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Aquaculture of *Colossoma macropomum* and Related Species in Latin America

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Introduction

Colossoma macropomum (Cuvier 1818), known as black pacu in the United States, is the second largest scaled fish after *Arapaima gigas* (Osteo-glossidae) in the Amazon basin, reaching weights of 30 kg in the natural environment (Goulding and Carvalho 1982). The fish has excellent characteristics for use in aquaculture (Campos 1986; Saint-Paul 1986, 1991; Van der Meer 1997), which include

- Reproducing under aquaculture conditions;
- Being low on the food chain;
- Accepting prepared feed;
- Being highly resistant to disease, handling, and poor water quality;
- Having rapid growth;
- Being amenable to high density;
- Having high market acceptability;
- Commanding a high price; and
- Also being marketable as an ornamental fish.

Countries in Latin America culturing *Colossoma* and similar species include Argentina, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Mexico, Panama, Peru, and Venezuela (Figure 1). *Colossoma macropomum* has also been introduced into the United States, Africa, and Southeast Asia (Lovshin 1995). Until recently, problems associated with larval production and nutrition, exasperated because much of the information about its culture is dispersed or unpublished, have limited viable aquaculture ventures with this group of Amazonian fishes. Brazil is the first country that has commercially cultured these characids (Da Silva et al. 1976).

Very few researchers have access to the advances in culture of characids because much of the research appears in agency reports and, to further complicate dissemination of information, appears in different languages. There are hundreds of papers scattered throughout the region that require scientific analysis to establish a successful cultural program. Approximately 54% of the publications/reports are in Portuguese, 40% are in Spanish, and very few are in English and other languages. This chapter is an attempt to compile some of the more relevant information on *C. macropomum* and related species.

Description of Species

Taxonomy

Three species of the family Characidae (subfamily Serrasalminae) are commonly used in aquaculture in Latin America; they are *Colossoma macropomum* (Cuvier 1818), *Piaractus brachypomus* (Cuvier 1818), and *C. mitrei* (Berg 1895). Taxonomy and brief morphological descriptions are provided for these and some related species.

Colossoma macropomum is a characid native to the Amazon and Orinoco River basins in South America. *Colossoma macropomum* is commonly called "tambaqui" in Brazil, "cachama negra" in Colombia, "cachama" in Venezuela, and "gamitana" in Peru. *Piaractus brachypomus*

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Figure 1.—Primary countries in Latin America where aquaculture of C. *macropomum* and related species occur.

has the common name of "pirapitinga" in Brazil, "cachama blanca" in Colombia, and "paco" or "pacu" in a number of South American countries. Fingerlings of these two species are often confused, but species identification is simple after 6 months of age. *Colossoma macropomum* has a long, bony adipose fin containing small rays, is colored gray/bronze or black dorsally fading to white ventrally, and a patch of black is often found in the area of the anal and caudal fin (Figure 2). *Piaractus brachypomus*, on the other hand, has a fleshy adipose fin and is silver dorsally with orange laterally and ventrally (Figure 2). Morphological and ecological information has often been the basis for the description of the species of *Colossoma*, with *P. oculus* (Cope 1871) and *C.*

nigripinnis (Cope 1878) now being recognized as the juveniles of *C. macropomum* (Cuvier 1818), while *C. bidens* (Agassiz 1829) is the juvenile of *P. brachypomus* (Cuvier 1818) (Machado 1982). As far back as 1929, for example, six species were recognized: *C. bidens, C. brachypomus, C. mitrei* (Berg 1895), *C. macropomum, C. nigripinnis,* and *C. oculus* (Machado 1982). Taxonomic problems originated from the use of a few species, or the use of juvenile forms. *Piaractus brachypomus* at 20–40 mm total length (TL) has many pink oval patches in the ventral region before the pelvic fins. The head is pink/silver, the belly is silver, the dorsal fin lacks color, and the caudal fin is pink. At 50–100 mm TL, it has dark spots dorso-ventrally, the anterior ventral region is red, as are the
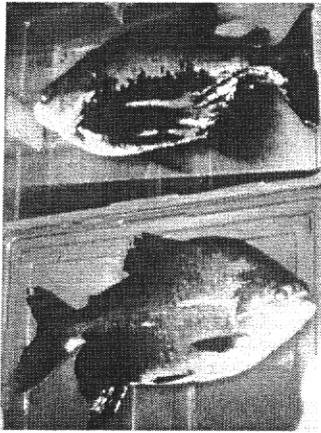
Figure 2.—Photograph of adult *C. macropomum* (upper fish) and *P. brachypomus* (lower fish). (Photo by Marcos de Jesus)

pectoral and pelvic fins. These characteristics were used to describe *C. bidens*, which is, in fact, the juvenile of *P. brachypomus*. At standard lengths (SL) greater than 20 cm, the color of *P. brachypomus* is gray and the caudal and dorsal fins are dark gray. When *C. macropomum* reaches 20–30 mm SL, it has an ocellus in the middle part of the body under the dorsal fin. The dorsal, adipose, pectoral, and pelvic fins lack color, and the anal fin is pink with black borders. When it reaches 30–60 mm SL, the body becomes darker in the posterior region, the ocellus is maintained, and the mandible becomes darker. *Colossoma macropomum* at this stage is

often identified as *C. oculus*. Then at 60–90 mm SL, the ocelli disappear, and it is often identified as *C. nigripinnis*, a juvenile of *C. macropomum* (Table 1).

The number of gill rakers in *P. brachypomus* is almost constant, however, in *C. macropomum*, they increase ontogenetically (i.e., it has 20 at 19 mm SL and 93 at 150 mm SL). *Colossoma macropomum* is the only species that has ossified rays in the adipose fin; these rays are more numerous and harder when the fish is older. Its swim bladder consists of two well-developed chambers connected to the esophagus. The anterior chamber is longer than the posterior, whereas, in *P. brachypomus*, the anterior chamber is smaller than the posterior (Machado 1982).

Britski (1991) taxonomically reviewed *Colossoma* to include three species, two of which, *C. macropomum* and *P. brachypomus*, occur in the Orinoco and Amazon River systems while the third, *C. mitrei*, inhabits the Parana-Uruguay River system.

Fossil fishes from the Miocene in La Venta fauna of the Magdalena River Valley, Colombia, were identified as *C. macropomum*. These fossils document a long and conservative history for a species that is highly specialized for feeding on streamside plants. The phylogenetically advanced position of *Colossoma* in the subfamily Serrasalminae implies that six related genera and other higher characid taxa originated at least 15 million years ago. The fossil

Table 1.—Chart summarizing the main differences between the three species.

	C. macropomum	P. brachypomus	C. mitrei
Synonyms	C. macropomum C. nigripinnis C. bidens	P. brachypomus C. brachypomus P. mesopotamicus	C. mitrei C. edulis
Common name	Tambaqui (Brazil) Cachama (Venezuela) Cachama (Venezuela) Black Cachama (Col.)	Pirapitinga (Brazil) Paco (Peru) Morocoto (Venezuela) White Cachama (Col.)	Pacu (Brazil)
Gill rakers (first arch)	84–107	33–37	20–38
Lateral line scales	78–84	88–89	108–128
Scales above lateral line	23–27	37–42	50–60
Scales below lateral line	20–22	27–34	49–56
Adipose fin with rays	present	absent	absent
Pyloric cecae	30–75	20–25	20–28
Maximum length (cm)	90	80	50
Maximum weight (kg)	30	20	10–12

References: Barbosa (1986), Britski (1991), and Machado (1982).

record suggests a formerly diverse Magdalena fauna that has suffered local extinction, perhaps associated with late Cenozoic tectonism (Lungberg et al. 1986).

Biology

Colossoma macropomum is widely distributed in South America, ranging from the Rio de La Plata to the Orinoco River system. This species inhabits the lakes bordering whitewater rivers (turbulent and brown from nutrient-rich sediment of Andean origins). During periods of low water, the adults leave the lakes and enter the main river channels where they spawn as water levels rise during the rainy season, and then when the water level drops, they return to the lakes (Lowe-McConell 1975; Goulding and Carvalho 1982; Saint-Paul 1991). Adult fish feed mainly on fruit and seeds, while juveniles (smaller than 4 kg) feed on zooplankton, insects, snails, and decaying vegetation (Goulding and Carvalho 1982; Campos 1986; Saint-Paul 1986; Lovshin 1995). Adults are exclusively frugivorous, showing a definite preference for the fruit of rubber trees *Hevea brasilensis* in the family Euphorbiaceae (Goulding 1982). Forty-eight different fruits were reported as possible food in flooded waters in the Ucayali River in Peru (Campos 1986).

Saint-Paul and Soares (1987) describe Serrasalmids of the genera *Colossoma* and *Piaractus* as being obligate gill-breathers that are encountered in the floodplain lakes of Amazon-ia, even when oxygen concentrations are below 0.5 mg/L. It was shown by experiments that fish of the family are able to use the oxygen-rich surface layer of the water for respiration in order to survive periods of habitat-induced hypoxia. This aquatic surface respiration (ASR) described in Saint-Paul and Soares (1988) entails an increase in locomotor activity and an ecomorphosis, involving the formation of a dermal extension (formed by edematous processes in the stratum spongiosum) of the lower jaw, apparently having a hydrodynamic function for using the surface layer. When the water is aerated, this dermal extension retrogresses to its original size. During long periods of oxygen depletion, *Colossoma* and *Piaractus* spp. aggregate in regions with macrophytic cover and survive there without displaying the usual pattern of ASR. Saint-Paul et

al. (1989) found that the plant *Eichhornia crassipes* discharges 2–3 mg O_2/dry weight/j/L from its roots, apparently meeting oxygen requirements of these fishes. They reported colossomid opercular movements changed from 35 movements/min when the oxygen concentration is 8 mg/L to 80 when it is 1 mg/L. However, when oxygen concentrations fall below 1 mg/L, opercular movements drop to less than 35 movements/min.

Food habitat studies of *C. macropomum* in the natural environment have been conducted by Goulding and Carvalho (1982), Saint-Paul (1984, 1985), Campos (1986), and Goulding (1988). These authors found the proportion of food items by category differs by season, though the proportion of zooplankton is always high. Saint-Paul (1984) found during high water periods from April to September, Cladocera (*Daphnia gessneri* and *D. cornuta*) predominate, contributing 90–95% of the planktons in the diet. During the period of low water level, Copepoda (primarily *Notodiaptomus amazonicus*) predominate, contributing from 52% to 58% of the zooplankton food items. Among the fruits and seeds found in the stomach, *Tabebuia barbata* (Bigoniaceae), cetico *Cecropia* sp. (Moraceae), vervena *Vitex cymosa* (Verbenaceae), and *Mabea* sp. (Bombaceae) were identified. As a third major food group, *Oryza perennis* was especially important in the diet during high water periods. Goulding and Carvalho (1982) found juvenile *C. macropomum* to be omnivorous to a maximum weight of 5 kg. The dietary basics are the fruits and seeds from the flooded forest and the zooplankton from the lakes. Saint-Paul (1985) describes how the annual fluctuation in the water level of the Amazon River system significantly changes the living conditions for juvenile *C. macropomum*, adding that due to a greatly reduced food supply during the low-water period, the fish must metabolize their reserved tissues, which reduces the glycogen-somatic index and the protein content of the filet. No change in the visceral fat content was found; however, though with rising water, an increase of glycogen content was detected. He also reported temporary fat storage, an adaptation by the fish to water level fluctuations and related environmental changes of the Amazon River.

An obvious morphological adaptation enabling frugivorous feeding is the dentition of

C. macropomum. This fish has large and powerful teeth, which permit it to eat many types and sizes of seeds. These teeth are heterodont, the medial ones being multicuspid molars, while those more laterally placed are premolars (Goulding 1980). Elongated gill raker spines are densely clustered on the gill arches, a condition characteristic of planktivorous fishes. The stomach of this fish is well developed, with adjacent pyloric cecae ranging in number from 30 to 75 and the length of its intestine being 2–2.5 times the body length (Saint-Paul 1985). Campos (1985), reporting on 16–18-kg individuals, found that the ratio of length of intestine to length of the stomach is 5.44, which is between those of *Prochilodus nigricans* (13.66), which is detritivorous, and *Plagioscium squamosisimus* (2.44), which is carnivorous.

The spawning period in the natural environment lasts from October until December in central Amazonia (Saint-Paul 1986), November and December in Peru, and in June in Venezuela. *Colossoma macropomum* spawns once a year in response to rising water levels during the rainy season, when they migrate to spawning areas of the main-stem rivers. Females release their eggs into the current where surrounding males fertilize them, and the semibuoyant eggs are carried by the current until hatching in approximately 17–20 h at temperatures at about 28°C. Further details on fecundity, induced spawning, and so forth, are presented below.

Fingerling Production

Broodstock spawning period.—The spawning period for *C. macropomum* corresponds to the rainy season, October to March in northeast Brazil, for example, but changes with environmental conditions. *Colossoma macropomum* become sexually prepared in apparent response to the rainy season; however, in locations where the rainy season is not well defined, such as in Venezuela, or is irregular, transferring broodstock to recently filled ponds near the spawning season has stimulated sexual maturation (Bello et al. 1989). In Betune, Brazil, where annual temperatures remain greater than 26°C, *C. macropomum* have been observed to reproduce during all months of the year.

Selection.—Broodstock are generally taken from the natural environment, although some have been produced in aquaculture stations. The fish are captured as fry, fingerling, juvenile, or adults and then are stocked in culture ponds and prepared as future broodstock. The selection of broodstock is made based on external characteristics during the spawning season, with some selection based on individual performance (growth rate, quantity and quality of semen, fertilization rate, fry production, etc.) at the more established culture centers.

Preparation and management of ponds.—Culturists use the same methods of pond preparation in all five countries where *C. macropomum* are primarily raised. The ponds are cleared and exposed to the sun for 2 d, disinfected using 25–80 g/m² of CaO (calcium oxide), and fertilized with chicken manure (100–200 g/m²) and/or inorganic fertilizer (15 g/m² of urea) to stimulate plankton production, particularly zooplankton.

Stocking density.—In most hatcheries, culturists are using a stocking density of 200–400 g fish/m² in monoculture systems. However, in some stations, this rate is reduced to 90 g/m² (Iquitos, Peru), 66 g/m² (southern Brazil), or 50 g/m² (northeastern Brazil). In Venezuela, the stocking density is as high as 700 g/m². In southeastern Brazil, *C. macropomum* broodstock are reared in polyculture, where they represent 50–75% of the total biomass. The secondary species are curimatá *Prochilodus cearensis*, bighead carp *Hypopthalmichthys nobilis*, and common carp *Cyprinus carpio.*

Water quality.—The water characteristics reported in the five countries as being highly suitable for *C. macropomum* are pH of 6–7, oxygen concentration at 5–8 mg/L, and hardness over 30 mg/L. In Colombia, the inflow of water used in *C. macropomum* broodstock rearing ponds is 24 L/s/ha, whereas in Peru, the inflow is 10 L/s/ha or less. In some hatcheries, new water is only provided to recover the loss from evaporation and seepage. One important criterion used in Peru is the maintenance of the transparence between 18 and 30 cm depth. If the transparence is lower than 18 cm, it is necessary to increase the flow of water, but if the transparence is higher than 30 cm, additional fertilizer is applied. Ponds are considered to have good productivity when 100 L of water filtered through a 150-mm-mesh net yields 2–3 mL of zooplankton.

Food.—Because of differences in feed ingredients available in the various countries where *C. macropomum* are raised, there exists a wide range of ingredients in prepared diets. The crude protein range of these diets is between 18% and 39%, and the supplied ration ranges from 1% to 5% of the wet body weight of fish. A diet with 28% crude protein, made with fish meal (10%), soybean meal (40%), wheat meal (25%) and corn meal (25%), has been successfully used with *C. macropomum* in Venezuela (Alves 1991). In Peru, a diet with soybean meal (20%), corn meal (20%), fish meal (15%), rice bran (20%), wheat bran (15%), manioc meal (8%), salt (1%), and vitamin premix (1%) has been used by culturists for several years with good success. The ration used in Peru is 3% of wet body weight. However, in southeast Brazil, the ration is variable in relation to the seasons of the year. In the warmer season (January–March), it is 5% of wet body weight, reduced to 1.5% of wet body weight in winter (March–September), and raised to 3% in spring (September–December).

Induction of Reproduction

Age of broodstock.—Males and females of *C. macropomum* reach sexual maturity in 3 and 4 years, respectively, when they have attained 3–6 kg of total weight. In some stations in Brazil, culturists have used the same spawners for over 12 years. In Peru, the spawners are generally used for no more than 4 years. The best spawners reported by researchers are those with ages between 4 and 7 years, with an average weight between 3 and 7 kg, though individuals weighing in excess of 10 kg are sometimes used (Figure 3).

Characteristics of sexual maturity.—No reliable method outside the spawning season is known to externally differentiate the sexes. Bulky and soft abdomens, as well as swollen protruding and reddish genital papillae, are the main criteria used in all five countries to select mature females for spawning. Male selection is based on semen ejaculation of white color, which should be dense and abundant as pressure is applied to the abdomen. Researchers in Panama use biopsy of *C. macropomum* ovaries to stage eggs (Pretto 1989). Eggs are placed in a solution of 5 mL acetic acid, 30 mL formaldehyde,
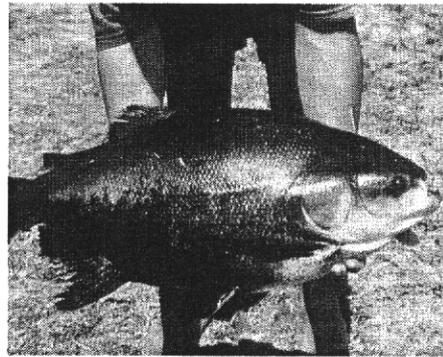

Figure 3.—*Colossoma macropomum* broodstock can weigh in excess of 10 kg. (Photo by Christopher C. Kohler)

and 60 mL ethyl alcohol (95%) and, after 3 min, are observed microscopically to determine the position of the seminal vesicle, with mature females having a peripheric seminal versicle. However, Brazilian researchers feel this method is of little practical value since *C. macropomum* eggs require hormonal injection in order to start the vesicle migration.

Induced spawning.—Hormonal injection in *C. macropomum* is intramuscular, in the dorsal region under the dorsal fin, or intraperitoneal, in the base of the pelvic fin. The induction is stimulated with natural and synthetic hormones. In Brazil, Peru, Venezuela, and Colombia, culturists use extracts of heteroplastic hyphophysis, especially from common carp hyphophyses. In some hatcheries in Colombia, the use of homoplastic hormones collected from wild *C. macropomum* is common. In Panama and Peru, the use of gonadotropin releasing hormones (GnRH) and their homologs or analogs, are frequently used. Another less commonly used hormone is human chorionic gonadotropin (HCG). In northern Brazil, where the first successful induced spawning events occurred (Da Silva et al. 1977), the broodstock receive intramuscular injections of saline solution containing ground pituitary glands taken from ripe *Prochilodus cearensis* at 6-h intervals with solutions containing increasing amounts of pituitary material. Spawning normally occurs after the fourth or fifth injection. Males are given a total of about three pituitaries/kg of body weight because of difficulty in obtaining sufficient milt. The dosage corre-

sponds to approximately 5.5 and 2.5 mg of dried pituitary per kilogram of female and male, respectively.

Hilder and Bortone (1977) describe a technique used in Venezuela to spawn *C. macropomum* not in sexual readiness. Fish were injected with preserved pituitaries collected from common carp, with both sexes injected at 0, 24, 48, 72, 96, and 124 h. Females between 20 and 30 kg received a total of 120 mg of carp pituitary divided into five initial doses of 6 mg each and two final injections of 30 and 60 mg. Males averaging the same weight received a total of 75 mg of carp pituitary divided in five injections of 6 mg each and two final injections of 15 and 30 mg. Eggs (water hardening swells them to ~2.6 mm diameter) hatch in 22–23 h at a water temperature of 26–27°C, with newly hatched fry averaging 3.8 mm TL. It was estimated that females weighing 10–15 kg could produce about 1 million eggs (Lovshin 1995). Fuller descriptions for spawning methodology for colossomids can be found in Espinoza (1988), Woynarovich (1986), and Carolsfeld (1989).

Extrusion and fertilization of eggs.—In all five countries, the females and males of *C. macropomum* are stripped using the dry method (Alcantara and Guerra 1992). Some technicians use anesthetics (5–15 ppm Quinaldine or 100–150 ppm 2 phenol-ethanol, or 100 ppm MS-222) to manipulate the spawners. A solution of physiological serum, or 1.4% urea, is used to increase the viability and motility of the spermatozoa. The response time to induce spawning differs from one station to another. The time most frequently reported ranges between 200 and 300 degree-hours following the last hormonal dose. Alcantara (1985) reports that the formula that expresses the relationship between temperature and spawning time in female *C. macropomum* is

Degree-hours = 1,635.91–43.33 (Number °C) ($r = -0.99$)

Colossoma macropomum does not usually spawn naturally in tanks after pituitary injection. Sexual products are stripped from both sexes, mixed together in a container (Figure 4), and cleaned with water before transferring the eggs to incubators. The formula that expresses the relationship between number of
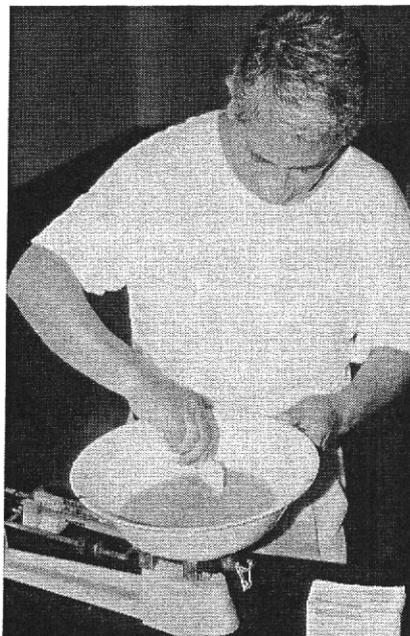

Figure 4.—Stirring of eggs and semen of *P. bracypomus* prior to activation with water. (Photo by Christopher C. Kohler)

eggs and wet weight (Alcantara and Guerra 1992) is

Number of eggs = 167,899 + 33,818 (wet weight fish in kilograms) ($r = 0.76\%$)

Incubation

Incubators.—Different kinds of incubators are being used in Latin America by various researchers, ranging from artisan incubators of 20–40 L, which are used inside of concrete tanks, to sophisticated incubators of fiberglass, acrylic or plastic, with capacity of 6 L (MacDonald type) or 60–200 L (Woynarovich type; Figure 5), the latter of which is most commonly used in the five countries.

The amount of eggs placed in each incubator generally ranges between 500 and 3,750 eggs/L. In Venezuela, however, culturists generally use 5,000 eggs/L. In some hatcheries, the eggs are disinfected with an iodine solution at 100 ppm for 5 min (pH = 7.0) before they are transferred to the incubator.

Water flow and quality.—The water pH ranges between 5.8 and 8.0, and the oxygen concentration between 4 and 8 mg/L. Water hardness
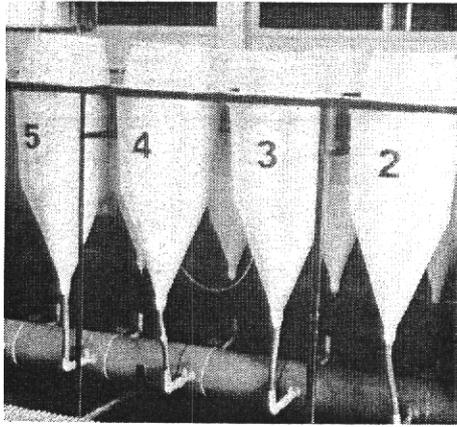
Figure 5.—Fiberglass Woynarovich incubators (500-L capacity) used for hatching fertilized eggs of *C. macropomum* and related species. (Photo by Fernando Alcantara)

ranges from 40 to 300 mg/L (Mariano Rebaza, Instituto para Investigaciones de la Amazonia Peruana, personal communication.) The reported optimum water temperature in the incubators is between 26°C and 29°C. Temperatures over 30°C are reported as lethal to *C. macropomum* eggs and larvae. The water inflows are between 0.5 and 0.8 L/min/incubators of 60 and 200 L of capacity, respectively. The water must be free of suspended particles and microorganisms.

Larval development.—The references used to describe development of *C. macropomum* from egg stage to postlarvae are the following: Valencia et al. (1986), Bermúdez (1979), and Alcantara (1985). The yellow-green eggs are nonadhesive, semibuoyant, megagamete, almost spherical in shape, and have a diameter of 1.3 mm. After fertilization, the hydrated eggs range in size from 2.2 to 2.8 mm in diameter. The incubation temperatures for larval development were the following: 27–29°C in Peru, 28–29.5°C in Venezuela, and 26.5°C in Colombia.

Following the methods suggested by Rugh (1968), the time schedule of *C. macropomum* development is the following:

1. Eggs become translucent, the perivitelline space widens, and the germinal disk becomes lens-shaped minutes after fertilization. The eggs are teloecithal and divide by discoidal cleavage (Browder et al. 1991).

2. First cleavage: 15 min (Alcantara 1985); 30 min (Valencia et al. 1986); 35 min (Bermúdez 1979) after fertilization. At this stage, the embryo has a diameter between 1.85 and 2.00 mm (Valencia et al. 1986). The first cleavage is meridional and nuclei are clearly visible.

3. Second cleavage: 30 min after fertilization (Alcantara 1985). This is also a meridional cleavage at the right angle to first plane of cleavage, which results in the formation of four equal blastomeres.

4. Third cleavage: 70–75 min (Valencia et al. 1986); 70–90 min (Bermúdez 1979). This cleavage is in a parallel plane to the first cleavage. At this time, the blastodisc appears rectangular in shape with no space beneath it.

5. Morula: 90 min (Valencia et al. 1986); 105 min (Bermúdez 1979); 120 min (Alcantara 1985). After the fifth cleavage, there are numerous myomeres and it is difficult to observe individual cells. This is a sensitive stage of development during which shaking may kill the embryos (Valencia et al. 1986).

6. Blastula: 4 h (Alcantara 1985); 2.5 h (Valencia et al. 1986) after fertilization. The small cells are tightly packed to form a blastodisc, which is slightly elevated above the yolk surface. At this time, a subgerminal cavity appears beneath the blastodisc.

7. Embryonic differentiation:
   • At 8 h, morphological differentiation of the head and tail begin and the first somites can be observed (Alcantara 1985). Valencia et al. (1986) observed the first somites at 270 min and differentiation of the optic vesicle from the auditory placoide at 335 min. Bermúdez (1979) observed the first somites, cephalic differentiation, and the optic capsules at 365 min. He observed the closed blastopore and embryonic fin at 575 min.
   • At 9 h, the embryo has 12 somites and ocular pigmentation (Alcantara 1985). Bermúdez (1979) observed 12 somites, optic capsule, otic (calcareous structure of inner ear) and brain tissue at 675 min. However, Valencia et al.

(1986) report 15 somites at 370 min, and 18 somites, with caudal fin differentiation at 445 min.

- At 600 min (Alcantara 1985); 790 min (Bermúdez 1979) the tail begins to differentiate and separate from the yolk sac.
- At 660 min (Alcantara 1985); 855 min (Bermúdez 1979) the heart starts to function. Valencia et al. (1986) observed the first pulsation or beating heart at 500 min. They observed 50 pulsation/min at 525 min when the embryo is 2 mm TL and the egg 3.5 mm diameter. Bermúdez (1979) ob served 50–55 pulsations/min at 915 min at 100–110 movements at around 11 h (Alcantara 1985).
- At 12 h, Alcantara (1985) observed contractions of the entire body, while Valencia et al. (1986) observed strong contraction of the body at 9.75 h.
- At 13 h, well-developed larvae are visible, with intense contractions of the tail inside the eggs. At this time, the embryo starts to rotate inside the chorion (Alcantara 1985). Bermúdez (1979) observed that at 19.3 h, the embryo strikes the membrane, the heart beats at 160–170 pulses/min and the egg has a diameter of 2.5 mm.

Hatching.—Alcantara (1985) reported that the embryo hatches at 14 h. Valencia et al. (1986) observed hatching at 12.5 h and Bermúdez (1979) at 20 h and 40 min (544.6 degree-hours) when water temperature was 26.7°C and 80 min earlier when the temperature was 28.8°C. In the hatching process, the larvae violently move their tails to break the membrane, with the tail region emerging first.

In general, the reported hatching times range between 12 and 21 h in the five countries. Hatching takes place in 17–19 h when water temperature ranges from 27–29°C. In Panama, hatching time is 21 h at temperatures between 24°C and 26.5°C. Bello et al. (1989) reported that in Venezuela, hatching takes place in 18 h when temperature ranged between 26°C and 27°C, but at 29°C, it took place in 14 h.

Newly hatched larvae average 3.8 mm (Hilder and Bortone 1977) and 3.6 mm TL (Bermúdez 1979). At this time, the larvae as-

cend to the surface. Their vertical movement is helped by the water flow and by caudal movements. At this stage, each larva has 30 pairs of somites and the vitelline yolk is 1.3 mm. At 51 h posthatch, a larva is 5.3 mm TL with a yolk sac of 0.8 mm in diameter. The caudal fin is better defined at this time and there is a rudimental pectoral fin over the highest part of the yolk sac. Eye pigmentation is more pronounced at this time. At 72 h posthatching, the total length of the larvae is 5.9 mm and yolk sac diameter is 0.3 mm. Blood-filled capillaries are visible at this time (Bermúdez 1979).

After the yolk sac has been entirely absorbed, Bermúdez (1979) designates the state as being postlarval. The postlarvae have a total length of 6.4 mm and increased eye pigmentation. The swim bladder is filled and horizontal swimming is facilitated by the presence of pectoral and caudal fins. After 191 h, postlarvae have a TL of 11.8 mm, have 35 pairs of somites, and the caudal fin is formed. When the individual is 18–20 mm TL and completely formed, it is considered to be a fry. The fry have numerous melanophores on the side of the body and are able to accept prepared food. Fry are ready to be stocked into ponds at this time.

Larval behavior.—Protozoans, rotifers, and small zooplankton are the first foods that the fry will accept. Recently hatched larvae swim in a vertical direction to the surface and then fall to the bottom. The larvae continue this behavior for 2–3 d after hatching. They are very active with very short periods of resting between movements. The larvae after 4–5 d of hatching have all their organs and are ready to take food from the environment. During the first 4–5 d, the larvae rely on the yolk sac for nourishment. During this time, larvae do not have pigmentation and *C. macropomum* larvae can die rapidly if they are constantly exposed to the ultraviolet rays of the sun. When the larvae rises to the surface to fill its swim bladder, it still has 20–30% of its yolk sac remaining. This yolk supply permits the larvae to survive during the critical period of adaptation to exogenous feeding. The larvae are considered as being premature during the period between hatching and when it fills its swim bladder. After it has filled its swim bladder, it is called a postlarvae and requires adequate oxygen concentration (6–8 mg/L), adequate temperature (25–29°C), and waste-

free water. Food in adequate quantity is also essential for postlarval growth and development and protection from its predators (i.e., Copepoda and Odonata). The principal cause of mortality of postlarvae *C. macropomum* is low availability of food. The postlarvae can be divided in premature postlarvae, which mainly feed on rotifers, and advanced postlarvae, which eat copepods, cladocerans, and can accept prepared feed. The postlarvae reach the advanced stage of development 10 d after the initial feeding day (15 d after hatching). At this time, they range in size from 1.5 to 2.0 cm TL.

Larviculture

When the larvae start to eat, and before the total reabsorption of the yolk sac, culturists often feed live food (freshly hatched nauplii of *Artemia* spp. or plankton from previously fertilized ponds) and/or with prepared food. In Venezuela, researchers use 2.0-m² tanks fertilized with ammonia sulfate (100 ppm), urea (10 ppm), and triple super-phosphate (10 ppm). With this system, they have produced an abundant supply of rotifers and cladocerans. The rotifers appear after 9–15 d, and the tanks are refertilized and the cladocerans are fed rice meal. In Peru, massive populations of *Brachionus* sp. (56 mL/L) have been produced with chicken manure (0.1 kg/m²) (Ascon 1988).

  After hatching, the manipulation of the larvae varies from one station to another. In some stations they are transferred to incubators of large capacity (Brazil) or to tanks or to nets (Peru). The stocking density in larviculture fluctuates between 10 and 500 larvae/L. The premature postlarvae can be reared using different containments such as aquaria, incubators, tanks, or earthen ponds. In these environments, the manipulation of the water used for incubation and larviculture is very important for good survival, including constant flows of water (2.5 and 4.0 L/min in incubators of 60 and 200 L, respectively) and/or aeration. The management of the water is accomplished with filtration, sterilization with ultraviolet light, regulation of pH and hardness, raising temperature, recycling water systems, elimination of predators, and with fertilization.

  Successful production of *C. macropomum* larvae depends on the production of live food

in adequate quality and quantity. The major groups of zooplankton produced in ponds are rotifers and two suborders of crustaceans: Cladocera and Copepoda. Many other invertebrates such as Anostraca, Ostracoda, and other aquatic insects are present in ponds as competitors or as predators of *C. macropomum* larvae. Zooplankton succession starts with the presence of rotifers, then the cladocerans and minor copepods, and finally the large copepods and cladocerans. This succession can be manipulated using fertilizers and insecticides. It has been demonstrated in Brazil that during the first 2 d of larvae culture, the *C. macropomum* postlarvae prefer to eat rotifers and nauplii, and then they eat cladocerans. Rotifers are more vulnerable than cladocerans, which in turn are more vulnerable than copepoda to suction-capture mechanisms (Batista et al. 1986a).

  The environmental factors that influence the production of fry in the first period of culture are adequate temperature (between 24°C and 29°C), quality and availability of food (the larvae prefer organisms of 0.15–0.20 mm, such as rotifers), oxygen concentration (optimum: 6–8 mg/L), presence of predators (primarily larvae of odonates and copepods), and meterological factors (precipitation over 17 mm/d and temperature over 30°C are lethal).

  Rotifer production is considered good when 1–3 mL is obtained after filtering 100 L of water from the nursery pond with a 20–180-mm mesh net. The development of the maximum population of rotifers occurs 4–5 d after filling the pond, and it remains so for 3–4 more days. *Colossoma macropomum* continues feeding upon zooplankton during the first year of culture.

  The most frequent zooplankton found in the stomachs of *C. macropomum* larvae and fry are the following: in the first days (5 d after stocking) only rotifers, after 10–12 d the smaller cladocerans and copepods become most important, and during the next 5–10 d of culture (15–30 d after stocking), the larvae eat all available cladocerans and copepods. They can also eat small larvae of insects such as chironomids and odonate larvae at this time (Guimaraes and Senhorini 1985). In Venezuela, Bello et al. (1989) reported the use of live *Artemia* spp. and cultured cladocerans as food for postlarval *C. macropomum*. In Venezuela, the culturists produced *Moina* and *Diaphanosoma* to feed postlar-

val *C. macropomum*. The cladocerans contain between 45% and 50% protein. The Venezuelan researchers reported that in tanks of 10–200 m², chicken food fermented for 3 d, and applied at a dose of 20 g/m²/week, produces 2,000–4,000 cladocerans/L. The best result reported by these authors using this system was the production of 2,300 postlarvae/m² in 27 d. Each postlarvae consumed 62–173 cladocerans daily.

The natural predators of larvae and fry are one of the main impediments to obtain good production (Batista et al. 1986b). The aquatic predators can be classified as micropredators or macropredators. The micropredators are the cyclopoid copepoda carnivores that attack *C. macropomum* larvae by breaking their skin and tail with their spiny appendages. During the first week of culture, the cyclopoid copepods are very dangerous to larvae. One hundred *Cyclops* spp. per liter of water in the pond can kill 90–95% of the stocked larvae (Batista et al. 1986a). The macropredators are animals that eat the fish larvae such as larval insects. Batista et al. (1986b) reported that the most predaceous insect larvae are the Odonata. They listed 14 predator species of odonates in Brazil; of these, 3 are the most frequent, namely: *Plantala flavescens, Coryphaeschna adenaxa,* and *Brachynesi* sp. These insects of the sub-order Anisoptera cause major predation. They reported that *P. flavescens* (Fabricius 1798) produce 400 eggs per female; its nymphs hatch in 114 h after eggs are laid with a total length of 1.0 mm. After 24 d, they attain 25 mm in TL. Nymphs are transformed into adults in 54 d. Batista et al. (1986b) tested the predator–prey relationship of odonate nymphs (20 mm) against *C. macropomum* larvae (7 mm TL). They used different densities of *C. macropomum*: 50, 100, and 150 larvae per aquarium, and in each one, they stocked one Odonata larvae. Predation in the three treatments was 31, 31, and 32 larvae, respectively. They found that one 2.0-cm *P. flavescens* nymph in 24 h could eat 32 *C. macropomum* larvae of 7.0 mm TL.

Preparation of ponds in larvae culture.—The most common techniques used to disinfect ponds are the use of calcium oxide (CaO) at a concentration of 60–200 g/m². Fertilization is accomplished using chicken manure at 100–300 g/m². Some stations in Peru use green or dried grass as an organic fertilizer, while others use urea at 2.5 g/m² or triple super-phosphate at 39–60 g/m².

The addition of calcium is very important for the preparation of ponds. The calcium kills potential predators and disinfects the sides and bottom of the humid empty pond. It also improves the buffer capacity of the water (Boyd 1990). The calcium (CaO) is applied in the first hour after dawn with doses varying between 60 and 200 g/m². The dose depends on the amount of organic matter in the pond and on the pH. Ponds with high concentration of organic matter and lower pH (<5) and hardness (<20 ppm) require higher amounts of CaO than ponds that have higher pH (6–8) and hardness (>20 ppm). The calcium must be completely distributed in moist form to avoid a reaction of CaO with CO_2 from the air forming calcium carbonate, which has less disinfectant effect. After 4–6 h, the CaO is mixed with the pond surface soil to avoid quickly changing pH of the water when it is added. Before the pond is filled, organic fertilizer is added in one of the following treatments: cow manure at 6,000–10,000 kg/ha, chicken manure at 2,000–4,000 kg/ka, or swine manure at 4,000–7,000 kg/ha. If the water does not respond to organic fertilizer, then 30–60 kg/ha of triple super-phosphate (45% P2O5) is supplied.

The inflow of water is controlled using a 150-mm-mesh net in order to avoid the introduction of eggs of potential predators. Biocides to control competitors and predators of *C. macropomum* larvae are being used less frequently. However, in some cases, culturists use organophosphates and petroleum byproducts (7.5 mL of petroleum plus 0.25 mL of motor oil for each m²).

Utilization of Bercaria Net.—This method has been used in Brazil since 1982. Researchers utilize a 333-mm-mesh net to cover the ponds where the larvae are stocked for a period of 6 d. From the nets, the larvae are then moved to another pond previously treated with an organophosphate, and stocked at a density of 8,000 larvae/m³. In this case, an air compressor is used to improve oxygen concentration (Batista et al. 1986b; Da Costa and De Melo 1986).

De Morais et al. (1986) used one net with 333-mm mesh (Type I) and the other with 1-mm mesh (Type II) in two steps for *C. macropomum* larvae culture. Young larvae at the stage when the mouth is still closed are transferred from the incubators to the Type I net where they are fed for 10 d with mixed powdered food (50%

crude protein) composed of soybean, fish meal, premixes of vitamins and minerals, and live food two times each day. Between days 10–20, the larvae are stocked in the Type II net where they receive formulated food. Finally, these fry are transferred to fertilized ponds.

In a more simplified system, Brazilian culturists first chemically treat with calcium and fertilizer as previously described, and after 5 d, the postlarvae are stocked in ponds previously filled with water up to 0.5 m depth. The pond is filled 7 d later to a maximum depth of 1.5 m.

In Colombia, the culturists use a system that produces up to 92% fry survival after 25 d (Valencia and Puentes 1989). Five days after hatching, larvae are stocked in concrete tanks where they are fed with microencapsulated (poultry) eggs (1 egg/100,000 postlarvae/24 h) and *Artemia* nauplii. After 5 d, the larvae are transferred to earthen ponds previously fertilized (2 d before stocking) with N-P-K (11–53–0) at 27 kg/ha. Larvae are subsequently fed prepared food (23% crude protein).

Stocking density of postlarvae.—In nearly all five countries, the stocking density of postlarvae in ponds fluctuates between 100 and 400/ m². However, in some stations in Brazil and Panama, the stocking density is 600/m². In most cases, fry production is accomplished in one step over 30–45 d (Colombia, Peru, Brazil, Venezuela). However, in Panama, culturists use a three-step method. In the first step (2 weeks), the postlarvae are stocked at a density of 400–600/m²; in the second step (15–30 d), the density is reduced to 50–60/m², and 30 d later, the density is reduced to 30/m². Fish at the third stage are 6–8 cm TL and can accept pelleted feed.

Prepared food in fry production.—Aquaculturists in all five countries start to provide prepared feed immediately after stocking the larvae. Commercial feed or diets prepared in their own hatchery (18–45% crude protein) are fed. This food is distributed over the border of the pond 5–6 times per day.

Cantelmo and De Sousa (1986a), testing the size of the food in relation with total fry length, reported that 0.7-mm-TL *C. macropomum* starved when fed with food sized 0.25 mm or larger. *Colossoma macropomum* with lengths of 1.0 cm TL accept food particles up to 0.25 mm (powder);

1.34-cm-TL fry accept food up to 0.35 mm; 1.93-cm-TL fry accept food up to 0.42 mm, and those with 2.85 cm TL accept food sized up to 1.41 mm. Ferraz de Lima and Castagnolli (1989) also reported the use of powdered food (0.25 mm) for *C. macropomum* less than 1 cm TL; grains (0.5–1.4 mm) for 1.5-cm TL fry, grains and pellets (1.4–5 mm) for juveniles less than or equal to 100 g, and pellets (5–7 mm) for those weighing over 100 g.

Larval growth.—The formula that represents the relation between age (days) with total length (mm) for *C. macropomum* during the first 29 d is

$$\text{Length (mm)} = 3.474 + 0.993 \text{ (Days) } r = 0.98$$

Colossoma macropomum reach lengths of 2.0–3.5 cm TL in 3–4 weeks, depending upon quantity and quality of natural and prepared food. Prepared food is very important from the sixth day after hatching. *Colossoma macropomum* must be maintained in the larviculture ponds for no more than 4–5 weeks, after which they are stocked in fish ponds or sold. The stocking density influences growth of the fingerlings. Fry stocked at the age of 15 d in two different densities (75 and 200 larvae/m²) had different final weights after 25 d (Giumarães and Senhorini 1985). The fry stocked at low density had a total weight of 3.5–3.8 g, while those stocked at high densities attained only 2.6–3.0 g.

Grow-Out Diets

No uniform fish diets are available in the region (Cantelmo and De Sousa 1986b; Ferraz de Lima and Castagnolli 1989; Menton 1989; Castagnolli 1991). According to Van der Meer (1997), the ideal crude protein level has been determined to be approximately 43% for *C. macropomum*. Van der Meer also concluded excess soy in the diet tends to decrease palability and growth rate. However, lower crude protein diets (~27%) have been successfully used in Peru for many years (F. Alcantara, Institute for Investigation of the Peruvian Amazon, personal communication), as well as in Brazil (Castagnolli 1991). The diets of wild *C. macropomum* are about 20–30% crude protein, with 75% of the protein being of plant origin (Araujo-Lima and Goulding 1997). Fish diets greatly in excess of 30% crude protein would not likely be economically feasible in Amazonia.

Small-scale farmers often feed their fish domestic and wild fruits and vegetables, such as guavas, mangoes, potatoes, cabbages, pumpkins, bananas, rubber-tree seeds, manguba seeds, rice, corn, and manioc (Araujo-Lima and Goudling 1997). Araujo-Lima and Goulding (1997) have even suggested the development of "fish orchards" for feeding fruit-eating Amazonian fishes. Only in South America have fish communities evolved fruit- and seed-eating as a major part of the aquatic food chain (Araujo-Lima and Goulding 1997). To some extent, these fish eat almost all fruit and seed species that fall into the water (Kubitzki and Ziburski 1993). Adults feed to some extent on zooplankton but fruits and seeds comprise the bulk of their diet. Although seeds seem to be preferred, large quantities of fleshy fruits are also consumed. Goulding (1980) and Kubitzki and Ziburski (1993) found that only occasionally are the seeds of these fleshy fruits masticated, but rather the fleshy fruit is swallowed whole and the seeds are defecated. Goulding (1980) has long proposed that the fruit-eating characins may play a double role as both seed predators and seed dispersal agents. However, this hypothesis has yet to be tested in controlled experimentation.

Culture Systems

Different types of aquaculture systems are used in Latin America and can be classified as extensive, semi-intensive, or intensive.

Extensive aquaculture.—Extensive aquaculture is developed in lakes and reservoirs in monoculture or polyculture with common carp, tilapia *Oreochromis niloticus,* and *Prochilodus nigricans* and *P. caeraensis.* The stocking density in this system is lower than 0.5 fish/m² and it starts with juveniles of 5 cm TL or longer. The supplementary feeding for *C. macropomum* is comprised of agricultural byproducts. In Panama in 1988, 200,000 *C. macropomum* juveniles were stocked in Lake Alajuela (Pretto 1989). Although there is no precise information of the total fishing of this lake, it has been reported that the fish averaged a total weight between 3 and 10 kg by 1991. In southeastern Brazil, under similar stocking procedures, *C. macropomum* weighed 1.5–3.0 kg after 13 months. Novoa and Ramos (1982) reported *C. macropomum* culture in ponds with areas ranging between 300 and 6,800 m², in an extensive system with only organic fertilization (chicken manure at 2,000 kg/ha/year). *Colossoma macropomum* with an initial weight of 46.6 g were stocked at a density of 0.38 fish/m². The daily growth reported was 1.68 g, the final weight was 616.8 g, and the average total production was 2,000 kg/ha/year.

Martínez (1984) tested the culture of *C. macropomum* fed with fruits in 300-m² earthen ponds. The stocking density reported was 0.21 fish/m², and the individual initial weight was 7.8 g. After 669 d, fish had a final weight of 1.8 kg and yielded a total production of 2,700 kg/ha/year.

Semi-intensive aquaculture. Colossoma macropomum fingerlings averaging 6 g in weight were transported from the Amazon River and stocked at 2,077/ha in three 355-m² earthen ponds located in Pentecoste, Brazil (Lovshin et al. 1980). Both ponds were fertilized twice during the first 6 months with 16 kg (450 kg/ha) of cow manure and four times with 600 g (16.8 kg/ha) of triple superphosphate. The fish were fed a pelleted diet (29% crude protein) 6 d per week at 3% of the standing crop of fish in the pond. The feeding rate was adjusted monthly based on growth calculation from monthly seine samples. After 405 d, 2,509 kg/ha of *C. macropomum* were harvested. The average weight was 1.25 kg (3.1 g/d). Survival rate was 97% and the feed conversion was 3.1.

Valencia and Puentes (1989) tested the production of *C. macropomum* juveniles in 200-m² earthen ponds at two stocking levels (5,000 and 10,000/ha). All fish were fed a pelleted chicken feed (23–27% crude protein) at 3% of the average standing crop of fish in each treatment. The initial average weight was 32–57 g. After 300 d, *C. macropomum* at the lower density had a total weight of 900 g, and those at the higher density weighed 368 g. The food conversion for both densities was 2.9 after 300 d. The average production was 8,280 and 9,760 kg/ha/year, lower and higher densities, respectively.

Lovshin et al. (1980) tested the production of *C. macropomum* in 350-m² earthen ponds at two levels of stocking using fingerlings produced on the Pentecoste Station, Brazil. The fish were stocked in triplicated ponds at a rate of 5,000 and 10,000/ha at an initial average weight of 24.5 g. All fish were fed a pelleted chicken feed (17% crude protein) at 3% of the average standing crop of fish in each treatment. Fish were

fed in the afternoon 6 d per week. After 6 months, the fish at the lower density had a total weight of 619 g, and those at the higher density weighed 424 g. Average production was 6,683 and 9,391 kg/ha/year, lower and higher densities, respectively. The average feed conversion was 2.8 for both groups. Growth was 4 and 2.8 g/d for the lower and higher densities, respectively.

Aparecido (1986) tested the growth and production of *C. macropomum* using twenty 350-m^2 ponds. He used four treatments: control, fertilization (chicken manure at 2,500 kg/ha/year), corn plus fertilization, and a prepared diet (20% crude protein). These experiments were repeated with three densities: 5,000, 10,000, and 20,000 fish/ha. Based on these studies, he suggested that the culture of *C. macropomum* should be divided in two steps: the first for the production of 200–300 g fish in 200 d of culture and the second to produce a fish of market weight (900–1,200 g). The density of stocking for the first step was suggested as 20,000/ha fed with corn plus fertilization, while the second step should use a balanced prepared diet. However, he did not suggest densities for the second step.

Phelps and Popma (1980) tested the culture of *C. macropomum* in 200-m^2 earthen ponds in Colombia. Fish were stocked at a rate of 10,000/ha with an average weight of 25 g and fed with pelleted chicken feed (15% crude protein) at 3% of their wet body weight 5 d/week. Feeding rates were recalculated every 2 weeks based on seine samples. After 6 months, the ponds were drained and all fish harvested. *Colossoma macropomum* had a production of 7,647 kg/ha/year with an average individual weight of 443 g. Food conversion was 1.45 and average weight gain was 2.3 g/d.

Da Silva and Melo (1984b) performed an experiment testing the growth and production of *C. macropomum* fed dried, shelled field corn. Three 355-m^2 earthen ponds were stocked with fish averaging 74 g each at a rate of 5,000/ha. Fish were fed corn daily at 3% of the average standing crop 6 d/week. Fish were fed broken corn for the first 3 months and whole corn for the remaining 9 months. Feeding rates were recalculated monthly based on seine samples. After 365 d, an average total production of 4,740 kg/ha was harvested. Fish averaged 948 g (2.18 g/d), survival was 92%, and conversion of corn to fish was 4.1–1.

Peralta and Teichert-Coddington (1989) compared in Panama *C. macropomum* production with Nile tilapia *Oreochromis niloticus* at two densities (2,500 and 10,000 fish/ha). Treatments were triplicated in 870 m^2 earthen ponds, and fish were fed a commercial diet (25% crude protein) and harvested after 129 d. Mean yield (kg/ha) for *C. macropomum* was 3,682 and 977, and for Nile tilapia 3,361 and 917 for high and low densities, respectively. The authors concluded that *C. macropomum* performed as well or better than Nile tilapia under the culture conditions employed.

Da Silva et al. (1978) in Pentecoste, Brazil, tested the influence of the all-male tilapia hybrid (female *O. Niloticus* × male *O. hornorum*) in polyculture with *C. macropomum*. A completely random design was used with two triplicated treatments. *Colossoma macropomum* of 25-g initial weight were stocked in 355-m^2 earthen ponds at a rate of 5,000/ha along with 5,000 all-male tilapia hybrids/ha with initial average weights of 18 g. Fish were fed 3% of the average wet body weight of *C. macropomum* only. A pelleted chicken diet (17% crude protein) was fed 6 d/week. After 6 months, the average final weights for *C. macropomum* and tilapia hybrids were 485 and 245 g, respectively. At this time, average production was 2,393 and 1,209 kg/ha, respectively, and total feed conversion was 1.7. After 365 d, the final weights were 1,189 and 748 g of *C. macropomum* and tilapia, while production levels were 5,640 and 3,299 hg/ha/year, respectively. Growth was 3.2 and 2.0 g/d for *C. macropomum* and tilapia, respectively. The total feed conversion was 2.8. Mortality was 5% and 11% for *C. macropomum* and tilapia, respectively.

To further test the influence of the all-male tilapia hybrid on *C. macropomum*, Da Silva et al. (1978) stocked in triplicated 355-m^2 earthen ponds the equivalent of 10,000 *C. macropomum*/ha together with 3,000, 4,000, and 5,000 tilapia hybrids/ha. Average initial weights of *C. macropomum* and tilapia were 39 and 13 g, respectively. Fish were fed pelleted chicken diets (17% crude protein) at 3% average wet body weight of *C. macropomum* only in each treatment for 6 d/week. After 360 d, the total average for the treatment stocked with 3,000 hybrids was 9,550 kg/ha/year, while the treatment with 4,000 hybrids/ha was 10,084 kg/ha/year, and the treatment with 5,000 hybrids/ha was 10,930

kg/ha/year. This experiment demonstrated an increase in total fish production through polyculture without significantly affecting growth of *C. macropomum*.

In Gualaca, Panama, *C. macropomum* were cultured in polyculture with freshwater shrimp *Macrobrachium rosenbergii* (Pretto 1989). *Macrobrachium* were stocked in triplicated 900-m² ponds alone and with *C. macropomum*. The species were stocked at densities of 0.1 *Macrobrachium*/m² and 0.28 fish/m² with average weights of 6.8 and 80 g, respectively. No significant differences were found after 5 months between the growth of the *Macrobrachium* cultured alone and those cultured in association with *C. macropomum*.

Da Silva (1983) and Pinheiro et al. (1991) reported that of all the experimental polyculture studies with *C. macropomum* in Brazil, the best combinations were those with *C. macropomum* at 5,000/ha, plus tilapia hybrids at 5,000/ha, plus common carp at 2,500/ha, all fed with chicken feed (19% crude protein). This polyculture combination yielded a production of 13,358 kg/ha/year. Good results were also reported with *C. macropomum* at 5,000 and 10,000/ha, plus tilapia hybrids at 3,000 and 10,000/ha. In these experiments, the reported production levels were 8,878–11,106 kg/ha/year using chicken feed (19% crude protein). These researchers also reported studies in which *C. macropomum* were stocked at 2,500/ha with tilapia hybrids at 5,000/ha plus common carp at 2,500/ha, all in association with swine (90 pigs/ha over the pond). After 89 d, *C. macropomum* growth increased from 44 to 360 g, hybrid tilapias from 30 to 360 g, and common carp from 39 to 337 g. The total production was 3,543 kg/ha/89 d and the food conversion was 2.2 (swine plus fishes). Only the swine received food, while *C. macropomum* and tilapias relied on natural food, and possibly the manure from the swine.

Net culture.—Nino and De Souza (1986) stocked 100 and 150 *C. macropomum*/m³ in nets of 6.5 m³. These fish were fed for 324 d with 40% crude protein pellets during the first 5 months and with 30% crude protein pelleted feed for the last 174 d. The feeding rate was 3.5% and 2.5% of the wet body weight for each period, respectively. The temperature was 25°C and oxygen concentration was 5 mg/L. The growth rates were 1.37 and 1.31 g/d for the lower and

higher densities, respectively. The equivalent production was 43.73 and 53.32 kg/m³/year.

Transport of Larvae and Fingerlings

Colossoma macropomum larvae should not be shipped until after they have filled their swim bladders and totally absorbed their yolk sacs (5–6 d after hatching). Gomes et al. (2002) found that 300 3–5 cm juveniles/10 L water/10 h transport time was a nearly ideal density, leading to zero mortality. The authors indicated that methylene blue and salt (NaCl) are commonly added during transport, but did provide concentration levels.

General Recommendation for *C. Macropomum* Culture

Proper care of domestic broodstock is very important for assuring good production of eggs and young. The culturist must provide conditions as optimum as possible for such factors as pond management, water quality, and food supply.

The hatchery must be located in a place where the mean annual temperature is 28°C (26–29°C), and the water has the following characteristics: pH = 6.5–8.0, oxygen concentration = 5–9 mg/L, and hardness = 20–80 mg/L. Chemical and physical manipulation are required if the parameters are out of these ranges.

The broodstock should be reared in 1,000–1,500-m² earthen ponds with 1–1.5 m depth. Dependable spawning cannot be obtained until female fish are at least 4 years old and males 3 years old when both sexes have achieved a total weight of 3–5 kg. Brood *C. macropomum* should only be used 3 or 4 years and should weigh 6–8 kg at the end of this time. The density in the pond used for rearing brood *C. macropomum* should not exceed 100–150 g/m² with a water flow of 8 L/s/ha. Spawning success and the quality of eggs and fry are improved if the productivity of the pond is high. Broodstock are stocked in previously fertilized ponds with CaO (200 g/m²/1 time) and organic fertilizer (swine manure: 2,000 kg/ha/year or chicken manure: 1,350 kg/ha/year). The addition of 30 kg/ha of P_2O_5 has been used in very few cases in *C. macropomum* culture and needs to be further evaluated. Control of the trans-

parence of the pond is necessary in order to maintain it between 18 and 30 cm depth, and the oxygen concentration must also be maintained over 5 mg/L.

Feeding schedules should reflect the nutritional status of the fish and be tailored to their respective life histories. *Colossoma macropomum* reared under poor water quality conditions, with low rations, poor quality food, and water of low temperature, produce fewer eggs and lower quality spawn, or do not reproduce at all.

The amount of food provided to *C. macropomum* depends on the water temperature and size of the broodfish. Above 26°C, the ration administered should be 2.5% of the wet body weight per day, but when temperature drops to 24°C or lower, the supply should be 1–1.5%. Normally the ration should be 2.5% of wet body weight until the spawning month and thereafter reduced to 2%. The broodstock should be fed with a diet containing at least 28% crude protein for 8 months postspawning. The following ingredients, which are common to all the five countries, are suggested for this period: fish meal (10%), soybean meal (40%), wheat bran (25%), corn meal (24%), and a vitamin/mineral premix (1%). Until further studies are conducted, a diet of at least 30% crude protein should be supplied to the broodfish 2 months before and 2 months after spawning.

Distinguishing between male and female *C. macropomum* prior to maturity is difficult. However, just prior to spawning, females and males can be differentiated by their external characteristics. The female has a bulky and soft abdomen; swollen, protruding and reddish genital papillae; and the male ejaculates white, dense, and abundant semen as pressure is applied to the abdomen. This is the best way to select mature broodfish without excessive manipulation. Before first spawning, culturists should separate the males from the females. Placing bands with different colors around the caudal peduncle is a simple method to distinguish stocks.

If selective breeding is used to manipulate broodstock, this should include the selection of priority characteristics such as improved growth, feed conversion, period and times of spawning, and postlarval survival rates. To avoid inbreeding, managers should select their broodstock from large, randomly mated populations. The addition of wild *C. macropomum* from the Amazon basin will improve the genetic diversity of the stock and avoid inbreeding depression.

Colossoma macropomum spawning is artificial and entails manually extracting sexual products from the fish. Spawning is induced by hormone injection. *Colossoma macropomum* must be fairly close to spawning as the hormone generally brings about the early release of mature sex products rather than the promotion of their development. The induction method most often used is injection of carp pituitary extract (CPE). Carp pituitary is finely ground, suspended in serum, and injected intraperitoneally. The first dose should be 0.5 mg/kg of body weight of the female in 0.5 mL of physiological saline. The second dose consists of injecting 5 mg/kg/body weight after an interval of 14 h. The male will receive only a single dose of 1–1.5 mg/kg body weight at the same time that the female receives the second dose. With these conditions, the ovulation and spawning should occur at 240 degree-hours from the last injection. If one uses homoplastic (*C. macropomum*) or heteroplastic (*Prochilodus* spp.) hyphophysis from the wild, one should select those that were collected 1 month before the beginning of the spawning time in the wild or in ponds. The use of GnRHa can be used if it is available and can be supplemented with Domperidone. The doses for GnRHa (LHRHa) should be 5–10 mg/kg/body weight for the female and 3–5 mg/kg for the male in two doses, about 10 h apart. The duration for ovulation depends on the temperature, stage of maturity, and on other uncontrolled factors (such as quality of the hormone used) by the culturist.

The best way to control spawning is by observing the broodstock after 200 degree-hours from the last injection. The female is ready to spawn when she starts to follow the male and rapidly moves her dorsal and caudal fins. During this time, she releases some eggs (20–50) in the tank. For females that are spawning for the first time, it is better to wait 10 min to permit the liberation of more eggs.

The use of anesthetics (20 ppm Quinaldine or 100 ppm MS-222) is recommended by most researchers; however, *C. macropomum* is an easy

fish to manipulate and can be stripped without any anesthetic. During stripping, the fish are held with their belly downward over a plastic pan and massaged, beginning forward of the belly and working backwards to force the gametes out. If either eggs or milt do not flow freely, the fish is not sufficiently ripe and should not be used. Fertilization of eggs is accomplished using the dry method (i.e. water is not introduced before the eggs are in the pan). Egg fertilization is accomplished in the following manner: 1) the milt is added to the eggs (1 mL sperm/100 of eggs) and mixed with a feather for 25 s; 30 mL of water/200 g of eggs is then added to the pan; 2) the gametes are continuously mixed with the feather for another 50 s; 3) 50 mL of additional water/200 g eggs is added; 4) after another 30 s, 200 mL of additional water/200 g eggs is added; and finally, 5) after another 20 s, 200 mL water/200 g eggs is added. The duration of all these steps must not be longer than 3 min. Usually, the hydrated eggs are placed in a 50-L incubator (Woynarovich, see Figure 3) at a density of 1.66 g/L (70–90 g/incubator). The major factors that affect the eggs in this step are water flow, light intensity, temperature, and oxygen concentration. The inflow of water at the beginning of incubation must be equivalent to 0.8–1.0 L/min, and after 5 h, should increase to 3–4 L/min. The culturist must protect the eggs from direct light (from cool fluorescent tube or from the sun), maintain the temperature between 26°C and 29°C, and the oxygen concentration between 5 and 8 mg/L. It is important to observe the stage of development of the larvae after 5 h of incubation in order to gauge the rate of larval development.

For control of the incubation period, the hour temperature unit, which is equal to N°C × N° day (degree-hour), can be used. Accordingly, at temperatures around 29°C, hatching should start after 12 h of incubation. The larvae can stay in the incubators for 4 or 5 d after hatching until they have absorbed their yolk sacs and start to accept live or prepared food. However, the best system is the use of an incubator of 200-L volume where the larvae are stocked for 5–10 d after hatching. At this time, the larvae are ready to be stocked in nursery ponds previously prepared with CaO (100–150 g/m²) and chicken manure (200 g/m²). Before the larvae are stocked in ponds, one should filter 100 L of water from the nursery pond with a 60-mm-mesh net and then add formalin to this sample, and, if the sedimented zooplankton is equal to 2–3 mL, the pond is ready to be stocked. The pond should be fertilized the same day of spawning. It is also necessary to control zooplankton production and predators in the pond. One day after fertilization and close to the hatching hour, the pond is treated with an insecticide to kill copepods and Ostracoda. This will permit the development of a high population of rotifers. *Colossoma macropomum* larvae should never be introduced before 5 d has elapsed from insecticide application. Alternatively, it is possible to use clothed nets (hapas) installed in the ponds in which postlarvae are stocked at a density of 10–18/L for 5 d and fed *Artemia* nauplii. However, this method has higher mortality than the method using insecticides. In order to control odonates, it is necessary to apply petroleum products 1 week after stocking the larvae.

The larvae are stocked at a density of 100–150/m² and are expected to survive at a rate of 30–70% after 30 d. During the first 10 d, a diet with 40–50% crude protein is offered: fish meal (50%), soybean meal (25%), yeast (20%), milk powder (3%), and vitamins and minerals (2%). For the next 20 d, the larvae should be fed a diet with 32% crude protein. The larvae are fed an equivalent of 0.5, 1, 2, and 3 kg feed/100,000 larvae/d for the first through fourth week, respectively. The size of the food during the 5 d after stocking must be less than 0.20 mm (dust), then between days 6 and 14, the food should have a diameter of 0.30–0.42 mm, and after 15 d of stocking, the size should be between 0.42 and 0.50 mm, and finally after 25 d, the fish can be fed particles from 1.5 to 2.0 mm. After 30 d, the *C. macropomum* have a total length between 2 and 3 cm and are ready to be stocked in production ponds.

The ponds used for fish production are prepared in the same manner as those for broodstock and larvae production (Figure 6). In monoculture, the fingerlings (2–3 cm TL) should be stocked at a density of 1 fish/m². In polyculture, the density should be 0.7 *C. macropomum* + 0.3 *Prochilodus.*/m² (combined stock: 1 fish/m²). The duration of the culture is 1 year. After that period, the *C. macropomum* should
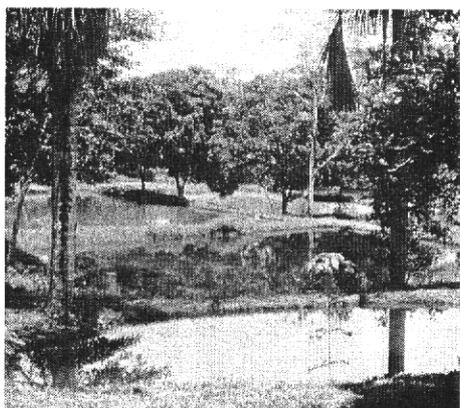
Figure 6.—Ponds used to raise *C. macropomum* and related species can be constructed in a manner that is amenable to the jungle landscape. Unlike rainforest lands cleared for row crops or terrestrial livestock, ponds will remain productive for decades. (Photo by Christopher C. Kohler)

Figure 7.—The aquaculture of *C. macropomum* and related species is improving food security in Latin America. (Photo by Christopher C. Kohler)

have a weight of 0.8–1.2 kg, which is acceptable in the marketplace. However, in some regions of Latin America, *C. macropomum* weighing half this size, or even less, are marketable during the rainy season when high waters in the Amazon River preclude commercial fishing.

The Future

Colossoma macropomum and related species exhibit excellent characteristics for development as an aquaculture species in Latin America. Fast growth rates, ability to utilize diets high in carbohydrates and plant proteins, resistance to poor water quality conditions, and high flesh quality, are a just a few of their beneficial characteristics for aquaculture. Moreover, aquaculture of *Colossoma* and *Piaractus* spp. should relieve some of the fishing pressure on these overharvested, native species, which have been suggested to play a crucial role in disseminating seeds from the flooded forest (Araujo-Lima and Goudling 1997). Accordingly, aquaculture of *C. macropomum* and related species may be ecologically as well as economically and nutritionally beneficial to the inhabitants of the Amazon basin (Figure 7). Future research should be directed to refining techniques for spawning and feeding these unique and delectable fishes.
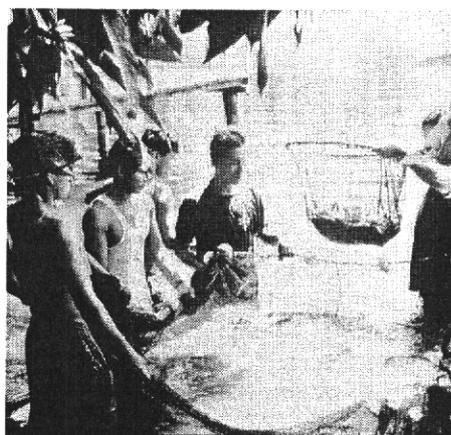
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