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Review

The culture potential and management problems of freshwater prawns (*Macrobrachium americanum* and *Macrobrachium tenellum*) in their native areas: the case for Mexico

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ABSTRACT. *Macrobrachium tenellum* and *M. americanum* are common freshwater prawns from the Americas' tropical and subtropical Pacific continental side. They have different biological attributes and are currently threatened by human impact on their ecosystems. Both species provide different quality products for human consumption and are intensively exploited without proper management. This study analyzes, discusses, and compares the available information for both species and their current status as a live resource.

Keywords: *Macrobrachium tenellum*; *M. americanum*; prawn; native species; knowledge

INTRODUCTION

The most diverse genus in the family Palaemonidae is *Macrobrachium*, mostly freshwater prawns (De Grave et al. 2008), including more than 200 species living in tropical and subtropical regions (Murphy & Austin 2005). There are many variations in the average size and reproduction, and habitat requirements (Pileggi & Mantelatto 2010). As juveniles and adults, they are benthic and often occupy caves, crevices under rocks, and submerged roots where they find shelter. They are omnivores eating detritus, algae, or dead animals and act as predators of aquatic invertebrates (Albertoni et al. 2003) and sometimes fish (Rodd & Resnick 1991). They are also prey for fish, birds, and reptiles (Taylor 1979).

Macrobrachium prawns may spawn several times per year, and large species may produce thousands of eggs at each spawning, carried under the abdomen during incubation (García-Guerrero & Hendrickx 2009). An embryo and larval development duration depend on the species and, mostly, water temperature (García-Guerrero 2010). According to Bauer (2011), females of most species feed, breed, and spawn in freshwater, but larvae are transported or released into saltwater shortly after hatching occurs, a life cycle termed amphidromous (McDowall 2007). In some species, larvae are probably released upstream and transported by the water flow towards the sea into coastal estuaries or lagoons. In other species, females might migrate downstream, carrying the eggs closer to coastal bays and estuaries where hatching takes place. Ling (1962) was perhaps the first to describe their life cycle, emphasizing that larval development includes at least 12 stages, most of them needing saltwater. Larvae are planktonic, and once they have turned into juveni-

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les, they migrate from the coast to freshwater continental bodies, thereby contributing to the flow of energy and different habitats (García-Guerrero et al. 2013). The distances can be from tens to hundreds of kilometers (Bauer 2011). Besides, these prawns are very important for the dynamics of river ecosystems in both coastal and inland water bodies because they remove and recycle organic matter (McDowall 2007, Bauer 2013). These characteristics place *Macrobrachium* prawns in a prime position in the list of adaptations and ecological roles in aquatic life.

According to the latest worldwide information (FAO 2020), world aquaculture production attained almost 114.5 million tons in live weight with a revenue of USD 263.6 billion in 2018, and from this amount, aquaculture of freshwater species produced 51.3 million tons. In agreement with FAO (2020), there is a gradual increase in freshwater aquaculture production. Most are fish, but this also includes freshwater prawns since, for the same year, production was almost 5% of the total world production. The most produced and exploited species globally are *Macrobrachium rosenbergii* and *M. niponesse*, both from Asia and their value is based on their large size, taste, high protein content, and appearance (New 2005). Worldwide, *M. rosenbergii* is the only species with a well-developed culture technique and with an established market. The freshwater prawn aquaculture pathway has been increasing steadily since 1980, and half of the production corresponds to *M. rosenbergii* produced in Asia (New 2009). In comparison, the production of other *Macrobrachium* species is low; only a few species possess the same features as *M. rosenbergii* and no available techniques exist yet for their culture.

Since some Latin American species are also exploited, part of the world's production comes from them, but it is less than 20% of the total amount. Accurate data are not available, but most production comes from artisanal fisheries performed by communities living near the rivers, often illegally and with captures never reported or documented in any official registry.

The most common native freshwater prawns in Latin America are, depending on the geographical area, *Macrobrachium acanthurus*, *M. amazonicum*, and *M. carcinus* on the Atlantic side and *M. americanum*, *M. digueti*, and *M. tenellum* on the Pacific side (García Guerrero et al. 2013). According to Chong-Carrillo et al. (2015), Brazil has provided significant research products, especially *M. amazonicum.* In that region, there exist also studies with other species such as *M. acanthurus*, *M. carcinus* and *M. olfersii*. Particularly, in Mexico, research efforts are focused on *M. americanum*, *M. carcinus* and *M. tenellum* because it is expected that native species are easier to maintain since they are already adapted to the weather and water quality. All negative consequences of the introduction of exotic species are avoided. Working with native species encourages sustainable aquaculture, preserves genetic resources, and maintains biodiversity (Ross & Beveridge 1995).

For most of these species, their basic biology is known, but information on populations in the wild or aquaculture is scarce. All these species are captured to some extent; the best collecting opportunities occur during the reproductive season because of rain and migration. All sizes are intensively captured, including berried females. This situation, together with poor management, pollution, and habitat destruction, might cause their decline or expiration if studies on their biology, ecology, and aquaculture are not performed, leading to the implementation of measures aiming to counteract this exploitation. Due to this situation, several research groups in Latin America are working with these native species.

The present study analyzes the current knowledge and status of the two most common and most captured species from the Pacific slope of Latin America: *M. americanum* and *M. tenellum*. Both are completely different in adult size and behavior, and habitat preferences make them different products. In addition, the required measures for its conservation and management are different.

Macrobrachium americanum

This species (Fig. 1) can reach a large size in the wild (almost 30 cm from tail to head) and is distributed along the Pacific coast from the north of Mexico to Peru (Holthuis 1952, Hendrickx 1992). Figure 2 shows the distribution of the species in Mexico. Most of the year, it lives in rivers that connect to the sea (Hernández et al. 2007), and large females can produce thousands of eggs. As larvae, they live in estuaries or coastal lagoons with saltwater, but they migrate to freshwater portions high up into the rivers as soon as they become juveniles. Probably, most adults remain there the rest of their lives in freshwater, with temperatures fluctuating between 19 and 25°C. They spent the day hiding in crevices, submerged roots, caves, or among rocks. The species is most active at night, being omnivorous and scavengers, but also predators. It is highly probable that females lay and incubate their eggs without migrating, releasing their larvae into the stream, transporting them to the saline coastal waters in several hours or days, depending on the current velocity. Males, especially large ones, mate soft females, are highly territorial and aggressive during the reproductive season. It is possible to find different age groups in the same place, but juve-

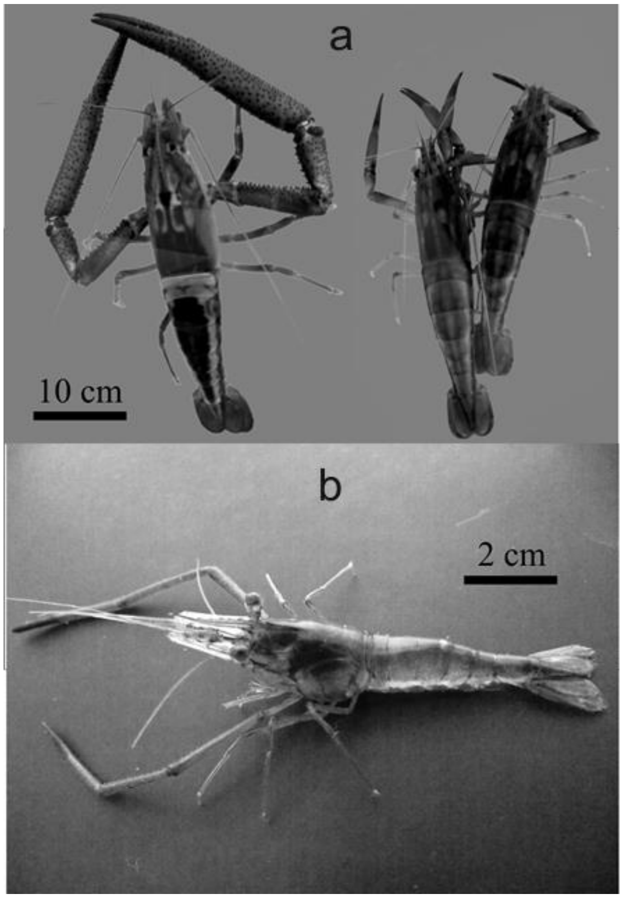

Figure 1. a) *Macrobrachium americanum* adult male (left) and females (right), b) adult female *M. tenellum.*

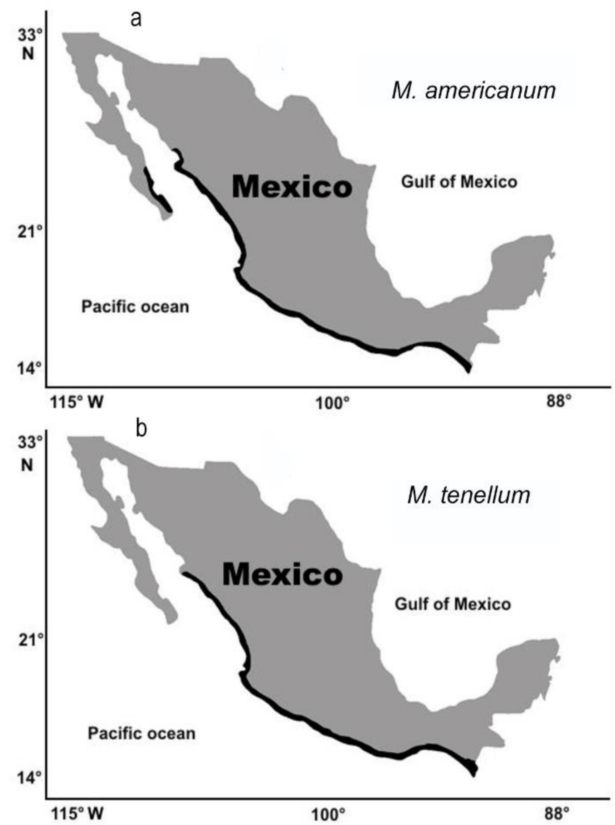

Figure 2. Geographic distribution of a) *Macrobrachium americanum* and b) *M. tenellum* in Mexico.

niles are found mostly in streams near the coast, whereas adults are distributed mainly in rivers of medium-altitude, often with lower water temperatures than those of the coast. In Mexico and over its entire geographic distribution, this prawn is captured using artisanal techniques, traps (Fig. 3a), harpoon, or by hand. Its culture has been attempted in ponds and concrete tanks (Fig. 3c), but still, there is no successful technique that can support commercial production. Monaco (1975) first attempted the culture from larvae to juveniles, feeding larvae with a prepared fresh fish meal, but their survival to this stage was quite low (<5%). Yamasaki et al. (2013) also tried the experimental culture of larvae fed with live food and reaching the juvenile stage, but survival was also lower than 10% until the juvenile stage. *M. americanum* larvae probably feed on zooplankton in the wild because these latter authors reported live *Artemia* nauplii as the best food in captivity compared to dry or freshly prepared meals.

The first known efforts to grow juveniles or adults in captivity were carried out by Arana-Magallón (1974), Ruiz et al. (1996), and Arana-Magallón & Ortega (2004). These authors cultured them in earthen ponds concluding that low densities and shelters were required due to their aggressiveness. Also, García-Guerrero & Apun-Molina (2008) studied the density effect on survival and growth of juveniles maintained with different types of shelter combinations, finding that better grew those kept at low density and with a shelter, supporting the idea of a low-density strategy to obtain good growth and survival. García-Guerrero & Hendrickx (2009) studied embryonic development in stages based on percentages, describing ten stages from oviposition to hatching. García-Guerrero (2009, 2010) studied the proximal composition of the embryos incubated at different temperatures, finding lipids as the main component used for energy needs, and protein as the most abundant component is the case with most crustacean embryos.

García-Guerrero et al. (2011) studied oxygen consumption depending on the size of the specimen and the water temperature. This study supports the fact that there is a direct correlation between rising temperatures and oxygen consumption, but only between 19 and 26ºC. López-Uriostegui et al. (2013) analyzed growth in cages, finding that the smaller the prawns at stocking,

Figure 3. a) Artisanal traps utilized for the capture of *Macrobrachium americanum* prawns in rivers in Mexico, b) cast nets utilized for the capture of *M. tenellum* prawns in rivers and coastal lagoons in Mexico, c) inland facilities utilized for the culture and maintenance of *M. americanum* stocks, d) inland facilities utilized for the culture and maintenance of *M. tenellum* stocks.

the better survival rates will be obtained at harvest. More recently, Méndez-Martínez et al. (2017) evaluated the effect of dietary protein content on juvenile growth rate, survival, and body composition, finding that dietary protein of 37.2% seems to be optimal for juvenile production at the experimental level. Méndez-Martínez et al. (2018a) studied the nutritional effect of enriched *Artemia* nauplii as food during larval culture and concluded that nauplii enriched with *Chaetoceros calcitrans* produced the best results. Méndez-Martínez et al. (2018b) evaluated the effect of different protein ratios in the diet on juvenile growth, and their results revealed that dietary protein-lipid proportions influenced the entire body protein, lipid, and carbohydrate contents; the lipid content in the body increased significantly when the dietary lipid level was increased from 60 to 140 g kg^{-1} in isoproteic diets. On the other hand, Pérez-Rodríguez et al. (2018) analyzed the effect of different dietary protein levels on juvenile growth and showed that a diet with 33% protein was the best in terms of costs and survival, whereas Soberanes et al. (2018) measured superoxide dismutase activity in prawns fed with different dietary levels of protein and lipid. They found that a diet containing 35% protein and 10% lipid was best since that diet contributed to preventing diet-induced oxidative stress and protected the integrity of super oxide dismutase antioxidant response.

The effect of stocking densities on blood chemistry and biochemical body composition of this prawn cultured and the Nile tilapia (*Oreochromis niloticus*) were evaluated by Santamaría-Miranda et al. (2018). The results revealed that a combination of 14 fishes per five prawns produced similar growth compared to a monoculture, with no effect on blood or hemolymph chemistry and proximal composition on any species. Thus, they stated that blood glucose concentration could indicate physiological changes for tilapia and prawns when cultured together. Ponce-Palafox et al. (2018) evaluated the influence of density on growth and survival with prawns cultured in a cage-pond culture system, concluding that growth was affected by density; a maximum increase of 6 ind m^{-2} resulted in the asymmetry of the prawn, whereas the density of 9 ind m^{-2} increased the number of small organisms. López-Uriostegui et al. (2020) analyzed the temperature-salinity interaction on growth and survival, finding that the final weight and total weight gain increased as temperature increased and, at the upper end, salinity had a linear synergistic effect, with a greater effect on growth at high temperatures. Parra-Flores et al. (2020), working *in vitro* protein digestibility and growth performance using no-conventional plant ingredients, observed that prawns digest animal ingredients more efficiently than plant ingredients, with squid and fish meal showing a tendency of higher values, supporting the carnivorous preferences of this species.

Due to the interest in cultivating this species for commercial purposes, all this previous research has been carried out. In the coastal regions of Mexico, *M. americanum* is a very appreciated cuisine product because of its attractive appearance as a prepared dish. However, preferred prawns are mostly those over 200 g; specimens might take several years to reach that size in the wild. It is unlikely to obtain these sizes in culture unless they are maintained at very low densities and for a long time, which is not compatible with commercial goals-given the instinctive aggressiveness of the species and the fact that molting specimens are highly exposed to cannibalism make its culture an arduous task under a proper economic scheme. As suggested by García-Guerrero & Apun-Molina (2008), the addition of shelters of various types might diminish cannibalism but raises the cost and involves additional work. Some authors have suggested individual culture to avoid cannibalism. However, facilities for the maintenance of isolated prawns would be quite expensive to build and manage, making this option only suitable for research purposes, unless future research drives this trend in other directions, something hard to achieve because of the nature of this species. Mating is another problem since the female should be soft-shelled to receive the spermatophore or sperm sac; this should be no problem in the wild since they can easily hide because prawns are dispersed, and there are numerous hiding options in rivers. However, they are highly exposed to predation by other specimens, even with a shelter, since hiding is difficult in a culture tank or pond.

On the other hand, a successful larval culture of the species is still far from being accomplished. Larvae require certain water salinity, which has not been accurately determined yet. As in most larval cultures, the hard part seems to be feeding (Monaco 1975, Yamasaki et al. 2013, Méndez-Martínez et al. 2018 a,b). These authors observed that dry prepared food is not a good option since *M. americanum* larvae are instinctive predators in the wild, and suitable live food could also be cultured or sometimes collected, which means additional work. Besides, *Artemia* nauplii are not a natural diet for *Macrobrachium* prawns. Nauplii could be too large to feed early larval stages (Yamasaki et al. 2013). Better live prey options should be investigated or, at least, finding out which food, prepared with fresh ingredients, could be attractive for *M. americanum* larvae.

For this species, there is a lack of published results of field studies. The current status of its populations in any water basin in which it is distributed is unknown in detail. However, human communities living in places where this living resource has been traditionally exploited ensure that its populations are lower every year and large sizes are harder to find, at least along the entire Mexican Pacific coastal basins. The species is almost absent now in certain communities in which they were quite common, such as Chacalapa, Oaxaca (15°49.74'N, 96°27.85'W), or they are now more restricted in distribution. Its total disappearance has even been observed close to human settlements. However, all this is inferred from anecdotal field observations or affirmed by local fishermen over generations familiar with the species exploitation in rivers. Formal quantitative studies are required to determine the current status of its populations in places where this fishing resource used to be common.

Macrobrachium tenellum

This species (Fig. 1) is distributed along the Pacific coast from the north of Mexico to northern Peru (Holthuis 1952, Hendrickx 1992). Figure 2 shows its geographic distribution in Mexico. Differently from *M. americanum*, it is dispersed in warmer waters close to the coast. It is a relatively small species, and females (10 cm or less) can produce hundreds of eggs. As larvae, they live in saline water of the estuaries, and as soon as they become juveniles, they might migrate further upstream, but most individuals stay in freshwater bodies near to the shore, as long as the water has low salinity (0-6) with temperatures fluctuating between 22 and 26°C. They spend the day mostly in the muddy bottom or within the riparian vegetation and are mostly active at night, being omnivorous and scavengers and, rarely, predators. Females lay and incubate their eggs in coastal areas or the lower portions of the rivers, releasing larvae into the saline coastal waters. Males, especially large ones, are territorial during reproductive season and mate with soft females. Adults are very common in rivers connected to the sea and coastal lagoons with low or no salinity. Adults and juveniles often share the same habitat.

In Mexico, the species can still be easily collected in the wild by hand or with cast nets (Fig. 3b), sometimes in high densities. It is still common due to the lower interest in this prawn as a marketable product, together with its higher resistance to human impact on rivers and coastal areas. Its culture has been attempted in artisanal ponds (Fig. 3d) with juveniles collected from the wild. The species can tolerate a wide and fluctuating temperature interval, salinity, and oxygen concentrations (Ponce-Palafox et al. 2002). In addition, this species quickly reaches sexual maturity, and it is possible to find berried females of only 3 cm length. It is subjected to intense fishing in coastal communities of rivers and coastal lagoons, but because of its small size, it is mostly used for consumption by the fishers themselves (García-Guerrero et al. 2013). Perhaps the complete background information on this species was provided by Espinosa-Chaurand et al. (2011) with a review of existing and available information on its biology and culture. However, initial studies on the biology and ecology (spatial-temporal distribution, abundance, life cycle) started during the 1970s with Guzmán (1975, 1976, 1977) studies in Guerrero, Mexico, coastal lagoons. These studies showed that the species was easy to find, collect, and handle in captivity than larger species such as *M. americanum*. On the other hand, Guzmán et al. (1977, 1978, 1981), Guzmán & Román (1983) and Guzmán (1987) revised other aspects of the species, such as distribution and abundance. All these studies stated that, at those times, this prawn was common, widespread, and easy to maintain in captivity, but no details on its specific nutrition or water quality requirements were provided. Ruiz-Santos (1988), Román-Contreras (1991) and Signoret & Brailovsky (2002) reached similar conclusions. Studies on the physiology of *M. tenellum* have been conducted by Cuevas-Félix (1980), Hernández et al. (1995), Hernández & Bückle (1997), and Rodríguez-Flores et al. (2012) analyzing the effects of temperature on the metabolic rate, which is also related to size. They concluded that the best growth was obtained at 29°C, but the final preferred temperature was 32.3°C, whereas maximum and minimum preferred temperatures depended on the previous history of the specimens. Studies by Aguilar (1995), Signoret & Soto (1997), and Aguilar et al. (1998) focused on osmoregulation and concluded that the species exhibited unchanged osmotic behavior from 0 to 20 of salinity, reaching the isosmotic point at 632 mOsm kg^{-1} and, beyond this point, it became a hyporegulator. They concluded that 21 seems to be the maximum salinity *M. tenellum* can tolerate, but at these conditions, growth is suppressed. García-Ulloa et al. (2008) performed studies to determine the effect of different isoproteic diets on growth and found that the final specific growth fluctuated from 1.82 to 60% total weight increase in animals fed with soya bean meal inclusion in the diet and from 2.62 to 100% total weight increase in animals fed with fishmeal diet; the mean final survival was 91.66%. Growth performance was not affected by the dietary soya bean meal included in the diet. Concerning the molt cycle, Yamasaki et al. (2012) determined its intervals in days depending on size. Prawns were divided into four groups according to weight, and the increase in size after molting among all groups was statistically different since there was an increase in the size of 6.1% in smaller prawns and 2.2% in larger ones. According to the authors, the duration of the molting cycle was not significantly different between smaller and larger prawns.

Other studies have contributed to the knowledge of morphometric parameters of the quality of the embryos (García-Ulloa et al. 2004), stating that this might be related to female size. Ponce-Palafox et al. (2005) and Ocaña-Luna et al. (2009) studied parasitism on the species and the diseases that affect it, respectively, finding infectious microbial diseases, not animal parasites, as the main cause of death in culture ponds. Navarro-Hurtado (2002) developed studies in polyculture with *Oreochromis* sp. The results showed that the yield for polyculture with high prawn density was 7981 kg ha^{-1} $cycle^{-1}$, and for low density, 7225.9 kg ha^{-1} $cycle^{-1}$. Since both densities had similar results in survival and growth, they suggested the higher density for production purposes.

On the other hand, the studies of Ponce-Palafox et al. (2002, 2005), Sánchez-Granados (2008), and Vega-Villasante et al. (2011) have contributed to our knowledge on culture techniques in earthen and semi-rustic ponds. These studies recommended raising this species in ponds with fresh water at 27°C, and O_2 up to 2.5 mg g^{-1}, at low density, using formulated meals as food. In addition, López-Uriostegui et al. (2014) studied the stocking density effect on growth and survival and observed that stocking density affected both in cage-pond systems and suggested the initial stocking density as the most determinant factor. Benítez-Mandujano et al. (2014) evaluated the growth of males and females in rustic ponds, recommending pond water with a temperature of 26.3°C, pH of 8.3, and dissolved oxygen at 7.4 mg L^{-1}. Vargas-Ceballos et al. (2016) studied parasitism on this species by bopyrid isopods, which seems common and lowers growth in parasitized specimens. Aréchiga-Palomera et al. (2016) evaluated the anesthetic effect of extracts of *Passiflora incarnata*, *Valeriana officinalis*, *Syzygium aromaticum*, and menthol to propose these compounds for better manage experimental practices. However, only the last seems to act as a stress-reduction compound. More recently, López-Uriosotegui et al. (2017) studied stomach repletion rhythms and found that the repletion index was highest during the day. Garduño et al. (2017) analyzed the growth and mortality of *M. tenellum* in San Pedro Mezquital River, Nayarit, Mexico, finding a very high variability in growth among specimens, even when coming from the same conditions. De los Santos et al. (2017a,b) performed research on the effect of dietary chitin and the effect of temperature and photoperiod on the digestion of that ingredient. According to these authors, the best final weight and specific growth rate resulted from diets with at least 20% chitin, and the worst corresponded to diets with 5 and 10% chitin. In this experiment, chitin in the diet did not have a significant effect on survival. Vargas-Ceballos et al. (2018 a,b) revised several fecundities and reproductive attributes of the species, observing that the total length of reproductive females ranged from 26.6 to 67.0 mm (average 44.2 ± 8.8 mm), and this was directly related to fecundity, which ranged from 253 to 10,384 eggs (average 2418 ± 2089 eggs) depending on female size. De los Santos et al. (2018) analyzed the effect of alpha (α) male presence on tanks' remaining specimens. This effect was one of the main limitations to grow specimens in captivity successfully because large dominant males inhibited the growth of smaller ones, causing a very heterogeneous growth in the culture unit with a lot of dwarf or undersized specimens, something unsuitable when a homogenous stock is required.

Montoya et al. (2018a) studied the enzymatic activity in the digestive tract of prawns fed meals with a certain protein amount and encountered significant differences with *Spirulina* sp. meal, with the highest digestibility followed by pork meal. The lowest digestibility was found in chickpea meals. Thus, ingredients based on vegetal protein could be readily digested by this species if they are included efficiently in the diet. Montoya et al. (2018b,c) also carried out the first studies concerning the design and test of several options addressed on evaluating the appearance and palatability of feed ingredients for experimental and commercial diets. They determined the potential of six ingredients of animal origin, showing that pork meal, fishmeal, feather meal, and shrimp meal were attractive and acceptable to prawns.

Hernández-Sandoval et al. (2018a) studied the effect of temperature on growth, survival, thermal behavior, and critical thermal maximum in juveniles. In contrast, Hernández-Sandoval et al. (2018b) analyzed the thermal preference, critical thermal limits, oxygen routine consumption, and active metabolic scope of the species. Both studies concluded that the preferred temperature was close to 28.5°C and acclimation temperature significantly affected the thermal tolerance. They stated that oxygen consumption routine rates increased as the acclimation temperature increased from 20 to 32°C and that the active metabolic scope for prawns was the lowest for individuals acclimated to 20 and 32°C and the highest value was obtained at 29°C.

Aréchiga-Palomera et al. (2018) studied the effect of the background color on the coloration of *M. tenellum* to determine its influence on chromatophore expression without supplementation of pigments in the food. Their results showed that prawns modified their pigmentation according to the different background colors of experimental aquaria. In turn, Peña-Herrejón et al. (2019) studied the effect of stocking density on growth and survival in prawns kept in a recirculating system and concluded that stocking density affected biomass weight gain and specific growth rate since lower values on both were observed at the highest density.

Even though *M. tenellum* is a common species, there are very few laboratory studies dealing specifically with its culture or production of its larvae and a reliable method for its production in controlled conditions, probably because larval culture is a very difficult task. Among the few efforts is the study by Figueroa et al. (2012) dealing with the effect of ammonia on larvae with concentrations from 2.89 to 185.48 mg NH_4-N L^{-1}. They compared its tolerance with that of other species, and their results suggested that *M. tenellum* exhibited slightly higher tolerance to ammonia in the first zoeal stage than more advanced larval stages. Vargas-Ceballos et al. (2018a,b) studied the effect of different salinities on the survival of embryos and newly hatched larvae; the highest survival was obtained at 10 of salinity (82%), whereas at 0 and 20 of salinity the survival was 60 and 55%, respectively. Vargas-Ceballos et al. (2020) evaluated the acceptance of live and inert food by early larval stages of *M. tenellum*, giving them micro-pulverized food, live newly hatched *Artemia*, a paste containing microalgae from biofloc, cooked egg yolk, and frozen *Artemia* nauplii. The larvae did not consume living or frozen nauplii, and the diets that had more acceptance were micro-pulverized food, cooked egg yolk, and biofloc. Nevertheless, a reliable method for successful larval development does not exist yet. *M. tenellum* larvae probably prefer a zooplankton diet in the wild, as inferred from their collection in rich planktonic waters.

Research to date suggests that *M. tenellum* has more possibilities to be successfully cultured compared to *M. americanum*. The species is less aggressive and more disposed to consume food with low animal protein content. It is also more resistant to high densities and low water quality, one of the primary criteria for this recommendation. The adults of *M. tenellum* can be aggressive during the reproductive season, especially larger ones or males. However, non-reproductive males seem to be quite tolerant of other individuals. This species grows fast in captivity, but heterogeneous growth among specimens of the same stock has been frequently observed. With time, a wide interval of sizes has been observed because of the presence of males. *M. tenellum* is much smaller than *M. americanum* and has a shorter life span and life cycle. They grow quickly with minimum requirements, are easy to catch, and still abundant in the wild. *M. tenellum* is intensively captured year-round in the vegetation or bottom along the riverbanks and coastal freshwater and low salinity environments. The species is particularly common during its juvenile stage and can be easily collected with a hand strainer or net in very large numbers. Residents of riverine communities with little or no income take advantage of these traits and gather juveniles in millions for selling them in local markets or for self-consumption. It is unknown how large this negative impact is, but the numbers are so large that a burden on the populations of this species can be expected. *M. tenellum* does not reach a size that allows the product to be sold as a high-return income product, but their populations seem to be less endangered, more resistant to human-intensive caching and habitat destruction than those of *M. americanum*. Consequently, riverine communities interested only in a supplementary additional farm product might be interested in the culture of *M. tenellum*. However, as in *M. americanum*, larval culture to obtain laboratory-reared juveniles is the most difficult task.

General facts

Many marketable species are not farmed because of technical limitations or insufficient research, and this seems to be the case of *M. americanum* and *M. tenellum*. According to previous studies on both species, limited tolerance to crowding and the difficulties of larval rearing seem to be the major concerns. The development of proper culture techniques requires overcoming different kinds of obstacles, depending on the species. Most publications about these species are not updated or analyze only a single problem. Other few studies analyzed or described technical problems related to the management of both species, such as Ponce-Palafox et al. (2002) in a technical report in which several biological and ecological traits and culture techniques are presented. In particular, for *M. tenellum*, these authors suggested genetic selection to improve culture potential and, for *M. americanum*, a selection that allows controlling territorial instincts of large specimens.

If a species has potential for aquaculture, its conservation in the wild should also be promoted. Information on the status in the wild is required. However, there is a lack of population or ecological studies for both species. In terms of abundance and distribution, many factors need to be studied to link this information with management in captivity. However, studies on both species are relatively new, even considering that they have been historically exploited. Such studies, either for cultivation or conservation, need a multidisciplinary approach (Chong-Carrillo et al. 2018), just as the study of *M. amazonicum* in Brazil carried out by several research groups, mostly directed by Dr. W.C. Valenti e.g. Araujo & Valenti 2007, 2011, Moraes-Valenti & Valenti 2007, Maciel & Valenti 2009, 2014, Arruda-Hayd et al. 2010, Moraes-Valenti et al. 2010, Preto et al. 2010, 2011). These studies include almost all required areas to be evaluated for a good understanding of the culture and mana-gement of this prawn, from larval production, reproduction, pond maintenance, or even management of wild populations. For example, Moraes-Valenti et al. (2010) analyzed the density effect overgrowth, one of the key factors that need to be controlled when maintaining prawns in captivity. According to these authors, the size asymmetry or disparate growth increases as density increases. Therefore, high densities should not be recommended if stock of regular sizes is wanted.

Araujo & Valenti (2007) studied feeding habits of larvae considering food acceptance of live and dry food and ingestion frequency. The authors stated that feeding *M. amazonicum* larvae with *Artemia* sp. before stage II or with an inert diet before stage IV is not recommended. It increases production costs and may impair water quality, but from stages IV to VI, feeding larvae with a combination of *Artemia* sp. and inert diet is required, whereas inert diet should be the main food item from stage VII onward. All these investigations make this species the best-studied freshwater prawn of Latin America. This knowledge could offer excellent guidance for cultivation or conservation programs of congeneric species, such as *M. americanum* and *M. tenellum*, even considering that they are different species with different requirements and status in the wild. Larval production is an urgent field to take care of, and perhaps the most critical topic to be resolved before their culture beyond experimental assays can be recommended. There is no available culture technique for larval rearing that puts wild populations as the only source of exploitation, either focused on fishing marketable sizes or juveniles gathering for pond stocking. Additional studies on the larval phase are needed because the culture beyond experimental assays requires well-developed larval production techniques to provide culture units with a quality stock of juveniles. The production of juveniles for stocking in areas where they are disappeared should be considered part of a management and conservation program.

The chances of successfully handling freshwater prawns in captivity are based on numerous previous studies not only with *M. amazonicum* but also on the few investigations with both species reviewed in the present study. These studies revealed that juveniles and adults are preferably carnivores and scavengers, but in captivity, they accept all kinds of food with some animal protein so they can be easily fed with commercial pellets. Larvae, however, need more special food and water quality characteristics, which are harder to control.

Other guidelines could be obtained by following existing ideas or techniques already developed for the Malaysian *M. rosenbergii* prawn for which cultivation techniques, introduced in the early 60s, have allowed an industry, which does not rely on fisheries (New 2009). As suggested by this author, this scheme would be recommended in warm areas of the planet where they incur no heating costs, which results in lower operating costs. As occurring in Asia with this species, the culture of native freshwater prawns could provide economic activity and help conservation programs of native prawns. Market considerations are also important when choosing a species to be cultured, in addition to technical and biological issues (Ross & Beveridge 1995). In agreement with these latter authors, it would be useless to develop the culture of a species with no market or with a low price. Low market values mean that only simple aquaculture techniques should be considered. Future research might answer if this is the case of *M. americanum* and *M. tenellum*.

The study of these two species could also be justified for conservation purposes, like recovering key ecological species that are disappearing. In this sense, better management practices for these prawns in the wild are also necessary because there is no reliable information on native prawn fisheries, and available reports are not accurate. This lack of information is because fisheries are uncontrolled, unorganized, or not monitored by authorities. In Mexico, reports on fishing of these prawns are not available, are incomplete, or the same species is recognized under different names or categories depending on the location. With no adequate information, only assumptions can be made about the status of every population of these species in the wild based on what occurs with other fisheries. It is expected that any overfished population will eventually collapse if no conservation measures are taken (Pauly et al. 2002).

The populations of *M. americanum* in Mexico seem to be disappearing, and those of *M. tenellum* is still common but less abundant than in past decades. Given the similarities in the social and cultural context of the other Latin American countries, this situation might occur across the continent. Also, in North America, populations of *Macrobrachium* species of the Mississippi River (USA), which are strongly subjected to fishing and exposed to pollution, decreased dramatically during the 20th century; while the populations of the same species in areas with little or no exploitation remained relatively stable (Bowles et al. 2000). The same authors also report the disappearance of *M. carcinus* in rivers of Texas (USA) after more than a century of overfishing. Proper management of any of these species should include developing techniques that allow their culture and promote the conservation of wild populations, which can only be reached by research initiatives covering the current knowledge gaps.

Research gaps for both species seem to be:

- The difficulty of raising larvae due to unknown feeding requirements of larval stages and water quality issues.
- No updated status of their populations in rivers and coastal lagoons.
- Lack of practical management programs.
- Lack of information about the effects of pollutants, such as agricultural insecticides and herbicides, heavy metals, soap, and other compounds, dumped into rivers by human activities.
- Little or no information on the impact of the reduction or loss of water flow in rivers and streams in which prawns live and move.
- Insufficient attempts to establish management and cultivation techniques.
- Insufficient knowledge about the impact of the deterioration of estuaries and mangrove habitats used as temporary or permanent habitats or nurseries.
- Limited research on the effect of accidental or deliberate release of exotic species of other crustaceans, such as the Australian crayfish *Cherax quadricarinatus*, can displace native species or even prey on them.

Slow-growing, easily stressed animals or those difficult to reproduce or feed in captivity are hardly good options for culture to generate economic profits. However, investigations on such species should be carried out for their native population's conservation in the wild those species are threatened. Of prime importance are temperature, oxygen level, and salinity on survival and growth because these are the major determinants of metabolism. Tolerance to crowding, handling, and feeding are mandatory fields as well. Important research areas are environmental physiology, nutrition, behavior, and larval rearing. The culture of native animals can modify their behavior, producing difficulties in the interactions among prawns, like competition or mating. It is necessary to determine their water quality requirements in captivity and feed them with proper diets to ensure rapid growth. Also, it is necessary to perform genetic studies that allow selecting docile and fast-growing specimens for culture purposes. Hybridization with other species of *Macrobrachium* and the study of their social structure (e.g. the role of dominant males) and other behavioral studies are open to the scientific fields. New (2005) stated that socio-economic and environmental research is also required for sustainable aquaculture and suitable harvesting, handling, and processing techniques of the product.

Studies whose purpose is to determine the culture potential of these species should consider the assumptions proposed by New (2009) for *Macrobrachium* prawns, who highlighted the following advantages and disadvantages:

Advantages:

1. It can be produced in inland facilities.
2. Females produce large numbers of eggs, and both mating and embryonic development can be achieved easily in the laboratory.
3. Pond culture is relatively easy at small and medium scales.
4. Prawns are suitable for polyculture, primarily with fish.
5. Better priced in the market in comparison with fish.

Disadvantages:

1. Given the aggressive nature of some species, the intensive culture is hard or with few success possibilities, at least according to current technologies.
2. Small larvae that are not easy to feed and have a long larval development with many stages.
3. The harvested product requires extreme care and fast output to stay cool.
4. In some regions, fishing is still cheaper, and prawns are easier to obtain from fishers.

Current knowledge for both species does not provide sufficient information about their true potential to be cultivated or propose management procedures for wild populations. Even so, aquaculture of local species by local people with limited resources seems to fit as a good model in this case, as recommended by the Food and Agriculture Organization of the United Nations (FAO). Research must be established to balance different areas of interest, such as economic, social, and ecological. Production of *M. tenellum* or *M. americanum* in Latin America with the same methodology used for *M. rosenbergii* in countries like China or India may not be possible. American *Macrobrachium* prawns have different biological attributes and limitations, and countries in Latin American, such as Mexico, have different economic, cultural, social, and environmental issues compared to Asian countries.

As proposed by Ross & Belveridge (1995) and Ross et al. (2008), a reliable goal might be related to the development of sustainable techniques for larval production and pond stocking at small-scale farms, aiming to balance the pressure that fisheries exert on wild populations and to provide additional income to farmers or fishers interested in the production of these prawns. However, the preservation of wild populations and their habitats must always be a priority.

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REFERENCES

Aguilar, M. 1995. Effect of the salinity on the respiratory metabolism, nitrogen excretion and osmoregulation in *Macrobrachium tenellum* of Mulege, Baja California Sur, Mexico. Master Thesis, Centro de Investigaciones Científicas de Ensenada, Ensenada.

Aguilar, M., Diaz, F. & Buckle, F. 1998. The effect of salinity on oxygen consumption and osmoregulation of *Macrobrachium tenellum*. Marine and Freshwater Behavior and Physiology, 31: 105-113.

Albertoni, E., Palma-Silva, C. & Esteves, F. 2003. Natural diet of three species of shrimp in a tropical coastal lagoon. Brazilian Archives of Biology and Technology, 46: 395-403.

Arana-Magallón, F. 1974. Experiencias sobre el cultivo del langostino *Macrobrachium americanum* Bate, en el noroeste de México. Simposio FAO/CARPAS sobre Acuicultura en América Latina, Montevideo, Uruguay.

Arana-Magallón, F. & Ortega, A. 2004. Rearing of the cauque prawn under laboratory conditions. North American Journal of Aquaculture, 66: 158-161.

Araujo, M. & Valenti, W. 2007. Feeding habit of the Amazon River prawn *Macrobrachium amazonicum* larvae. Aquaculture, 265: 187-193.

Araujo, M. & Valenti, W. 2011. Efeito da intensidade luminosa no desenvolvimento larval do camarão-da-amazônia, *Macrobrachium amazonicum*. Boletim do Instituto de Pesca, 37: 155-164.

Aréchiga-Palomera, M.A., Del Rio Zaragoza, O.B., Guerrero-Galván, S.R. & Vega-Villasante, F. 2016. Evaluation of natural extracts with anesthetic properties in juveniles *Macrobrachium tenellum*. Pan American Journal of Aquatic Sciences, 11: 251-257.

Aréchiga-Palomera, M.A., Montoya, C.E., Mendoza-González, A. & Vega-Villasante, F. 2018. Background color effect on the pigmentation of prawn *Macrobrachium tenellum*. Latin American Journal of Aquatic Research, 46: 610-614.

Arruda-Hayd, L., Lemos, D. & Valenti, W. 2010. Ontogenetic variation in ammonia excretion during the early life stages of the Amazon River prawn, *Macrobrachium amazonicum*. Journal of the World Aquaculture Society, 41: 107-115.

Bauer, R. 2011. Amphidromy and migrations of freshwater shrimps. II. Delivery of hatching larvae to the sea, return of juvenile upstream migration, and human impacts. New Frontiers on Crustacean Biology, 157: 168-188.

Bauer, R., 2013. Amphidromy in shrimps: a life cycle between rivers and the sea. Latin American Journal of Aquatic Research, 41: 633-650.

Benítez-Mandujano, B., Ponce-Palafox, J., López-Uriostegui, F., González-Cortes, N. & Arias-Rodríguez, L. 2014. Crecimiento en machos y hembras del langostino *Macrobrachium tenellum* en estanques rústicos en el estado de Nayarit, México. Investigaciones en Ciencias Biológicas (Biotecnología, Alimentos, Acuacultura y Recursos Naturales), 1: 254-264.

Bowles, D., Aziz, K. & Knight, C. 2000. *Macrobrachium* (Decapoda: Caridea: Palaemonidae) in the contiguous United States: A review of the species and assessing threats to their survival. Journal of Crustacean Biology, 20: 158-171.

Chong-Carrillo, O., Vega-Villasante, F., Arencibia-Jorge, R., Akintola, S.L., Michán-Aguirre, L. & Cupul-Magaña, F.G. 2015. Research on the river shrimps of the genus *Macrobrachium* (Bate, 1868) (Decapoda: Caridea: Palaemonidae) with economic importance: strengths and weaknesses shown through scientometrics. Latin American Journal of Aquatic Research, 43: 684-690.

Chong-Carrillo, O., Vega-Villasante, F., Maciel, C., Álvarez-González, C.A., Michán-Aguirre, L. & Arencibia-Jorge, R. 2018. Scientometrics of the genus *Macrobrachium* by using the regional database PERIÓDICA. Latin American Journal of Aquatic Research, 46: 581-588.

Cuevas-Félix, M. 1980. Tasas respiratorias del langostino *Macrobrachium tenellum* (Smith). Tesis de Licenciatura en Biología, Universidad Nacional Autónoma de México, Ciudad de Mexico.

De Grave, S., Cai, Y. & Anker, A. 2008. Global diversity of shrimps (Crustacea: Decapoda: Caridea) in freshwater. Hydrobiologia, 595: 287-293.

De los Santos-Romero, R., García-Guerrero, M., Vega-Villasante, H. & Nolasco-Soria, H. 2017a. Effect of dietary chitin on digestive enzyme activity, growth, and survival of *Macrobrachium tenellum* juvenile prawns. Latin American Journal of Aquatic Research, 45: 130-138.

De los Santos-Romero, R., García-Guerrero, M., Alpuche, J. & Cortes-Jacinto, E. 2018. The effect of alpha males and shelter type on growth and survival of the longarm prawn *Macrobrachium tenellum* (Smith, 1871). Latin American Journal of Aquatic Research, 46: 551-557.

De los Santos-Romero, R., García-Guerrero, M., Vega-Villasante, F., Cortés-Jacinto, E. & Nolasco-Soria, H. 2017b. Effect of photoperiod and temperature on growth and activity of digestive enzymes in juveniles of the longarm river shrimp *Macrobrachium tenellum* (Smith, 1871) (Caridea: Palaemonidae). Journal of Crustacean Biology, 45: 130-138.

Espinosa-Chaurand, L., Vargas-Ceballos, M., Guzmán-Arroyo, M., Nolasco-Soria, H., Carrillo-Farnés, O., Chong-Carrillo, O. & Vega-Villasante, F. 2011. Biología y cultivo de *Macrobrachium tenellum*: estado del arte. Hidrobiológica, 21: 99-117.

Food and Agriculture Organization (FAO). 2020. The state of world fisheries and aquaculture 2020. Sustainability in action. FAO, Rome.

Figueroa, L.G., Hernández, R.M. & Gutiérrez, L.M. 2012. Acute toxicity of ammonia on *Macrobrachium tenellum* (Smith) larvae. Revista Internacional de Contaminación Ambiental, 28: 145-150.

García-Guerrero, M. 2009. Proximate biochemical variations in eggs of the prawn *Macrobrachium americanum* (Bate, 1869) during its embryonic development. Aquaculture Research, 40: 575-581.

García-Guerrero, M. 2010. Effect of temperature on the consumption rate of main yolk components during the embryo development of the prawn *Macrobrachium americanum* (Crustacea: Decapoda: Palaemonidae). Journal of the World Aquaculture Society, 41: 84-92.

García-Guerrero, M. & Apun-Molina, J.P. 2008. Density and shelter influence the adaptation to wild juvenile cauque prawns *Macrobrachium americanum* to culture conditions. North American Journal of Aquaculture, 70: 343-346.

García-Guerrero, M. & Hendrickx, M. 2009. External description of the embryonic development of the prawn *Macrobrachium americanum* based on the staging method. Crustaceana, 82: 1413-1422.

García-Guerrero, M., Orduña Rojas, J. & Cortes Jacinto, E. 2011. Oxygen consumption of the prawn *Macrobrachium americanum* (Bate 1868) over the temperature range of its native environment and in relation to its weight. North American Journal of Aquaculture, 73: 320-326.

García-Guerrero, M., Becerril-Morales, F., Vega-Villasante, F. & Espinosa-Chuarand, L. 2013. Los langostinos del género *Macrobrachium* con importancia económica y pesquera en América Latina: conocimiento actual, rol ecológico y conservación. Latin American Journal of Aquatic Research, 41: 651-675.

García-Ulloa, M., Rodríguez, H. & Ogura, T. 2004. Calidad del huevecillo de dos especies de langostino (Palemonidae) del género *Macrobrachium* (*M. rosenbergii*, De Man 1879 y *M. tenellum*, Smith, 1871) variando la dieta de los reproductores: índices morfométricos. Avances en Investigación Agropecuaria, 8: 1-8.

García-Ulloa, Gomez, M., López-Aceves, L.A., Ponce-Palafox, J.T., Rodríguez-González, H. & Arredondo-Figueroa, J.L. 2008. Growth of fresh-water prawn *Macrobrachium tenellum* (Smith, 1871) juveniles fed isoproteic diets substituting fish meal by soya bean meal. Brazilian Archives of Biology and Technology, 51: 57-65.

Garduño, D., Pérez, P., Lorán, R. & Martínez, R. 2017. Growth and mortality of *Macrobrachium tenellum* (Decapoda: Palaemonidae) in the San Pedro Mezquital River, Nayarit, Mexico. Hidrobiológica, 27: 359-367.

Guzmán, A.M. 1975. Biología, ecología y pesca del chacal *Macrobrachium tenellum* en lagunas costeras del Estado de Guerrero. Informe Técnico I. Centro de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Ciudad de Mexico.

Guzmán, A.M. 1976. Biología, ecología y pesca del chacal *Macrobrachium tenellum* en lagunas costeras del Estado de Guerrero. Informe Técnico II. Centro de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Ciudad de Mexico.

Guzmán, A.M. 1977. Biología, ecología y pesca del chacal *Macrobrachium tenellum* en lagunas costeras del Estado de Guerrero. Informe Técnico III. Centro de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México, Ciudad de Mexico.

Guzmán, A.M. 1987. Biología, ecología y pesca del langostino *Macrobrachium tenellum* (Smith, 1871) en lagunas costeras del estado de Guerrero, México. Tesis de Doctorado en Ciencias del Mar (Oceanografía Biológica y Pesquera), Universidad Nacional Autónoma de México, Ciudad de México.

Guzmán, A.M. & Román, R. 1983. Parasitismo de *Probopyrus pandalicola* (Isopoda, Bopyridae) sobre el langostino *Macrobrachium tenellum* en la costa pacífica de Guerrero y Michoacán, México. In: Arana, P.M. (Ed.). International Conference on Marine Resources of the Pacific, 16-20 May 1983, Viña del Mar, Chile, pp. 345-357.

Guzmán, A.M., Cabrera, J. & Kensler, C. 1977. Notes on *Macrobrachium* species in México. In: Hanson, J.A. & Goodwin, H.L. (Eds.). Shrimp and prawn farming in the western hemisphere. Dowden Hatchinson & Ross, Pennsylvania, pp. 315-316.

Guzmán, A.M., Kensler, C. & Granados, B. 1978. Los langostinos del género *Macrobrachium* en México y sus posibilidades de cultivo. II Simposio de la Asociación Latinoamericana de Acuicultura, 13-17 Nov 1978, Ciudad de Mexico, Mexico, pp. 28-31.

Guzmán, A.M., Rojas, G. & González, D. 1981. Ciclo anual de maduración y reproducción del chacal *Macrobrachium tenellum* y su relación con factores ambientales en las lagunas costeras de Mitla y Tres Palos, Guerrero, México (Decapoda: Palaemonidae). Anales del Instituto de Ciencias del Mar y Limnología, 9: 67-80.

Hendrickx, M.E. 1992. Guía de campo de las especies comerciales marinas y de aguas salobres de la costa septentrional de Sur América. In: Cervigón, F., Cipriani, R., Fischer, W. & Garibaldi, L. (Eds.). Fichas FAO de identificación de especies para los fines de la pesca. FAO, Rome.

Hernández, M. & Bückle, F. 1997. Thermal preference area for *Macrobrachium tenellum* in the context of global climatic change. Journal of Thermal Biology, 22: 309-313.

Hernández, M., Bückle, F. & Díaz-Herrera, F. 1995. Preferred temperature of *Macrobrachium tenellum* (Crustacea, Palaemonidae). Rivista Italiana di Acquacoltura, 30: 93-96.

Hernández, L., Murugan, G., Ruiz, G. & Maeda, A. 2007. Freshwater shrimps of the genus *Macrobrachium* (Decapoda Paleamonidae) from the Baja California Peninsula, Mexico. Journal of Crustacean Biology, 27: 351-369.

Hernández-Sandoval, P., Díaz-Herrera, F., Díaz, J., Martínez, C. & García-Guerrero, M. 2018a. Effect of temperature on growth, survival, thermal behavior, and critical thermal maximum in the juveniles of *Macrobrachium occidentale* (Holthuis, 1950) (Decapoda: Caridea: Palaemonidae) from Mexico. Journal of Crustacean Biology, 38: 483-488.

Hernández-Sandoval, P., Díaz-Herrera, F., Re-Araujo, D., López-Sánchez A., Martínez, A., García-Guerrero, M. & Rosas, C. 2018b. Thermal preference, critical thermal limits, oxygen routine consumption and active metabolic scope of *Macrobrachium tenellum* (Smith, 1871) maintained at different acclimation temperatures. Latin American Journal of Aquatic Research, 46: 558-569.

Holthuis, L.B. 1952. The Decapoda of the Siboga Expedition. Part XI. The Palaemonidae collected by the Siboga and Snellius expeditions with remarks on other species II. Subfamily Pontoniinae. Siboga Expeditie 39a10: 1-253.

Ling, S. 1962. The general biology and development of *Macrobrachium rosenbergii* (De Man). FAO Fisheries Reports, 57: 3-17.

López-Uriostegui, F., Ponce-Palafox, J. & Arredondo, J. 2014. Effect of stocking density on growth and survival of the prawn *Macrobrachium tenellum* cultured in a cage-pond system. North American Journal of Aquaculture, 76: 164-169.

López-Uriostegui, F., Ponce-Palafox, J., Lango, F., Castañeda, M., Arenas, V. & Vega-Villasante, F. 2017. Stomach repletion rhythms of the caridean shrimps, *Macrobrachium americanum* and *M. tenellum* (Crustacea: Decapoda) in a caged-pond system. Pakistan Journal of Zoology, 49: 973-977.

López-Uriostegui, J., Ponce-Palafox, J., Benítez-Mandujano, J., Benítez-Valle, A., Gómez-Gurrola, J., García-Ulloa, M., et al. 2013. Crecimiento del camarón de río cauque (*Macrobrachium americanum*) a diferentes tamaños de siembra en jaulas. Industria Acuícola, 9: 10-12.

López-Uriostegui, F., Ponce-Palafox, J., Lango, F., Castañeda, I., Galaviz-Villa, S., Castillo-Vargas, S. & Ruiz-Luna, A. 2020. A response-surface analysis of temperature-salinity on growth and survival of the caridean shrimp *Macrobrachium americanum* (Bate, 1868). Pakistan Journal of Zoology, 52: 1903-1909.

Maciel, C. & Valenti, W. 2009. Biology, fisheries, and aquaculture of the Amazon River prawn *Macrobrachium amazonicum*: a review. Nauplius, 17: 61-79.

Maciel, C. & Valenti, W. 2014. Effect of tank color on larval performance of the Amazon River prawn *Macrobrachium amazonicum.* Aquaculture Research, 45: 1041-1050.

McDowall, R.M. 2007. On amphidromy, a distinct form of diadromy in aquatic organisms. Fish and Fisheries, 8: 1-13.

Méndez-Martínez, Y., García-Guerrero, M., Arcos-Ortega, F., Martínez-Córdova, L., Yamasaki, S., Pérez-Rodríguez, J. & Cortés-Jacinto, E. 2018b. Effect of different ratios of dietary protein-energy on growth, body proximal composition, digestive enzyme activity, and hepatopancreas histology in *Macrobrachium americanum* (Bate, 1868) prawn juveniles. Aquaculture, 485: 1-11.

Méndez-Martínez, Y., García-Guerrero, M., Lora-Vilchis, C., Martínez-Córdova, L., Arcos-Ortega, F., Alpuche, J. & Cortés-Jacinto, E. 2018a. Nutritional effect of *Artemia* nauplii enriched with *Tetraselmis suecica* and *Chaetoceros calcitrans* microalgae on growth and survival on the river prawn *Macrobrachium americanum* larvae. Aquaculture International, 26: 1001-1015.

Méndez-Martínez, Y., Yamasaki, S., Cortés-Jacinto, E., García-Guerrero, M., Martínez-Córdova, L., Rivas-Vega, M. & Arcos-Ortega, F. 2017. Effect of dietary protein content on growth rate, survival, and body composition of juvenile cauque river prawn, *Macrobrachium americanum* (Bate 1968). Aquaculture Research, 48: 741-751.

Monaco, G. 1975. Laboratory rearing of larvae of the palaemonid shrimp *Macrobrachium americanum* (Bate). Aquaculture, 6: 369-375.

Montoya, C., Nolasco-Soria, H., Vega-Villasante, F., Carrillo-Farnés, O., Álvarez-González, A. & Civera-Cerecedo, R. 2018a. *In vitro* protein digestibility of animal, vegetal and microbial feed ingredients for *Macrobrachium tenellum*. Latin American Journal of Aquatic Research, 46: 495-501.

Montoya, C., Nolasco-Soria, H., Vega-Villasante, F., Carrillo-Farnés, O., Álvarez-González, A. & Civera-Cerecedo, R. 2018c. Attractability and palatability of ingredients in longarm river prawn *Macrobrachium tenellum* feed. Latin American Journal of Aquatic Research, 46: 615-620.

Montoya, C., Carrillo-Pérez, C., Nolasco-Soria, H., Álvarez-González, A., Carrillo-Farnés, O., Civera-Cerecedo, R. & Vega-Villasante, F. 2018b. Evaluation of different maze systems for the determination of feed attractability for longarm river prawn *Macrobrachium tenellum*. Latin American Journal of Aquatic Research, 46: 604-609.

Moraes-Valenti, P. & Valenti, W. 2007. Effect of intensification on grow out of the Amazon River Prawn, *Macrobrachium amazonicum*. Journal of the World Aquaculture Society, 38: 519-526.

Moraes-Valenti, P., Atique de Morais, P., De Lima-Preto, B. & Valenti, W. 2010. Effect of density on population development in the Amazon River prawn *Macrobrachium amazonicum.* Aquatic Biology, 9: 291-301.

Murphy, N. & Austin, C. 2005. Phylogenetic relationships of the globally distributed freshwater prawn genus *Macrobrachium* (Crustacea: Decapoda: Palaemonidae): biogeography, taxonomy, and the convergent evolution of abbreviated larval development. Zoologica Scripta, 34: 187-197.

Navarro-Hurtado, A. 2002. Cultivo de (*Ictalurus punctatus*) tilapia hibrida (*Oreochromis niloticus vs.*

Oreochromis mossambicus) y langostino (*Macrobrachium tenellum*), en estanques semirústicos. Tesis de Maestría, Universidad de Colima, Colima.

New, M. 2005. Freshwater prawn farming: global status, recent research and a glance at the future. Aquaculture Research, 36: 210-230.

New, M. 2009. History and global status of freshwater prawn farming In: New, M.B., Valenti, W.C., Tidwell, J.H., D'Abramo, L.R. & Kutty, M.N. (Eds.). Freshwater prawns: biology and farming. Wiley-Blackwell, Oxford.

Ocaña-Luna, A., Martínez-Guzmán, L. & Sánchez-Ramírez, R. 2009. Nuevo registro del parásito *Probopyrus pacificensis* (Isopoda: Bopyridae) en el sur de Nayarit y norte de Jalisco, México. Revista Mexicana de Biodiversidad, 80: 259-261.

Parra-Flores, A., Ponce-Palafox, J., Barreto-Altamirano, A., Spanopoulos, M., Castillo, M., Gaxiola, G., et al. 2020. *In vivo* and *in vitro* protein digestibility and growth performance of animal and no-conventional plant ingredients for river prawn *Macrobrachium americanum* (Caridea: Palaemonidae). Aquaculture Research, 51: 3652-3663.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T., Sumaila, R., Walters, C., et al. 2002. Towards sustainability in world fisheries. Nature, 418: 689-695.

Peña-Herrejón, G., Sánchez-Velázquez, J., García-Trejo, J., Soto-Zarazúa, M. & Rico-García, G. 2019. Effect of stocking density on growth and survival of the prawn *Macrobrachium tenellum*, cultured in a recirculating aquaculture system. Latin American Journal of Aquatic Research, 47: 342-348.

Pérez-Rodríguez, J., Yamasaki, S., García-Guerrero, M., Martínez-Porchas, M., Méndez-Martínez, Y., Latournerié-Cervera, J. & Cortés-Jacinto, E. 2018. Growth and survival of juvenile cauque river prawn *Macrobrachium americanum* fed with diets containing different protein levels. Latin American Journal of Aquatic Research, 46: 534-542.

Pileggi, L.G. & Mantelatto, F.L. 2010. Molecular phylogeny of the freshwater prawn genus *Macrobrachium* (Decapoda, Palaemonidae) with emphasis on the relationships among selected American species. Invertebrate Systematics, 24: 194-208.

Ponce-Palafox, J., Arana-Magallón, F., Cabanillas-Beltrán, H. & Esparza-Leal, H. 2002. Bases biológicas y técnicas para el cultivo de los camarones de agua dulce nativos del Pacífico Americano *Macrobrachium tenellum* (Smith, 1871) y *Macrobrachium americanum* (Bate, 1968). Memorias del Congreso Iberoamericano Virtual de Acuicultura 2002, pp. 534-546.

Ponce Palafox, J., González Salas, R., Romero Cruz, O., Toussaint, I., Arredondo, J., Esparza-Leal, H., & García-Ulloa, M. 2005. Enfermedades del camarón de agua dulce *Macrobrachium tenellum* y *M. rosenbergii* durante el cultivo comercial en estanques rústicos en empresas rurales. Revista Electrónica de Veterinaria, 6: 1-12.

Ponce-Palafox, J., López-Uriostegui, F., Lango, F., Castañeda, M., Galaviz, I., Montoya, J. & Esparza-Leal, H. 2018. Influence of density on growth and survival of freshwater prawn *Macrobrachium americanum* (Bate, 1868) (Caridea: Palaemonidae) cultured in a cage-pond system. Spanish Journal of Agricultural Research, 16: 125-131.

Preto, J.M., Kimpara, P., Moraes-Valenti, P. & Valenti, W. 2010 Population structure of pond-raised *Macrobrachium amazonicum* with different stocking and harvesting strategies. Aquaculture, 307: 206-211.

Preto, B., Kimpara, J., Moraes-Valenti, P., Rosa, F. & Valenti, W. 2011. Production strategies for short term grow-out of the Amazon River prawn *Macrobrachium amazonicum* (Heller 1862) in ponds. Pan-American Journal of Aquatic Sciences, 6: 1-8.

Rodd, H. & Reznick, D. 1991. Life history evolution in guppies. III. The impact of prawn predation on guppy life histories. Oikos, 62: 113-119.

Rodríguez-Flores, R., Morfin, M., Espinosa-Chaurand, L., Basto, M. & Vega-Villasante, F. 2012. Optimum temperature and thermal preference of the river shrimp *Macrobrachium tenellum* in the tropical coast of the Mexican Pacific. Boletim do Instituto de Pesca São Paulo, 38: 121-130.

Román-Contreras, R. 1991. Ecología de *Macrobrachium tenellum* (Decapoda: Palaemonidae) en la laguna Coyuca, Guerrero, Pacífico de México. Anales del Instituto de Ciencias del Mar y Limnología, 18: 87-96.

Ross, L.G. & Beveridge, M. 1995. Is a better strategy necessary for development of native species for aquaculture? A Mexican case study. Aquaculture Research, 26: 539-547.

Ross, L.G., Martinez-Palacios, C.A. & Morales, E.J. 2008. Developing native fish species for aquaculture: the interacting demands of biodiversity, sustainable aquaculture and livehoods. Aquaculture Research, 39: 675-683.

Ruiz-Santos, H. 1988. Estudio de edad y crecimiento del langostino *Macrobrachium tenellum* (Smith, 1871) en la laguna de Tres Palos, Gro. Tesis de Maestría, Universidad Nacional Autónoma de México, Ciudad de Mexico.

Ruiz, M., Peña, J. & López, Y. 1996. Morfometría, época reproductiva y talla comercial de *Macrobrachium americanum* (Crustacea: Palaemonidae) en Guanacaste, Costa Rica. Revista de Biología Tropical, 44: 127-132.

Sánchez-Granados, O. 2008. Adaptabilidad del camarón de rio nativo (*Macrobrachium tenellum*) en estanques de arcilla bajo un régimen natural/controlado y su influencia en su crecimiento y reproducción en el área de Chaguantique. Informe Técnico de Proyecto. REDISAL-Consejo Nacional de Ciencia y Tecnología de El Salvador, San Salvador.

Santamaría-Miranda, A., Rojo-Cebreros, H., Sainz-Hernández, J., Apún-Molina, J., García-Guerrero, M., García-Ulloa, M. & Ponce-Palafox, J. 2018. Effects of stocking densities in blood chemistry and biochemical body composition of Nile tilapia *Oreochromis niloticus* and the prawn *Macrobrachium americanum* in polyculture. Latin American Journal of Aquatic Research, 46: 512-517.

Signoret, P. & Brailovsky, D. 2002. Population study of *Macrobrachium tenellum* (Smith 1871) in Coyuca de Benítez Lagoon, Guerrero, Mexico. Modern Approaches to the Study of Crustacea, 25: 122-129.

Signoret, P. & Soto, E. 1997. Comportamiento osmoregulador de *Macrobrachium tenellum* y *Macrobrachium acanthurus* (Decapoda: Palaemonidae) en diferentes salinidades. Revista de Biología Tropical, 45: 221-226.

Soberanes, M., Méndez-Martínez, Y., García-Guerrero, M., Ascencio, F., Violante, J., García-Ibáñez, S. & Cortés-Jacinto, E. 2018. Superoxide dismutase activity in tissues of juvenile cauque river prawn (*Macrobrachium americanum* Bate, 1868) fed with different levels of protein and lipid. Latin American Journal of Aquatic Research, 46: 543-550.

Taylor, J.A. 1979. The foods and feeding habits of subadult *Crocodylus porosus* Schneider in northern Australia. Australian Wildlife Research, 6: 347-359.

Vega-Villasante, F., Martínez-López, E., Espinosa-Chaurand, L., Cortés-Lara, M. & Nolasco-Soria, H. 2011. Crecimiento y supervivencia del langostino (*Macrobrachium tenellum*) en cultivos experimentales de verano y otoño en la costa tropical del Pacífico mexicano. Tropical and Subtropical Agroecosystems, 14: 581-588.

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Vargas-Ceballos, M., Badillo-Zapata, D., Chong-Carrillo, O., Ponce-Palafox, J., Hernández-Hernández, L. & Vega-Villasante, F. 2020. Intake of different food sources in the first zoeae stages of *Macrobrachium tenellum* (Decapoda: Palaemonidae). Latin American Journal of Aquatic Research, 48: 1-6.

Vargas-Ceballos, M., López-Uriarte, E., García-Guerrero, M., Wehrtmann, I.S., Ríos-Jara, E. & Vega-Villasante, F. 2018b. Fecundity, egg volume and reproductive output of *Macrobrachium tenellum* (Crustacea: Palaemonidae) from the northern coast of Jalisco, Mexico. Latin American Journal of Aquatic Research, 46: 502-511.

Vargas-Ceballos, M., Vega-Villasante, F., García-Guerrero, M., Chong-Carrillo, O., Badillo-Zapata, D., López, U.E. & Wehrtmann, I.S. 2018a. Salinity effect on embryonic development and survival of the first zoeal stage of *Macrobrachium tenellum* (Smith, 1871) (Crustacea, Palaemonidae) Pan-American Journal of Aquatic Sciences, 13: 273-281.

Vargas-Ceballos, M., López-Uriarte, E., García-Guerrero, M., Vega-Villasante, F., Román-Contreras, R., Akintola, S., et al. 2016. Infestation of *Probopyrus pacificensis* (Isopoda: Bopyridae) in *Macrobrachium tenellum* (Caridea: Palaemonidae) in the Ameca River, Jalisco, Mexico: prevalence and effects on growth. Pan-American Journal of Aquatic Sciences, 11: 39-46.

Yamasaki, S., García-Guerrero, M., Vega-Villasante, F., Castellanos-León, F., Cavalli, R. & Cortés-Jacinto, E. 2013. Experimental culture of the river prawn *Macrobrachium americanum* larvae (Bate, 1868), with emphasis on the stocking density effect on survival. Latin American Journal of Aquatic Research, 41: 793-800.

Yamasaki, S., Ruiz-Fregozo, M., Vega-Villasante, F., Espinosa-Chaurand, L., Cortés-Jacinto, E. & García-Guerrero, M. 2012. Contributions to the biology of moulting and growth of the long arm river prawn *Macrobrachium tenellum* (Decapoda Palemonidae) in Mexico. Archives of Biological Sciences, 64: 651-658.