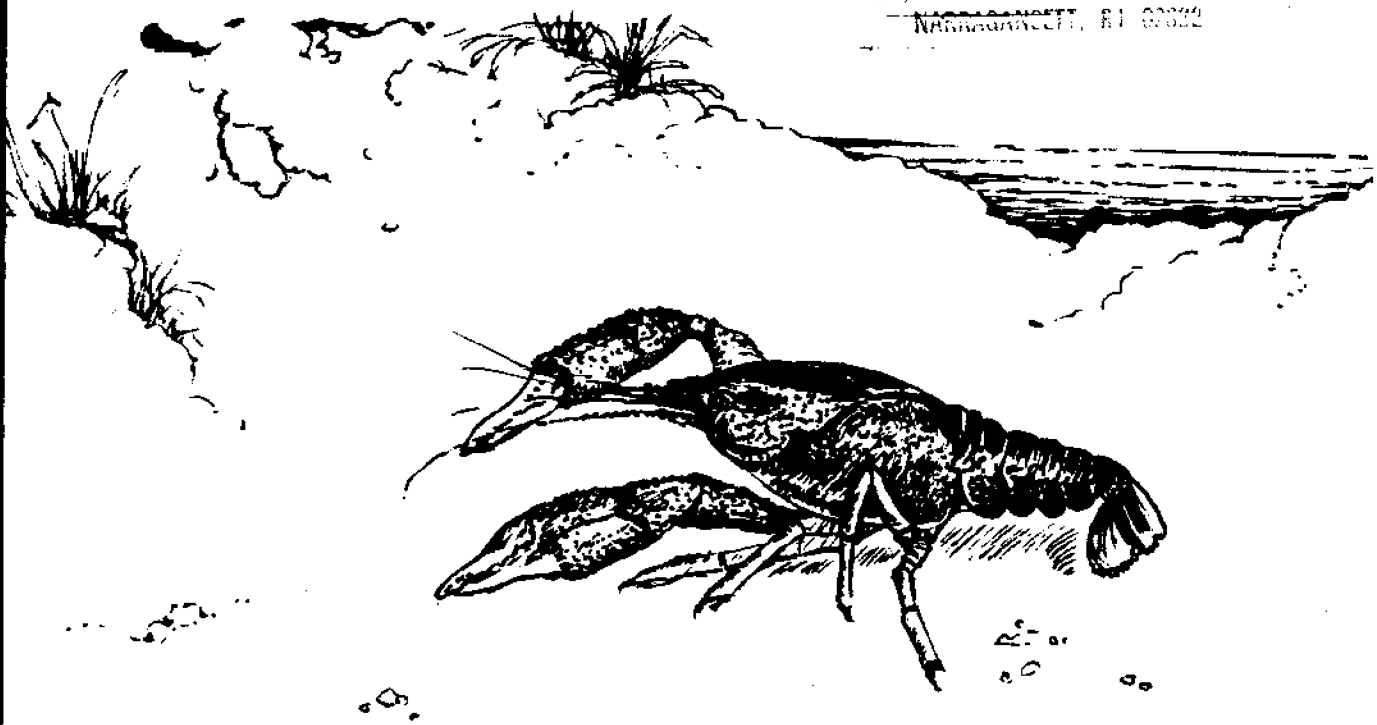
PRODUCTION GUIDELINES FOR CRAWFISH FARMING IN SOUTH CAROLINA



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COLUMBIA, SC

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INTRODUCTION

The overwhelming success of crawfish farming in Louisiana has generated a lot of interest among South Carolinians to try to grow crawfish in the state. An excellent cash crop, crawfish are relatively easy to grow. Preliminary studies completed by the Soil Conservation Service of the U. S. Department of Agriculture and the Lowcountry Resource Conservation and Development Project indicate that crawfish can be produced commercially in South Carolina.

Crawfish farming holds many advantages over traditional fish culture operations. These include the following:

(1) Initial investment, primarily for pond construction and purchase of brood stock, is relatively low.

(2) Since crawfish reproduce naturally in ponds, the brood stock is generally seeded only once to start a self-continuing population.

(3) The larval stages, as well as the maturing crawfish, do not require special diet or care.

(4) Growth is rapid. Crawfish born in the fall can be harvested the following spring.

(5) Crawfish in ponds can feed on a variety of food items, primarily vegetation and organisms associated with decomposing organic matter.

(6) Crawfish may be marketed either for bait or for food.

In South Carolina, present and prospective crawfish farmers have an additional advantage which the farmers in Louisiana do not have. Unlike in Louisiana, where natural fishery production accounts for about 60% of total annual crawfish production, South Carolina growers do not have to compete with production from natural populations. This insures relatively constant good prices for pond-raised crawfish. Furthermore, many areas in the state are swampy or marginal lands not utilized for agriculture or any other ecomonic purposes; these may be used for crawfish farming.

Crawfish culture basically requires the establishment of a self-perpetuating crawfish population in a restricted area. With good pond management, the population can be maintained indefinitely while getting good production every year. Since crawfish farming in South Carolina is still in its developmental stage, the experience in other states, notably Louisiana, will serve as the basis for the following guidelines on pond culture of crawfish.

In the southern United States, the species primarily cultured is the red swamp crawfish (_Procambarus clarkii_). Sometimes, the white river crawfish (_Procambarus acutus acutus_) is also cultured together with the red crawfish. The basic differences between the two are shown in Fig. 1. The two species generally have similar life history and habits. However, the white river crawfish cannot tolerate hot water and low dissolved oxygen conditions as well as the red crawfish. Furthermore, the red crawfish has greater egglaying capacity than the white crawfish. The following guidelines are primarily for culturing the red crawfish in an open pond environment.

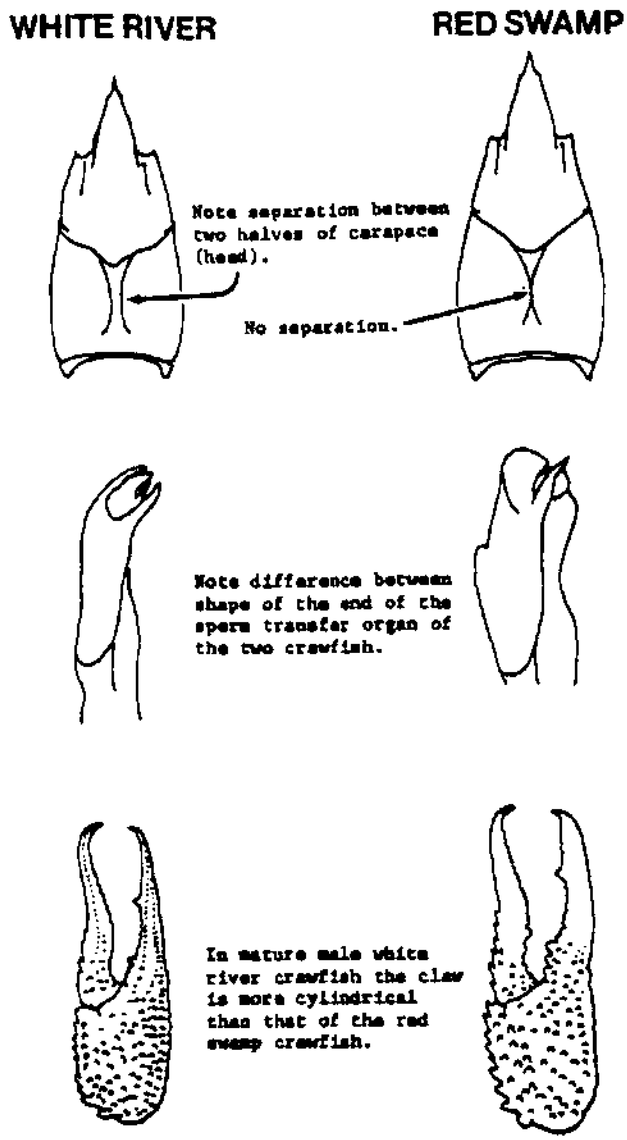

Fig. 1. Differences between the white river crawfish and red swamp crawfish. Mature adults also differ in coloration: red crawfish has dark red sides and reddish-black upper surfaces; white crawfish is very light brown with dark (black/brown) stripes down the upper surface of the tail.

GENERAL BIOLOGY OF CRAWFISH

A knowledge of the general biology of the crawfish is necessary for a better understanding of culture requirements and proper pond management. The following description of crawfish biology puts primary consideration on the aspects that will help the crawfish farmer deal with the organism in his pond.

General Anatomy (Fig. 2)

The crawfish has a body composed of a linear series of jointed segments, conventionally grouped into three body regions: head, thorax and abdomen. Each true segment bears one pair of jointed appendages which are modified for different functions. This jointing of the body and appendages is necessary to allow movement since the whole crawfish in encased in a hard and rigid cuticle or "shell" strengthened by saturation with calcium and other minerals. The shell, known as the exoskeleton, acts as a support for the internal organs and provides the mechanical framework for the attachment of muscles.

The segments in the head and thorax have become fused into a compact structure called the *cephalothorax*. The cephalothorax is covered on the back by a one-piece shell called the *carapace*, which extends on the sides to cover the gills and the bases of the thoracic appendages (*pereiopods* or "walking legs"). The carapace projects in front over the bases of the eyes and antennae as the *rostrum* which ends in a sharply-pointed *acumen*. On the top portion of the carapace is a concave-sided, median area termed the *areola*, which is used as one of the identifying characteristics of the different species.

The shell of the abdomen is composed of six overlapping strongly arched plates. The abdominal plates are connected by a thin layer of pliable cuticle

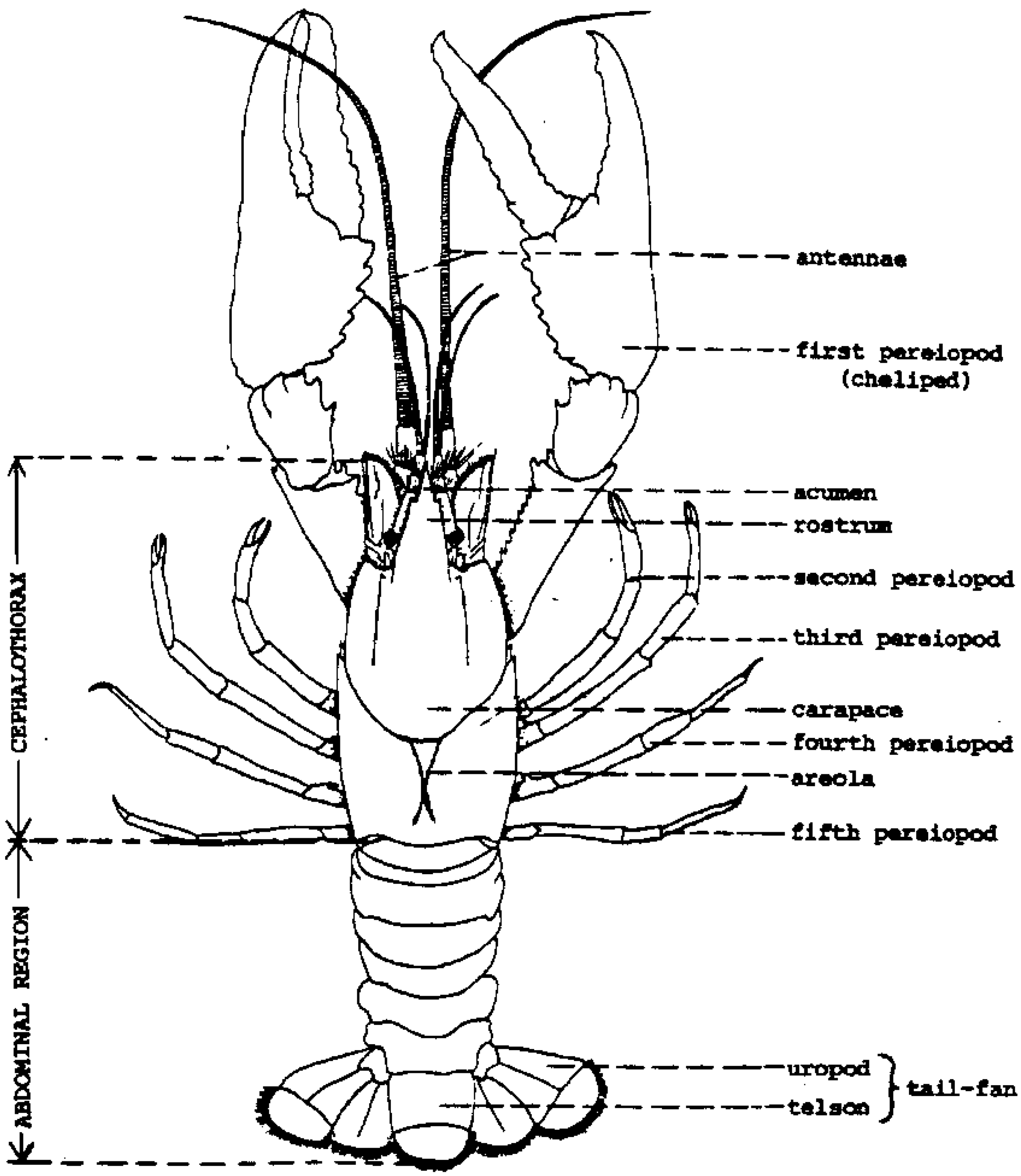

Fig. 2. The general anatomy of the crawfish.

which allows the abdomen to be flexible and to be curled forward under the body. The sixth abdominal segment bears a flat terminal *telson* or tail and a pair of flat two-branched *uropods* collectively forming the broad "tail-fan" of the animal used for swimming.

The appendages of the crawfish are arranged in serial segments and vary in form for a diversity of functions. Some of the head appendages (*antennae*, *antennules*) are sensory devices while others (the *mandibles* and *maxillae*) are grouped around the mouth and are generally concerned with grasping and tearing food and conveying the pieces to the mouth. The first three pairs of thoracic appendages (the *maxillipeds*) aid the maxillae in processing food. The next five pairs of thoracic appendages (the *pereiopods* or "walking legs") are elongated and used mainly for feeding and locomotion. The first three pairs of "walking legs" end in grasping claws or *chelae*. The chelae or claws of the first pereiopods are greatly enlarged and provided with strong muscles. These modifications allow the first pereiopods to be used for specialized activities such as procuring food, mating, burrowing and defense. The remaining four pairs of pereiopods are used for walking and sometimes for cleaning parts of the body.

On the underside of the abdomen are five pairs of short, weak appendages called the *pleopods* or swimmerets. In female crawfish, the first pair of swimmerets is reduced in size and single-branched, while the last four pairs are two-branched and are used as places of attachment for the incubating eggs. In male crawfish, the first two pairs of pleopods are highly modified to form accessory sexual organs which serve to transfer sperm from the male to the seminal receptacle of the female during copulation. The first pleopods (known as *copulatory stylets*) are hard and rigid and are used as the most important single character to identify crawfish species. The second pair of swimmerets are also elongate but not as hard and rigid as the first pair, and are used in conjunction with the first pair during copulation.

Sexual Differences

Mature crawfish exhibit clear external sexual characteristics which easily distinguish the sexes. Males usually have larger claws and narrower abdomens than the females. In the male crawfish, the first two pairs of abdominal appendages (pleopods) are highly modified as accessory sexual organs for sperm transfer. The sperm duct openings are visible on the inner bases of the fifth walking legs.

Mature males have two alternating forms. Form I is the sexually competent form. It is characterized by enlarged claws, increased length and hardness of all spines, and presence of prominent, strong hooks on the bases of the third and fourth pair of walking legs (the legs bearing the large claws are the first pair of walking legs). The copulatory stylets (the modified first pair of swimmerets) are hard with sharply pointed processes and the central projection has a horny, amber appearance. Form II occurs during the period between seasons of reproductive activity and closely resembles the juvenile form. The exoskeleton is less robust, the hooks are shorter and weaker, and the first pleopods are more blunted and less rigid.

In the female crawfish, the first pair of swimmerets are greatly reduced. Located between the bases of the fourth and fifth walking legs is a grooved, calcified area known as the sperm or seminal receptacle. This organ receives the sperm from the male and holds it until the time of fertilization. The genital pores are on the basal segments of the third pereiopods.

The sexual differences are summarized in Fig. 3 and Table 1.

Table 1. Distinguishing characteristics of female and male (Form I and II) crawfish.

Feature	Female	Form I Male	Form II Male
Claws	Smaller	*Larger*	Large
Abdomen	Broader	*Narrower*	Narrower
Site of Genital Pores	On basal segments of third pereiopods	On basal segments of fifth pereiopods	
First Pair of Pleopods	Reduced in size	Modified as copulatory stylets: *Hard, sharply pointed*	Less rigid, blunted
Second Pair of Pleopods	Normal (similar to other pairs)	Modified: elongated, bent forward	
Hooks on 3rd and 4th Pereiopods	None	*Prominent, strong, long*	None

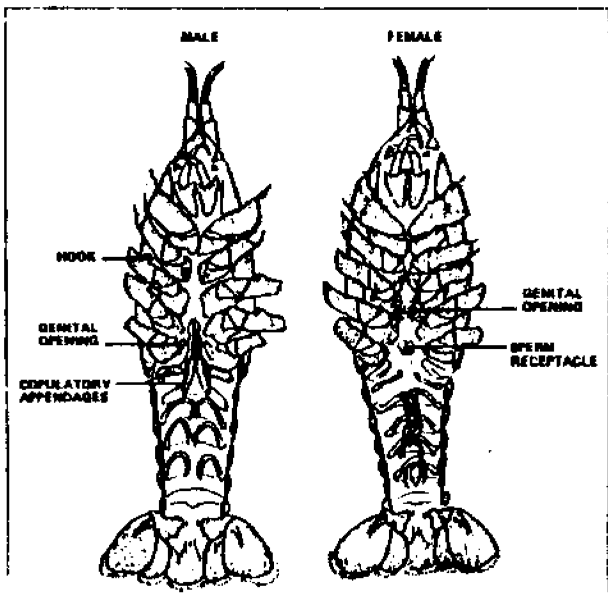

Fig. 3. Ventral views of Form I male and female crawfish, showing major differences.

Life History

The peak of the breeding season occurs in late May and early June. During the mating season, the breeding males are in Form I stage and their sperm ducts are full of recently formed sperm. The male actively seek out a mating partner. During copulation, the male crawfish deposits sperm into the seminal receptacle of the female where it is stored until egg-laying in September and early October.

Shortly after the peak of the breeding season in early summer, when water temperatures of 85-90°F are prevalent, the female burrows on the shore near the water's edge, usually in heavy weeds under chunks of mud and debris as protection from predators. The burrow is essentially vertical, usually two to four feet deep, and generally reaches the water-table level. Each burrow is capped with a plug of dirt if the female inside has been fertilized; an unfertilized female leaves the burrow open until a male enters. The plug also serves to prevent entry of snakes, frogs and other predators. Young crawfish and unpaired males do not burrow; instead they seek shelter in the mud or in naturally occuring holes during summer when their habitats are drying up. Some additional matings may occur in the burrows, but the crawfish are believed to be essentially inactive until September or early October when eggs are laid.

As the eggs are laid, they are fertilized by the sperm held in the seminal receptacle of the female. After fertilization, they are attached to the pleopods or swimmerets by a sticky substance called glair. Sometimes a female will lay eggs that are unfertilized. Infertile eggs are orange and will be dropped by the female within a matter of days; fertile eggs are dark gray to black. The number of eggs a female may carry varies in direct proportion to female size. A female may carry from 100 to 700 eggs. In general, the larger the female, the greater the number of eggs carried.

Although the eggs are generally laid while the female is in the burrow, sometimes a female will lay its eggs in the open water. The female carries the eggs in her underside until they hatch. Hatching takes place about two to three weeks after oviposition; the peak of the hatching season occurs in early fall. After hatching, the larvae stay attached to the female for a few days. When hatching occurs in the burrow, the young crawfish usually suffer from overcrowding and lack of food when they leave the mother crawfish. After complete detachment from the mother, the young crawfish usually seek shelter in dense plant growth in shallow water near shore or along the banks of ponds.

Feeding primarily on the tender shoots and young leaves of vegetation, the young crawfish grow rapidly especially if the water temperature is about 60°F or more. They can grow to market size (when they cannot slip through a 3/4 inch mesh net) in two to three months under ideal conditions; maturity may be reached in less than six months after hatching.

Growth

The growth in size of crawfish is prevented between molts by the rigid, inexpansive exoskeleton or shell. In order to grow, the crawfish must shed its exoskeleton periodically; this process is known as molting or *ecdysis*. Thus the crawfish grows in a series of abrupt steps rather than in an uninterrupted progression. The animal eats for a period and builds tissues internally. Then, it splits the exoskeleton at a point between the back surfaces of the carapace and the abdomen, and crawls out, shedding all of its protective shell. The body is soft at this time and can expand rapidly before the new shell hardens and prevents further growth. The molting processes are a complex physiological cycle controlled chiefly by temperature, light, and hormonal conditions.

Great differences in growth rate are usually found among crawfish in a habitat or even in the same brood. These differences are probably due to varying activities and amounts of food consumed. The average increment of growth as determined from measurements of carapace length before and after a molt is about one-eighth of an inch. Under South Carolina conditions, fast growth occurs in spring. On the average, there are about 40 crawfish per pound in February, 30/lb. in March-April and 15-20/lb. in May-June.

Food Relationships

Crawfish are generally omnivorous; they will eat dead and living plant and animal matter. They eat all kinds of succulent aquatic vegetation, preferably water primrose, alligator weed, smartweed, duckweeds and other tender plants. They can also eat non-aquatic plants such as white clover, alfalfa, Bermuda grass, sorghum and various millets. About 20% of the diet consists of insect larvae, worms and any other aquatic animal material they can find, especially in decaying vegetation. Vegetative material contains large amounts of microscopic animals, particularly during the stage of decomposition. Crawfish are seldom predacious on larger animals as fish but they will kill and eat other crawfishes which have recently molted and are still soft.

In turn, crawfish are eaten by various fish, wading birds, frogs, turtles, snakes, raccoons, otter and opposums. The young crawfish are especially vulnerable to these predators. Among the fishes known to prey on crawfish are bowfin, green sunfish, warmouth, catfish (especially bullheads) and large-mouth bass, among others.

SITE SELECTION CRITERIA

Investing into crawfish farming should be approached deliberately with decisions based on sound facts and not on wishful thinking of raking money from a mud hole. As in most systems of aquaculture, it is crucial to select suitable sites for crawfish culture operations. The selection of a suitable site determines pond construction costs and strongly influences the economic viability of the operations. The following guidelines should be considered when choosing a site for crawfish farming.

Topography

The best sites for crawfish ponds are in small, stable drainage areas where the possibility of flooding is remote. Ideal locations are on land that is relatively flat or nearly so, with 0.1% slope or less. This means that for each 100 linear feet, the elevation changes 0.1 of a foot. Another good location is a small basin requiring only small dikes to dam it up. Both types of locations can insure consistent pond water depths of about 18 to 36 inches. Irregular bottom contour may be undesirable since it interferes with complete draining. If ponds are situated in marginal areas, they can be constructed in such a way that the bottom contour is relatively flat or gently sloping downwards to the drainage outlets. With proper pond construction, the topography of the site should permit the ponds to be drained completely when needed without much pumping. If a site chosen is subject to flooding, it is important to build strong dikes higher than the historic high-water mark in the area.

Vegetation

Kinds of natural vegetation in the proposed site may affect the success of the crawfish culture operations. Areas of dense growth of water hyacinth, cattail, and other plants that do not provide food for the crawfish, are not recommended unless management procedures are undertaken to eradicate these undesirable plants before ponds are stocked. Densely wooded areas also are not good sites for crawfish ponds since clearing of such trees and underbush may entail additional construction costs. Furthermore, wooded ponds usually have poor wind circulation, and with added decaying leaves, can cause oxygen depletion. Water in wooded ponds is also generally acidic, with low pH and low total hardness, which are not conducive to good crawfish growth.

Accessibility

Accessibility to the ponds is also of some importance since ponds not readily accessible are seldom well-managed. However, the farmer should be aware of potential poaching in ponds conveniently located and must plan accordingly. If vehicular traffic is necessary on a dike, it should be designed for that purpose.

Soil Considerations

The two most important aspects of soil quality for a crawfish pond are soil composition and soil chemistry. The pattern of best soil type correlated with good crawfish production is still not completely clear. Crawfish are found in the wild and can be cultured in many soil types. Before constructing a pond, it is wise to have the site evaluated. It must also be kept in mind that soil composition is highly variable, even within small areas.

It is best to construct ponds on soils with good water-holding capacity. Recommended soils are those with high clay content; soils in present crawfish ponds in South Carolina have at least 35-55% clay and they retain water relatively well. Clayey soil has good water retention and at the same time facilitates the burrowing by crawfish during the reproductive season. The best soils for ponds are clays, silty clays and sandy clays. Some soils have silty surfaces that should be scraped off and the silty clay or clay layers below used for construction of the dikes.

Primary considerations for soild chemistry are the soil pH, inherent fertility of the soil, and pesticide contamination. Optimal soil pH for crawfish production is about 6.7 to 7.0. Slightly acidic soils with low pH may need liming to bring the pH to optimum levels. Studies have shown that soil types have less effect on crawfish production than water hardness. A relatively high soil pH insures that the total hardness of pond waters would be above the minimum levels of 20 parts per million (ppm or mg/liter of calcium carbonate). A soil pH of about 6.7 is correlated with water total hardness of 50 ppm.

The inherent fertility (the presence of primary plant nutrients such as nitrogen, phosphorus and potassium) of the soil strongly influences the quantity of crawfish that can be produced in a pond. The importance of secondary plant nutrients, such as calcium, has been also documented. The calcium in soil and water is significantly important for the growth and survival of crawfish. Soil tests should be made to determine the amounts of nutrients present in the soil and the lime requirements of the pond.

Ponds located in heavy agricultural areas may have soils contaminated by pesticides. It has been documented that high concentrations of endrin, dieldrin and other common pesticides and herbicides in soil cause the water to become toxic to crawfish when the pond is flooded. In assessing possible pesticide pollution, the farmer must consider not only soil at the prospective pond site but also the potential of contamination by air- or water-borne pesticides in the area.

Water Requirements

Two important aspects to be considered when selecting an area for crawfish ponds are the quantity and the quality of water supply available for the ponds.

Water Quantity

Water should be available in sufficient quantity to fill the pond easily when needed or to compensate for water losses. The available water should be enough to

(1) Compensate for evaporation losses - Since crawfish ponds utilize relatively shallow water depths, there is a high surface area to volume ratio which causes higher evaporation rates relative to water volume, especially during the hot periods.

(2) Compensate for seepage losses - Soil used in crawfish impoundments vary in porosity; regardless of soil type, ponds lose some water by seepage.

(3) Replenish pond water and thus furnish or regulate oxygen available in pond water - Oxygen depletion can occur in ponds especially during hot periods and when there is much decaying vegetation. Depletion detected early may be corrected by draining some water from the pond and replenishing it with oxygen-rich water. Sufficient water volume should be available for a rapid change of pond water within 3-4 days when needed.

Water Quality

To insure good crawfish production, there should be a constant supply of good, non-contaminated water for the pond. A good quality water supply should have at least the minimum levels (details below) of oxygen content, temperature, total hardness, pH, dissolved mineral contents and other water characteristics required for good crawfish growth and production.

Although crawfish can survive for some time in low oxygen concentrations in water, abrupt changes in dissolved oxygen in the lower end of the scale can cause mass mortality of crawfish. Juvenile and molting crawfish are especially susceptible to oxygen tensions of less than 1.0 ppm. Oxygen content of the water should be at least 3.0 ppm.

To insure provision of minerals (primarily calcium and magnesium) needed by the crawfish for basic metabolism and for shell formation during the molting process, water hardness of at least 50 ppm is required. (Water below 50 ppm total hardness is considered soft water). Soft water results in thin, soft shells as well as poor growth and survival. Studies have shown that as water hardness increases up to 200 ppm, growth and survival also increase.

Cultured crawfish have been observed to do well at pH levels as low as 5.8 and as high as 8.5. However, the recommended pH levels are between 6.5 and 8.0. Crawfish in acidic water (low pH) tend to have thinner shells which may hamper good survival.

Lastly, the water supply should be relatively free of contaminants and pollutants, such as insecticides, herbicides, petroleum compounds and other substances, potentially toxic to crawfish. Although the effects of many pesticides, herbicides and other compounds on crawfish have not been fully studied, the following substances are now known to be toxic to crawfish: methyl parathion, endrin, DDT, Sevin, Bidrin, Didrom, phosphamidon, pryethrum, commercial creosote stock dips, coal tar creosote, orthodichlorobenzene, sodium cyanide, turpentine, ortho cresole, cresylic acid, miscible pine oil, nicotine, carbon bisulphide, phenothiazine, calcium cyanamid, and the organophosphates Guthion and Azodrin. Generally, insecticides are the most toxic substances tested so far. Caution must be taken when using water supply near crop drainages.

Water Sources

Water sources for a crawfish farm may be groundwater or surface water. Both sources have their own advantages and disadvantages as shown in Table 2. Some problems associated with each water source may be solved as follows:

(1) *Low Oxygen Content:* Water may be run from some distance through a series of baffles or over rocky substrate, splashed on a platform, or otherwise broken up into small droplets by other methods, for oxygenation before introduction into the ponds.

(2) *Presence of noxious gases:* Same as for solution for low oxygen content to dissipate the gases.

(3) *Presence of predators or competitors in water source:* Place a series of screens (hardware cloth or wire screens) of various mesh sizes in front of the incoming water to prevent unwanted organisms, both the adult and larval forms, from entering the ponds.

(4) *Large silt load:* If stream water with large silt load is used, it is best to let the silt precipitate out in a settling pond before putting the water into the ponds.

(5) *High iron content in well water:* Same as for solution to large silt load.

The crawfish farmer should try to determine the general quality of the prospective water source by having it checked by the Soil Conservation Service beforehand. Generally, stagnant lakes and water sources with recent fish kills should be avoided as source of water for the ponds. Groundwater sources are the most desirable as a water supply as long as they are properly oxygenated. Good springs are preferred since pumping costs are eliminated. Wells are also desirable if pumping costs are not a problem to the farmer. Surface water sources can be used if they are relatively free of contaminants and pollutants and procedures taken to eliminate unwanted organisms before the water is put into the ponds.

Table 2. Advantages and disadvantages of potential water sources for crawfish aquaculture.

WATER SOURCE	ADVANTAGES	DISADVANTAGES
1. GROUNDWATER (in general)	-Usually pollution-free	-May entrain hydrogen sulfide, methane and other noxious gases toxic to crawfish
	-In limestone areas, water is hard, with considerable dissolved calcium	-In granitic areas, water tends to be soft and low in dissolved minerals
	-Normally, with constant temperature	-Low oxygen content
a) Springs	-Same as for groundwater in general -Require no pumping to get the water to the surface	-Same as for groundwater in general -Some springs may dry up or have reduced discharge during dry months
b) Wells	-Same as for groundwater in general	-Same as for groundwater in general -May require pumping -May have high iron content
2. SURFACE WATER	-Generally well-oxygenated	-Greater risks for pollution problems
a) Streams	-pH and dissolved mineral content may be high depending on topography and type of substrate	-May have large load of dissolved and suspended organic matter, silt and pollutants -Contain organisms of various types which may be predators or competitors of crawfish -There may be legal problems with diversion to ponds
b) Lakes, Ponds	-More constant pH, dissolved and suspended nutrients and minerals than streams -Lower silt load than streams -If large enough, no problem of drying out in hot months	-May require pumping to get water to ponds -Disease risks higher than in streams since water is generally stagnant -Possible problems of predators and competitors being introduced into ponds -Possible conflict of usage with others

POND CONSTRUCTION

Proper pond construction insures better control of factors such as water and vegetation management, water circulation and harvesting. Technical assistance from personnel of the Soil Conservation Service should be sought when constructing the ponds.

Two primary types of ponds may be used: embankment and excavated ponds. Embankment ponds are formed by constructing a dam, dike, levee or similar above-ground structure to impound water. Excavated ponds are constructed by removal of soil from an area to form a depression or hole which is then filled with water. Some sites may require both embankment and excavation to obtain the desired water-holding capacity. Embankment ponds may be made in a variety of topographic conditions and may be flooded or drained by gravity flow. Excavated ponds need to be constructed in relatively flat topographic conditions and may require pumping of water for flooding or draining purposes. The choice of the pond type depends on the topography of the site, soil type, water source and other factors. Whatever type of pond is constructed, certain aspects of building ponds require some attention.

Size Considerations

Ponds of all sizes may be used for crawfish farming. Large ponds (larger than 10 acres) have less construction costs per acre of water, have higher crawfish population carrying capacity, and are more subject to wind action making them less susceptible to oxygen deficiency. Small ponds have more construction costs, but insures rapid flooding and draining and ease of controlling vegetation during dry periods, are easier and quicker to harvest, and provide ease when treating crawfish for disease and parasites.

In general, crawfish ponds can range in size from less than an acre to about 20-40 acre "one-family" operations to over 300 acre systems, necessitating the employment of 10-20 harvesters/helpers. Crawfish crops are generally greatest in ponds smaller than 10 acres, apparently because there is more dike area for burrowing relative to total surface area in small ponds than in large ponds. It is recommended that ponds for bait crawfish farming should not exceed five acres since extended production of bait-sized crawfish depends on differential flooding and high population densities. Whatever size of pond the farmer chooses, the pond should have an average water depth of about 18 inches, preferably 12 to 36 inches, to inhibit bird predation, and must be drainable.

Dikes

Perimeter dikes should be high enough to keep flood waters out and wide enough to allow vehicular traffic when needed. The dike construction area should be cleared of any standing timber, stumps, logs, roots and other organic material; they will rot eventually, causing leakage. Soil used for dike construction, whether excavated from the pond site or from a carefully selected borrow area, must have low permeability to prevent excessive water loss by seepage. Dikes should be well vegetated to prevent erosion; common bermuda grass and bahia grass may be used for this purpose.

Top Width

There are several different recommendations to determine the top width of an earthen dam or dike, including those of the Soil Conservation Service and some engineering textbooks. These may be summarized as follows. For a dam or dike ten feet high or less, the minimum top width should be about six feet. If the dike is to be used as a roadway for vehicular access to the pond, top width should be at least 12 feet, and preferably 14-15 feet. A two-foot wide shoulder should be provided on each side of a roadway to prevent raveling. To facilitate harvest, dike repair and monitoring of the pond, access is always necessary to at least one side of the pond; it is usually best to provide access to all sides.

Side Slopes

The side slopes of the dike depends on the type of soil used. Slopes of 3:1 (horizontal to vertical) are most commonly recommended since mowing and other equipment may be more safely used on them. In highly stable soils, the slopes may be reduced to 2.5:1 on each side of the dikes, or to 2:1 on one side and 3:1 on the other side so that the combined slopes are 5:1 for both sides. Unstable soils may need 4:1 or flatter slopes.

Dike Height

The final dike height depends on freeboard, settlement allowance and water depth. Freeboard is the distance between the water line in the pond and the tope of the dike; about one to two feet of freeboard is needed for crawfish perimeter dikes. For dikes with ponds up to about 200 yards long, freeboard should be one foot; ponds from 200 to 450 yards long should have about 1½ foot freeboard; and for ponds exceeding 450 yards in length, freeboard should be at least two feet.

Even if the dike is constructed by layer-by-layer compaction, some settlement will occur, depending on the soil material used. Settlement allowance should not be less than 10% of the dike height. For dikes built without extensive compaction, the settlement allowance should be 20 to 25% of the dike height. For dikes built in organic slush or mud, up to 40 or 50% should be allowed for settlement.

Bottom Profile

It is not essential that the pond bottom be absolutely level; small "humps" appearing when the water is gradually let down afford places for the crawfish to burrow in. To facilitate drainage, the pond bottom should slope toward the drain outlet with a minimum slope of 0.1% (0.1 foot vertical fall per 100 feet horizontal distance); preferably, the slope will range from 0.3 to 0.6%.

Pond Drainage System

One deciding factor in the success or failure of a crawfish farm is water circulation. To facilitate circulation, it is necessary to provide not only an adequate inflow of water but good drainage as well.

Water Inlet

A well-constructed water inlet should be able to (1) assure a regular and controllable supply of water for the pond, (2) prevent the escape of crawfish, and (3) keep out undesirable fish and other organisms from being introduced into the pond. To meet the last two conditions, screens with mesh sizes small enough to keep out the young stages of undesirable organisms may be installed at the mouth of the water inflow of the pond. To ensure a regular, controllable flow into the pond, valves to control water flow rate should be attached to inflow pipes if pumping or gravity flow through pipes is used, or vertical sluices may be constructed if water flows through an inflow gate or trunk. In general, the pump or water inflow gate should be located at the highest point or elevation of the pond. If a pump is used, the output capacity of the pump should match the size or capacity of the pond. Inflow rate of the water should be capable of completely changing the water in the pond in about 3-4 days. This is especially important when rapid draining and reflooding is needed to flush deoxygenated waters from the pond during very warm months when oxygen depletion is likely to occur.

Pond Outlet

Drain pipes or outflow gates should be located as far away from inlet pipes or inflow gates as possible to permit thorough mixing of fresh water in the pond. Drains should be screened with ½ inch mesh or smaller screens to prevent the escape of crawfish and should be large enough to allow complete draining of the pond in three to four weeks. Thus a well-constructed drain system should be able to control the level of the water when the pond is being filled, prevent escape of crawfish, and permit progressive draining.

A well-designed pond generally has two outlets, which may be combined into one structure, depending on the size of the pond and the contributing watershed area other than the pond, if any. There should be a *mechanical spillway* that carries the normal expected outflow from the pond when draining and during small rainfall events. An *emergency spillway* designed to evacuate excess water during storms or heavy rains may be needed to prevent pond water from overtopping the dikes. Just like in the inflow system, structures or devices such as sluices, a series of removable boards and valves, should be provided in the drain to control the outflow when needed. The drain outlet should be located in the lowest spot in the pond to allow complete drainage. It may be helpful to gravel the pond bottom of the immediate area of the drain to prevent its being scoured or clogged with silt.

<u>Several Ponds in One Area</u>

For a series of ponds constructed in one area, the ponds should be built so that each one may be individually flooded and drained. With no water passing from one pond to another, the spread of disease and passage of waste from one pond to the other are prevented. This system also makes possible draining any pond for harvest or repairs without affecting other ponds. This is especially important for sequential flood/draining necessary for good bait crawfish production.

PRODUCTION GUIDELINES

The pond culture of crawfish is based primarily on the simulation of the natural hydrological cycle to which the crawfish life cycle is adjusted in natural habitats. The crawfish farmer should establish, maintain and manage a self-sustaining population of crawfish in his pond. This requires initial stocking, proper control of water and vegetation, and reasonable harvesting that will insure adequate stock for the next season.

Stocking

Stocking of the "seed" crawfish is necessary the first year, after which the population, if properly managed, should be self-sustaining. Ponds are usually stocked with adult crawfish from late April to mid-May. The ponds should be flooded for at least two weeks before stocking and have some vegetation or other form of cover for the crawfish. Freshly caught crawfish should be used for stocking purposes and pond-spawned crawfish are preferable since they are more or less used to pond systems and are less likely to migrate from the pond after stocking. The crawfish should be placed in the pond as soon as possible after being caught or harvested and kept cool and damp until that time. To reduce predation on newly stocked crawfish, the stock should be released in densely vegetated areas, or in the deepest water, far from the pond edge, if little cover is present.

Stocking Rates

Stocking rates will vary with existing conditions of the pond. In ponds where crawfish are already present, 20-25 pounds per acre may be stocked. In a densely vegetated pond with no existing crawfish population, a stocking rate of 40-50 pounds per acre is recommended. Densely wooded ponds and open ponds with sparse vegetation should be stocked at 45-60 pounds per acre. Ponds with no or very little natural vegetative cover requires a higher stocking rate because of higher predation losses; up to 100 pounds per acre may be stocked in these ponds, depending on price and availability.

The above stocking rates are based on medium to large crawfish (13-17 per pound). It is highly recommended that sexually mature crawfish in a ratio of at least one female to one male should be used for stocking; a ratio of one male to three or four females will insure heavier reproduction.

Restocking

In properly managed ponds, further stocking is generally not necessary. There should be enough adult crawfish present after harvest to insure adequate stock for the next season. Harvesting should be stopped when trap catch is less than half a pound per trap per day during the few weeks before draining of the pond. Ponds with less than fifty pounds per acre at the time of draining should be restocked to this level prior to drainage. This will insure that enough crawfish are present to produce further crops.

Water Management

An important management procedure in crawfish culture is the manipulation of water level and quality. This involves the draining and flooding of the ponds at the right time to insure reproduction by the mature crawfish and the production of young crawfish, respectively.

Draining

Every year ponds should be drained in late spring or early summer to simulate the summer drought of the hydrological cycle in the natural habitats of the crawfish, during which time the crawfish burrow and reproduce. Although crawfish may be able to reproduce even when there is water year round, draining accomplishes three functions. First, it forces the crawfish to burrow more or less during the same period, thereby insuring simultaneous reproduction which would yield heavy recruitment of young crawfish during the flooding time. Secondly, draining and the subsequent drying out of the pond allow annual grasses and semiaquatic plants such as alligatorweed, smartweed and water primrose to grow and become established in the pond, insuring enough vegetation for food and cover for the young crawfish after the pond is flooded. Lastly, draining facilitates the implementation of measures for control of unwanted vegetation and predators, as well as work on pond and/or dike repair, if needed.

Water should be drained gradually in late June or early July. A quick method to determine when to start draining is to look for burrows of early burrowing females; if burrows can be seen, usually along the banks or under logs or heavy debris in the pond, the farmer should start draining. Slow draining is preferable to allow young crawfish to seek hiding places for the summer and let the adults have time to find suitable burrowing areas. Fast draining will strand some crawfish which are not ready to burrow and expose them to predators. Pond draining should proceed no faster than two or three inches per day.

Flooding

After a period of drying, during which time the crawfish reproduce in the burrows, ponds are flooded to insure that the newly hatched crawfish will have ample water. Flooding softens the burrow plugs and allows the female and the young crawfish to escape from the burrow and start feeding and drowing. Flooding should take place when the water is still warm enough to promote rapid growth and cool enough to hold more oxygen, thereby slowing vegetative decay and increasing the oxygen content of the water.

It is generally recommended that flooding takes place in the late September and early October. The farmer can determine exactly when to flood by digging up a few burrows and observing the condition of the eggs or hatched young of the burrowed females. If the females are in berry with dark eggs, the farmer should be ready to flood the pond in two or three weeks. If the young crawfish have hatched out but still are clinging to the underside of the females, it is best to flood within a week. If the young crawfish have left the females and are freely swimming in the burrow water (this can be determined by siphoning with plastic tubing the water from the burrows), immediate flooding is needed. Checking the burrows should be done at least once a week starting in early September.

Water Circulation

Water quality in the pond is a key factor to good crawfish production. Under certain conditions, oxygen depletion may occur. This usually happens during the warm fall and spring months when vegetation is decomposing rapidly. This problem may be alleviated by good water circulation. The cheapest and easiest way to improve circulation is to exchange every seven days, if not sooner, the pond water with good oxygenated water. This will flush out the deoxygenated water and bring in fresh water. Another way is to recirculate the water by pumping. In large ponds where water exchange may be a problem, mechanical aerators may be used; however, this method may be quite expensive. Partial replacement of water seems to be the best way.

Vegetation

Vegetation in ponds serves as food and cover for the crawfish as well as access to the water surface when dissolved oxygen levels are low. The crawfish will eat a variety of plants. The more tender plants are generally the most desirable, especially for the young crawfish. Any animal matter that pond crawfish get is the result of natural production and their own foraging. The crawfish farmer, then, should encourage the growth of suitable food plants and discourage undesirable vegetation. Plants used as crawfish food and cover should be capable of surviving and growing during the dry period and when the pond is reflooded. Proper water control and the elimination of large undesirable plants are the most effective ways of assuring adequate vegetation for the crawfish.

Desirable Vegetation

The following plants are generally considered to be the desirable vegetation in a crawfish pond.

(1) Alligatorweed (*Alternanthera* spp.) - An excellent food and cover, this plant can grow luxuriantly in many areas. It may be seeded into a pond by raking it out of ditches and other bodies of standing water and scattering it in the pond during the water drawdown in June-July.

(2) Water primrose (*Ludwigia* spp.) - Considered as good or even better than alligatorweed, this plant does not grow as thick as alligatorweed and is more tolerant to extremely cold weather.

(3) Smartweed (*Polygonum* spp.) - A fair food and cover plant, it grows naturally and easily in most ponds and looks like water primrose.

(4) Pondweed (*Potamogeton* spp.) - Another fair food and cover plant, it also grows naturally in ponds and are generally submerged.

A number of other plants occurring naturally in ponds, such as duckweed (*Lemma*) and *Elodea*, are also fair food and cover plants. A mixture of alligatorweed, water primrose and smartweed seems to be the ideal vegetation in a crawfish pond.

The crawfish will also eat soft, non-aquatic plants such as alfalfa, Bermuda grass, sorghum and various millets, particularly when they start to decay. If native plant species, such as smartweed, water primrose or alligatorweed, are not present, then browntop millet, Japanese millet, ryegrass, or any other tender grasses can be planted in the pond bottom. Plant the millets in strips 15 to 20 feet wide across the pond. Fertilization of the water is not necessary for crawfish culture, unless it is needed to get the food plants growing.

Cover Patterns

The question of how much vegetation cover is required still needs further study. Too much vegetation may hamper harvesting and cause severe oxygen depletion when it decomposes; too little vegetation may not provide enough food and cover. Generally, cover in the form of rooted, semi-aquatic plants should be present over at least 25% of the pond bottom during drawdown to provide protection for burrowing and young crawfish. At least a similar amount of vegetation, especially along the edges and shallower areas of the pond, is also needed during flooding to provide food and refuge for young crawfish. If not enough vegetation is present, hay or brush may be placed in the pond. If emergent, semi-aquatic vegetation is present, they should be regulated so that about 50% of the pond is open to wind circulation; this will improve water circulation and oxygenation.

Control of Unwanted or Excess Vegetation

There are other naturally occurring plants in ponds which generally interfere with harvesting, shade out the more desirable ones, cause potential water quality problems when they decay, and are inedible by the crawfish. Measures must be taken to control them. Three types of control measures may be used to rid ponds of nuisance vegetation: mechanical, biological and chemical.

In *mechanical vegetation control*, the crawfish farmer either physically removes the undesirable plants or alters the environment to create conditions discouraging the growth of nuisance plants. Hand removal of undesirable plants by pulling, raking, cutting or digging may be accomplished in small ponds during the drying period; this may not be practical in large ponds. Some vegetation may also be mowed (bush hogged) and disked under. The water drawdown is also an effective tool for controlling some aquatic weeds since it results in the dessication or drying out of underwater weeds and compaction of bottom mud. Prevention of the build-up of nutrients in the pond water by periodic exchange of the water from a nutrient-free source will reduce some aquatic plant growth. Rooted aquatic plants such as alligatorweed, smartweed and primrose utilizing nutrients in bottom sediments will remain unaffected.

Biological vegetation control relies on the use of animals to consume the unwanted vegetation. Plant-eating fish such as grass carp and mouth-brooders (tilapia) are usually used to consume weeds and algae. However, they may also eat the vegetation needed by crawfish; besides, their introduction into ponds may cause some legal problems. Before introducing them into the ponds, the farmer should check state regulations with the S. C. Department of Wildlife and Marine Resources. Other fishes, such as goldfish, golden shiners, and minnows, that do not eat crawfish and generally feed on algae, may be used; but they are of little use to the crawfish farmer with a week-choked pond.

Chemical control of nuisance weed and algae growths is generally an effective means but it also involves certain risks. In many cases, an application of weed-killing chemicals kills a lot of plant material which can cause oxygen depletion. As shown in Table 3, some algaecides and herbicides used to control unwanted plants also kill the desirable vegetation; hence their use is quite limited in crawfish ponds. If used, assistance from proper authorities (Soil Conservation Service and S. C. Department of Health and Environmental Control) must be sought, and care taken in handling and applying them by following the recommendations or directions on the manufacturers' labels.

Whatever method is used to control unwanted or excess vegetation, it must be realized that weeds and algae are a continuing problem from year to year and thus procedures must be taken regularly to control them. Among the more dominant pest plants in crawfish ponds are the following:

(1) Cattails (*Typha* spp.) - Tough, emergent plants, they are usually the most common, persistent pest plant in ponds. They can usually be controlled if caught early when individual plants may be pulled out. If dense growths occur, discing or plowing the affected areas at least five inches deep immediately after the pond is dry may be helpful. Proper herbicidal treatment may also be needed.

(2) Mat or filamentous algae (green scum) - Long thread-like plants forming large floating mats, they are primarily winter vegetation. They hinder harvesting by fouling traps and are prone to die off suddenly during hot weather in early spring, causing pollution problem. Partial removal of

Table 3. Chemicals registered by the U. S. Government for use as vegetation control in aquaculture waters.

Common Names and Genus of Plants Controlled by the Chemical	HERBICIDAL CHEMICALS*				
	Copper Sulfate	2, 4-D	Diquat	Endothall	Simazine
Alligatorweed *(Alternanthera)*		X			
Arrowhead *(Sagittaria)*		X		X	
Bulrush *(Scirpus)*		X			
Cattail *(Typha)*			X		
Coontail *(Ceratophyllum)*		X	X	X	
Duckweed *(Lemna)*		X	X		X
Elodea *(Elodea)*		X	X	X	
Fanworth *(Cabomba)*				X	X
Filamentous Algae (various species)	X		X	X	X
Muskgrass *(Chara)*	X		X	X	X
Naiad *(Najas)*		X	X	X	X
Pondweed *(Potamogeton)*		X	X	X	X
Rush *(Juncus)*		X			
Smartweed *(Polygonum)*		X			
Stonewort *(Nitella)*	X		X	X	X
Water Hyacinth *(Eichhornia)*		X			
Water Milfoil *(Myriophyllum)*		X	X	X	X
Water Lettuce *(Pistia)*			X		
Water Primrose *(Ludwigia)*		X	X		

*Examples of Registered Trade Names of the Herbicides:

Copper sulfate	:	*Cutrine*
Diquat dibromide	:	*Diquat*
Endothall	:	*Aquathol, Hydrothol*
Simazine	:	*Aquazine*

NOTE: Copper sulfate should not be used in waters of low hardness because of increased toxicity under this condition. Endothall can control submerged aquatic plants, while 2, 4-D can control better rooted plants with floating leaves. Simazine is generally effective against all types of aquatic plants, including algae.

floating algal mats may be effected by rigorous water circulation, either by pumping or flushing part of the water and "floating out" the mats, by hand removal, and careful algaecidal treatment. Technical assistance should be requested when this algal problem is detected.

(3) Water Hyacinth (*Eichhornia crassipes*) - These plants may be free-floating or rooted in mud. Their broad and large leaves can practically cover the whole surface of the pond if dense growths occur, shading the submerged desirable plants and minimizing wind and water circulation. They may be removed by hand or chemically treated with the assistance of federal or state agencies. They should not be permitted to pass on through the pond to areas downstream.

(4) Bull-tongue, black-rush, arrowhead and similar emergent plants may also be present but they seldom reach problematical densities when ponds are dried every year. They may be controlled in the same way as cattails.

On occasion, alligatorweed may grow too thick, keeping water temperature down and hindering harvesting. Strips 8-12 feet wide over 30-40% of the total pond area may be cleared by discing or raking the pond bottom during the dry period.

Supplemental Feeding

A primary advantage of crawfish culture over traditional fish culture is that the crawfish derive their nutrition from natural production of plants and organisms associated with decaying matter. If a good cover crop of desirable vegetation is present in the pond, no supplemental feeding is required. Studies have indicated that the addition of pelleted and extruded commercial fish feeds in experimental ponds can produce significant increase in crawfish production. However, high cost and low feed conversions of the artificial feeds make them uneconomical as yet in commercial crawfish operations.

Agricultural forages and byproducts such as hay, sweet potato vines and trimmings, rice bran and stubble and cotton seed cake, among others, serve as excellent sources of supplemental food and may be added to ponds. Experiments have also shown that pelleted hay sold as rabbit or goat food can support molting and body maintenance requirements of crawfish. These products may be used as supplemental food in ponds with poor vegetation or as starter diets during the first few weeks of crawfish production in newly-built ponds without properly established vegetation. Pelleted hay may also be used as maintenance ration for bait-sized crawfish until needed or sold.

Caution must be exercised when adding supplemental feed to crawfish ponds particularly during warm periods when the added decaying matter may cause water quality problems. The supplemental food materials should be added at a rate of no more than one-fourth that which could be grown naturally over the pond area. The supplemental feed should be spread out and not piled in one area. Such material may be added at three-week intervals when water temperatures are above 55°F. The farmer should watch for signs of low oxygen levels and be ready to circulate or exchange water and/or remove some of the feed.

Liming of Ponds

The addition of lime in aquaculture ponds is practiced by many farmers to bring up certain soil and water parameters to optimal levels. The favorable influence of liming on good crawfish production may be attributed to the following:

(1) Liming increases the pH of bottom mud, increasing availability of nutrients especially phosphorus for utilization by plants, thereby increasing bottom productivity. It also raises the pH of acidic water to desirable levels.

(2) Liming raises the alkalinity of the water, thereby increasing the availability of carbon dioxide needed by plants as well as buffering against drastic daily changes in pH.

(3) Liming increases total hardness by addition of minerals such as calcium required by crawfish for their molting and other metabolic processes.

(4) Liming brings about the precipitation of excessive organic matter in suspension in water. The mineralization of organic matter reduces the risks of spreading certain diseases and parasites associated with decomposition as well as the risk of oxygen deficit since the oxygen content will, indirectly, be higher.

Thus, liming is indispensable when the water pH and alkalinity are too low, and when there is too much organic matter. Before addition of lime, the farmer should have the soil and water in his pond analyzed. The exact amount to be added is dependent on factors such as initial soil and water conditions and the chemical relationships among them. Generally, enough lime should be added to bring up the soil pH level to 6.7 to 7.0. Usually, about 500 to 1000 pounds of lime are added per acre; the exact dosage, however, has to be determined experimentally. Hence it is best to lime ponds a little at a time until the desired levels of soil and water parameters are reached. Agricultural limestone is generally the preferred liming material. Hydrated lime and quick lime are less desirable since they can be toxic and if used in large amounts, may raise the water pH so high that crawfish may die. There is no comparable practical treatment to correct very high pH; addition of acidic materials is not generally effective.

At the time of liming, the lime should be spread as uniformly as possible over the complete surface either of the bottom or of the water. Liming the soil should preferably be done when the bottom is damp during the drying period. The beneficial effect of liming is generally not destroyed by a single draining. Hence, after the first massive addition of lime, re-checking the relevant soil and water conditions should be done before putting in additional lime.

Harvesting

For maximum yield, a crawfish pond must be harvested intensively throughout the production season; however, care should be taken to leave enough reproductively active crawfish to serve as broodstock for the next season. Harvesting ponds is quite tedious since it is generally done manually with the use of baited wire traps which should be run daily.

Methods

Crawfish traps vary in size, shape, type and construction, depending on the preference of the crawfish culturist. The traps are basically cylinders of wire fencing or similar material that have funnel-shaped openings through which the crawfish can enter. The wire mesh depends on the size of crawfish needed to be caught. Traps made of 3/4-inch chicken wire or hardwire cloth will trap only market-size (three inches and larger) crawfish, while those made of 1/2-inch mesh will retain bait-size (1-1/4-inch and larger) crawfish. Most crawfish farmers construct traps that are 24 to 36 inches long. Among the preferred types of traps are:

(1) Modified minnow traps with wider funnels and mesh sizes,

(2) Stand-up traps with two or three bottom entrance funnels and open top; the traps are propped up on stakes to leave the open end above the water surface, and

(3) Pillow-shaped traps which are similar in conformation to the stand-up type, except that the non-funnel end is pinned shut; the traps may be set flat on the bottom in deeper water or propped up partly out of water.

The catch efficiency of the above three types seems to be about the same. Two experimental traps being tested in Louisiana show better catching efficiency than the standard traps. The first one is a large cone-shaped, six-funnel trap that rests on the bottom with the funnels protruding in toward a central bait well. The top of the cone is open and protrudes above the water surface. The second experimental trap has two entrance funnels into a bait area and one funnel from the bait area to a holding area. It is made by taking a pillow-shaped trap and making a large exit funnel out of the non-funnel end of the cylinder; another cylinder of wire is attached to the exit funnel to form a holding area. Although the two experimental traps are more effective than the standard traps, they are more difficult to construct and to handle in the field.

Whatever trap type is used, it is important that, if needed, a portion of the trap would be above the water surface to allow the trapped crawfish access to atmospheric oxygen during times of low oxygen levels. This need for propping up the trap may be solved by emptying the traps once or twice daily during hot days when oxygen depletion is more likely to occur. It is recommended that from 15 to 25 traps per acre should be used for daily trapping.

For bait, cut fish and fish heads are usually used, with gizzard shad being the most preferred type. Other good baits are carp, alewifes and other oily trash fish. Since crawfish prefer fresh animal matter, the bait used should be fresh or fresh frozen. When changing baits, the harvester should not throw the old bait or the remains of it into the pond; otherwise, added decayed matter will compound water quality problems.

Crawfish may also be caught with minnow seines in ponds where absence of dense vegetation permits it. Seines are especially useful for collecting soft crawfish and those about to molt since these crawfish hardly move at all from their hiding places.

When to Harvest

The crawfish crop may be trapped from as early as late November through approximately mid-June or just before water drawdown. The crawfish hatched in late September and early October could attain market size by mid-December, providing there is adequate food and still mild water temperature (above $50^{o}F$). While the young crawfish are growing, many adult crawfish especially the spawned-out females are still present. These holdover crawfish should be harvested in late November-early December to provide more space and food for the young of the year. Many of the adults will reach the end of their life span during winter and thus will be "lost" if not harvested during this period. This one-and-a-half to two month period after reflooding will have given these adults which have been in the burrows ample time to feed and "fill" out their tails. Harvesting one or two weeks immediately after flooding will usually yield only hollow-tailed crawfish.

Harvesting may be spotty in January and February when water temperature is well below $50^{o}F$ since crawfish are generally inactive during periods of low temperature. Intensive harvesting should commence when water temperature starts rising above $50^{o}F$, usually in mid-March or early April, and continue until just before draining. However, if during the few weeks before drawdown, the average catch is less than half a pound per trap per day, it is better to stop trapping; this will insure that enough crawfish will be left as brood-stock for the next season.

The intensity of trapping may vary, depending on the changing status of the pond population. If signs of overcrowding and stunting are noted during the winter and early spring months, as indicated by the presence of many Form I males less than 3 inches long, as well as the presence of dense growths of algae and small organisms on the shells of immature crawfish, heavier trapping should be done to decrease the population density. This could be done by using more traps or running the traps more frequently than usual. The problem of underharvesting or overharvesting may be partly solved by monitoring the population dynamics of the crawfish.

Production Schedule for Raising Food Crawfish

The guidelines presented above are generally the standard cultivation techniques used to produce crawfish marketed as food (3 inches and larger). The general sequence of pond management activities follow closely the different periods of the crawfish life cycle as shown in Table 4. Thus, the draining of the pond coincides with the burrowing and generally quiescent period of the crawfish in early summer. During the dry period of the pond, weed and predator control measures can be implemented; pond and dike repair work can also be done. Reflooding in early fall assures the availability of good water for the young crawfish to grow in. Harvesting can then be done starting in late fall-early winter through late spring-early summer when the pond is drained again.

Sometimes, incidental catches of small crawfish (less than three inches long) may also be sold as bait, which is another lucrative market. Bait-size crawfish are generally available in well-managed ponds from about six weeks after fall flooding into February-March. However, since bait crawfish are usually in demand during spring and summer when most of the crawfish have grown much larger to food-size ranges, or when ponds are dry, some modifications to the general production schedule for raising food crawfish have to be made.

Raising Bait Crawfish

Bait crawfish are generally small — 2 to 2-3/4 inches long. If a farmer decides to raise crawfish to be sold either as live or frozen bait

Table 4. Summary of crawfish pond culture procedures correlated with the life cycle of crawfish.

	: J : F : M : A : M : J : J : A : S : O : N : D :
*Crawfish Life Cycle Periods**	
Breeding	: : : :xxxxxXXXXXXXXXXXX:xxxx : : : : : :
Burrowing	: : : : : : xxxXXXXXXXXXXXXXXXXXXX : : :
Egg-laying	: : : : : : : xxxxxxxxxxxXXXXXXXXxx: : :
Hatching	: : : : : : : : xxxxxxXXXXXXXXXXXXXXxx :
Recruitment	xxxxxxxxxxxxx : : : : : : XXXXXXXXXXXXXXXXXXXXXX
Growth	xxxxxxxxxxxxxxXXXXXXXXXXXXXXXXXXXxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxXXXXXXXXXXXXXxx
Pond Management Activities	: : : : : : : : : : : : :
Pond Construction Finished	: : : XXXXXXXXX : : : : : : : :
Flooding (New Pond)	: : : :XXXXXXXXX : : : : : : : :
Stocking (New Pond)	: : : : XXXXXXXXX : : : : : : : :
Draining	: : : : : : XXXXXXXXX: : : : : :
Pond Improvement/Repair	: : : : : : : XXXXXXXXXXXXXX : : :
Weed/Fish Control	: : : : : : : XXXXXXXXXXXXXXXXXXX: : :
Burrow Checking	: : : : : : : : XXXXXX: : : :
Reflooding	: : : : : : : : : XXXXXXXX: : :
Population Monitoring	:X X X:X X X: : : : : : : :X X X:X X X:X X X:
Harvest (Old Pond)	:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX : : : : : XXXXXXXXX:
(New Pond)	:XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX : : : : : : XXX:

*For the crawfish life cycle periods, large X indicates peak of activity, while small x shows activity also reported during the times noted.

for game fish, he must beforehand locate or establish markets and must be able to provide the needed product in adequate quantities at appropriate times. Under optimal food and water conditions, crawfish can grow rapidly to food-size ranges within six to eight months after fall flooding. Production for fish bait then entails discouraging rapid growth as well as sustaining production of smaller crawfish through the normal growing season. The two management techniques that have been shown to extend production of bait-size crawfish are sequential, delayed flooding of several small ponds and overpopulating each pond. The procedures retard growth, delay maturation and cause overcrowding and stunting of crawfish.

Management Modifications for Bait Crawfish Ponds

Since extended production of bait crawfish depends on differential flooding and high population densities, ponds for this system of crawfish culture ideally range from a tenth of an acre to one acre in size. Ponds up to but not exceeding five acres may also be used. At least three small ponds are needed; each should be built with its own inflow and outflow systems so that it can be flooded and drained without affecting the others.

Stocking should be done from late April to late May. Ponds with existing crawfish populations should be stocked at a rate of about 50 pounds per acre; other ponds may be stocked up to 100 pounds per acre.

Draining should begin in mid-May at a rate of two to three inches per day. In heavily-stocked ponds, flooding in mid-August, mid-September or mid-October will yield bait-size crawfish within six weeks after flooding and will continue to produce small crawfish into spring from subsequent hatches and recruitment. Alternatively, ponds drained in mid-summer and reflooded in November and early December will produce bait-size crawfish during spring since cold weather with low water temperatures (less than $60^{o}F$) slows growth.

Supplemental feeding is not recommended in ponds used for bait crawfish production. Vegetation naturally growing in the pond when it is dry will provide enough sustenance if a 75% ground cover is present.

Generally, crawfish growth is retarded at the two to 2-3/4 inch range when density is very high. The crawfish farmer should monitor his ponds closely to insure that the bait-size crawfish can be harvested and processed or sold before the crawfish become fully mature and hard at small sizes. Harvesting may be started six weeks after flooding in ponds flooded in August to October and during early spring in ponds flooded in November and December. Traps used to harvest food-size crawfish may be used; however, mesh sizes of 1/4 to 1/2 inch to retain the smaller crawfish would be better. With staggered flooding of several ponds, continuous harvest of bait-size crawfish is possible over extended periods.

It should be kept in mind that, aside from the modifications stated above, all other pond management procedures with regards to soil, water and vegetation conditions should also be implemented when raising crawfish for bait.

POND MONITORING

A critical consideration in proper pond management is monitoring the population dynamics or the changing status of the multi-age population of crawfish in the pond. Pond monitoring can provide the farmer with some information if he has a crop and on the conditions of the crawfish as well as give him an idea of the magnitude of the possible crop. This is particularly important because (1) crawfish numbers are not known when ponds are flooded since the population is self-sustaining with the offspring providing the crop and broodstock for successive years, and (2) crawfish do not reproduce all at once; hence, several groups of young crawfish are recruited or become part of the pond population during fall and winter. The number of groups or age-classes of crawfish, their strength or numbers of individuals within each age-class, their growth and survival, and food availability are the factors that determine overall pond production. Pond monitoring essentially erquires frequent collection of crawfish samples in order to determine age-classes, growth rates and crop potential yield.

Collection of Crawfish

Small crawfish, less than two inches long, may be sampled with a small mesh (about one-half inch or smaller) dip-net, available commercially. Crawfish of these size-ranges can usually be taken along the vegetation cover in the edges and shallower portions of the pond. As the crawfish grow to more than two inches in size, they become more difficult to dip-net and a small mesh (one-fourth to one-half inch) trap should be used. Sampling should be done regularly, at least once every two weeks after flooding in order to monitor effectively the population.

Samples should be taken at different areas of the entire pond to insure getting representative samples; one dip every 20 paces around the edge of the entire pond will suffice when collecting with a dip-net. One should try to obtain about 50 to 100 crawfish with a dip-net and a similar number with small mesh traps for measurements. The number of dips and the number of crawfish caught should be noted. At least two small mesh traps should be maintained per surface area to sample larger crawfish. The samples from the dip-net and the traps should be kept separate.

Measurements and Computations

Measurement of individual crawfish is necessary to determine age-classes and to monitor growth patterns. To make measurements easier, a simple measuring board can be made by gluing a flat 6-inch plastic ruler with millimeter markings on a flat board with a head board butting it. Measure the crawfish from the tip of the rostrum to the tip of the telson by placing it belly-side down on the measuring board. It might be easier to use metric measurements (millimeters) in order not to work with cumbersome fractions. Record each measurement in the proper size-class on a sheet similar to Table 5; this will be the raw data from which relevant computations on the status of the crawfish population can be made.

Crawfish Densities

Densities of crawfish, the number of crawfish per unit area, can be calculated by dividing the number of crawfish caught with a dip-net by the area sampled. The area sampled is the area that the net covers multiplied by the total number of dips made. For example, if a dip-net covers an area of 2 square feet and total number of 20 dips is made, with 100 crawfish caught, the crawfish density will be 2.5 crawfish per square foot:

Table 5. An example of a record sheet for data on crawfish measurements needed for monitoring pond population.

Type of Sample: Dip-net | Number of Crawfish Measured 100 | Date: November 15, 1980

SIZE CLASS IN MILLIMETERS

	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100-104	105-109
	///	卌-卌 卌-卌	卌-IIII	卌-III	卌-II	卌-卌 卌-III	卌-IIII	IIII	卌-II	卌-卌 I	//	/	/								
No./Size Class	3	20	9	8	7	18	9	4	7	11	2	1	1	0	0	0	0	0	0	0	0
Percent	3	(20)	9	8	7	(18)	9	4	7	(11)	2	1	1	0	0	0	0	0	0	0	0

Type of Sample: Small mesh trap | Number of Crawfish Measured 100 | Date: November 15, 1980

	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100-104	105-109
								/	卌-II	卌-卌 卌-II	卌-卌 I	卌-IIII	卌-卌	卌-IIII	卌-卌 卌-I	卌-I	II	卌-卌	/	/	
No./Size Class	0	0	0	0	0	0	0	1	7	17	11	9	10	9	16	6	2	10	1	1	0
Percent	0	0	0	0	0	0	0	1	7	(17)	11	9	10	9	(16)	6	2	(10)	1	1	0
		↑ Young-of-the Year				↑ Young-of-the-Year				↑ Young-of-the-Year					↑ Holdover Juveniles			↑ Holdover Adults			

Note: Encircled numbers are the modes, corresponding to the different age-classes of crawfish in the population.

$$\text{Density} = \frac{\text{Number of crawfish}}{\text{Area covered by dip times number of dips}} = \frac{100}{2 \times 20} = 2.5$$

The calculated density can then be used to approximate population size or the total number of crawfish in the pond (see below).

Determination of Age-Classes

From the raw data of length measurements, one can determine the different age-classes and relative abundance of the individuals in each age-class as follows:

(1) Count the number of crawfish in each size-group and the number of all crawfish in the sample.

(2) Calculate the percentage of crawfish in each size-class using the formula

$$\frac{\text{Number of crawfish in each size-class}}{\text{Total Number of crawfish in the sample}} \times 100 = \text{Percentage}$$

(3) The most prominent percentages are known as the *modes* and represent the various age-classes in the crawfish population. Some crawfish of an age class will be larger or smaller than the majority of the members of that age-class, thus accounting for the numbers on either side of the modes.

As monitoring continues regularly, one will be able to see the shift in the modes from the left to the right, with the average size increasing, corresponding to the growth of the crawfish. Sometimes, this method may not show clearly the different modes; practice and advise from technical workers may be sought for the explanation of the data.

Determination of Average Crawfish Size

The average size of the crawfish in the pond population may also be computed from the length measurements by the formula

$$\text{Average size} = \frac{\text{Total of all size measurements}}{\text{Total number of measurements}}$$

The total of all size measurements may be found more easily by multiplying the number of crawfish in one size-class by the mid-point of that size-class and then adding up all the resulting numbers for all size-classes. The total number of measurements is actually the total number of crawfish measured.

Growth Rates

Calculation of growth rates indicates how fast the crawfish are growing and gives the crawfish culturist an idea of when his crawfish will reach harvestable or marketable sizes. Growth rates may be determined by the following methods:

(1) *Using the modes of percentages in the size-class data*: Generally, the modes of each age-class will shift to the right on the record sheet from one sampling period to the next. The amount of shift of the mode of one age-class gives the growth rate of the crawfish in that age-class for the interval between samplings. The growth rate may be calculated by finding the difference between the mid-points of the modal size-class of the crawfish in a particular age-class during two consecutive samplings and dividing that difference by the number of days or weeks elapsed between the two samplings. For example, if the first age-class of young-of-the-year crawfish has a modal size-class of 50-54 millimeters (mid-point = 52) on December 1 and a modal size-class of 60-64 millimeters (mid-point = 62) on December 15, the growth rate will be computed as follows:

$$\frac{\text{Modal size on December 15 - Modal size on December 1}}{\text{Number of weeks between December 1 and December 15}} = \text{Growth rate}$$

$$\frac{62\text{ mm} - 52\text{ mm}}{2\text{ weeks}} = 5\text{ mm per week}$$

Thus, with a growth rate of 5 mm per week, crawfish in this age-class will reach the marketable model size-class of 75-79 millimeters (mid-point = 77; about 3 inches) in about three weeks, computed as follows:

$$\frac{\text{Desired modal size} - \text{Modal size on last sampling}}{\text{Growth rate}} = \text{Time to reach desired size}$$

$$\frac{77 - 62}{5} = 3 \text{ weeks}$$

In this example, then, this particular age-class of young-of-the-year crawfish can be harvested by the second week of January.

(2) *Using the average sizes*: Calculation of growth rates based on the average sizes of crawfish during two consecutive sampling periods is similar to the above computations, where the average size replaces the modal mid-point number. It must be noted that the average size will be more variable between samplings depending on the presence of many small or large crawfish in a sample; the actual average size may even be reduced if the younger and smaller age-classes are caught more often than the older and larger ones.

Estimation of Population Size

The estimation of the total number of crawfish in the pond gives the culturist information on the magnitude of his potential crop and on whether or not restocking is needed. Estimation of population size is quite difficult, but good approximations may be achieved by either of the following methods:

(1) *Using density data*: The calculated density as described earlier may be used to approximate the population size by multiplying it by the total area of the pond. For example, if the calculated density in a one-acre (=43,450 square feet) pond is 2.5 crawfish/square foot, the estimated population is

2.5 crawfish/square foot x 43,450 square feet = 108,625 crawfish.

(2) *Mark-recapture method*: Basically, the method consists of capturing a portion of the population, marking them for identification and releasing them back into the pond. At a later time, the population is sampled again, and the proportion of recaptured marked crawfish is used to compute the population size. Crawfish may be marked by clipping a small piece off their uropods with a paper-puncher. To make the estimate more reliable, at least 100 crawfish should be marked and no crawfish should be added or taken out of the pond before the second sample is taken.

For example, a culturist marked 100 crawfish and released them back into the pond. One week later, he re-sampled the population by trapping 500 crawfish. Of the 500, 5 were marked crawfish. The population size can then be estimated as follows:

$$\frac{\text{No. of marked crawfish released} \times \text{No. of crawfish in 2nd sample}}{\text{No. of marked crawfish in 2nd sample}} = \text{Population size}$$

$$\frac{100 \times 500}{5} = 10{,}000 \text{ crawfish}$$

The accuracy of the population estimate can be increased by taking additional samples over a period of time. This method is most effective when it is done during the time when no additional hatching or recruitment is occurring, usually about February-March. The farmer should try to sample all the size-classes by using traps with different mesh sizes.

Estimation of Potential Yield

If the culturist catches very few crawfish through fall and winter with a dip-net (on the average, less than 0.5 crawfish per dip), he can assume a poor potential yield, probably less than 300 pounds per acre, if that much. The presence of several age-classes of young-of-the-year crawfish and the sustained catch of about one small crawfish per dip during the period from mid-December to mid-February indicates a probable yield of about 500 pounds per acre, or more, especially if survival is good.

A good rule of thumb to determine good survival is to follow the changes in the average size of dip-net caught crawfish. Average size should gradually increase to about 50-65 mm (2-2½ inches) by late February-early March. This indicates fairly good growth and survival. If the average number of young crawfish is about one or more per dip, but the average size fluctuates much and does not approach 50-65 mm (2-2½ inches) by late February-early March, survival is probably low. There may be intense fish predation on young crawfish or water quality problems such as low oxygen levels which have caused high mortality.

An early sign of the problem of overcrowding and stunting is the consistent catch of three or more small crawfish per dip during fall. Average size could increase through winter and early spring, but it will be more gradual. If young-of-the-year crawfish are not abundant by mid-November and early December, poor yields can be expected.

When using small mesh traps, the farmer could expect that catch during the winter months would be generally low (less than a pound per trap per night during late February and March. Even when regular traps are already used to harvest marketable-size crawfish, it is still a good idea to continue using small mesh traps at the same time to follow the growth of the smaller crawfish to harvestable size. If catch in regular traps drops and catch of small crawfish in small mesh traps is poor, further yields could be expected to be low. If catch in regular traps falls off but many small crawfish are caught in small mesh traps, yields could be good later in the harvesting season.

Well-managed crawfish ponds can yield harvests of 750-1000 pounds per acre, particularly if water quality is good, predatory fish are absent, and at least 50-60% of each young-of-the-year age-class survive. However, the crawfish farmer should keep in mind that a good potential yield is one thing and the actual harvested yield is another matter. Proper and intensive harvesting should be done to realize the potential yield.

POTENTIAL PRODUCTION PROBLEMS

The production of crawfish in open ponds is a complex interaction of environmental conditions, available resources and the population dynamics of crawfish. As such, crawfish culture has its associated problems which have the potential to make or break the enterprise. These potential problems include predation by other organisms, disease and parasitism, and problems related to soil, water and vegetation conditions. These problems can cause high mortality of the cultured crawfish.

Predation

Predation by fish, birds, raccoons, bullfrogs, snakes, turtles, salamanders, large aquatic insects, and other organisms, is a problem confronting the crawfish farmer. The best protection against most of these predators is abundant vegetation cover for the crawfish. A water depth of at least 18 inches is also sufficient to deter wading birds from eating the crawfish. Proper pond management techniques can also drastically cut down losses due to predation. A potentially more serious problem is posed by fishes and predacious insects, which may require additional measures.

Control of Fish

The most serious predators of crawfish in ponds are fish, notably the sunfishes, bowfins and bullheads. A sunfish, for example, can eat up to two dozen very small crawfish in a 24-hour period. The best method of controlling predatory fishes is to prevent them from entering the pond by screening the water inflow and outflow systems or by using water supply without fish populations in it. Screening inflow pipes or canals may sometimes be difficult since small mesh screens easily clog up and require constant cleaning. In addition, even with small mesh screens, fish eggs and larvae can sometimes enter the pond. If fish do not get into the ponds, the annual draining and drying of ponds can substantially reduce fish populations. In certain cases, however, chemical fish control may have to be done to eradicate predatory fishes not otherwise taken care of by other measures.

Two commonly used fish poisons are rotenone and antimycin A. Roteone applied at concentrations of 2-3 parts per million will kill the predatory fish; a concentration of 5 ppm, however, will kill young crawfish. Antimycin A (sold under the trade name *Fintrol 5*) can kill green sunfish, bullheads and bowfins at concentrations of 0.2, 50, and 200 parts per billion (ppb), respectively. However, it is also toxic to young crawfish at concentrations of 68 ppb and greater, with tolerance increasing with increase in size. Whatever fish toxicant is used to control fish, the following should be kept in mind:

(1) Advice and guidance should be sought from qualified authorities.

(2) Manufacturer's recommendations should be followed.

(3) When using antimycin A as toxicant, crawfish ponds should not be poisoned for bullheads and bowfin when crawfish less than one inch long are predominant.

(4) The cost of applying antimycin or rotenone will vary depending on the concentration required to kill fishes in a particular pond, which in turn depends on the pH, the water temperature and the alkalinity of that pond. Rotenone appears to be cheaper and safer to use against bullheads and bowfin; antimycin may be cheaper to use against green sunfish.

(5) After application of the fish toxicants, the dead fish floating on the water surface should be collected and taken out of the pond to minimize water quality problems when they start to decay.

Control of Predacious Arthropods

Even when predacious vertebrates such as fish are eliminated from the ponds, there might still be predatory organisms present which can decimate young crawfish. These are the specialized aquatic insects and spiders, which despite their relatively small sizes, can reach tremendous concentrations and kill a lot of small crawfish. These predacious arthropods include:

(1) *Dragonfly nymphs*: Recognized by an extending lower jaw folded like a hinge, the nymphs of some dragonfly species can reach a length of four inches. Preferring submerged vegetation where they can hide, the dragonfly nymphs are major predator of small crawfish because of their rapid growth and size.

(2) *Water beetles:* The predacious diving beetles (Dystiscidae) may reach sizes of three inches and are very voracious, feeding on all kinds of aquatic insects, tadpoles, small fish and small crawfish. The larvae have well-developed mouth parts for piercing and sucking prey, including small crawfish.

(3) *Water bugs:* The giant water bugs (Belostomatidae), characterized by flat oval bodies and found at the bottom of shallow ponds with the tips of their abdomens at the surface, can devour organisms as large as tadpoles, salamanders, small fish and young crawfish. Their poisonous saliva immobilizes and kills their prey.

(4) *Back swimmers:* Since they swim on their backs, the "back swimmers" (Notonectidae) may be easily distinguished from other aquatic bugs. Reaching lengths of 1/4 to 1/2 inches, the adults feed on young crawfish, as well as tadpoles, fish and other insects. Sometimes, their eggs which are small granules can be found on crawfish shells. They can reach tremendous numbers and could account for a large portion of mortality of tiny crawfish.

(5) *Fisher spiders:* The fisher spiders (*Dolomedes*), one of the common aquatic spiders in North America, can dive and remain submerged for long periods. They feed mainly on insects by paralyzing the prey and sucking the body juices from them, but will occasionally attack fish, tadpoles and crawfish. It has been observed that a large (2 inches) fisher spider can paralyze and carry away a crawfish of similar size.

In most fish pond culture situations, these predatory arthropods are kept in check by large fish and the vegetation that protects them is eliminated or controlled. However, in crawfish culture systems, vegetation cannot be totally eliminated since it is a vital component of the culture operation, nor can large fish be kept in ponds since they will eat the crawfish. Other techniques of control of insects and other unwanted invertebrates have very limited usage in crawfish ponds. These techniques are:

(1) *"Oiling":* An adequate control for "air-breathing" arthropods such as the water beetles, water bugs, back swimmers and spiders which come to the water surface for air is the periodic application of a well-mixed 50:50 mixture of diesel fuel and cottonseed oil or crankcase oil at a rate of 1-2 gallons per acre. When the air-breathers return to the surface for air, the openings in their breathing tubes get clogged with the oil. However, oiling is effective only when waters are fairly free of emergent vegetation which hinders the movement of the oil slick surface. Hence, it could be effective only in standing water such as ditches just before ponds are flooded. Ponds could also be treated in spring if the vegetation becomes sparse and control is deemed to be really necessary.

(2) *Chemical poisons:* The chemicals recommended for control of all forms of aquatic insects such as methyl parathion, Lexone and Baytex will also kill crawfish. The poisons are probably useful only in ditches just before ponds are flooded or in newly-built and flooded ponds without any crawfish. Care-

ful advice should be sought before using the poisons.

(3) *Use of mosquitofish:* The mosquitofish *(Gambusia affinis)* can limit the numbers of predacious dragonfly numphs and may be of value in crawfish ponds. Mosquitofish are readily available in natural waters throughout the state and they can easily be captured by the crawfish farmer for stocking in his ponds. Care must be taken to insure that predatory fish are not accidentally introduced with mosquitofish.

Disease and Parasitism

In high density culture systems, disease and parasite problems can become prominent obstacles to successful production. Early detection and treatment of diseases and parasites is often crucial to insure good pond yield. Crawfish usually do not experience severe disease and parasite problems if proper culture management techniques are followed and the crawfish are not stressed. Physical injury, extremes in oxygen levels, temperature shock, inadequate nutrition, and a variety of toxins and pollutants in the water can all stress the crawfish and leave them vulnerable to infections. Thus, the primary disease prevention measures are a healthy environment and adequate nutrition for the crawfish.

So far, widespread diseases of crawfish in pond culture situations have not been reported. However, the potential occurrence of disease outbreaks which can wipe out a crawfish population in a pond is still there. A variety of bacteria, fungi, protozoans, worms and other organisms are known to affect crawfish. Some of the more common diseases and parasites are:

(1) *Shell disease:* Also known as "black spot" or "brown spot" disease, it involves the development of dark lesions on the exoskeleton or shell of the crawfish and is thought to be caused by chitin-destroying bacteria and

secondary microbial infective organisms. The abnormality may first appear as small, round depressions that eventually form irregular sites of enlarged erosion of the shell. Usually, the affected crawfish eliminates the disease by shedding the infected shell during molting, unless the infection has gone too deep in which case the crawfish dies. The disease appears to be highly contagious, especially in overcrowded conditions.

(2) *Filamentous bacteria infestation:* Usually occurring on body surfaces and gills, a heavy infestation of filamentous bacteria may interfere with respiration when the gills become clogged. It is usually associated with high levels of dissolved organic matter in the water.

(3) *Fungal infection:* Fungi are notorious disease agents of crawfish, especially of the eggs and early juvenile stages. They can infest the various parts of the crawfish, particularly in the gills and poorly protected tissues on the underside of tail and joints.

(4) *Microsporidian infection:* Microsporidia infect the muscular tissues, especially in the abdominal region, of the crawfish, giving a whitish coloration to the affected organism. As the disease progresses, the infected crawfish becomes whiter - a whitened tail clearly shows this.

(5) *External parasites and ectocommensals:* These various organisms attach themselves to the body surface of the crawfish. Molting by the crawfish provides periodic relief from the build-up of these organisms.

If some crawfish in the pond show any of these conditions, the crawfish culturist should examine more crawfish to determine how widespread the condition is in the population, and consult qualified persons. The infected crawfish should be taken out of the pond or holding container and sent to competent persons for diagnosis.

To counter-act some of these disease problems, the following prophylactic measures may be taken:

(1) More careful handling of the crawfish to prevent physical injury.

(2) Provision of adequate food can help reduce aggression among individual crawfish.

(3) Reduction of stocking density/population density by intensive harvesting to prevent overcrowding and minimize contagion.

(4) Massive water replacement or exchange when significant numbers of crawfish show abnormal conditions to minimize the build-up of organic matter in which the infectious microorganisms flourish.

The use of chemotherapeutics in aquaculture is still subject to clearance and approval by the government and in most cases, the treatment levels still need definitive research. The use of chemicals to control disease-causing organisms and parasites is also an additional source of stress since the amount required to kill a disease or parasitic organism is similar to the level that can cause mortality in the host crawfish. Great care must b taken to insure that treatment levels provide sufficient dosage to control the pathogenic organisms but are not levels toxic to crawfish. It must also be noted that the effects on crawfish of the many chemotherapeutic agents have not been adequately evaluated; similarly, the effects of water quality parameters with respect to the chemicals have not been studied sufficiently. If chemicals have to be used, proper authorization should be obtained and manufacturers' recommendations followed.

Other Potential Problems

Some of the other potential problems a culturist may encounter have been mentioned in the other sections and are summarized in Table 6.

Table 6. Some potential problems that may be encountered in crawfish pond culture operations. (For problems related to soil, water and vegetation conditions, see relevant sections).

Problem	Sign(s)	Probable Cause(s)	Recommended Action/Possible Solution
1. Oxygen Depletion	-"Black" water - Crawfish seen clinging to vegetation near the water surface -Dense floating mass of decaying algal mats or aquatic plants	-Poor quality of water supply - Heavy decomposition of vegetation -Poor water circulation	-Use only good quality water with oxygen levels of at least 3 ppm -Flush the pond rapidly and exchange with fresh, oxygenated water -Aerate inflowing water or recirculate pond water with a pump
2. Stunting	-Presence of many Form I males less than 3 inches total length -Presence of many small (2-2½ inches) immature crawfish with extensive growths of algae and assorted organisms on their shells	-Overcrowding: population too dense, with many age-classes -Inadequate harvesting -Not enough food available	-Harvest undersized mature crawfish by using smaller mesh size traps or smaller trap entrances -Use more traps and run traps more frequently than usual -Increase food supply by adding supplemental food materials such as hay
3. Thin-shelled crawfish	-Brittle shells of large crawfish, even after few days after molting	-Acidic waters - Low water hardness & pH -Inadequate mineral supply	-Add agricultural limestone to bring up water hardness and pH to optimal levels and provide mineral requirements
4. Hollow-tailed crawfish	-Tails of large crawfish contain very little meat	- Caught crawfish are females which just finished reproducing -Inadequate food supply	-Do not harvest immediately after flooding -Let females that have reproduced eat and "fill up" for about 1-2 months before harvesting -If inadequate vegetation present, add supplemental feed materials.
5. Low Production	-Low yield even with optimal soil, water and vegetation conditions	-Abundance of fish predators -Low reproduction -Escape of crawfish from pond	-Implement fish control measures -Restock pond with crawfish as additional broodstock

PROGNOSIS FOR CRAWFISH FARMING IN SOUTH CAROLINA

There is a very good potential for crawfish farming in South Carolina. Given continued support and technical assistance by federal and state agencies, it could become a viable enterprise throughout the state, especially in non-arable and marginal lands not otherwise used for profitable activities. The success of the few present crawfish farmers is a good indication that crawfish farming could become an important economic activity in South Carolina. The present technology for crawfish farming is such that it can serve as a source of supplemental income even for those people with full-time jobs. However, there is still a lack of data on the full potential of crawfish farming in the state. The following discussion presents consideration of other factors which can help turn crawfish farming into a widespread economic activity.

Crawfish Production in Other Systems

Although the guidelines presented here are geared for crawfish production in open pond environments, other areas such as deep existing ponds, wooded sites and marshy areas with no good craining/flooding systems may also be used. These sites are not generally recommended for optimum crawfish production but if otherwise unused, may still be utilized to provide some crawfish crops; production in these systems, however, should not be expected to be as high as in open pond systems.

Since crawfish can complete successful egg-laying and brooding in the water column, there is some promise for the use of existing deep ponds as crawfish production units. In such cases, complete eradication of fish populations through the control measures discussed earlier would have to be done before crawfish are stocked. Vegetation, at least along the shallower portions of such ponds, should be well-established.

Coastal sites with some seawater intrusion may also be utilized since it has been established that crawfish will tolerate and can thrive in waters with salinity levels between three and eight part per thousand. Precautions must be taken so that no rapid changes in salinity occur, particularly during the egg-laying and hatching period from September to October.

Polyculture

There is also some promise for the simultaneous production of fish and crawfish in the same system. Fish and crawfish may be raised together at the same time as long as the fish chosen do not prey on crawfish or compete for the utilization of vegetation for nutrition. The prime fish candidates of polyculture with crawfish are bait fishes such as golden shiners and fathead minnows which can provide supplemental crop to the crawfish farmer. If these bait fishes are raised with crawfish, a harvest basin may be dug up near the drain outlet for easier harvesting of the fish during water drawdown. They may have to be re-stocked every year.

Predacious commercial fish and crawfish may be readily grown together provided physical separation is maintained by raising the fish in cages. Caged channel catfish have been grown together with crawfish in ponds, with the crawfish production nearly twice as much than in ponds without the catfish. The crawfish may have benefited from the catfish food not eaten by the fish in terms of supplemental nutrition. In such situations, larger fingerlings of catfish should be used and the cages should have meshes small enough to prevent the escape of the catfish.

Economic Considerations

Studies on the economic aspects, particularly on market demand and cost and profit analyses, of crawfish farming have yet to be done for South Carolina. Present prices of about $1 a pound of crawfish can give a farmer with a well-constructed and well-managed pond producing 500 to 1000 pounds an acre an income ranging from $500 to $1000 per acre in one growing season. Since expenditures are generally low, the farmer may net quite a sizable amount.

Expenditures for a crawfish farm operation may be categorized into initial expenses and maintenance costs. Initial costs include expenses for pond construction, purchase of broodstock, water supply equipment and materials (pumps, pipes, construction materials for water trunks, etc.), traps or materials for traps, and if necessary, holding tanks for harvested crawfish. Maintenance costs include expenditures for vegetation/fish control, pond/dike repairs, bait and maintenance of water supply euqipment.

Thus, the prospective crawfish farmer should have estimates made of the costs before starting operations by consulting with contractors, Soil Conservation Service personnel, and present crawfish farmers. He should look also into the crawfish market in his immediate area and must consider future expansion problems related to land, labor and water supply. Crawfish farming can be economically productive if proper attention is given to all aspects of it before and during culture operations.

CHECKLIST FOR PROSPECTIVE CRAWFISH FARMERS

Crawfish farming takes care, attention and planning to make it a viable economic activity. This check list, adapted from various sources, is included here to guide anyone interested in starting a crawfish farming operation. All the points are interrelated and decision on one item has a bearing on the others. The prospective crawfish farmer should answer or estimate them as best as he can to determine if crawfish farming will be a good business enterprise for him.

- * -

I. CAPITAL FINANCING

(A) Have you sufficient capital over and above the immediate costs of purchase of land, if required, and pond construction?

(B) Would you be able to have funds for a fixed overhead per surface acre for pond repairs, maintenance and improvements for further productivity?

(C) Are you aware of any tax concession, or possibility for loans, if any, available to crawfish farmers in your area?

II. PHYSICAL FEATURES

(A) Impounded Areas

(1) Are adequate sites available for ponds both for present needs and future development?

(2) Can the ponds be located or constructed to permit complete drainage and drying as well as rapid flushing of water if needed?

(3) Is there danger of loss of stock due to storms, floods, or erosion? Would you be able to minimize such danger?

(4) Is the proposed site close enough to possible markets?

(5) Is the site accessible enough, with good raod access and available electricity, if needed?

(6) Can you protect your ponds from poachers at a reasonable cost?

(B) Adjacent Areas

(1) Is there access for vehicles, particularly for delivery of materials and hauling of harvested crawfish?

(2) Is there room for storage sheds, holding tanks, pump house and emergency generator if necessary, and farming equipment?

(3) Is electricity readily available?

(C) Soil

(1) Is the soil clayey enough to have good water retention?

(2) Does the soil have the minimum quality requirements, such as pH and relatively free of contaminants/pollutants?

(3) Can you have your soil analyzed periodically at a reasonable cost?

(D) Water

(1) Is there good quality, reliable constant water supply at or near pond site?

(2) Is the water supply of sufficient quantity to achieve rapid flooding of the pond if needed?

(3) Is the water supply relatively free of predatory fish/insects, contaminants and pollutants that might be introduced into the crawfish ponds?

(4) Do you know the minimum and optimum requirements of water supply needed for crawfish culture? Does your water supply have water parameter levels above the minimum requirements?

(5) Could the water quality in the pond be improved if necessary? Are you familiar with the methods to do this?

(E) Pollution

(1) How can you detect contaminants or pollutants entering your farm?

(2) How can you prevent contaminants or pollutants from being introduced into the ponds?

(3) What recourse will you have in case of loss of stock due to pollution?

(4) Can technical assistance be readily obtained for detection/prevention of pollution and at what costs?

III. BIOLOGICAL ASPECTS

(A) Are you familiar enough with the general biology of the crawfish? Have you read the literature available on it?

(B) Do you know the environmental conditions required by crawfish? Does your site provide these?

(C) Are you familiar with the growth rates and survival patterns of crawfish in pond systems?

(D) How much production per unit area can be expected in your proposed site?

(E) Vegetation

(1) Is there enough desirable vegetation in your pond?

(2) Can you readily seed and establish dense growth of the desired aquatic plants?

(3) Are you familiar with weed control methods and their corresponding costs?

(F) Predator Control

(1) Can you prevent the entry of predators/competitors in the ponds?

(2) Are you aware of the methods and their corresponding costs for predator control?

(G) Disease and Parasitism

(1) Can proper conditions such as clean water and good flushing be provided to prevent disease risks?

(2) Will you be able to detect/prevent the recurrence of disease, parasites and abnormalities of crawfish?

(3) Do you understand how disease are transmitted in crawfish systems and what an epidemic can do?

(4) Do you know where to get assistance for identifying and controlling diseases? What are the costs involved?

IV. OPERATIONS

(A) Broodstock

(1) How can broodstock be obtained? At what cost?

(2) Do you know the stocking density needed for your pond?

(B) Are you farming to raise crawfish to be sold as bait or as food? Are you familiar with the differences or modifications in production schedule/methods depending on whether crawfish are grown for bait or food market?

(C) Feeding

(1) Is the proper quantity and quality of vegetatation readily available for crawfish nutrition in the pond?

(2) Would you be able to decide when to put supplemental feeds, if needed?

(3) Are you familiar with the good and bad effects of supplemental feeding?

(D) Equipment

(1) What equipment is required for your operation to become economically viable?

(2) Is this equipment readily available or does it have to be custom made or imported?

(3) Have you allowed expenses for repair and maintenance of equipment?

(E) Operating Costs

(1) Calculate as best you can production and processing costs.

(2) What will be your costs for overhead and operations?

(3) Will you be able to compete in the market with other crawfish producers?

(F) Harvesting

(1) What will be the easiest and most economical way to harvest your crawfish crop?

(2) When is the most desirable time to harvest the crawfish crop?

(3) Will you have the manpower and equipment to do intensive harvesting to meet market demands?

(4) Is bait readily available when you need it? Do you have facilities to store large quantities of bait?

(G) Processing Harvested Crawfish

(1) What facilities do you have or plan to have for handling crawfish from harvest to market?

(2) In what condition do you expect to sell your crawfish? Alive, frozen or processed? Do you have facilities for any one of these?

V. MARKETING

(A) What markets are available for crawfish in your immediate area? In nearby areas?

(1) As food delivered to market or sold on the spot?

(2) As bait for sale to bait stores or sport fishermen?

(3) As stock for other farmers?

(B) Are these markets constant and reliable?

(C) Will your production be able to meet the market demands?

VI. MANAGEMENT

(A) Can you employ enough personnel at reasonable wages/salaries to carry out phases of your operation?

(B) Do you or your hired personnel, if any, have enough knowledge and understanding of the crawfish biology and culture requirements?

(C) Would you have enough time to monitor and manage your pond?

(D) Are you familiar with culture management procedures to maintain and possibly increase good crawfish production in your system?

(E) What safeguards can be built into your operations for emergencies? Will routine checks be made on the chemical and biological quality of the water as well as the changing conditions of the crawfish? What will be the costs for these?

(F) What facilities are avilable and what costs will be involved for experiments to increase production and/or selective breeding programs, if needed?

(G) What is the cost of maintaining biological and business records?

(H) Do you know the full procedures in event of an emergency in the farm?

VII. FUTURE EXPANSION

(A) Is additional area available for enlarging your operations should later expansion is desired?

(B) Can you foresee possible future uses of the area you intend to use as crawfish farm if at some time the operation becomes unprofitable?

(C) Would you have the necessary capital, equipment and personnel in case of expansion of your operations?

IX. LEGAL ASPECTS

(A) Are you familiar with the various regulations, pond construction restrictions and permit requirements for crawfish farming in your area?

(B) Do you have to obtain necessary discharge permits for the water drained from your ponds? Will there be any conflict with the general public or private persons regarding the use of your prospective water source?

(C) Are you aware of and familiar with the regulations of the Environmental Protection Agency, the Food and Drug Administration, and the South Carolina Department of Health and Environmental Control regarding the use of chemicals to control diseases, parasites, weeds, and predators in your ponds?

(D) Are you required in your area to obtain marketing license to sell your crawfish?

(E) If you plan to process your crop before marketing, are you familiar with the regulations, permits and standards required for processing and packaging crawfish products?

SELECTED REFERENCES

The following publications are available that might prove useful to persons considering crawfish culture. They may be available at public or college libraries. If not, persons interested to read them may make arrangements with their public libraries to have the publications borrowed from the University of South Carolina library in Columbia.

Applied Biochemists, Inc. 1979. *How to identify and control water weeds and algae.* Applied Biochemists, Inc., Mequon, Wisconsin. 64 pp.

** A good identification guide to aquatic vegetation, with recommendations on their control. May be obtained from Applied Biochemists, Inc., 5300 West County Line Rd., Mequon, Wisconsin 53092 @ $4.95.

*Avault, J. W., Jr. 1972. Crawfish farming in the United States. In: S. Abrahamsson, ed. *Freshwater crayfish: papers from the First International Symposium on Freshwater Crayfish, Austria, 1972.* pp. 239-250.

** A general overview of crawfish farming. Includes a list of researchers and their addresses who are working on different aspects of crawfish biology and culture.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. *Aquaculture: The farming and husbandry of freshwater and marine organisms.* Wiley-Interscience, New YOrk. 868 pp.

** Good sections on general principles and economics of aquaculture. Extensive discussion of culture management techniques of many species, which may be adapted for crawfish culture.

Bennett, G. W. 1962. *Management of artificial lakes and ponds.* Reinhold Publishing Corp., New York. 283 pp.

** A good reference book for pond management techniques, particularly vegetation and fish control.

Boyd, C. E. 1979. *Water quality in warmwater fish ponds.* Auburn University, Auburn, Alabama. 359 pp.

** Discusses in detail the principles, management and measurements of water quality in ponds. Includes sample problems in determining application/treatment rates of chemicals and other substances put into ponds, lime, e.g. chemicals for fish and weed control.

Hobbs, H. H., Jr. 1972. *Crayfishes (Astacidae) of North and Middle America.* Identification Manual No. 9. Biota of Freshwater Ecosystems. Environmental Protection Agency, Water Pollution Research Contribution Series. 173 pp.

** Comprehensive identification guide of crawfishes.

*Hun er, J. V. and J. W. Avault, Jr. *Producing crawfish for fishbait*. Center for Wetland Resources, Louisiana State University, Baton Rouge, La. Sea Grant Publication No. LSU-Tl-76-001. 23 pp.

** Discusses production guidelines for raising crawfish for fishbait and for obtaining soft-shelled crawfish.

Huet, M. 1972. *Textbook of fish culture. Breeding and cultivation of fish.* Fishing News Books Ltd., Farnham, Surrey, England. 436 pp.

** Good chapters on pond management including detailed discussion on construction, layout, maintenance and improvement of ponds, primarily for fish ponds. The procedures are adaptable for crawfish culture. A good reference book on fish cultivation for crawfish farmers interested in polyculture of fish and crawfish.

Johnson, S. K. 1977. *Crawfish and freshwater shrimp diseases*. Texas A & M University, Sea Grant College Program, College Station, Texas. TAMU-SG-77-605. 19 pp.

** Excellent handbook, with many colored and black and white photographs, designed as information source and field guide for diseases, parasites, and abnormalities of crawfish. Single copies may be obtained free of charge from the Department of Marine Resources Information, Center for Marine Resources, Texas A & M University, College Station, Texas 77843.

*La Caze, C. 1976. *Crawfish farming*. Louisiana Wildlife and Fisheries Commission Fisheries Bulletin No. 7. 27 pp.

** Excellent manual for crawfish production primarily for Louisiana situation, but the management procedures are readily adaptable to South Carolina conditions. May be obtained from Louisiana Wildlife and Fisheries Commission, P. O. Box 44095, Capitol Station, Baton Rouge, Louisiana 70804

Penn, G. H., Jr. 1943. A study of the life history of the Louisiana red-crawfish, *Cambarus clarkii* Girard. *Ecology*, Vol. 24, No. 1. pp. 1-18.

** Givesdetailed information on the biology of the red crawfish.

Stickney, R. R. 1979. *Principles of warmwater aquaculture*. John Wiley & Sons, New York. 375 pp.

** A broad overview of warmwater aquaculture, with good sections on water systems, water quality, disease and parasitism and their control, and the cultivation of fish with potential for polyculture with crawfish.

Wheaton, F. W. 1977. *Aquacultural engineering*. John Wiley & Sons, New York. 708 pp.

** A good reference book on construction and engineering aspects of aquaculture systems, giving details on the application of engineering principles and procedures to the culture of aquatic organisms. Some chapters provide handbook data summarizing physical, biological, and design data usable to aquaculturists.

Wishart, M. A. and H. A. Loyacano. 1974. *A survey of edible crawfish from the coastal plain of South Carolina.* Completion report for Coastal Plains Regional Commission, Department of Entomology and Economic Zoology, Clemson University, Clemson, S. C.

** Gives information on crawfish species found in South Carolina.

NOTE: References above with single asterisks (*) are obtainable from the Publications Clerk, 249 AG Center, Louisiana State University, Baton Rouge, Louisiana 70803. Ask also for a list of more than 50 publications on different aspects of crawfish biology and culture, obtainable also from the same office.

Other References

The following trade journals and publications publish crawfish-aquaculture articles as well as the latest developments on the different aspects of aquaculture and farm pond management. They may be available in some libraries or may be subscribed to personally, at least the trade magazines/journals.

Scientific Publications:

Aquaculture (Elsevier/North-Holland, Inc., Journal Information Centre, 52 Vanderbilt Avenue, New York, N. Y. 10017).

Proceedings of the Southeastern Association of Game and Fish Commissioners.

Proceedings of the World Mariculture Society (Louisiana State University Division of Continuing Education, 174 Pleasant Hall, LSU, Baton Rouge, Louisiana 70803).

The Progressive Fish-Culturist (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402).

Trade Journals/Magazines:

Aquaculture Magazine (formerly The Commercial Fish Farmer & Aquaculture News; subscriptions of $12/year may be sent to Aquaculture Magazine Subscription Department, P. O. Box 2451, Little Rock, Arkansas 72203).

Farm Pond Harvest (Free brochure and subscription rates may be obtained from Farm Pond Harvest, Box AA, Dept. C, Momence, Illinois 60954).

Fish Farming International (Fishing News Books Limited, 1 Long Garden Walk, Farnham, Surrey, England).

The National Fisherman (The National Fisherman, Camden, Maine 04843).

Related publications may also be obtained from the local offices of the Soil Conservation Service, Fish and Wildlife Service, S. C. Wildlife and Marine Resources Department, Clemson University Agricultural Extension Service.

ADDENDUM

The following publication, which came out shortly after this manual of guidelines was completed, provides an excellent synthesis of data on the biology and culture of crawfish. It is highly recommended for present and prospective crawfish farmers and it may be obtained from The Louisiana Sea Grant College Program, Center for Wetland Resources, Louisiana State University, Baton Rouge, LA 70803.

J.V. Huner and J.E. Barr. 1980. *Red swamp crawfish: biology and exploitation.* Louisiana State University, Baton Rouge, La. Sea Grant Publication No. LSU-T-80-001. 148 pp.