops are not cultivated in the same field during consecutive years to aid in the control of diseases and weeds. Therefore, crawfish production, which follows rice cultivation, does not occur in the same location in consecutive years. Under that method, three crops per field can be realized in two years. Dependent on a variety of factors, some producers may elect to plant another crop, such as hay, pasture or grain sorghum, or leave the field fallow instead of planting soybeans after the crawfish season. The field rotational approach is based on sufficient land resources to allow staggered crops in different fields within a farm and is the preferred cropping system for the larger commercial rice farmers. The advantages of the system over crop rotation within the same field are that each crop can be better managed and the crawfish production season can be extended. Furthermore, by rotating physical locations each year, overpopulation is rarely a problem, and often, crawfish size is larger because of lower population densities.

Crawfish yields under this management approach are not commonly as high as with monocropping systems, but, with proper management, yields can routinely exceed 900 kg/ha. Some disadvantages of this rotational strategy relative to crawfish production in permanent or semi-permanent ponds are: 1) crawfish must be restocked each year, 2) inadequate populations of crawfish sometimes result and 3) frequently, the bulk of the harvest occurs late in the season when seasonal declines in prices are common and marketing is difficult because of an abundant supply of crawfish, often exacerbated by peak harvest in the capture fishery.

Integration of Agriculture and Aquaculture

Notwithstanding the size and significance of the crawfish aquaculture industry today, few people make their sole living culturing crawfish. It is still mostly a secondary enterprise. Rice farmers comprise the largest share of commercial crawfish producers. Because they have the desired flat land with a suitable soil type, established irrigation systems, much of the necessary farming equipment and the organic residue base following grain harvest, it is an easy and logical choice for many rice farmers to include crawfish as a second, off-season crop. Rice farmers began incorporating crawfish into their operations early in the developmental phase of crawfish aquaculture. However, until profits from farm enterprises waned substantially in the early 1990s, crawfish harvests were generally regarded as incidental crops. Production inputs and efforts were minimal and derived income was considered to be extra income for the farm. In the past decade, this has changed considerably. Currently, with rice and other agronomic commodity prices at record lows and farming expenses at all-time highs, most rice/crawfish farmers now regard crawfish aquaculture as an indispensable component of their integrated farming system. In fact, many farmers have come to rely on revenues from crawfish harvest to substantially supplement the family farm income.

Status and Outlook for the Industry

The Louisiana crawfish aquaculture industry has not been without its share of impediments and hardships. Marketing difficulties have always been omnipresent because of the seasonality, 4 - 8 months per year of live product and competition with harvests from the capture fishery. Supply in excess of live market demand was traditionally processed for the tail meat, placed in frozen storage and marketed off-season. However, marketing difficulties have been compounded by massive imports of inexpensive crawfish tail meat from the People's Republic of China beginning in the early 1990s. Although an antidumping tariff has been imposed on much of the imported Chinese meat by the United States Department of Commerce, approximately 90 percent of Louisiana's domestic crawfish meat market has been lost. Of the 102 crawfish processing plants in operation in Louisiana in 1989, less than a dozen remain. Demand for Louisiana crawfish is now limited to mostly live product, which exacerbates production and marketing difficulties.

Seasonal variations in yield and unpredictable returns are also problematic. Because crawfish production relies on natural recruitment from indigenous or supplemented broodstock, favorable or non-favorable weather patterns often affect reproduction and growth, thus, yield and harvest size. Record low yields were recorded in Louisiana during the drought years of 2000 and 2001 and, in extremely wet years with mild winters, yields are often comprised of small, low-value, or non-marketable crawfish.

Notwithstanding the constraints and unpredictability, crawfish culture represents one of the strongest agricultural entrepreneurial opportunities in the state. At a time when profits of many of the traditional agronomic and animal industries are declining, potential for crawfish aquaculture remains strong. Though not without its difficulties, crawfish aquaculture seems to be the choice for many farmers struggling with other crops, as well as the occasional landowner who wants to incorporate a harvestable crop with conservational and recreational land uses.

This low-input approach to aquaculture may also be one of the more respectable models for sustainable aquaculture because it exemplifies judicious use of resources with minimal environmental impacts while providing sound economic benefits to communities (Caffey *et al.* 1996). Moreover, crawfish production systems provide substantial artificial wetlands, an important aquatic habitat for wildlife and a suitable replacement for much of the diminishing natural wetlands (Huner *et al*. 2002).

In summary, the extensive approach to crawfish aquaculture, as practiced in Louisiana, is an effective enterprise for producers, is acceptable to many conservationists, and truly can be deemed as one of the success stories for aquaculture and Louisiana.

Notes

[1]Rice Research Station, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, P. O. Box 1429, Crowley, Louisiana USA 70527-1429.

[2]Aquaculture Research Station, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, Baton Rouge, Louisiana USA 70820

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