Chapter 2. Crawfish Biology

Procambarus clarkii (red swamp crawfish) and *P. zonangulus* (white river crawfish), the two species of commercial importance found in Louisiana crawfish ponds, have similar ecological requirements. As a result, it is not uncommon to find both species in the same pond. Both species are associated with natural cycles of flooding and drying common to much of Louisiana, and both construct burrows, in which they survive and reproduce during temporary dry periods. There are some differences between the two species, but care must be taken when reviewing information about the white river crawfish (see "How Are Crawfish Classified?" in chapter 1) because early references may refer to this species as *P. acutus acutus*, or *P. zonangulus*.

The red swamp crawfish produces more, but smaller, eggs than the white river crawfish, and it is capable of spawning year-round in the South. It appears to do better in more nutrient rich-waters than those of the white river crawfish. White river crawfish are seasonal spawners, usually spawning only in the autumn in the southern United States. Feeding rates have been found to be greater for the red swamp crawfish at temperatures in excess of 86 F, indicating a possible competitive advantage at higher temperatures. In contrast, the white river crawfish may grow faster at lower temperatures, and it typically reaches a slightly greater maximum size. Usually the red swamp crawfish are found in greater abundance in waters with lower dissolved oxygen (DO) content.

In general, both species are adapted to the conditions found in commercial crawfish ponds, and both respond well to the low input systems of production used in Louisiana. The abundance of one species or the other may vary among and within culture ponds over time, but the red swamp crawfish most often dominates and is the most desired species in the marketplace. White river crawfish are most often found in greatest numbers in ponds that are used to culture crawfish year after year.

How these two species interact in crawfish ponds is not fully understood, but one hypothesis is that the red swamp crawfish tends to dominate in more ponds because of greater reproductive potential and a more prolonged reproductive season. No major difference in growth rate and survival between the two species has been observed under typical culture conditions. Some researchers suggest that later pond flooding dates (late October to November) may favor the white river crawfish because of its tendency to spawn later and its slightly larger hatchlings. These factors would provide an advantage over red swamp crawfish young that hatched at the same time. Recent research suggests that whichever species successfully produces large numbers of babies first during autumn months will predominate in the pond for the rest of the season. Much information is lacking, however, regarding interactions of these two species.

These two species are often similar in appearance, especially at a young age. They can be easily identified, however, by experienced persons. Despite efforts to exclude white river crawfish from many farms, both species will thrive under routine culture practices, and they often coexist in production ponds. No evidence exists of natural hybrids between these two species. Several books provide an excellent overview of the anatomy and biology of these and other crawfish species.

Red Swamp Crawfish

- *Procambarus clarkii*
- 70% – 80 % of annual catch in Louisiana
- Two halves of the carapace (head) meet to form a thin line
- Almost always have a blue-gray pigmented line on the underside of the tail
- Less elongated and more flattened claws than white river crawfish when mature
- Darker walking legs than white river crawfish
- Red pigment on adult bodies (except for rare color variations) – not always so with juveniles
- Lay eggs any time but mostly during fall and winter months
- Produce up to twice as many eggs as white river crawfish
- Thrive in systems flooded early in the fall
- Hatchlings smaller than white river crawfish
- Prefer swampy habitats
- Most young appear from September through December but can be found in all months
- Usually mature from April through June
- Native range is northeastern Mexico and the south central United States
- Commercially valued in Louisiana
- Introduced to many countries

White River Crawfish

- *Procambarus zonangulus*
- 20%-30% of annual catch in Louisiana
- Space called an "areola" separates each half of the carapace (head)
- No pigmented line on the underside of the tail as adult or juvenile
- More elongated and cylindrical claws than red swamp crawfish when mature
- Lighter walking legs than red swamp crawfish
- Never has red pigment on its body – sometimes adults can look pink
- Lay eggs only during mid- to late fall in Louisiana
- Produce fewer and larger eggs than red swamp crawfish
- Thrive in systems flooded in late fall
- Hatchlings larger than red swamp crawfish
- Prefer flooded wetlands with flowing, well-oxygenated water
- Usually mature from April through June
- All young appear from September through December in Louisiana
- Commercially valued in Louisiana
- Native range is Alabama, Louisiana, Mississippi and Texas
- Endemic only to the United States

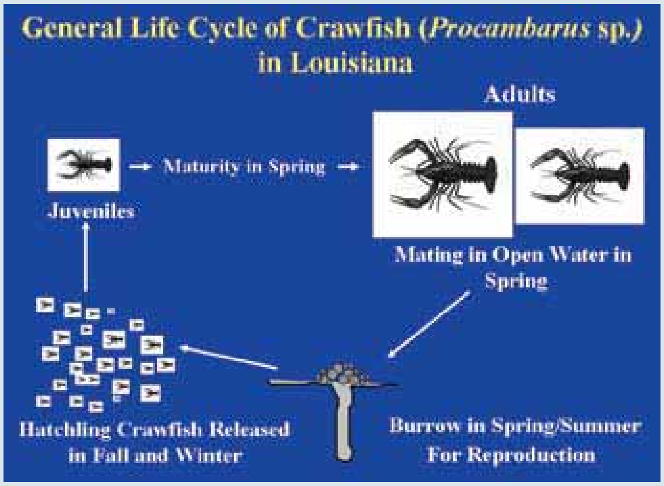


Figure 2.1. A diagram of the crawfish life cycle.

Figure 2.3. Crawfish burrows appear near the waterline in ponds when mature crawfish begin burrowing for reproduction. Burrows may or may not have the typical "chimney" associated with the entrance.

Life Cycles

Based on their distribution in North America, the red swamp and white river crawfish are classified as "temperate" species; that is, they will tolerate cold winter conditions. Both species, however, possess a number of traits that are usually associated with animals that live in warm waters. These species are short-lived (2 years or less), have high juvenile survival and can alternate between reproductively active and inactive forms. Moreover, *P. clarkii* is capable of spawning year-round in the southern United States, and some females can reproduce more than once per year.

These crawfishes have life cycles that are well-adapted to farm production strategies (Figure 2.1). Mature animals mate in open water where sperm is stored in a special receptacle, after which the female retreats to a burrow to eventually spawn. Burrowing activity can occur at any time but is most prevalent in late spring/early summer in Louisiana. Although spawning can take place in open water, the burrow provides protection while the fertilized eggs or young are attached to the underside of their mother's tail (Figure 2.2). Females carrying eggs or hatchlings are highly susceptible to predators, because they cannot use their normal tail-flipping escape response.

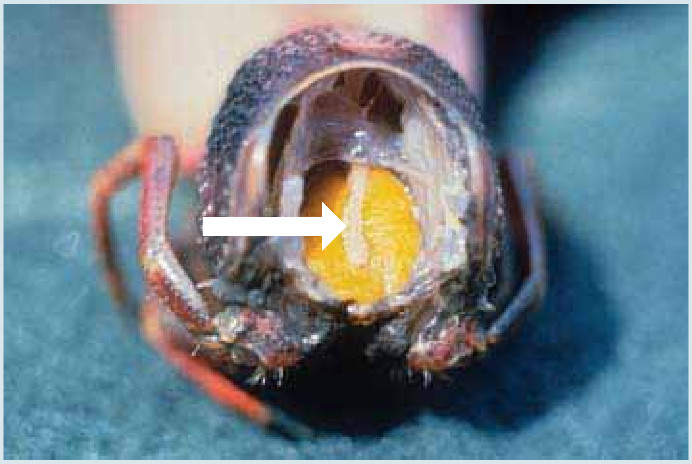
Figure 2.2. Crawfish eggs are typically laid and fertilized in the burrow where they become attached to the swimmerets on the underside of the female's tail.

Crawfish of all ages and sizes, whether mature or immature and male or female, will dig or retreat to burrows to survive periods of dewatering. Crawfish ponds are usually drained during the summer months to allow for planting and growth of vegetation. Prior to draining, some mature crawfish burrow near the waterline (Figure 2.3). As the water level drops, additional crawfish burrows appear lower on the levee and are sometimes found on the pond bottom; however, the burrows on the pond floor often contain a high percentage of non-reproductive crawfish, such as males and immature juveniles.

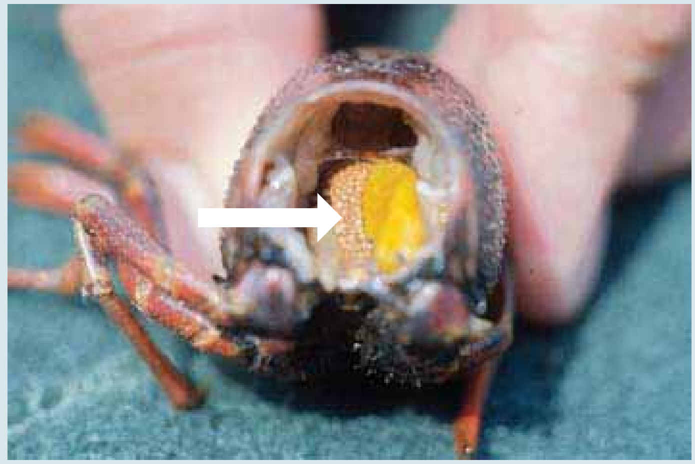
Ovarian (egg) development in mature females is temperature dependent, usually beginning prior to burrowing and reaching completion within the burrow. Developing eggs within the ovary become rounded, increase in size, and change from a light color to dark as they mature (Figure 2.4). At maturity, the large black eggs are shed from between the walking legs, are fertilized externally and are then attached to the swimmerets on the underside of the tail with an adhesive substance called glair. Although crawfish can survive in high humidity within the burrow, some standing water is necessary for successful reproduction. The number of eggs laid varies with female size and condition, but large red swamp or white river crawfish females can have more than 500 eggs.

The hatching period depends on temperature and usually takes about 3 weeks. Hatched crawfish are attached to the female's swimmerets through two molting phases, after which they resemble an adult crawfish and begin to feed. Hatchlings instinctively remain with the female for several weeks after their second molt although they are no longer attached. It is critical that the female and her young leave the burrow within a reasonable time because little food is available in burrows. When conditions force the crawfish to remain in the burrow, increased mortality can occur.

Pond flooding or heavy rainfall is usually necessary to encourage female crawfish to emerge from their burrows. Females emerge with their young (or sometimes with eggs) attached to their tails (Figure 2.5), and advanced hatchlings are quickly separated from their mother as she moves about in the open water. Because reproduction is somewhat synchronized in pond-reared crawfish, ponds are routinely flooded in autumn to coincide with the main period of reproduction. White river crawfish are autumn and winter spawners, but red swamp crawfish reproduction may occur at any time. Peak reproduction of



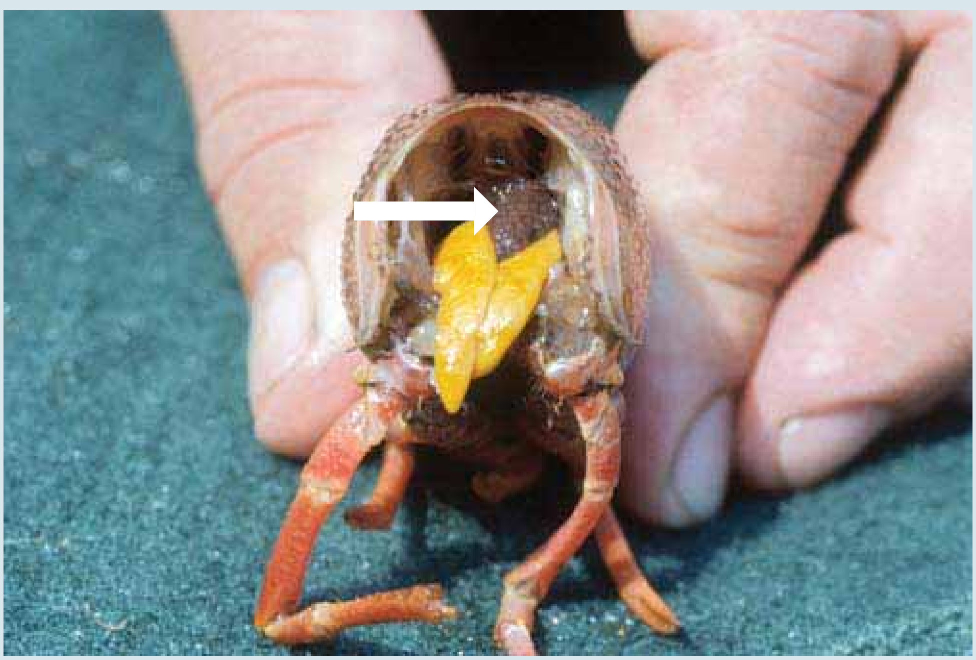
White eggs



Tan eggs

Yellow eggs

Brown eggs



Black eggs

Figure 2.4. Eggs in various stages.

Figure 2.5. Female with hatchlings attached to swimmerets beneath the abdomen.

red swamp crawfish, however, usually occurs in autumn, with minor pulses (or "waves") of hatchlings entering the population later. Extended reproduction and differential growth typically result in a population of mixed sizes in most ponds.

As with all crustaceans, a crawfish must molt or shed its hard exoskeleton to increase in size. Frequent molting and rapid growth occur in production ponds when conditions are suitable. Growth rate is affected by a number of variables, including water temperature, population density, oxygen levels, food quality and quantity, and to a lesser extent by genetic influences. Harvest size is typically reached 3 to 5 months after hatching for fall recruits, but it can be attained in as little as 7 to 9 weeks under optimum conditions.

When males and females molt to a reproductively active stage, growth ceases. Sexually mature individuals exhibit distinct characteristics, including darker coloration, enlarged claws, and hardened sexual structures. Mature males also develop prominent hooks at the base of the third and fourth pair of walking legs. The appearance of mature crawfish in the population usually increases as temperatures rise during late spring. Females will mate (often several times) after molting to a mature form and then begin the process of constructing burrows at the water's edge on levees.

Burrow Ecology

Several studies have provided more detail of crawfish burrows, but, in brief, crawfish cultured in Louisiana dig simple (unbranched), nearly vertical burrows, usually 40 inches or less in depth (Figure 2.6). Burrows serve as refuges from predators and provide moist or humid environments necessary for crawfish to survive through dry periods. Louisiana crawfish have evolved over millions of years to reproduce within the protection of their burrows. Most burrows are built at night and may require several days to complete. Crawfish burrows are usually dug by a single individual, and the burrow diameter is determined by the size of the crawfish. The burrow extends downward into a chamber slightly larger than the diameter of the tunnel.

Water levels in burrows vary with the moisture conditions in the soil. Free water at the bottom of the burrow is more often associated with "trapped" water than the actual water table of the soil. Walls of the burrow and terminal chambers are extensively worked by the crawfish, possibly to ensure good seals. The terminal chamber normally contains wet slush when water is not present, which serves as a humidifier. The entrance of the completed burrow is eventually closed with a mud plug (Figure 2.7), sometimes having a chimney or stack of the soil removed during excavation. Burrow entrances at the water's edge are often associated with natural cover, such as vegetation or woody debris. Over the course of the summer, weathering and covering by vegetation may make the burrow entrance undetectable.

Figure 2.6. An exposed crawfish burrow showing depth and construction.

Burrows usually contain a single female, or sometimes a male and female together, but occasionally they may contain additional crawfish. Successful survival and reproduction within the burrow depends on many factors, such as the severity and length of the dry period, characteristics of the burrow (such as depth, soil type and moisture) and health of the animal. Immature crawfish and crawfish forced to burrow by rapidly dropping water levels may construct shallow burrows that will not have sufficient moisture for survival during lengthy dry periods or drought. Soil types with limited clay content or soil with very high clay content that cracks when dry also may limit crawfish survival while in burrows.

Figure 2.7. Active crawfish burrows will eventually become sealed with a mud plug or cap. With time and weather, and covering of vegetation, the burrow entrance may become inconspicuous.

Once sealed in, crawfish are confined to the burrow until the hard plug that seals the entrance is sufficiently softened by external moisture from flooding or rainfall. Pond flooding, especially when associated with heavy rainfall, facilitates and encourages the emergence of crawfish from burrows.

Crawfish Population Structure

The appearance of new hatchlings in a pond is referred to as "recruitment," and these crawfish usually constitute the bulk of the annual harvest, even when significant numbers of holdover juvenile crawfish are present after flooding. Pond crawfish populations usually include (1) holdover adults from the preceding production season or stocking, (2) holdover juveniles from the preceding season and (3) the current young-of-the-year (YOY) recruits.

The number of age classes and numbers within age classes comprise the overall crawfish density. Crawfish density and population structure have a great impact on overall pond yields and size of crawfish at harvest. The highest densities and most complex population structures usually occur where crawfish have been grown in the same location for several consecutive seasons. In new ponds and ponds held out of production for a year or longer, crawfish density is often lower and the number of age classes is fewer. In these situations, crawfish are often larger and more uniform in size; however, overall yields may be considerably lower.

Population Dynamics

Unlike most aquaculture ventures, where known numbers and sizes of juveniles are stocked, crawfish aquaculture in Louisiana relies on natural recruitment (reproduction) from mature animals (either stocked or already present) to populate the pond. Population density depends largely on broodstock survival, successful reproduction and survival of offspring. Density is mainly influenced by environmental conditions over which producers may have little or no control. Additionally, improper management after autumn flood-up, including low oxygen levels, abundance of predators or pesticide exposure can negatively impact crawfish populations and subsequent production even when broodstock survival and reproduction are high.

Because of this lack of influence and control over population levels, population density and structure is probably the most elusive aspect of crawfish production. Extended reproduction periods and the presence of carryover crawfish from previous season often result in several size or age groups of crawfish being present in a pond at any given time. These various size/age groups are what make up the population structure.

Figure 2.8. Soft, freshly molted crawfish (top) and its cast exoskeleton (bottom).

Although "natural recruitment" in crawfish farming has many advantages, a significant disadvantage is that crawfish producers have little means of accurately controlling or even determining population density and subsequent yield. Available sampling methods are crude and currently include dip net sweeps and use of "test" traps. These methods are highly variable and subject to many sources of bias or error. Producers generally do not have a good assessment of their populations until harvesting is well underway in late spring, after pond temperatures have increased substantially.

Molting

As with all crustaceans, a crawfish must molt or shed its hard external shell ("exoskeleton") to increase in size (Figure 2.8); hence, the growth process involves periodic molting interspersed with inter-molt periods. Approximately 11 molts are necessary for young crawfish to reach maturity. A molt cycle is recognized as having five major stages, but it should be understood that the process is actually continuous. The inter-molt phase is the period in which the exoskeleton is fully formed and hardened. During this phase, crawfish feed actively and increase their tissue and energy reserves. Preparation for molting takes place in the pre-molt stage. This includes the formation of the new, underlying (soft) exoskeleton while a re-absorption of the calcium from the old shell occurs. During the late pre-molt period, crawfish cease feeding and seek shelter or cover.

Molting is usually accomplished in minutes. The brittle exoskeleton splits between the carapace (head) and abdomen (tail) on the back side, and the crawfish usually withdraws by tail flipping. During the "soft" phase that follows, the soft exoskeleton expands to its new, larger dimensions. Hardening (calcification) of the new exoskeleton takes place during the post-molt period, which can be divided into two phases. Initial hardening occurs when calcium stores within the body are transported to the new exoskeleton. Calcium is stored in the body both in soft tissue and for a short period in two hard "stomach stones" or gastroliths (Figure 2.9) located in the head, on each side of the stomach. These stones disappear during the initial hardening period after molting. The second phase of hardening is by absorption of calcium from the water. As crawfish resume feeding, further hardening of the new shell occurs.

Molting is hormonally controlled, occurring more frequently in younger, actively growing animals than in older ones. The

Figure 2.9. Gastroliths are found in the "head" portion of molting crawfish and are associated with temporary calcium stores.

increase in crawfish size during molting, and the length of time between molts, can vary greatly and are affected by factors such as water temperature, water quality, food quality and quantity, population density, oxygen levels and to a lesser extent by genetic influences. Under optimum conditions, crawfish can increase up to 15 percent in length and 40 percent in weight in a single molt.

In culture ponds, frequent molting and rapid growth occur during spring because of warming waters and adequate food sources. The appearance of mature crawfish increases as the season progresses. Rapid increases in temperature (above 80 F) may stimulate onset of maturity at smaller sizes, especially under conditions of overcrowding and food shortages. "Stunting," the condition whereby crawfish mature at an undesirably small size, is a problem in many ponds.

Nutrition

Crawfish have been classified as herbivores (vegetation eaters), detritivores (consumers of decomposing organic matter), omnivores (consumers of both plant and animal matter) and, more recently, obligate carnivores, which means that they "require" some animal matter in the diet for optimal growth and health.

Crawfish have been known to ingest living and decomposing plant matter, seeds, algae, epiphytic organisms, microorganisms and an assortment of larger invertebrates such as insects and snails. They also will feed on small fish when possible. These food sources vary considerably in the quantity and quality in which they are found in the aquatic habitat. Living plants, often the most abundant food resource in crawfish ponds and natural habitats, are thought to contribute little to the direct nourishment of crawfish. Starchy seeds are sometimes consumed and may provide needed energy, but intact fibrous plant matter is mostly consumed when other food sources are in short supply. Aside from furnishing a few essential nutrients, living plant matter provides limited energy and nutrition to growing crawfish.

Decomposing plant material, with its associated microorganisms (collectively referred to as detritus) is consumed to a much greater degree and has a higher food value. The ability of crawfish to use detritus as a mainstay food item, however, appears to be very limited. Fortunately, in a typical crawfish pond environment numerous animals besides crawfish rely on the microbe-rich detritus as their main food source. Mollusks, insects, worms, small crustaceans and some small vertebrates depend on detritus (Figure 2.10) and, when consumed by

Figure 2.10. A myriad of invertebrates in crawfish ponds, fed by decomposing plant fragments (top), furnish crawfish with the high quality nourishment needed to sustain maximum growth.

crawfish, these animals furnish high-quality nutrition. Scientists have realized that for crawfish to grow at their maximum rate, they must feed to a greater extent on these high-protein, energy-rich food sources.

Sufficient evidence has been established to indicate that although crawfish must consume high-protein, high-energy sources to achieve optimum growth, they can sustain themselves for some time by eating intact and decomposing plant sources and even bottom sediments containing organic debris.

Supplemental feeds are not routinely provided to crawfish aquaculture ponds. Commercial culture of crawfish relies on a self-sustaining system for providing nourishment to crawfish, as occurs in natural habitats where crawfish are abundant. An established (or at least encouraged) vegetative forage crop provides the basis of a complex food web (Figure 2.11) that ultimately fuels production of crawfish with harvests that typically average 400-600 pounds per acre and can often exceed 1,000 pounds per acre.

Plant fragments from the decomposing vegetation provide the "fuel" that drives a detrital-based production system, with crawfish at the top of the food web. As a result, the main means of providing nutrition to crawfish in aquaculture is through establishing and managing a forage crop. Ideally, once ponds are flooded in the fall, a constant and continuous supply of plant fragments fuels the food web from which crawfish derive their nutrition. (Also see chapter 5.)

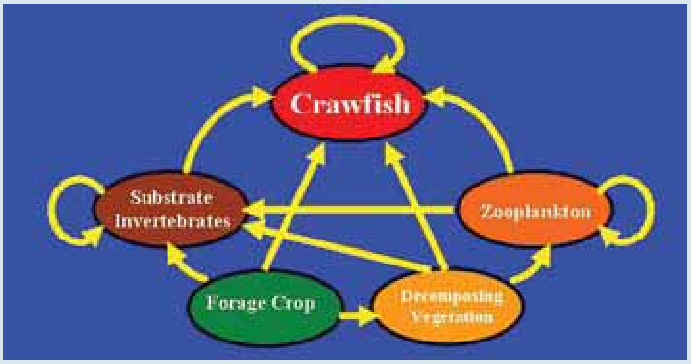


Figure 2.11. A simplified diagram of the nutrient pathways of the food chain in crawfish ponds, with the forage crop serving as the principal fuel and crawfish at the top of the food chain.