Biology, Fisheries, and Aquaculture of the Amazon River Prawn *Macrobrachium amazonicum:* A Review

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Abstract

The Amazon River prawn *Macrobrachium amazonicum* is widely distributed in South America, and has a high economic value for fisheries and aquaculture. The species has a very wide phenotypic plasticity and its many local populations show morphological, physiological, and ecological differences. Reproductive strategy, egg size, larval development, growth rate, and population structure are site-dependent. Artisanal fisheries are very important in Amazonia and in many reservoirs of the Northeast region. However, appropriate management plans are needed for both fisheries and marketing in order to assure long-term sustainability. Aquaculture is a promising alternative for the exploitation of this species. The hatchery, nursery, and grow-out phases can be carried out on small, medium, or large scales in intensive systems. The main constraints are the low fecundity and the heterogeneous growth, which require further research.

Key words: *Macrobrachium,* Amazon River prawn, life history, ontogenetic development, population biology.

Introduction

The Amazon River prawn, a member of the family Palaemonidae, is widely distributed in lakes, reservoirs, floodplains, and rivers in tropical and subtropical regions of South America. This prawn occurs in Guyana, Surinam, French Guiana, Brazil, Colombia, Venezuela, Peru, Ecuador, Bolivia, Paraguay, and Argentina. Its distribution includes all the main eastern South American river basins, including the Orinoco, Amazon, Araguaia-Tocantins, São Francisco, and La Plata (Paraná and Paraguay River basins), as well as the smaller rivers of the South Atlantic Basin in the northern, northeastern, and eastern coasts of Brazil (Holthuis, 1952; 1966; Davant, 1963; Rodríguez, 1982; Coelho and Ramos-Porto, 1985; Ramos-Porto and Coelho, 1990; López and Pereira, 1996; Pettovello, 1996; Bialetzki *et al.,* 1997; Magalhães, 2000; 2001; 2002; Melo, 2003; Valencia and Campos, 2007). Some consider that *M. amazonicum* was introduced by human action into the upper Paraná (Magalhães *et al.,* 2005), São Francisco, and Brazilian northeast and east coastal river basins (Ramos-Porto and Coelho, 1998). Because of this very wide occurrence, there are many local populations, which are probably genetically isolated. Therefore, wide intraspecific morphological, physiological, and ecological differences occur, which make this species a very interesting model for biological studies.

M. amazonicum is the freshwater decapod of greatest economic importance in the eastern South American subcontinent. It is widely exploited by artisanal fisheries in northern and northeastern Brazil, and is widely consumed by indigenous peoples and Brazilians of all economic groups (Moraes-Riodades and Valenti, 2001). In addition, this prawn shows a high potential for aquaculture (Kutty, 2005; New, 2005). In the current decade, intense research effort has been directed toward developing the technology for commercial culture of this species (Moraes-Valenti and Valenti, 2010).

Despite the high biological and economic importance of *M. amazonicum,* its life history is poorly understood. In addition, most of the available information is obscure, including articles published in local languages (mainly Portuguese and Spanish), abstracts presented in local meetings, and master's and doctoral theses. In this contribution, we review aspects of its biology, fisheries, and *Aquaculture,* and suggest new avenues for future research. We have avoided citing "gray literature" if equivalent, more accessible publications exist.

External Morphology and Systematics

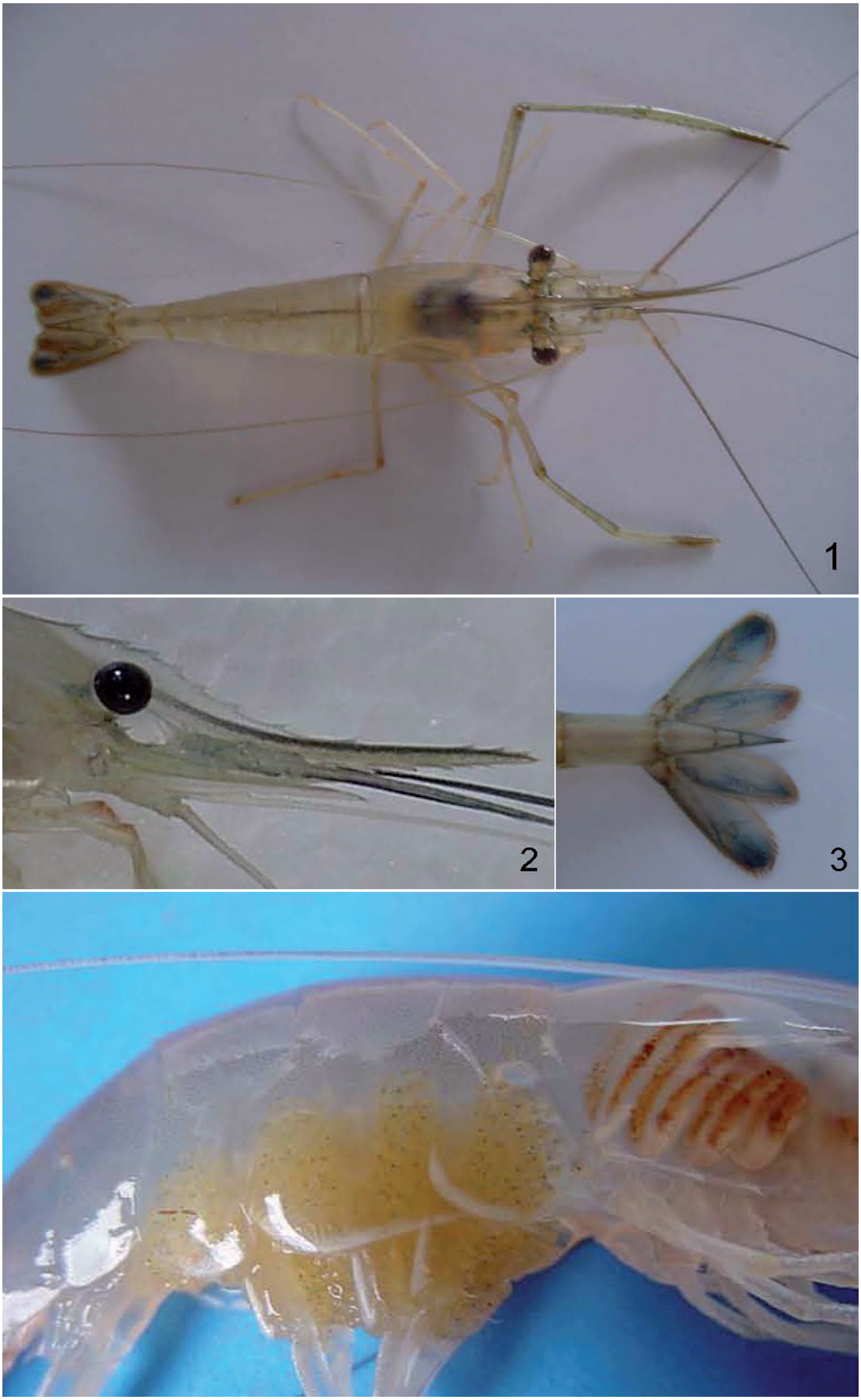
The morphology of *M. amazonicum* (Figs. 1 to 4) has been described in reports by Holthuis (1952), Davant (1963), Melo (2003) and Magalhães *et al.* (2005). The rostrum is elongated, with an upturned tip that passes the distal end of the scaphocerite. The upper surface is lined with 9 to 12 irregularly arranged teeth, of which the first seven form a basal crest over the orbit. The lower surface bears eight to ten teeth. The carapace and abdomen are smooth, and the tip of the pleura of the fifth abdominal segment has a small but distinct spine. The telson is conical and tapers gradually towards a sharp tip with very short posterior bristles that do not extend beyond the tip. The second pair of pereopods is relatively long, with the carpus extending beyond the scaphocerite. The dactyls are ¾ the length of the chelae and are covered with a thick layer of bristles. The chelae are elongated and lined with widely spaced spinules.

The above description is based only on large males, and male morphotypes, females, and juveniles are not considered. In addition, there is substantial variability among different populations. A detailed understanding of this variation is essential for the morphological identification of the species, as well as for the prediction of growth and production parameters under captive conditions. A comprehensive external morphological description including all forms was recently presented by Vergamini (2009), based on literature and the author's personal observation.

Moraes-Riodades and Valenti (2004) identified four distinct male groups among animals born from the same egg clutch raised in aquaculture ponds. There are differences in the morphology, color, and variation in the cheliped spines, as well as the proportion of each joint. The four morphotypes are termed Translucent Claw (TC), Cinnamon Claw (CC), Green Claw 1 (GC1), and Green Claw 2 (GC2). There are also differences in body size, with adults of GC1 and GC2 reaching the largest sizes, and TC the smallest. Distinct morphotypes of *M. amazonicum* have recently been recorded in the natural environment, both in the eastern Amazon region, on the Marinas Channel in Santa Bárbara on the coast of the state of Pará, Brazil (Silva, 2006; Silva *et al.,* 2009); – and in northeastern Brazil, on the Jaguaribe River in Itaiçaba on the coast of the state of Ceará (Santos *et al.,* 2006). However, Vergamini (2009) found only TC and CC males in populations from inland waters, such as the Pantanal and Paraná Basin rivers. Therefore, the different male morphotypes are a characteristic of the species, but the development, or lack of development, of the complete male population structure may be site-dependent.

The females are normally smaller than the males, and have fewer spines on the second pair of pereiopods. They brood their eggs on the pleopods, and have an incubation chamber formed by the arching and elongation of the abdominal pleura (Fig. 4). Juveniles are translucent, with the second pair of pereiopods slender, and the telson bearing a pair of plumose setae and with the inner spines overreaching its tip. The available descriptions for females and juveniles are very poor and unsuitable to distinguish *M. amazonicum* from other syntopic species of *Macrobrachium.* Research on the correct identification of females and juveniles of *M. amazonicum* is urgent and essential to further studies on its population biology and fishery.

In general, *M. amazonicum* is divided into coastal populations, which inhabit rivers close to estuarine waters, and continental populations, which live in rivers, lakes, and other inland waterbodies. The two groups differ significantly in external morphology and meristic characters (Porto, 2004; Vergamini, 2009). Based on these traits, Porto (2004) suggested that the two groups be considered as distinct species. Previous to Porto's suggestion, Bastos (2002), using molecular analysis of mitochondrial cytochrome oxidase subunit I (COI mtDNA), demonstrated that continental populations from the Araguaia-Tocantins Basin differed from La Plata Basin populations. Recently, Vergamini (2009), using molecular data of 16S rRNA and COI mtDNA, showed that both continental and coastal populations form a single monophyletic clade, and the genetic divergence rates are at the intraspecific level. In addition, she has identified three groups of populations: Eastern Amazonia; La Plata Basin; and coastal river basins in northern



Figures 1-4. *Macrobrachium amazonicum:* (1) adult male; (2) lateral view of rostrum; (3) dorsal view of telson; (4) ovigerous female, incubation chamber.

and northeastern Brazil, which includes the lower Amazon and Tocantins rivers and the South Atlantic Basin. Although these conclusions may need confirmation using other genetic markers, the necessity of reporting the origin of the population in all studies on *M. amazonicum* is clear

Life Cycle and Ontogenetic Development

The life history of *M. amazonicum* has been investigated in the natural environment (Odinetz-Collart, 1987; 1990; 1991a; Odinetz-Collart and Moreira 1989; Moreira and Odinetz-Collart, 1993; Odinetz-Collart and Magalhães, 1994; Odinetz-Collart and Rabelo, 1996), in aquaculture conditions (Moraes-Riodades and Valenti, 2002; Moraes-Riodades and Valenti, 2004), and in the laboratory (Vargas and Paternina, 1977; Guest, 1979; Romero, 1982). The life cycle is comprised of egg, larval, juvenile, and adult phases. The female undergoes a pre-mating molt and then the male deposits a spermatophore on her abdominal region. About 20 h after the prenuptial molt (Romero, 1982), the female releases the eggs, which are then fertilized and pushed onto the pleopods. Egg size varies from 0.14 to 0.27 mm^3 (Odinetz-Collart and Rabelo, 1996). Embryonic development takes 12 to 18 days (Guest, 1979; Gamba, 1984; Magalhães, 1985). The newly released eggs are deep green, and then change to light green, deep yellow, light yellow, and finally translucent just before hatching (Rego *et al.,* 2004). The larva hatches as a free-swimming zoea and passes through 9 to 11 larval stages (Guest, 1979; Vega Pérez, 1984; Magalhães, 1985). From stage I to VI, the larvae are zoeae and, after that, become decapodids (Anger *et al.,* 2009). Larval development takes 20 to 23 days in small vessels in the laboratory (Guest, 1979; Magalhães, 1985; Anger *et al.,* 2009), but in hatchery tanks, 80% of the larvae undergo metamorphosis in 18-19 days at 28°C and salinity 10 to 12 (Vetorelli, 2008). After metamorphosis, the juveniles swim rapidly in the water column, but then assume a benthic habit, walk on the substrate, and climb vertical surfaces. The subsequent period of somatic growth may last only 2 months in aquaculture ponds (Moraes-Riodades, 2005). The prawns mature as they attain 45-60 mm (Guest, 1979; Moraes-Riodades and Valenti, 2002; Silva and Sampaio, 2004; Silva *et al.,* 2005; Sampaio *et al.,* 2007), but first female maturity at 33 mm in a Venezuelan lake was reported (Gamba, 1997). After maturation, males may differentiate into the four morphotypes, following the sequence TC, CC, GC1, and GC2 (Moraes-Riodades and Valenti, 2004).

Gonadal maturation produces permanent and/or cyclic changes in the growth pattern, external morphology, and reproductive organs. The relationship between cheliped length and carapace length is isometric as the juveniles grow, but shows a slight positive allometry in females and a strong positive allometry in males, suggesting that the importance of chelipeds may be different in these groups (Moraes-Riodades and Valenti, 2002). The male maturation process is related to the morphotypes. Internal anatomical changes were described by Papa (2007), but the complete mechanism and temporal variation are unclear. All morphotypes are mature and produce fertile gametes, but there are differences in the androgenic gland and the CC form produces few spermatozoids (Papa, 2007). Females undergo a cyclical maturation process. A preliminary study of oocyte development was provided by Chaves and Magalhães (1993), and all the ovarian stages were described by Ribeiro (2006), based on macroscopic observation and histological and ultrastructural characterization. Five stages were defined, from undeveloped (stage I) to mature (stage V). The ovary is very small and translucent at stage I, whitish at stage II, and greenish at stage III. At stage IV the ovary is green, whereas at stage V it is deep green and occupies almost the entire coelomic cavity of the cephalothorax. All stages can be recognized in live females by inspecting the dorsal portion of the cephalothorax and observing the gonads beneath the transparent carapace. All oocytes produced in each cycle are released in a single spawning. A new ovary cycle may begin just after spawning, when the environmental conditions are appropriate.

The female reproductive cycle depends on the combined action of the ovaries and hepatopancreas (Ribeiro, 2006). The latter is a large yellowish-brown organ, which occupies much of the cephalothoracic cavity; it is divided into right and left lobes, both consisting of blind-ended hepatopancreatic tubules (Franceschini-Vicentini *et al.,* 2009). The hepatopancreas has important functions concerned with the absorption, synthesis, and liberation of nutrients, and possibly the synthesis of steroids (estradiol, progesterone, and testosterone). Ribeiro (2006) observed that the levels of estradiol and progesterone increase steadily during stages I and II, which coincide with the previtellogenic phases. There is then a significant decrease in these steroids at stage III, when transfer of material from the hepatopancreas to the ovary and oocytes occurs. Estradiol and progesterone decrease progressively throughout the remaining ovarian maturation stages. The lowest levels of these hormones are observed at stage V, which may be related to spawning.

The general development of all the larval stages was described by Guest (1979), Vega Pérez (1984), and Magalhães (1985). Zoeae I are ~2.8 mm long (Magalhães, 1985) and ~60 µg dry weight (DM) (Hayd *et al.,* 2009). Molts occur every 2-3 days (Anger *et al.,* 2009). Both length and weight increase continuously during development (Anger *et al.,* 2009; Hayd *et al.,* 2009), but the growth rate is higher from zoeas III to VI. Newly hatched larvae have sessile eyes and a rudimentary mouth and thoracic appendices. Pleopods appear as buds at stage V and are biramous in zoea VI. The rostrum is smooth until stage IX, when 6 dorsal teeth appear. After metamorphosis, animals have a rostrum with dorsal and ventral teeth. Newly metamorphosed prawns are ~5.4 mm long (Magalhães, 1985) and weigh ~5 mg (Vetorelli, 2004). The dry weight is about 1 mg (Maciel, 2007; Vetorelli, 2004; 2008). There are some small differences in larval development between animals from coastal and continental populations (cf. Guest, 1979; Gamba, 1984; Vega Pérez, 1984 and Magalhães, 1985), and significant intrapopulational variability not previously described in the literature was reported by Anger *et al.* (2009) for animals from a coastal population.

Recently metamorphosed prawns are generally termed post-larvae in the aquaculture literature (Wickins and Lee, 2002; Brown *et al.,* 2010). After at least 15 days, they are called juveniles until they mature. However, Anger (2001) pointed out that the term post-larva should be used only for transitional forms, in which distinction between larva and first juvenile is not possible. To avoid confusion, we will use “juvenile” from metamorphosis to maturation.

Hayd *et al.* (2008) described the major molt stages of *M. amazonicum* larvae. The molting cycle is divided into three major stages: A-C (postmolt and intermolt stages combined), D (premolt), and E (ecdysis). The postmolt and intermolt stages were grouped because of the rapid larval development and the abrupt integumental changes that occur immediately after the molt. In early stage A-C, the cuticle is still thin and water is absorbed, so that the larval body expands and rapidly attains its final size and shape. In final stage A-C, the larva reinforces the cuticle, and the epidermis shows conspicuous tissue growth. In stage D, apolysis is evident, and the development of new setae and appendages begins. Stage E begins with a rupture of the dorsal exoskeleton between the cephalothorax and the abdomen, followed by rapid retraction of the abdomen from the old exoskeleton.

The metabolic rate of *M. amazonicum* is proportional to the body weight in embryos, larvae, and early juvenile stages (Hayd *et al.,* 2009). However, weight-specific excretion rates exhibit two distinct phases: embryo to zoea II, and zoea III to day-14 juveniles (Hayd *et al.,* 2009). Because this species uses only internal energy reserves from the yolk during the embryo, zoea I, and frequently zoea II stages (Araújo and Valenti, 2007), it seems that the use of exogenous food is the main factor to promote metabolic changes and increase weight-specific excretion rates.

Growth of *M. amazonicum* has been studied only in coastal populations. The growth pattern follows the von Bertalanffy model during post-larval ontogenetic development (Guest, 1979), but there are changes in the animal’s shape. The weight/length relationship shows negative allometric growth (Flexa *et al.,* 2005). The chelipeds, rostrum, and total length of juveniles grow at the same rate, but the cephalothorax shows a slight positive allometry in relation to the abdomen (Moraes-Riodades and Valenti, 2002). The total length/carapace length relationship shows negative allometry, indicating that the cephalothorax growth rate is higher than the total growth rate (Moraes-Riodades and Valenti, 2002). In adults, the cephalothorax is about 45% of total length (Romero, 1982; Silva *et al.,* 2002a) and weight (Silva *et al.,* 2002a; Flexa *et al.,* 2005). Growth is density-dependent (Moraes-Valenti and Valenti, 2007; Penteado *et al.,* 2007). Males attain 160 mm and 30 g, whereas females reach 140 mm and 17 g (Moraes-Valenti and Valenti, 2010). However, much smaller animals are normally obtained in the wild (Silva *et al.,* 2002a; 2005) or in aquaculture ponds (Moraes-Valenti and Valenti, 2007). Juveniles, females, TC, and CC males are almost translucent, whereas GC1 and GC2 males are darker. Light gray, cinnamon, and greenish pigments are frequent. Body color may vary according to the background color of the habitat, as occurs in most *Macrobrachium* species. Moraes-Riodades and Valenti (2004) suggested that GC2 males are the dominant and the most actively reproducing males, whereas GC1 could be a transition form. However, Papa *et al.* (2004a, b), Papa (2007), and Silva *et al.* (2009) demonstrated that the morphology of the testes of GC1 and GC2 are very similar and suggested that they should be grouped. However, the four morphotypes may have different breeding displays, and therefore behavioral studies are needed to understand the reproductive role of each morphotype.

Habitat and Ecology

M. amazonicum inhabits lacustrine, floodplain, and lotic environments in tropical and subtropical flatlands (plains and high plains). It is very abundant in sediment-rich waters of the Amazon River basin (Magalhães, 1985; Odinetz-Collart, 1991b), the Orinoco River delta (López and Pereira, 1996; Montoya, 2003), the rivers and lakes of the Pantanal (Magalhães, 2000; 2001), reservoirs of the Paraná River basin (Bialetzki *et al.,* 1997; Magalhães *et al.,* 2005), and reservoirs of the semi-arid region of the Brazilian Northeast (Coelho and Ramos-Porto, 1985; Ramos-Porto and Coelho, 1990; 1998; Arraes and Ramos-Porto, 1994). However, it is rare in acidic (pH 4.5-5.5), nutrient-poor blackwater streams in Amazonia (Odinetz-Collart and Rabelo, 1996) and does not occur in low-order mountain streams. The larvae are planktonic and live in open waters, or among aquatic macrophytes, submerged grasses, and tree branches at depths from 0-2 m (Moreira and Odinetz-Collart, 1993; Bialetzki *et al.,* 1997). In a Central Amazonian lake, larvae were observed engaging in vertical migration, coming to the surface at nightfall to take advantage of the more oxygenized water and the greater abundance of food resources at this level (Moreira and Odinetz-Collart, 1993). Juveniles swim close to the water surface (Bialetzki *et al.,* 1997) and probably in the entire water column; they also can settle and walk on horizontal and vertical substrates. Adults are benthic and associated with flooded substrates (*e.g.,* tree trunks and leaves that are permanently submerged or covered by water in the rainy season) or patches of floating aquatic vegetation (Magalhães, 2000; 2001; Montoya, 2003; Magalhães *et al.,* 2005).

Macrobrachium amazonicum tolerates a wide range of variation in the main water physical and chemical characteristics. Larvae are strongly euryhaline and survive at salinities from 0 to 30 (Guest and Durocher, 1979; MacNamara *et al.,* 1983; Moreira *et al.,* 1986; Zanders and Rodrígues, 1992); however, the optimum range varies among populations. Larvae and juveniles of a Paraná River basin population were sampled in freshwater with conductivity ~60 µS/cm, temperature varying from 20 to 30°C, and pH 5.7 to 7.4 (Bialetzki *et al.,* 1997). In hatchery tanks, larvae from Amazonian coastal populations develop well at 10-16 salinity, 28-30°C, and pH 7.8-8.4 (Maciel, 2007; Vetorelli, 2008). Moreira *et al.* (1986) observed better survival at 28 than at 30°C for larvae of an Amazonian coastal population maintained in 125 mL bowls from hatching to metamorphosis. Silva *et al.* (2005) and Montoya (2003) reported the occurrence of adults in oligohaline waters (0.5 to 5 salinity) of the Pará River estuary (eastern Amazonia) and the Orinoco River delta, respectively. Adults and juveniles of Amazonian coastal populations occur in freshwater, in temperatures from 26 to 30°C, oxygen from 2.1 to 6.9 mg/L and slightly acid pH (6.2-6.8) (Silva *et al.,* 2002a, b; Silva *et al.,* 2005; Flexa *et al.,* 2005). Adults were observed in the Orinoco basin in temperatures around 28°C, oxygen from ~3.5 to ~7.7 mg/L and acid pH (5-6) (Montoya, 2003). In the Jaguaribe River (South Atlantic Basin, North and Northeast region) a year of sampling near the bottom showed temperatures from 27.5-31°C, dissolved oxygen from 4.6 to 6.1 mg/L and pH from 7.4 to 8.4, as well as the presence of a large population of *M. amazonicum* (Sampaio *et al.,* 2007). In some reservoirs in northeastern South America, prawns live in ion-rich alkaline waters: 700-4200 µS/cm and pH 7.3-9.9 (Odinetz-Collart, unpublished data). In aquaculture ponds, they are raised in temperatures from 24-32.5°C, dissolved oxygen 1.7-13.2 mg/L, pH 6.2-9.6, conductivity 47-175 µS/cm, total alkalinity 27-96 mg/L, and Secchi transparency 25-90 cm (Moraes-Riodades *et al.,* 2006; Keppeler and Valenti, 2006). Newly metamorphosed juveniles maintained in tanks at 17°C died during the first week, and survival was 2.8-fold lower at 21°C than at 25°C (Araújo and Valenti, 2003). Therefore, low temperatures may limit the southern geographical distribution of this species. The limits of tolerance for ecological factors are population-specific and may vary in individuals of a species inhabiting different sites. However, it seems that *M. amazonicum* has a high intra-populational tolerance for environmental variables. Extensive data are available from aquaculture tanks and ponds, but data from wild populations are too sparse to confirm this hypothesis.

The reproduction pattern of *M. amazonicum* may vary according to temperature, precipitation, and hydrological characteristics. In aquaculture ponds, reproduction stops at water temperatures below 20°C. In general, *M. amazonicum* breeds throughout the year, but there is a reproductive peak during the rainy season in Orinoco Basin rivers and lakes (Romero, 1982), central Amazonia (Odinetz-Collart, 1988; 1993), eastern Amazonia (Silva *et al.,* 2002a; Silva *et al.,* 2005; Silva *et al.,* 2007), northeastern South America (Bragagnoli and Grota, 1995; Da Silva *et al.,* 2004; Sampaio *et al.,* 2007), central-western Brazil (Porto, 1998), and southern Brazil (Bialetzki *et al.,* 1997). However, continuous reproduction with no relationship with precipitation was observed in the Jaguaribe River in northeastern South America (Sampaio *et al.,* 2007). *M. amazonicum* spawns year-round in Amazonian lakes, but shows highly seasonal spawning in large rivers of the same region (Odinetz-Collart and Magalhães, 1994). The increase in river flow appears to act as a catalyst for gonadal maturation, and it may be a strategy for the larvae to disperse to estuaries (Odinetz-Collart and Magalhães, 1994). Odinetz-Collart (1993) reported three reproductive peaks in central Amazonia: in the mid-high-water season, mid-falling-water season, and during low water. However, in the Tocantins River (eastern Amazonia), a mass spawning occurs during the mid-falling water season (receding seasonal floods, locally known as "vazante"), which could be a strategy to ensure transportation of the larvae to the estuary (Odinetz-Collart, 1993; Odinetz-Collart and Magalhães, 1994).

The considerable variation observed in reproductive and developmental traits seems to be related to the species' very wide geographical distribution and habitat. The influence of the environment on reproductive parameters is evident from the data from the Tocantins River (western Amazonia, Brazil) following the flooding of the hydroelectric Tocantins Reservoir. After two years, the population in the reservoir was breeding in September (dry season), had a smaller mean size, more precocious sexual maturation, and a larger proportion of females than the population downriver from the dam (Odinetz-Collart, 1991b). The time scale of the isolation is not compatible with the evolution of genetic differences. Given this situation, either the species is endowed with extraordinary adaptive flexibility, or both continental and coastal populations were originally present in the Tocantins River.

Some papers have described several juvenile recruitment events during the year. This pattern was recorded in eastern Amazonia, at the town of Cametá on the lower Tocantins River (Silva *et al.,* 2005), Vigia on the Pará River estuary (Silva *et al.,* 2002a), Combú Island in the Guamá River (Silva *et al.,* 2007), and in central Amazonia (Odinetz-Collart, 1993). However, the data presented are not conclusive, and further studies are necessary to clarify the recruitment in *M. amazonicum* in the different Amazonian populations. In a Paraná Basin population, high recruitment was observed in December (Bialetzki *et al.,* 1997). There is no information for the South Atlantic Basin or Pantanal populations.

The size of the eggs in each brood varies according to the distance of the breeding site from the sea. Odinetz-Collart and Rabelo (1996) observed that egg size increased as the distance from the ocean increased, which suggests a progressive divergence of the continental and coastal populations. These authors analyzed populations at distances of up to 3,410 km (Guaporé River) from the sea, including Cametá (120 km), Tucuruí Reservoir (330 km), Manaus (1225 km), and Tefé Lake (1750 km), and described the apparent "fresh-waterization" of the more distant populations. Accordingly, in reservoirs of the Northeast region, the smallest eggs were found in the waterbodies with the highest concentrations of dissolved salts, whereas the largest eggs were found in environments with low conductivity (Odinetz-Collart *et al.,* 1997).

There is a direct relationship between the number of eggs and the size of the female in *M. amazonicum,* which follows a linear model (Lobão *et al.,* 1986; Scaico, 1992; Odinetz-Collart *et al.,* 1997; Da Silva *et al.,* 2004). However, fecundity is also considerably affected by environmental factors, in particular the distance from the sea (Fig. 5). In inland habitats, fecundity is probably influenced by the availability of nutrients and dissolved salts. The variation among different populations is high: the maximum fecundity in Paraná-Paraguay Basin populations (Goiás and Mato Grosso do Sul, Brazil) is no more than 500 eggs per female (Porto, 1998; Hayd, 2002), but reaches 1,500 to 3,000 eggs in the South Atlantic Basin (Scaico, 1992; Odinetz-Collart *et al.,* 1997; Da Silva *et al.,* 2004), 1,000-3,500 eggs in the Orinoco Basin (Romero, 1982; Gamba, 1984; López and Pereira, 1996), and may attain 3,000-5,700 in northeastern Pará (Araguaia-Tocantins and South Atlantic basins) (Odinetz Collart and Magalhães, 1994; Bastos, 2002; Araújo, 2003). Very large (110 cm total length) and well-nourished females may produce 6,000 to 7,000 eggs in aquaculture tanks (Ribeiro *et al., submitted*). The fecundity of *M. amazonicum* is relatively low in comparison with other South American prawns with potential for farming, such as *Macrobrachium acanthurus,* able to produce ~17,000 eggs (Coelho *et al.,* 1982; Valenti *et al.,* 1989) and *Macrobrachium carcinus,* with up to 194,000 eggs per female (Coelho *et al.,* 1982; Lobão *et al.,* 1985). The Amazon River prawn compensates for lower fecundity through its continuous breeding.

Variations in the larval development of *M. amazonicum* are observed across its wide geographical distribution. Coastal populations depend on brackish water to complete the larval phase (Guest, 1979), whereas continental populations complete their development in fresh water (Romero, 1982; Magalhães, 1985; Gamba, 1984), reinforcing the existence of physiologically distinct populations. Moreira *et al.* (1986), based on laboratory studies, reported that the larvae of *M. amazonicum* from eastern Amazonia (a coastal population) are unable to survive in fresh water, and develop best in salinity between 10 and 18, a pattern typical of a catadromous species. Surprisingly, larvae of a well-established population in a reservoir of the Paraná Basin, very far from the sea, placed in fresh water collected at their locality of occurrence, died in less than two hours, but developed well in brackish water (Augusto *et al.,* 2007). In addition, larvae of *M. amazonicum* have never been observed in estuarine zones, and the dependence on brackish water of coastal populations was inferred based on laboratory results. Therefore, the association between larval development and brackish water in natural environments remains obscure, and further research may reveal unexpected news.

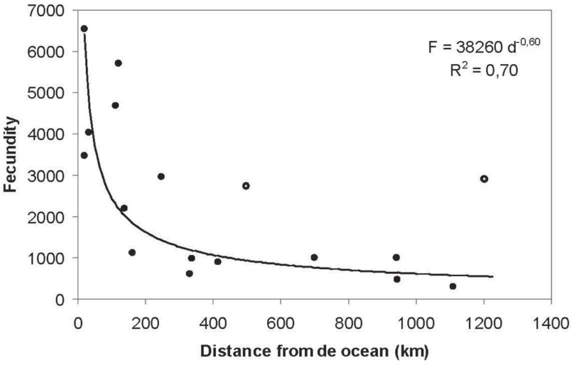


Figure 5. Relationship between fecundity (F) and distance of a population of *Macrobrachium amazonicum* from the coast (d). (Data obtained from Gamba, 1984; Scaico, 1992; Odinetz-Collart and Magalhães, 1994; Odinetz-Collart *et al.,* 1997; Porto, 1998; Bastos, 2002; Bastos, unpublished data; Hayd, 2002; Vieira, 2003; Araújo, 2003; Da Silva *et al.,* 2004). Open symbols indicate data that were not included in the regression analysis.

There are no studies on larval feeding in the natural environment. However, the larvae are presumably carnivorous predators that feed on zooplankton. Laboratory experiments have shown that the zoea I is lecithotrophic, zoea II is facultatively lecithotrophic, and zoea III actively ingests exogenous food (Araújo and Valenti, 2007; Anger and Hayd, 2009). This pattern suggests an adaptation to live in food-limited environments during the initial development. In the laboratory, larvae feed on live *Artemia* from zoea II onward, but after zoea IV, an inert diet rich in animal material is well ingested and is always preferred from stage VI on (Araújo and Valenti, 2007; Maciel, 2007). Therefore, the larvae are really polytrophic and may eat organic particles even in the wild. In this case, the larvae may also play an important role in detritus food chains. Studies should be developed to elucidate the trophic status of larvae in natural environments.

The adult body size is larger, with length varying from 17 to 150 mm, in the areas of eastern Amazonia influenced by the presence of brackish waters, such as Combú, an island in the Guamá River near the city of Belém (Silva *et al.,* 2007), the upper Tocantins River at Cametá (Silva *et al.,* 2005), and the Pará River estuary at Vigia (Silva *et al.,* 2002b). In populations in inland areas isolated from the coast, prawns are smaller and have precocious sexual maturation (Odinetz-Collart, 1991a, b). In accordance with the apparent effect of river flow on development, animals caught in rivers with strong currents tend to be larger (mean body length = 106 mm) than those from "várzea" (white-water seasonally flooded forest) lakes, where the mean length is 60 mm (Odinetz-Collart and Moreira, 1993).

The population structure of *M. amazonicum* is density-dependent in aquaculture ponds. At high densities (40-80/m²), the prawns are smaller and the numbers of dominant males and reproductive females decrease significantly (Moraes-Riodades and Valenti, 2006; Moraes-Valenti and Valenti, 2007). This may be due to intrinsic regulatory mechanisms of the species and/or competition for space and/or natural food. In some wild populations, there are more females than males (Odinetz-Collart, 1987; 1988; 1991b; 1993; Silva *et al.,* 2005; Sampaio *et al.,* 2007). Conversely, males are more frequent in other wild populations (Silva *et al.,* 2002a, b) and in aquaculture ponds, in which their proportion significantly increases during culture (Moraes-Riodades, 2005; Preto, 2007). Therefore, growth, male morphotypes, reproductive females, and sex ratio may vary in different populations and/or may be affected by environmental factors.

M. amazonicum juveniles and adults are omnivorous and probably opportunistic. Romero (1982) observed that prawns from eastern Amazonian lagoons eat algae (genus *Chara*), aquatic insects, and detritus, which are abundant. Analysis of stomach contents in animals from central Amazonia has revealed filamentous algae, diatoms, remains of plants and animals (oligochaetes, insect larvae, and fish), and fine sediments (Kensley and Walker, 1982). Microalgae predominated in the stomach contents of adults from a reservoir population in northeast Brazil (Souza *et al.,* 2007; Sampaio *et al.,* 2008); Bacillariophyceae and Cyanophyceae were the main items observed, and Nematoda, Rotifera, Crustacea, macroalgae, and remains of plants were also present (Sampaio *et al.,* 2008). In aquaculture conditions, they eat several kinds of processed diets (humidity < 13%) based on plant and/or animal raw material, and cannibalism of dead and live animals is frequent. *M. amazonicum* may comprise as much as 80% of the biomass of macrocrustaceans in Amazonian várzea lakes (Odinetz-Collart, 1988; 1993). Therefore, this species may play an important role in the food web, energy flow, and material cycling in these environments. Studies on the feeding habit and nutrition of *M. amazonicum* are few, and should be carried out to improve understanding of the function of this species in natural food webs and to provide scientifically based information to feed prawns in aquaculture.

Some coastal populations in Amazonia are infested by the isopod parasite *Probopyrus bithynis* (Fig. 6). The parasite develops in the gill chamber together with the host, causing deformities in the carapace and external characters of the immature female, and infertility (Odinetz-Collart, 1993). In the Tocantins River, infestation rates vary from 4 to 11% of the total population, but can attain 55% of females (Odinetz-Collart, 1993). There are no records of this isopod in the population of *M. amazonicum* from the Tucuruí Reservoir, whereas parasitized animals can be found downriver from the dam, providing evidence of the isolation of the two populations (Odinetz-Collart, 1988). Odeinetz-Collart (1993) suggested that the populations of *M. amazonicum* and *P. bithynis* are interacting in a stable way in the Tocantins River.

Available information shows that *M. amazonicum* exhibits a very wide phenotypic plasticity. Reproductive strategy, egg size, larval development, growth rate, and population structure are site-dependent. It seems that the main factors that affect these traits are the hydrological and physical characteristics of the environment, including rainfall and flooding, water flow, temperature, and the distance from brackish water, as well as intra-specific competition. However, other biological factors such as food availability, inter-specific competition, and predation pressure should be investigated. Probably the adaptive flexibility of *M. amazonicum* has evolved in response to the environmental variability faced by the species. In addition, the geographical isolation might result in genetic isolation and a lack of gene flow between populations.

Figure 6. The parasitic isopod *Probopyrus bithynis* in the gill chamber of *M. amazonicum.*

Fisheries

There is no current data on the fisheries production of *M. amazonicum.* At the end of the past decade (1999), this species accounted for about 85% of the Brazilian freshwater prawn wild harvest (New *et al.,* 2000). During the past decades, artisanal fisheries have been widespread in traditional Amazonian communities of the Brazilian states of Pará and Amapá (Odinetz-Collart, 1987; Silva *et al.,* 2002a, b; Vieira, 2003; Vieira and Araujo-Neto, 2006) and in the public reservoirs of the semi-arid Northeast Brazil (Gurgel and Matos, 1984; New *et al.,* 2000). In western Amazonia near Manaus, this species is exploited for subsistence consumption or for use as bait, and the local market is supplied by fisheries in Pará. In the Paraná-Paraguay Basin, *M. amazonicum* is fished only for use as bait for carnivorous fish.

In some parts of Brazil, *M. amazonicum* has been introduced as a forage species for omnivorous and carnivorous fish. In the states of Paraná (Bialetzki *et al.,* 1997) and São Paulo (Magalhães *et al.,* 2005) and in the Northeast (Gurgel and Matos, 1984), the habitats were colonized rapidly. There is no commercial fishery in Paraná or São Paulo, but the species has long been considered an important fishery resource in the public reservoirs of the semi-arid Northeast. These artificial lakes can support the activities of 100-300 fishermen, each producing 500 to 1,500 kg of head-on prawns per year (Paiva *et al., nd*). Some speculate that there is a degenerative genetic inbreeding in these populations, leading to a decrease in prawn individual size. However, there is as yet no scientific basis to support this hypothesis.

The fishing techniques include baited traps, locally called "matapis" or "covos", seine nets, dip nets, and throw nets (Odinetz-Collart, 1993; Vieira, 2003), although baited traps are most often used. The traditional fishery of *M. amazonicum* in Amazonia is based on the use of matapis (Fig. 7). These traps are produced locally, using strips of the stalk of the "jupati" palm (*Raphia vinifer*) tied together with the "graxama" liana (*Cydista aequimoctialis*) (Simonian, 2006). The most frequently used bait is the grated endosperm of "babaçu" palm fruits (*Orbinya speciosa*). Matapis are normally made by women, who have only recently become directly involved in shrimp fishing, in particular in the communities of Barcarena (Simonian, 2006) and Gurupá (Pinto and Moreira, 2005). Each matapi catch varies according to the site (Table I), season, and the experience of the fishermen; it may vary from a few grams (30-50 g) to as much as a kilogram per trap per night (Odinetz-Collart, 1993). Some fishermen use pens to maintain the live prawns caught each day until they can sell to middlemen. These pens are kept submerged and generally can stock 10-42 kg of prawns, for about ten days (Vieira, 2003; Pinto and Moreira, 2005; Simonian, 2006). Unfortunately, the mortality in such pens is very high.

The Amazon River prawn fishery is characterized by periods of abundance and scarcity, which are referred to by local fishermen as "harvest season" ("safra") and "slack" or "between-harvest season" ("entressafra"). In central Amazonia near Manaus, the fishery increases in the várzea lakes during high water, while it is more common in the rivers during low water (Odinetz-Collart, 1993); the prawns are caught in abundance along the banks of the Amazon River during low water, when they are migrating from the várzeas (Odinetz-Collart, 1993). During the high-water (flood) period, the relatively strong currents reduce the yield. A similar pattern is observed on the lower Amazon River in the estuary, where the yield increases after the rainy season (Vieira, 2003). According to local fishermen, the prawns are difficult to capture during the flood season, when the population disperses into the várzea. The prawns are also smaller during this period, indicating a reproductive peak. On the lower Tocantins River, the yield is larger in years of greater flooding, and increases in the months following the high-water period (Odinetz-Collart, 1993). In the 1980s, the catch of *M. amazonicum* at Cametá on the lower Tocantins ranged between 10 and 30 tons per month during the slack and

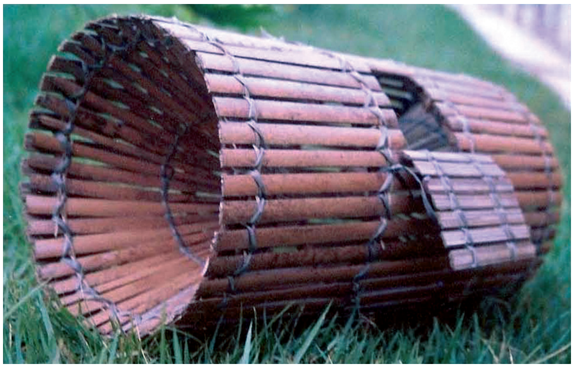


Figure 7. "Matapis," traditional traps used to catch *Macrobrachium amazonicum* in Amazonia.

Table I. Productivity of matapi traps used for the *Macrobrachium amazonicum* fishery in Amazonia.

Mean catch (g/matapi/night)	Site	Details	Reference
54	Pará Island Maniva River	Amazon River estuary (Flood period)	Vieira, 2003
115	Pará Island Maniva River	seasonal flood receding, locally known as "vazante"	Vieira, 2003
1.000	Cametá City Tocantins River	In 1981 (before the flooding of the Tucuruí Reservoir)	Odinetz-Collart, 1991a
370	Cametá City Tocantins River	In 1985 (after the flooding of the Tucuruí Reservoir)	Odinetz-Collart, 1991a
250	Cametá City Tocantins River	In 1987	Odinetz-Collart, 1991a
200	Central Amazon Amazon River	Used as bait for the carnivorous fish *Cichla* sp.	Odinetz-Collart, 1993

harvest seasons, respectively (Odinetz-Collart, 1987). At that time, prawns accounted for 25% of the total fisheries during the high-water season (January to April), increasing to 80% soon afterward (May and June).

It was assumed in the past that the abundance of prawns has determined the frequency of fisheries activities, rather than the inverse, in Amazonia (Odinetz-Collart, 1993). The availability of prawns "self-regulated" the fisheries, allowing the species to reproduce and recruit new generations. However, currently, some areas are being over-exploited, as indicated by the decline in the mean size of the individuals captured. Silva *et al.* (2007) monitored the growth of prawns on Combú Island near Belém in Pará, and recorded a decline in body size, which they attributed to levels of exploitation above the reproductive capacity of local populations. Roadside prawn sellers on the main interstate highway (BR 316) near Mosqueiro Island, Belém, stated that their prawns come from Pará and Amapá Islands during the inter-harvest season, because the local prawns (Santa Bárbara, Pará) are generally too small to sell. Local communities on Tambioca Island in the town of Barcarena in Pará have also reported that *M. amazonicum* has become increasingly scarce and smaller in size (Simonian, 2006).

Recently, strategies for increasing the sustainability of local prawn fisheries have been developed in Gurupá and Barcarena in Pará. They include the use of large mesh pens to stock captured prawns for up to seven days, when the small ones escape through the mesh; as a result, only the larger individuals are marketed, and command a higher price in local markets (Pinto and Moreira, 2005). In 1997, prawns were sold at 400 pieces/kg, but after five years of management, the size of the prawns doubled to 200 pieces/kg and their commercial value increased three-fold (U$ 1.20 or R$ 2.50) (Pinto and Moreira, 2005). In addition, the fishermen have been encouraged to organize their activities formally, and to include the local women in the production process.

The fishery of *M. amazonicum* is one of the principal economic activities of many communities in the Amazon River estuary, including the islands of Marajó and the Bailique Archipelago in northern Brazil. Within this area, Vieira and Araújo-Neto (2006) estimated that 77 fishermen use a total of 3,300 matapis as well as 11-m-long seines (25-35 mm mesh), resulting in catches of up to 750 kg of prawns/month. According to the Amapá State Science and Technology Research Institute (IEPA), approximately 50 tons of prawns were landed per year at Igarapé da Fortaleza, the principal local port, between 1998 and 2000. However, the activity seems to be in equilibrium, due to the self-regulation of fisheries by environmental fluctuations and the slack season (Vieira, 2003).

The construction of hydroelectric dams on many Amazonian rivers may significantly affect the *M. amazonicum* fisheries. Odinetz-Collart (1991b) recorded a progressive decline in catches downriver from the Tucuruí Dam (at Cametá) from 179 t in 1981 (prior to the reservoir flooding) to 121 t in 1985 (post-flooding), and then 60 t in 1986, 91 t in 1987, and 62 t in 1988; the pattern of seasonal variation was unaltered. According to this author, it remains unclear whether the decline in productivity was actually due to the damming of the river or to other factors such as overfishing or changes in the practices of the local fishermen. Many of them stopped catching prawns in order to work on the industrial fishing boats exploiting the fish stocks accumulated in the reservoir. Therefore, the effect of dammed rivers on *M. amazonicum* fisheries is still poorly understood. There is a need to know how the dams affect *M. amazonicum* populations, and to suggest actions to mitigate any negative effects on this local fishery resource.

M. amazonicum is the species of freshwater prawn most widely appreciated by the population of the Amazon region, where it is consumed by all social classes. However, there is little prospect for supplying the expanding market because of the decline in yield in many areas. In addition, the fluctuating periods of abundance and scarcity, related to both the biology of the species and the local hydrological regime, make it difficult to supply prawns with the regularity demanded by markets. Therefore the financial returns are small; a fisherman's monthly income is typically less than the national minimum wage (US$ 220 – R$ 450) during the harvest season, and much lower during the slack season. Therefore, the low and irregular yield seems to be the weakest link in the production chain, which limits its social and economic sustainability. The current level of stock exploitation and poor environmental conservation signal the need for governmental regulation.

Despite these difficulties, the *M. amazonicum* fishery is the most important economic activity in many regions of eastern Amazonia, where the species is still abundant. In these areas, the precariousness of local processing is an important constraint. An additional problem with the quality of the product is the presence of isopod parasites (Fig. 6), which make the prawns unmarketable. Therefore, it is necessary to organize and consolidate processing practices at the community level in order to improve quality and profitability.

The exploitation of the Amazon River prawn requires appropriate local management plans for the fisheries and marketing to assure long-term sustainability. However, science-based information is still sparse. The fluctuations in seasonal yield and the recent decrease in the stocks are still poorly understood. Many believe that this decline is mainly due to over-exploitation, but there is insufficient information to support this hypothesis. The removal of riparian vegetation is increasing in the regions where the fisheries are most active, and may cause significant sedimentation of waterbodies and changes in the allochthonous food, affecting the habitat and food availability for *M. amazonicum.* Research focusing on changes in the habitats and food chain may clarify this subject. In addition, studies on population dynamics in the areas where fisheries are carried out are essential and urgent to determine the reproductive potential, stock sizes, maximum fishery effort, and maximum sustainable yield. Fishing communities should be organized and educated in sustainable fisheries practices and to improve the processing and marketing strategies, increasing the selling price. The establishment of cooperatives and community associations is an option that may help to provide the infrastructure for the appropriate processing, storage, and sale of the product, with the primary aim of reducing losses and obtaining better prices.

Aquaculture

Considering the expanding market for the Amazon River prawn and the difficulties faced by the fisheries, aquaculture may be an important alternative to supply this species. The farming of native prawns is a worldwide trend (Kutty and Valenti, 2010), and has important implications for the maintenance of local biodiversity, as well as avoiding problems caused by the introduction of exotic species. In China, the production of the local species *Macrobrachium niponense* has already surpassed that of *Macrobrachium rosenbergii* (FAO, 2009), and in India, there is a research effort concentrated on the native species *Macrobrachium malcolmsonii* (Kutty and Valenti, 2010). In Brazil, *M. amazonicum* is the native freshwater prawn that has generated most interest for aquaculture (New, 2005). This species may adapt well for intensive or extensive farming, given its less-aggressive behavior and its ability to grow in reservoirs, ponds, and fishponds. Although *M. amazonicum* is much smaller than *M. rosenbergii,* its survival rate is higher and its metamorphosis faster. It is larger than *M. nipponense* and has a similar larval developmental cycle and productivity.

Farming a species requires broad-based research into all aspects of the production process. The initial steps in the development of *M. amazonicum* culture were taken in the last decades of the past century (Cavalcante, 1977; Vargas and Paternina, 1977; Coelho *et al.,* 1981, 1982a, b; Barreto and Soares, 1982; Valenti, 1985; Alves, 1986; Lobão *et al.,* 1987; Roverso *et al.,* 1990; Rojas *et al.,* 1990; Lobão *et al.,* 1994). However, the introduction of *M. rosenbergii,* which arrived in Brazil with well-established farming technology, led to the abandonment of research on native species (Valenti, 1993). Over the past few years, a multidisciplinary and multi-institutional research group has been established in order to develop a technological package for the farming of *M. amazonicum.* This group involves more than 15 Brazilian and foreign institutions, graduate programs, professional scientists, and many students throughout Brazil, and has already achieved significant advances. The program outline can be accessed at the site: www.caunesp.unesp.br/pesquisa/Projetos%20integrados/projeto%20pesquisa_camarao.php.

The general technology for farming *M. amazonicum* was recently reviewed by Moraes-Valenti and Valenti (2010). Hatchery tanks can be stocked in high densities, using natural or artificial salt water at inland sites (Vetorelli, 2008), and productivity can reach 70 postlarvae/L (Vetorelli, 2004). General feed-management guidelines have also been established (Araújo and Valenti, 2007; Maciel, 2007), while Vetorelli (2008) has demonstrated the economic viability of the commercial hatchery. In the grow-out phase, the prawns can be reared in intensive or semi-intensive systems, at densities of 10-80 individuals per m^2, with survival rates above 60% (Moraes-Valenti and Valenti, 2007). Productivity varies between 508 (10 individuals/m^2) and 2,051 (80/m^2) kg per hectare in five and a half months, with mean weights of 7.0 g to 3.6 g, respectively, potentially reaching ~4,500 kg/ha/year. Moraes-Riodades *et al.* (2006) confirmed that production can be intensified (80/m^2) without causing significant changes in water quality, that is, with low environmental impact. These practices also improve both the economic and environmental viability of prawn farming, primarily by optimizing the use of space and water. The grow-out process also allows a selective harvest at regular intervals (twice a month) without altering the characteristics of the water, sediments, or effluents (Keppeler and Valenti, 2006). This demonstrates that it is possible to adapt farming strategies to the target market, in particular by regulating production to provide animals on a weekly basis. Some studies have shown that the farming of the Amazon River prawn is a low-impact activity (Kimpara, 2004; 2007; Moraes-Riodades *et al.,* 2006; Keppeler and Valenti, 2006). Other studies have focused on the physiology of the larvae (Hayd, 2007) and adults (Papa *et al.,* 2004a, b), the management of juveniles in the nursery phase (Araújo and Valenti, 2005; Sampaio *et al.,* 2004; Penteado *et al.,* 2007), and the use of feeding trays in the rearing ponds (Preto *et al.,* 2008). However, further studies are necessary for better understanding of the species' fecundity, nutritional requirements, heterogeneous growth, and the processing of the harvested prawns.

Although the technology for farming *M. amazonicum* is well advanced, it is still necessary to validate these techniques for large-scale farming operations. In this case, the primary difficulty is not the research itself, but the scarcity of government support for the development of this activity. Establishing *M. amazonicum* farms requires regular supplies of juveniles and technical assistance. Another problem faced by the potential producers is the difficulty of obtaining a farming license and financial credit in some countries.

Recent research has shown that *M. amazonicum* can be successfully farmed. Hatchery, nursery, and grow-out phases can be carried out on small, medium, or large scales in intensive systems. Farms can be set up close to or far from the coast, providing an important alternative strategy for regional development. The main constraints are the low fecundity and the heterogeneous growth, which need further research. Valenti (2002) stated that the farming of freshwater prawns can be a sustainable activity, which can promote social and economic development without causing major environmental impact. The success of prawn farming depends on a strong and well-organized production chain (Valenti and Tidwell, 2006). Obviously, this depends on efforts to consolidate different sectors, including research, development, technology transfer, legislation, credit, general infrastructure, processing, distribution, and marketing.

Marketing

Macrobrachium amazonicum may have commercial value as bait for sport fishing, as an ornamental pet, as live food for carnivorous ornamental fish, and for human consumption. There is a large market for bait prawns in areas where sport fishing is common, such as the Pantanal and Amazonia; this is technically feasible and highly profitable (Valenti *et al.,* 2008). The potential for the aquarium trade should also be evaluated. *M. amazonicum* as human food has a substantial market in the Brazilian states of Pará and Amapá and in almost all of northeastern Brazil (Moraes-Valenti and Valenti, 2010). Its meat has a firm texture and a more intense flavor than that of

M. rosenbergii (Moraes-Riodades and Valenti, 2001). In addition to its agreeable flavor, *M. amazonicum* is rich in nutrients and is an excellent source of proteins and essential fatty acids, in particular EPA and DHA (Furuya *et al.,* 2006). The lipid composition makes it suitable for inclusion in cardiovascular diet therapy (Nassar, 1998). Because there is no commercial aquaculture production of *M. amazonicum,* the market is supplied by fisheries production.

The development and expansion of the human food market is limited by two primary factors: the irregularity of supplies and the poor quality of the product. The fishery varies seasonally, and there are no appropriate facilities for processing and providing regular supplies. Therefore, prawns cannot be offered on a regular basis, an important market requirement. Prawns are normally sold "in natura", or artisanally salted, cooked, or dried. This obviously results in poor hygiene conditions and significant losses from spoilage. Most fishermen are unable to store their product and must therefore accept the prices offered by middlemen (Vieira and Araújo-Neto, 2006).

M. amazonicum is sold in open-air markets in many waterside communities and small towns in Amazonia and northeast Brazil. It is also sold in some large Brazilian cities such as Manaus, Belém, and Macapá (Amapá). Salted Amazon River prawns can be found plastic-wrapped in all the principal supermarkets, and appear on the menus of the best restaurants and hotels in Belém. Many tons are sold annually at the Ver-o-Peso market in Belém and along the main highways in eastern Pará (Fig. 8). Prawns generally are sold head-on, fresh or salted, with no refrigeration. Sometimes they are marketed in crushed ice, but this supply is unavailable in most locations in Amazonia and the Brazilian Northeast. The most common form of artisanal processing is salting, which involves boiling the prawns in salt water for up to 20 minutes, followed by 24 hours of draining (Pinto and Moreira, 2005; Simonian, 2006). Two processing plants were recently (2002) installed in the Bailique Archipelago and on Fortaleza Creek in Amapá. Unfortunately, both of these plants have poor facilities and are currently operating below their full capacity (Vieira, 2003). The wholesale price paid to fishermen at Fortaleza Creek is about US$ 1/kg (R$ 2) for head-on fresh prawns, whereas the local retail price is US$ 2-2.50/kg (R$ 4-5) for ungraded and US$ 4-5/kg (R$ 8-10) for graded product (Vieira, 2003).

Figure 8. Roadside prawn vendors on Mosqueiro Island, state of Pará, Brazil.

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