Review

North Atlantic white shrimp *Litopenaeus setiferus* (Decapoda: Penaeidae) as an aquaculture target species for farming: a review

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ABSTRACT. *Litopenaeus setiferus* has been described as an economically important native species ranging from the north Atlantic along the coast of the Gulf of Mexico to Florida. Its reproduction has been studied in captivity, as well as some aspects of its nutritional physiology, diseases and adaptation to various environments, including nurseries. In terms of growth, *L. setiferus* has been compared with *L. vannamei* for its performance in ponds. As a native species, *L. setiferus* benefits local fisheries and is also used as a bait shrimp for recreational activity. The present review covers background information and recent advances in research and development efforts to determine its potential both for aquaculture in ponds and intensive biofloc systems (BFT), as well as for the stocking of fishing grounds. The collective research advances for this species presented in this review could help to sustain various strategies, including highly intensive techniques, to rehabilitate *L. setiferus* in connection with potential institutes.

Keywords: *Litopenaeus setiferus*; native species; reproduction; larval rearing; farming; biofloc system; diseases

The northern white shrimp *Litopenaeus setiferus* (Linnaeus, 1767) is one of the species with the highest commercial value in the Atlantic, but the decline in its natural populations places this species in an ecologically sensitive situation, not only for production but also for conservation. *L. setiferus* is caught from North Carolina to Florida in the Gulf of Mexico. Both the United States and Mexico share the eastern coast from New Jersey to Florida and from Tamaulipas to Campeche. Its distribution is at approximately 2 to 90 m depth in muddy bottoms, with organic matter, sand and clay. Juveniles and adults can be found in estuarine areas (FAO, 1980).

Thus, *L. setiferus* is a euryhaline species, which can grow in various salinities either at sea or in low-salinity brackish water. In the coastal zone of the Gulf of Mexico, mangrove destruction has decreased areas essential to the first phases of its life cycle. Oil platforms

and thermoelectric plants, as well as tourism, are also sources of estuarine habitat alteration and loss of marine habitat as well. Ports, dredging, fuel exploration, oil spills and the introduction of exotic flora and fauna have contributed to the anthropogenic impacts of their natural populations. Such impacts have increased the effects of natural events (*e.g.*, red tides, hurricanes, tropical storms, upwellings and northern and southern winds, including El Niño, La Niña) and have contributed to the decline in fishery resources (Arenas-Fuentes & Jiménez-Badillo, 2004).

Over the last 10 years, exotic species, such as *Litopenaeus vannamei* (king prawn; Wakida-Kusunoki *et al.*, 2011) and *Penaeus monodon* (giant tiger prawn; Fuller *et al.*, 2014) were reported in the Gulf of Mexico, although both species present but not settled along the Mexican coast. The low frequency of specimens found in lagoons and coastal areas, during a monitoring pro-

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gram for artisanal and industrial fisheries, indicated an absence of well-established populations of giant tiger prawn or white shrimp. Specimens examined did not carry eggs; additional sampling and long-term monitoring are needed to assess the potential impact on native species (Wakida-Kusunoki *et al.*, 2013).

Given the current situation for natural populations of *L. setiferus*, aquaculture remains an option for conservation. Shrimp farms are widely based on domesticated exotic species from many regions and can enhance the sustainability of native species (Gaxiola *et al.*, 2008). Therefore, more studies are needed to elucidate methods to nurture and produce *L. setiferus.*

Shrimp fisheries

Historically, fishing in the Gulf of Mexico has been a substantial economic activity in this region. Commercial fishing also can indirectly generate jobs in processing and side services, which are common both in Mexican and U.S. waters, with many industries including *L. setiferus* (Gracia, 2004).

The life cycle of white shrimp starts on the continental shelf between 4 and 40 m depth (Williams, 1984), where fertilized eggs are derived from currents and 12 to 14 h later nauplii emerge and are sustained on its reserves. At between 12 to 15 days of age, planktonic larvae move to the coast in search of refuge areas in lagoons or estuaries until they reach the post-larvae stage (Pls), when they graze on submerged vegetation. In these nurseries, they spend 7-9 months before migrating back to the sea as adults (Renaud, 1986; Zein-Eldin & Renaud, 1986; Chow *et al.*, 1993; Misamore & Browdy, 1996; Rosas *et al.*, 1999, 2004). *L. setiferus* has been extensively studied as a potential resource for fisheries, as well as its relationship with populations, recruitment and overfishing (Gracia, 1991, 1996, 1999). Gracia & Soto (1990) described one nursery, a refuge and grazing zone for Pls and pre-adults, in Laguna de Términos (southern Gulf of Mexico).

Some studies on larvae in coastal lagoons have included an analysis of currents and migration of larvae at Carmen and Laguna Machona (Gierloff-Emdem, 1977; Flores-Coto *et al.*, 2010). Models and simulation programs have been developed (Diop *et al.*, 2007) to estimate significant relationships among the abundance of the initial life stages, temperature and salinity. At the same time, loss of wetlands and high discharge of rivers have been related to low abundance. Biological factors, such as the number of juveniles in early life stages, can be used to predict later abundance, with a similar relationship between late juveniles and adults caught per unit of effort.

Baker *et al.* (2014) presented a model to determine the effects of juvenile growth and mortality on natural populations and determined that modest changes could have a greater impact on the size of fishery stocks than mortality in previous decades. It was suggested that variability in juvenile survival could be a strong driver of adult population size. Processes that regulate growth and mortality need to be understood for effective management of coastal nurseries and stocks established in coastal lagoons regulate both parameters for juveniles (Minello & Zimmerman, 1991).

Ecology and behavior

Based on species for fisheries, Zimmerman & Minello (1984) and McTigue & Zimmerman (1991) studied their behavior and how it related to ecology in the entire ecosystem. Differences between responses of *Farfantepenaeus aztecus* and *L. setiferus* led to the conclusion that both species were omnivorous; however, differences in feeding were based on the degree of carnivory or herbivory. Such differences could reflect partitioning strategies and life histories linked to temporal food availability. *F. aztecus* gained the specialized advantage through being more carnivorous during the spring months when *L. setiferus* are absent. Conversely, it gained an advantage through herbivory during the summer months and fed on unimportant sites and resources, suggesting that vegetable debris may have limited value for shrimp, although this finding remains inconclusive.

The relationship between the abrasive material in the gut and the ability to digest debris needs to be studied. Beseres & Feller (2007) have shown that white shrimp are major consumers of macrobenthos, but they prefer live prey and decrease the abundance of macrobenthos through predation, both in experimental enclosures in the lab and the field. Therefore, predation takes precedence as a determinant in the seasonal cycle. White shrimp, being mobile, have densities that widely fluctuate both inter- and intra-annually; therefore, densities vary in both space and time.

Webb & Kneib (2004) measured weight gain and movement of *L. setiferus* in the tidal stream sub-system of the Duplin River, Sapelo Island, Georgia, over two years. A total of 15,974 juveniles (40-80 mm total length) were marked with an encoded microfiber and released into the shallow upper reaches of the four tidal streams and marshes. Such a habitat can achieve a balance between adequate habitat (space) at low tide, which increases residence time and the density of juveniles, thereby providing sufficient intertidal forage habitat and a predatory refuge at high tide to promote high weight gain and survival of juveniles. The study provided spatially explicit information on growth rates

and the degree of movement within nursery grounds, as well as the initial steps needed to meet the challenge of maintaining a quality nursery for sustainable shrimp fisheries, and meeting other demands associated with human development in watershed estuaries.

Reproduction

King (1948) described the general anatomy and histology of the reproductive organs of *L. setiferus* and the principles of gross developmental changes in organ size, as well as color related to histological and cytological changes. Thus, a field worker, without access to a microscopy lab, could more accurately determine and record the stage of development. Such methods provide a basis for shrimp observations on reproduction, and such details are now fully known. For example, a female could potentially spawn more than once during a single breeding season, although the occurrence of this was unknown. Later studies confirmed and documented this in detail with electron microscopy (Bauer & Cash, 1991; Chow *et al.*, 1991). The spermatophore structure inside the male ejaculatory duct was described just after ejaculation, thereby completing previous information (Ro *et al.*, 1990). The vas deferens work to obtain the supporting matrix, and they consolidate and orient the spermatozoid, as well as secrete some acellular components and store the developing spermatophore.

L. setiferus thelycum is open, and therefore, the fertilization of eggs is closely related to the proper transfer and adhesion of the spermatophore because the spermatozoa are transported and protected by the structure. The spermatophore is expelled from the terminal ampoule through the genital pore (Bauer & Cash, 1991). During the expulsion process, two halves are assembled outside the body, forming a complete spermatophore, and the structures facilitate anchoring to the surface of the female's thelycum (Ro *et al.*, 1990; Chow *et al.*, 1991). Castille & Lawrence (1989) evaluated *F. aztecus* and *L. setiferus* maturation using visual, histological and biochemical observations. Changes in carbohydrate, lipid and protein contents were described for the gonads and digestive glands of both males and females and the terminal portion of the male reproductive tract. Leung-Trujillo & Lawrence (1987) tested the effects of captivity on the sperm quality of *L. setiferus* from the Gulf of Mexico. No significant decline in quality or quantity of sperm occurred until the third week of captivity. The average life of sperm decreased to 20.7% during the 5th week in captivity. Bray *et al.* (1990) obtained females via hybridization of *L. setiferus* and *L. schmitii*. Their results are indicative of the phylogenetic relationships and genomic compatibility of these species. Misamore

& Browdy (1997) evaluated the potential for spontaneous hybridization between *L. setiferus* and *L. vannamei*. Prezygotic barriers to hybridization were evaluated by utilizing quantitative analysis of the behavioral interactions that are associated with mating, artificial insemination, and a novel *in vitro* fertilization technique for the two species that was achieved by an upwelling of a concentrated sperm suspension under a spawning female.

Misamore & Browdy (1996) observed the mating behavior of *L. setiferus* and *L. vannamei* and compared it with that of other species. Video analysis and visual observations indicated four sequential stages. During the chase stage, males closely followed the female, mirroring changes in the female's direction. In the probe stage, the male approaches the female ventrally and probes the region of the female with its antennae. The embrace stage is characterized by the inversion of the male and juxtaposition of its ventral surfaces with the female and the wrapping of its pereiopods around the female's shell. In the final stage, the flex stage, the male collapses its uropod, holds its abdomen slightly, and rotates perpendicular to the female's midline, forming a U-shape around the female. *L. vannamei* exhibited mating behavior similar to that of *L. setiferus*. However, the reduction in angle rotation and abdominal curvature during the flexion stage differed from that of *L. setiferus*. A generalized model of mating behavior within the *Litopenaeus* was proposed. This study provided a great deal of information; however, the breeding problem of the species has not yet been solved. However, there are major advances in research to find an appropriate model for captive maintenance.

Thus, from the first report of success in maturation and spawning of *L. setiferus* under lab conditions, the difficulty of males in transferring the spermatophore (Brown *et al.*, 1979) was associated with bacterial infections. Alfaro *et al.* (1993) found that the genital apparatus of a male *L. setiferus*, blackens, with detrimental effects on mating when animals are kept under controlled maturation/reproduction conditions. A progressive, melanized condition of the male reproductive tract was associated with a bacterial infection. It was suggested that a progressive syndrome involving bacterial invasion, perhaps only in advanced stages or having more than one etiology, may be involved in the deterioration and blackening of the male reproductive system.

Sandifer *et al.* (1984) tried to implement artificial insemination. They attempted manual expulsion of spermatophores until they found that shrimp with melanized terminal ampullae generally did not expel a spermatophore following electrical stimulation. Additionally, Rosas *et al.* (1993) found it necessary to look

for a better method of insemination without manipulation for *L. setiferus* because they do not regenerate quickly after electroejaculation.

Many studies have been conducted to elucidate the possible causes of the decrease in reproductive quality in males defined as a "degenerative syndrome of the male reproductive system", and characterized by a progressive decrease in the number of spermatozoa and an increase in the percentage of abnormal and dead cells (Chamberlain *et al.*, 1983; Talbot *et al.*, 1989). Melanization and low numbers of viable sperm cells have been common features in *L. setiferus* populations in the southern Gulf of Mexico (Pascual *et al.*, 1998). In the benthic community, where the population feeds (Rosas e*t al.*, 2004), structural changes as a result of environmental disturbances caused by marine pollution and deleterious effects of high temperatures affect reproductive quality. Some hypotheses include that genotoxic damage results from an accumulation of estuarine phase pollutants or that crossbreeding increases as a consequence of population reduction because of overfishing. Pascual *et al.* (2003b) found differences in sperm quality between populations at the extremes of the distribution range, which results in 20 times fewer spermatozoa for populations in the southern Gulf of Mexico than those in populations in the north Atlantic region. There is an inverse relationship between temperature and reproductive activity and sperm quality.

Laboratory results showed that there is a marked effect of temperature on sperm quality of adult male *L. setiferus*. Above 26°C, an increase in the proportion of abnormal cells was observed, indicating a reduction in the reproductive potential of the organisms. Although shrimps have a high metabolic capacity to tolerate differing experimental temperatures (Sánchez *et al.*, 2002), the effects on sperm quality showed that their reproductive system is much more sensitive than that of energy metabolism to temperature changes. The results showed that *L. setiferus* is a species sensitive to changes in temperature, and can be an indicator species of changes caused by global warming or the El Niño phenomenon in this region of the Gulf of Mexico (Rosas *et al.*, 2004).

Goimier *et al.* (2006) evaluated the effects of dietary protein levels on blood indicators of protein metabolism and immune condition (blood protein, hemocyanin, osmotic pressure and hemocyte concentrations), and reproductive capacity of preadult *L. setiferus* males (F^0). Their results indicated that an immune reaction could occur in response to dietary protein, with excess dietary protein (DP) affecting several physiological functions, including sperm synthesis and quality. The hemocyte concentration in shrimp fed excess protein

could activate an attack on sperm cells in the vas deferens, thus, provoking a loss of sperm quality. The results indicated that an optimal DP of 45% could maintain a broodstock bank of *L. setiferus*, and favor placing it in a medium with abundant protein sources of microbial origin, as in the case of intensive biofloc systems (BFT). In doing so, a better immunological condition could be stimulated, which would generate better growth and reproductive capacity.

Physiology and nutrition

Bottino *et al.* (1980) analyzed fatty acids (FA) of three species of shrimp from the Gulf of Mexico, white (*L. setiferus*), brown (*F. aztecus*) and pink (*F. duorarum*), periodically for one year. There were variations in FA levels compared to water temperature and a lag period of one month between a change in temperature and a corresponding change in FA composition. This slow change in shrimp FA suggests that the change occurs through the food chain and not through an endogenous adjustment. These experiments indicate that diet exerts a strong influence on body lipid composition, and in contrast, an endogenous synthesis or modification occurs to a lesser degree. Lee & Lawrence (1985) investigated the relationships between protein level, size, apparent digestibility, digestive enzyme activities and *L. setiferus* growth. They found higher digestive enzyme activities with a diet having 22% protein and concluded this might be evidence of an adaptation to a diet that contains fewer digestible proteins.

McTigue & Feller (1989) measured the weight of gut content (GC) relative to body weight (BW) to determine whether bowel fullness remained constant overtime, or the variations were correlated with the variation in light and tides. *L. setiferus* juveniles did not exhibit any clear temporal trend in the increase or decrease intestinal content relative to BW, although the maximum content was observed in the morning. Factors responsible for the timing of the maximum are unknown but may be associated with activity level between night and day.

Rosas *et al.* (1995) determined the role of digestive gland (DG) in the respiratory metabolism of *L. setiferus* adult males as a step toward proposing a feeding scheme based on the DG activity cycle. The metabolic activity of DG was high 6 h after feeding, and this could indicate that assimilation started 2 h after food intake, peaking 6 h after feeding. Eight hours after feeding, the rate of O_2 of DG decreased and fell to values similar to those recorded for animals subjected to 72 h of fasting. In other words, there was a high correlation between the rate of O_2 and glucose concentration in the hemolymph, and between the rate of O_2 in DG and glycogen concentration in DG after feeding. Gallardo *et al.*

(1995) presented a basic scheme for *L. setiferus* larvae based on diatoms (*Chaetoceros ceratosporum*), flagellates (*Tetraselmis chuii*) and *Artemia* nauplii.

These authors concluded that an increase in algae concentration and *Artemia* indicates a pattern of development of the digestive system associated with larvae development. Such a pattern is considered to improve larvae production under controlled conditions. García *et al.* (1998) studied the dietary protein (DP) requirements of *L. setiferus* and *F. duorarum* postlarvae (Pls) through growth, survival and yield to conclude at 50% crude protein (CP), despite evidence provided by studies on the dietary habits of these two species that recorded differences in the animal/vegetable ratio of the diet with growth. Guzmán *et al.* (2001) investigated the effects of protein and energy content on digestive enzyme activity, and the growth and survival of *L. setiferus* Pls under controlled conditions. Dietary carbohydrates (cbh) cannot spare protein because the growth rate obtained by *L. setiferus* fed diets containing 200-300 g kg^{-1} protein was low ($P < 0.05$).

Renaud (1986), Martínez *et al.* (1998) and Rosas *et al.* (1998, 1999) stated that dissolved oxygen (DO), unlike temperature, is an environmental regulator of shrimp metabolism. Its direct intervention provides a regulatory role in the ability to obtain energy respired through oxidative phosphorylation. A relatively small reduction in DO, 1 mg L^{-1}, caused a reduction of up to 25% in energy channeled into biomass. Therefore, it is possible to infer that an abundance of *L. setiferus* in the tropical coastal environment, along with DO level, could be of great help to determine the health of the ecosystem.

Alcaraz *et al.* (1999a,b) measured the combined effect of ammonium, nitrite and DO on Pls consumption and reported that *L. setiferus* was more sensitive than *P. monodon* to the same pollutant. Taboada *et al.* (1998) assayed the effects of protein level on the growth rate, survival, pre- and postprandial O$_2$ uptake, and ammonia excretion of *L. setiferus* juveniles. The protein appeared to be an energy substrate when in the feed (50% crude protein [CP]) or lipid (30% CP). Under these conditions, *L. setiferus* achieved the highest weight gain with a 30% protein diet, whereas prawns used food more efficiently (Rosas *et al.*, 1996).

Brito *et al.* (2000) studied growth rate, soluble protein content, O$_2$, ammonia excretion and digestive enzymatic activity in *L. setiferus* Pls with four feeding regimes, including combinations of *Artemia* nauplii (AN) new hatch, microparticulate commercial feed, and microalgae. Partial replacement of AN by an artificial diet, with or without the addition of algae for the initial Pls stage benefited growth and nutritional status of *L. setiferus* Pls. Gallardo *et al.* (2002) studied the adequate level of replacement of AN and microalgae by a microparticulate diet for *L. setiferus* larvae. In the absence of algae, the replacement of AN resulted in slow development with lower resistance to salinity and reduced growth and survival relative to that of algae-fed larvae.

Brito *et al.* (2004) quantified the amount of energy channeled for growth (P), maintenance (R), excretion (U) and exuvia (Ev) in six dietary treatments during the initial development of *L. setiferus* Pls and *L. vannamei* tested at 28°C and salinity of 35. The results showed some divergence between these two species during the early Pls stages, but only when animals were in a poor physiological condition because of an inefficient diet. NA, which was partially replaced by a commercial microparticulate diet plus an algae supplement, was integrated with a high-quality diet for both species, thereby producing high-growth efficiency.

Arena *et al.* (2007) studied the effects of different levels of carbohydrates (cbh) and CP (23cbh-35CP, 12 cbh-45CP and 55CP-0 cbh) on the growth rate and α-amylase and phenotypic expression in *L. setiferus*. The specific α-amylase activity was inversely proportional to cbh concentration in diets, which indicated a protein-inducing effect of the diet. Phenotypic expression, measured by allelic frequency, showed that different alleles were affected by DP, wherein the alleles were reduced according to the protein level. Alleles b and c showed an increase in expression based on protein concentration, which demonstrated that these alleles were responsible for increased amylase activity when fed high levels of DP. The modulating role of dietary components in enzymatic activity has been previously discussed (Lovett & Felder, 1990).

Various investigations showed some usefulness of blood parameters as tools to monitor the physiological conditions of wild and cultured shrimp exposed to diverse environmental conditions. Sánchez *et al.* (2001) observed that a change in water temperature between 27 and 30°C produced variation in the levels of protein, lactate, glucose, triglycerides, cholesterol and the immune response in wild adults of *L. setiferus*. Under captive conditions, protein, triglyceride and cholesterol levels were lower than those observed in wild-caught animals (Smith *et al.*, 2003).

The levels of hemocyanin (OxyHc), blood protein, glucose, triacylglycerols, cholesterol and lactate in juvenile *L. setiferus* and *L. vannamei* were determined to set a baseline for functional nutritional status under experimental or cultivated conditions in tanks simulating commercial conditions (Pascual *et al.*, 2003a). Food quality was the factor that controlled the levels of metabolites in blood, suggesting that these parameters

determine whether a wild population is well-nourished or under pressure, and can be associated with some severe environmental disturbances (Rosas *et al.*, 2001, 2002).

Rosas *et al.* (2002) showed that cultured shrimp are well adapted for the use of protein as a source of energy and for growth to maintain osmotic pressure and produce glycogen and glucose by glycogen. Additionally, the immune system, with a strong protein base, depended significantly on protein metabolism (Vargas-Albores & Yepiz-Plascencia, 2000). It is well documented that *L. setiferus* juveniles are subject to sudden changes in salinity in the coastal lagoons where they live, but are also exposed to daily variations in temperature or DO (Rosas *et al.*, 1997). Under such conditions, juveniles need to adjust osmotic pressure as a result of being in a more diluted environment. In the process of physiological adjustment at low salinity, shrimp will use a pool of free amino acids to reduce the increase cell volume caused by water intake to reduce protein concentration in the hemolymph (Rosas *et al.*, 2001).

Aquaculture

In the 1990s, because of the information generated, interest in the cultivation of shrimp under controlled conditions began. Thus, a growing concern about viral diseases and the severe difficulties experienced by shrimp breeders in South Carolina trying to obtain *L. vannamei* Pls free from infectious hypodermal hematopoietic necrosis virus (IHHNv) provoked another assessment of the potential for the culture of the native *L. setiferus* (Sandifer *et al.*, 1993). Parker & Holcomb (1973) and Parker *et al.* (1974) first showed that *L. setiferus* was the best native shrimp species for aquaculture. However, Sandifer *et al.* (1993) demonstrated that the performance of *L. vannamei* was superior to that of *L. setiferus* in semi-intensive ponds.

Thus, after the first experiments, Waddell Mariculture Center from the Mariculture Research and Development Center conducted cycles of cultivation in 1985-1989. In 1985, nurseries of 0.l and 0.25 ha stocked with *L. setiferus* were obtained from the Continental Fisheries Hatchery Ltd., Panama City. Three tanks, 0.1, 0.25 and 0.5 ha, were stocked with *L. vannamei* Pls from the Amorient Aquafarm larviculture in Hawaii that were certified free of pathogens. *L. vannamei* and *L. setiferus* were stocked with Pls 7-9 at an initial density of 12 m^{-2} for 147 days. In the 1989 experiment, *L. setiferus* Pls produced at the Waddell Mariculture Center from captive-breeders and South Carolina wild stock were stocked at two densities, 40 and 60 m^{-2}, in 0.1 ha nurseries. Identical nurseries were

stocked with *L. vannamei* Pls from a private hatchery in Costa Rica at 60 m^{-2} for 145 days.

The 1985 yield for *L. setiferus* was slightly higher than that of previously high levels from intensive farms. The 1989 experiment showed for the first time that it was feasible to intensively culture *L. setiferus* and produce the highest yield (5-8 t ha^{-1} $crop^{-1}$) ever achieved with the species. Overall, survival and yield levels with *L. setiferus* fell within the range of previous intensive culture results with *L. vannamei* at similar population densities. However, *L. setiferus* was 2 g lighter than *L. vannamei* at harvest. These data reinforced the findings of McKee *et al.* (1989) and Browdy *et al.* (1991) with *L. vannamei.* They showed better growth and yield for *L. vannamei* than *L. setiferus* and concluded that South Carolina should preferentially culture *L. vannamei*.

However, it appeared that nurseries provided a suitable environment for the "normal" growth of *L. setiferus*, even at densities that were many times higher than those found in the wild. However, the maximum growth rate recorded for this species in the wild was not reached in the cultures. Sandifer *et al.* (1993) found that the main disadvantage was the low growth rate for *L. setiferus*, and no commercial hatchery was interested in producing Pls. The advantages are that it is not a natural host for IHHNv, breeders are available in the local environment, they are native to the region, and there are no problems with physical and chemical characteristics.

The Pls supply for *L. setiferus* had limited commercial value for at least several years. Additional research on nutrient requirements, population density effects on growth, as well as necessary changes in nursery management procedures had to be evaluated for *L. setiferus* to be an alternative species for aquaculture. Williams *et al.* (1996) tested different stocking densities in a recirculation system with *L. vannamei* and *L. setiferus*. The growth rate of *L. setiferus* was lower than that of *L. vannamei. L. setiferus* showed a high-density tolerance similar to that of *L. vannamei*; therefore, it may be fit for density-intensive growth. Depressed growth rates of *L. setiferus* appeared independent of stocking density or water quality, but their cause must be solved to achieve growth rates similar to that of *L. vannamei*.

A few years later, and with a growing interest in live or frozen bait for recreational fisheries, interest in intensive cultivation of *L. setiferus* returned, although economic profitability studies had not yet been conducted. Samocha *et al.* (1998) conducted a study to evaluate whether intensive shrimp farming developed for *L. vannamei* could be used successfully to produce *L. setiferus* of bait size in outdoors nurseries of southern Texas. The study evaluated the effects of two high-stocking densities, two feeding types and two water circulation systems on growth and survival after 120

days to determine whether the economic viability of the *L. setiferus* bait facility in Texas could be improved (Samocha *et al.*, 1998). Shrimp bait size, average weight 5-7 g, was reached in 90 to 120 days of culture. Mean survival value in the four nurseries stocked at 700 Pls 6 m^{-2} was 58.1% ("high exchange"), whereas the mean survival value of four ponds stored at 350 Pls 6 m^{-2} ("low exchange") was 65%. The difference in survival between "high exchange" and "low exchange" was 6%. A negative value reduced performance, high density negatively affected survival, and there was a 10% survival in nurseries fed a high protein ratio. Samocha *et al.* (1998) concluded that *L. setiferus* Pls stocked at 700 Pls m^{-2} in a small outdoor nursery, for 6 g bait in 94 days, with a 75% survival led an extrapolated yield of 31 m in ha^{-1} with a commercial ration. The study also suggested that production nurseries should be equipped with a 1 hp paddle aerator to support high biomass, and a similar installation of a bottom aeration grid, air transport pump and a nursery divider in the center.

Preliminary economic analysis and effect testing suggested that, under the conditions of the study, feed had the most significant effect on survival, growth and profitability. Efforts to develop a more complete and balanced feed for *L. setiferus* may be the technological advancements needed to make shrimp bait production more economically viable (Samocha *et al.*, 1998).

Palomino *et al.* (2001) evaluated the effects of stocking density and water exchange on the growth rate, survival and performance of *L. setiferus* Pls under laboratory conditions. The experiment was conducted with Pls (PL$_{10}$ to PL$_{40}$) at 50, 150, 250 and 350 shrimp m^{-2}, and several water exchanges per day (0, 6, 12 and 18%). The maximum growth rate was obtained for shrimp with a 12% water exchange per day at all densities. There was a reduction in maximum growth rate with density, with the highest values for shrimp stocked at 50 and 150 shrimp m^{-2} (mean value 0.53 mg d^{-1}) and the lowest values for shrimp stocked at 350 shrimp m^{-2} (0.24 mg d^{-1}). Thus, this study reported the lowest values for growth rate.

Valenzuela *et al.* (2002) placed *L. setiferus* at a stocking density of 40 Pls m^{-2} in 20,000 L tanks in marine and low-salinity water. There was a slight tendency for higher growth in low-salinity water tanks during the first 75 days. However, at the end of the experiment (116 days), the mean final wet weight of 15 g was obtained for the marine water tanks, whereas a lower mean final wet weight of 10 g in the low-salinity water tanks. There was a growth rate of 0.92 g week^{-1} in marine water and 0.61 g week^{-1} at low salinity. Improving culture conditions and providing live food inside the nursery (green water), may aid in the success in the cultivation of this species. A recent review of new shrimp culture technologies has been conducted, and it was suggested to use these technologies for the culture of shrimp as live bait, for *L. setiferus*, *F. duorarum* and *F. aztecus*. These technologies included the use of mature wild females and spawning in the laboratory, intensive nursery systems without water exchanges, adequate rations and all possible biosecurity measures (Gandy, 2007).

Perez-Velazquez *et al.* (2013) studied salinity in a range of 1-48 g L^{-1} on the performance (weight gain and survival) of *L. vannamei* and *L. setiferus* at 20, 24 or 28°C. Low growth and survival of *L. vannamei* were noted after 21-28 days at 2 and 4 g L^{-1} and 20°C; 8 and 32 g L^{-1} significantly increased survival at this temperature, which indicated that low temperature was critical for survival at low salinity. A substantial improvement in the growth rate of *L. vannamei* at 24°C was not optimal compared to the growth rate at 28°C. Regardless of salinity, high survival rates at 24 and 28°C allowed for a variable growth rate.

Unlike *L. vannamei*, *L. setiferus* reared for 28 days at 24°C showed better growth performance at 8 g L^{-1} compared to 2, 16 and 32 g L^{-1}. Under similar experimental conditions, *L. setiferus* had considerably lower weight gain and survival than *L. vannamei* based on previous literature (between 0.35 and 0.45 g week^{-1}).

Perspectives

The current situation regarding the shrimp industry poses challenges that need to be overcome. To replace fishmeal, the formulation of foods that will help to mitigate the effects of diseases, incorporate the appropriate use of natural foods, prebiotics and probiotics, reduce the use of antibiotics, and manage microbial ecology, among other factors, will be the focus of research on cultivated prawns. Research on nutrition and food will be mainly influenced by market variables, pressures on environmental policy and the availability of inputs, among other factors. Specifically, studies that have been conducted with this species have generated important advances in the production of larvae with an already established and proven scheme, especially where there are problems to avoid, such as the deterioration of the captive males, which limits reproduction, and the intensive production of good quality Pls of this species. The formulation of special feeds for different shrimp species is a basic necessity. However, perhaps the best option is to provide shrimps with an environment rich in microorganisms that provide excellent water quality and generate ecological succession to maintain heterotrophic bacteria and invertebrates up to nematodes. Thus, improving nutrition and immunology status, such as work carried

out with biofloc, should continue until optimal conditions for survival and growth are determined.

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