

Effect of sex ratio on reproduction, fecundity, and fertility of Montezuma dwarf crayfish (*Cambarellus montezumae*, Saussure 1857) in closed aquaculture systems

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ABSTRACT

Objective: to evaluate the effect of sex ratio on reproductive aspects of dwarf crayfish (*Cambarellus montezumae*) in aquaculture recirculating systems.

Design/Methodology/Approach: three treatments with female-to-male sex ratios (2:1, 3:1, and 5:1) were used. The organisms were collected from the wild, acclimated, and subsequently placed into a recirculating aquaculture system. Reproductive variables such as the number of fertilized eggs and the number of offspring released per female were measured.

Results: sex ratio had no effect ($p > 0.05$) on fecundity, fertility, or frequency of ovigerous (egg-bearing) females per treatment. Fertilization rate exceeded 50%. This suggests the existence of other independent factors (either on females or males) which contribute to reproductive success.

Limitations/Implications of the study: this study confirms the polygamous behavior of males, which is a characteristic of other crustacean. It is found, then, that reproduction can be optimized by modifying female to male ratios. In addition to considering factors such as water quality, female size, and environmental conditions.

Findings/Conclusions: sex ratio is not a key factor for improving Montezuma dwarf crayfish reproduction in controlled systems. We recommend prioritizing the optimization of environmental conditions, and selecting high-quality broodstock to increase reproductive efficiency.

Keywords: crayfish, Mexican acocil, sex ratio, reproduction.

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INTRODUCTION

The importance of aquaculture in global food security has increased in recent years, particularly in crustacean production systems. Some of the most important species in terms of production volume and commercial value are *Litopenaeus vannamei* [Boone, 1931] Pacific white shrimp; *Procambarus clarkii* [Girard, 1852] red swamp crayfish; *Eriocheir sinensis* [H. Milne-Edwards, 1853] Chinese mitten crab; *Penaeus monodon* [Fabricius, 1798] giant tiger prawn; *Macrobrachium nipponense* [De Haan, 1849] East Asian river prawn; and *Macrobrachium rosenbergii* [De Man, 1879] giant river prawn (FAO, 2018).

Due to the growing importance of their commercial value, some of these species are introduced to environments out of natural distribution (Norzagaray Campos *et al.*, 2012; Platas-Rosado and Vilaboa-Arroniz, 2014). This leads to problems associated with technological, ecological, and even cultural value, since studies and improvements in production processes are directed at those species with the highest economic value (Cerón-Ortíz *et al.*, 2019; FAO, 2024).

Furthermore, there is a risk of displacement of native species, destruction of their habitat and even the loss of traditional knowledge due to population decreasing of those species that were the basis of the diet in riverside communities (Moctezuma, 1996; Arredondo-Figueroa *et al.*, 2011).

The economic importance of endemic species is low worldwide (FAO, 2024). Mexico is a country with great potential for native aquaculture species. However, a lack of scientific studies promoting the generation of new technologies has limited the development of local species cultivation (Norzagaray Campos *et al.*, 2012; Platas-Rosado and Vilaboa-Arroniz, 2014).

Montezuma dwarf crayfish, known in Mexico as acocil (*Cambarellus montezumae* Saussure 1857), is widely distributed in Central Mexico in rivers and related freshwater ecosystems (Avilés-Quevedo and Vázquez-Hurtado, 2006). It is described with a great potential for aquaculture because of a great adaptation capacity to different conditions in terms of space, water quality, and feed (Arredondo-Figueroa *et al.*, 2011; Cerón-Ortiz *et al.*, 2015).

Although studies on this crayfish have focused mainly on aspects of geographical distribution (Álvarez and Rangel, 2007; Barba-Macías *et al.*, 2015) and taxonomy (Gutiérrez-Yurrita and Morales-Ortíz, 2002; Rojas *et al.*, 2002), some studies regarding cultivation have demonstrated the aquaculture potential of the species (Latournerié Cervera *et al.*, 2006; Cerón-Ortiz *et al.*, 2015; Gallardo-Pineda *et al.*, 2015; Cerón Ortiz *et al.*, 2019).

The development of new aquaculture production systems must consider multiple factors such as the species used, life cycle, environmental requirements, and reproductive maturity time, among others (Thieman and Palladino, 2010). To a large extent, reproductive success depends on environmental and ecological parameters. In particular, egg production in crustaceans depends on water temperature, feeding, sexual maturity, spawning frequency, fecundity, and fertility (Lizárraga-Cubedo *et al.*, 2008).

Another factor that determines the structure and reproductive capacity of a population is the sex ratio (Piferrer, 2009). Selecting the correct sex ratio optimizes the reproductive time and effort of both males and females to achieve the desired number, volume, and quality of spawning.

Some studies conducted on crayfish reported optimal sex ratios of 2:1 (two females per one male) (Arredondo-Figueroa, 2011); even 1:1 (Cerón-Ortiz *et al.*, 2019), which are attributed to antagonistic behavior, density, and intrapopulation competition, among others. Likewise, reproductive parameters such as fecundity and fertility are reported in association with morphometric characteristics of females (Álvarez and Rangel, 2007; Arredondo-Figueroa *et al.*, 2011). Even the size at first reproduction was observed as

relevant (Cerón-Ortiz *et al.*, 2019); in addition to other factors such as environmental quality or food availability (García-Padilla, 2014).

Most studies in crustaceans consider females as the determining factor of reproductive parameters such as fertility and egg fecundity. However, male sperm quality is also a variable that must be considered in the reproductive success of a population, which can be indirectly evidenced in the quality of fertilized embryos and the production of viable eggs (Pérez-Rodríguez, 2017). It is also important to consider whether male sperm reserves allow them to mate with more than one female in the same reproductive period and what is the maximum number of females that a single male can fertilize (Carmona-Osalde *et al.*, 2004; Gowland-Sainz, 2018).

Based on the above, to solve the question How does the sex ratio affect reproduction, fecundity, and fertility in crayfish farming? We posed the hypothesis that the male is the variable which determines reproductive success and spawning quality in crayfish farming. The objective of the study was to evaluate the effect of sex ratio on reproductive aspects of Montezuma dwarf crayfish (*Cambarellus montezumae*) in an aquaculture recirculating system.

MATERIALS AND METHODS

Collection and acclimatization

Wild Montezuma crayfish (*Cambarellus montezumae*) were obtained and divided by sex into two recirculating ponds at an average temperature of 18 ± 2 °C and a water exchange rate of 500 mL per minute. Acclimatization was implemented for three weeks; organisms were fed with shrimp feed “El Pedregal” brand (45% protein, 10% fat); feed portion was 6% of the biomass every two days. Oviparous females found after collection and acclimatization were discarded of the experiment and isolated from the experimental group.

Experimental design

The experiment was established in a recirculating aquaculture system at the facilities of the aquaculture bioengineering laboratory of the Inter-American Institute of Water Sciences and Technology (19° 23' 58" N, 99° 42' 52" W; altitude 2609 m).

After acclimatization of organisms, 30 females and 9 males (39 experimental organisms) were randomly selected; biometric measurements were performed. Total body weight (TW), which was measured with an analytical balance [Bel Engineering MG314Ai with 0.0001 g readability]; and total length (TL), measured from the tip of the acumen to the posterior margin of the telson (Álvarez and Rangel, 2007). They were subsequently arranged in 60 L experimental units in a 3×3 randomized block design. Treatments consisted of three sex ratios: T1: two females per one male (2:1); T2: three females per one male (3:1); T3: five females per one male (5:1). The organisms used in the experiment were randomly assigned to each block, ensuring that they had similar morphometric characteristics. Males had an average length of 46.9 mm and an average weight of 1.8 grams; Females had a length range from 28 to 45 mm, and weight from 0.7 to 2.3 grams (Table 1).

The experiment lasted 14 weeks (April-July 2024) at an average temperature 16.7 ± 1.6 °C, with a minimum of 12 °C and a maximum of 22 °C. The presence of

Table 1. Distribution of experimental organisms (*Cambarellus montezumae*) by treatment (sex ratio).

Treatment	TLf	TWf	TLm	TWm
T1	34.3 mm	1.7 g	47.7 mm	1.6 g
T2	34.4 mm	1.5 g	45.7 mm	2.2 g
T3	37.6 mm	2.0 g	47.3 mm	1.6 g

TWf: average female weight; TLf: average female length; TWm: average male weight; TLm: average male length.

ovigerous females was checked every third day; when an ovigerous female was identified, it was removed from the system and replaced with another with similar morphometric characteristics.

In order to reduce possible antagonistic behaviors between organisms, each experimental unit had two PVC shelters (standard tube, ½” in diameter × 1 ½” long) for each experimental organism.

Additionally, the experimental organisms were provided with balanced shrimp feed crushed with a mortar to ensure conditions close to ad libitum feeding.

Fecundity (number of eggs per female)

Fecundity, the number of eggs released and retained by a female under the abdomen in a single spawning (Hernández and Palma, 2003), was evaluated by counting eggs attached to the pleopods; in addition, we recorded female total weight and length (Figure 1).

Fertility (number of offspring per female)

To estimate the number of live offspring released by an ovigerous female, the organisms were placed individually in 4 L containers (Figure 2), which contained a PVC



Figure 1. Ventral view of a fertilized female *Cambarellus montezumae* with eggs (black mass) that remain attached to the pleopods by a mucilaginous substance throughout incubation. Photo: Javier García-Olvera.



Figure 2. Montezuma crayfish larvae (*Cambarellus montezumae*) attached to the abdomen of an ovigerous female. Photo: Javier García-Olvera.

shelter with complete water replacement every third day until hatching and expulsion of their offspring.

At the time of expulsion of the crayfish fry (none attached to the female's abdomen), the female was removed from the 4 L container. Biometry was performed of total female weight and length, and the offspring inside the container were counted.

Statistical analyses

The data obtained were analyzed using the statistical software IBM SPSS[®] for Windows v. 24.0; A non-parametric Chi-square test was applied to the number of ovigerous females to find differences ($p \leq 0.05$) among treatments. Data on fecundity and fertility were verified as normal distributed (Shapiro-Wilk). After normality was proved, data were analyzed with a one-way analysis of variance test. In case of the opposite, this is, a non-normal distribution, a Kruskal-Wallis test for independent samples was applied.

RESULTS AND DISCUSSION

Frequency of ovigerous females

The number of females in the different treatments is shown in Table 2. The percentage of ovigerous females was 45%, 53%, and 50% of the females available for treatments T1, T2, and T3, respectively. Non-significant differences were found among treatments ($p \leq 0.05$).

Results show that, at least in the ratios evaluated, males had the same reproductive capacity (close to 50%) to fertilize available females, regardless of the sex ratio. A question arises then about why in any evaluated sex ratio, successful fertilization was only achieved in approximately 50% of females. There are factors inherent to the biology of the species that were not controlled in the experiment, such as mate selectivity, dominance, mating behavior or resistance, etc. (Barki, 2008). Those factors could be the cause for that 50% of non-ovigerous females, rather than the loss of energy experienced by males, due to the number of fertilized females.

Table 2. Frequency distribution of ovigerous (*Cambarellus montezumae*) females by treatment.

		Females		Total
		Non-ovigerous	Ovigerous	
Treatment	1	6	5 (45%)	11
	2	9	10 (53%)	19
	3	15	15 (50%)	30
Total		30	30	60

A polygamous behavior is reported in other decapods, such as the Red-clawed lobster (*Cherax quadricarinatus* [von Martens, 1868]), whose polygamous behavior is used to benefit culture, since sex ratio does not influence their reproduction. Authors of that study suggested to use female-biased ratios to increase the number of fertilized females per culture area (Yeh and Rouse, 1995). Thus, this polygamous behavior can be used in conjunction with a higher female-to-male ratio to optimize Montezuma dwarf crayfish reproduction.

On the other hand, the absence of competition among males may be a factor that facilitates copulation with a greater number of females. Arredondo-Figueroa *et al.* (2011) reported that in 1:2 ratios (female to male), males suffered higher mortality due to competition. Those authors suggested to consider this in setting reproduction densities, both for other studies and for batch culture. Since the presence of two or more males in the same pond could negatively influence reproduction rates, due to antagonistic competition behaviors for territoriality and sexual partners.

In spite of the polygamous role, reproductive efficiency, and lack of competition experienced by male crayfish, it is evident that the participation of the adult female is also crucial in the egg fertilization process. Females identify and determine the best environmental conditions for spawning (temperature, water quality, food availability, among others), and the influence of the culture environment on those conditions (Hernández and Palma, 2003). Some characteristics of the breeders, such as sexual maturity, morphometry, or age also have influence.

Rodríguez-Serna y Carmona-Osalde (2002) and Arredondo-Figueroa *et al.* (2011) reported that the metabolic expenditure of the culture is less when it is carried out in recirculating aquaculture systems, since organisms save more energy for reproduction. Therefore, when close to ideal environmental conditions exist within a controlled production system, the effect of the proportion of ovigerous females can be attributed more to behaviors inherent to the biology of the species and not to the effect of the reproductive capacity of males. This indicates that at least the reproduction frequency of females is not determined by the sexual proportion of males and therefore is a cultivation parameter that is not decisive in the efficiency of obtaining ovigerous females (García-Padilla, 2014).

Fertility (number of eggs per female)

The completely random distribution of females and males in the treatments allowed for representativeness of weights and sizes to evaluate their possible effect. Fertility results did not show significant differences among treatments ($p < 0.05$). The data suggest, at least in

the proportions evaluated, that regardless of the sex ratio used in reproduction, Montezuma dwarf crayfish fertility is not affected by the availability of females per male. Lizárraga-Cubedo *et al.* (2008) reported that the number of available partners was a limiting factor for male reproduction under natural conditions. However, under culture conditions male crayfish were capable of copulating with the largest number of available females without suffering any energy expenditure that significantly affects fertility.

Although in other crustaceans it has been reported that dominant males tend to limit their sperm release to increase the chances of fertilization of females (Barki, 2008), in the case of the proportions evaluated in Montezuma crayfish in our study, this phenomenon did not occur or it was insignificant. On the other hand, although energy expenditure is greater in females than in males (Lizárraga-Cubedo *et al.*, 2008), the number of eggs females produce is a factor related to the size of the abdomen, rather than to sexual ratio. This agrees with Álvarez and Rangel (2007) and Arredondo-Figueroa *et al.* (2011).

This situation seems to indicate that a large part of the effects on fecundity in the crayfish depend on the characteristics of the female. Such as female body size (García-Padilla, 2014) or on the environment, as quality of the medium, feed type and quality (Montemayor Leal *et al.*, 2010) or temperature (Gallardo-Pineda *et al.*, 2015). This effect of female characteristics on fecundity has been described in other species of cambarides, as *Procambarus clarkii*; *Cambarus longulus longulus* Girard 1852; *Orconectes kentuckiensis* Rhoades 1944; *Orconectes rusticus* Girard 1852; or *Cambarus shufeldtii* Faxon, 1884 (Barki, 2008).

Female weight, female length and correlations to fecundity

The average number of eggs ($\bar{x} = 62$) per ovigerous female in this study had limits within a minimum of 17 and a maximum of 115 (Figure 3). Thus, this average number of eggs obtained exceeds those found under similar conditions ($\bar{x} = 45$) in recirculating aquaculture systems (Arredondo-Figueroa *et al.*, 2011), those ($\bar{x} = 41$) in 40 L tanks (Cerón-Ortiz *et al.*, 2019); or those ($\bar{x} = 50.7$) under natural conditions (Álvarez and Rangel, 2007). This fact demonstrates that the reproductive conditions in recirculating aquaculture systems, especially those used in our study, were optimal for reproduction and allowed organisms to reach a reproductive capacity similar to, or even higher than, that in natural conditions.

The correlation between total body weight and total body length of females ($r^2 = 0.817$) was high in terms of body proportion. However, the body weight to fecundity ($r^2 = 0.568$) and total length to fecundity ($r^2 = 0.460$) correlations did not show evidence that female crayfish could produce a greater number of eggs as their weight or size increases (Figure 4). For most crustaceans (Pandian, 2016) and in other studies on Montezuma crayfish (Moctezuma, 1996; Álvarez and Rangel, 2007; Arredondo-Figueroa *et al.*, 2011), high correlations between fecundity and size are reported. This is due to the number of eggs is limited by the incubation space available in the female abdomen (Hernández and Palma, 2003; Álvarez and Rangel, 2007).

Regarding the size and weight at which ovigerous females were obtained, from a total body weight of 0.8 g and a total body length of 30 mm, fecundities higher than 45 eggs per clutch were obtained (Figure 3, Figure 4) which is the overall average found under

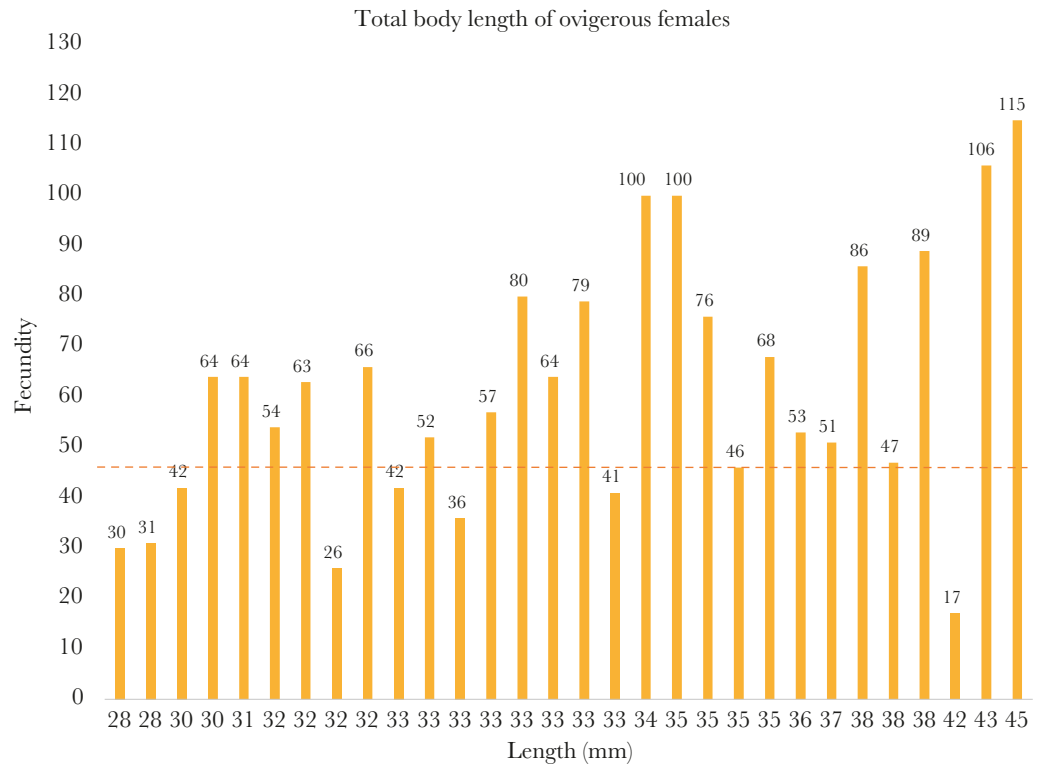


Figure 3. Average number of eggs produced individually according to size (total length) of females (*Cambarellus montezumae*).

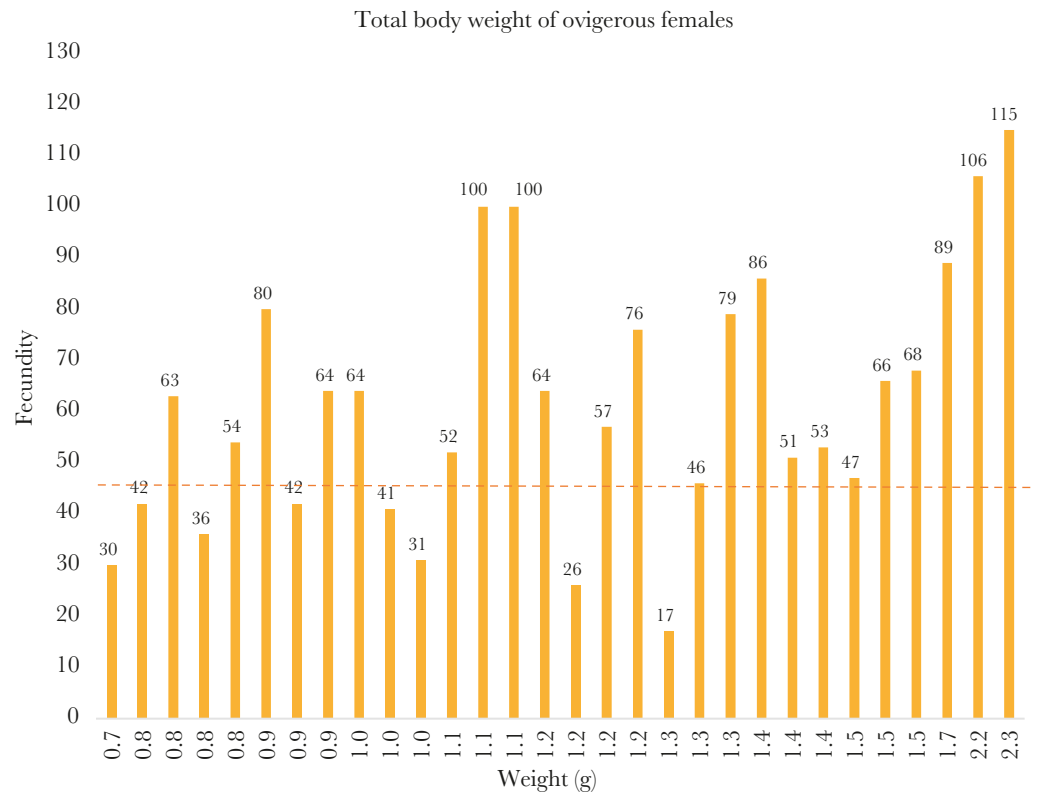


Figure 4. Number of eggs produced individually according to body weight of females (*Cambarellus montezumae*).

similar conditions in other studies (Arredondo-Figueroa *et al.*, 2011). This data agrees with Álvarez and Rangel (2007) who referred obtaining ovigerous females from 24 mm and suggested a capture length of 30 mm for the size of the breeders. These biometric data can be a reference for the selection of females in Montezuma crayfish farming.

However, it is essential to emphasize that the size of the females is not the only variable of interest that should be used to estimate and obtain an optimal reproductive capacity in the breeders in Mexican acocil farming. There are other variables that can significantly affect fecundity such as age of the females, season of the year, physicochemical conditions of the water, size of the eggs, or feed availability, among others (García-Padilla, 2014; Pandian, 2016). These variables should be considered in subsequent studies to determine the best conditions for obtaining optimal fertility for this culture.

Fecundity results suggest that female-biased reproduction proportions can promote the production of a greater number of eggs per pond (Yeh and Rouse, 1995), due to the possibility of containing a greater number of females per square area in the culture systems and therefore a greater egg productivity.

Fertility (number of offspring per female)

A total of 444 hatched crayfish fry were obtained, with a $\bar{x} = 15$ average of offspring per ovigerous female (Figure 5), with a minimum of 0 and a maximum of 86. Fertility results showed non-significant differences among treatments ($p > 0.05$). Therefore, in the



Figure 5. Montezuma crayfish fry (*Cambarellus montezumae*) expelled in a single spawning by a single female. Photo: Javier García-Olvera.

sex ratios evaluated, one male can copulate with a greater number of females without affecting the quality of the spawning or the hatching of the offspring.

Crayfish fry hatched and were released from the female abdomen between 30 and 50 days after being fertilized (Figure 5), with a \bar{x} = 44-days average incubation period. The discrepancy found in relation to other studies, which used a similar methodology (Moctezuma, 1996; Cerón-Ortiz *et al.*, 2019), could indicate that the quality of the spawning is not significantly affected by sex ratio, but is determined by the incubation conditions of the eggs. This could affect the survival of those eggs initially carried by the female.

Gallardo-Pineda *et al.* (2015) reported in *Cambarellus patzcuarensis* [Villalobos 1943], that increasing temperatures may reduce the incubation period, which could explain the hatching ranges found. Furthermore, the fact that higher temperatures have effects on female survival and fertility opens the possibility of in vitro incubation of fertilized eggs to increase the hatching percentage and optimize the offspring obtained. This possibility is important for subsequent research.

CONCLUSIONS

Sex ratio between males to females had non-significant effects on reproductive indicators, such as fecundity and fertility. Males used had the same reproductive capacity. However, there may be biological factors inherent to the females that determine reproductive success, such as dominance, territoriality, size, weight, age, size at first reproduction, among others. Finally, in the number of fertilized and hatched eggs, no evidence was found of significant differences related to the number of females with which the male mated. In terms of productivity, this information can be used for reproductive strategies in conservation, and commercial production systems of Montezuma dwarf crayfish.

REFERENCES

- Álvarez, F., & Rangel, R. (2007). Estudio poblacional del acocil *Cambarellus montezumae* (Crustacea: Decapoda: Cambaridae) en Xochimilco, México. *Revista Mexicana de Biodiversidad*, 78(2), 431-437. <http://www.scielo.org.mx/pdf/rmbiodiv/v78n2/v78n2a18.pdf>
- Arredondo-Figueroa, J. L., Vásquez-González, A., Núñez-García, L. G., Barriga-Sosa, I. de los Á., & Ponce-Palafox, J. T. (2011). Aspectos reproductivos del acocil *Cambarellus (Cambarellus) montezumae* (Crustacea: Decápoda: Cambaridae) en condiciones controladas. *Revista Mexicana de Biodiversidad*, 82(1), 169-178. <https://doi.org/10.22201/ib.20078706e.2011.1.369>
- Barba-Macías, E., Carmona-Osalde, C., Quiñones-Rodríguez, L., & Rodríguez-Serna, M. (2015). Registros nuevos de cambáridos (Crustacea: Cambaridae: Procambarus) en la cuenca del Grijalva-Usumacinta, Tabasco. *Revista Mexicana de Biodiversidad*, 86, 620-628. <http://www.scielo.org.mx/pdf/rmbiodiv/v86n3/1870-3453-rmbiodiv-86-03-00620.pdf>
- Barki, A. (2008). Mating Behaviour. In: E. Mente (Ed.), *Reproductive Biology of Crustaceans: Case Studies of Decapod Crustaceans*, Science Publishers, pp. 223-265.
- Carmona-Osalde, C., Rodríguez-Serna, M., Olvera-Novoa, M. A., & Gutiérrez-Yurrita, P. J. (2004). Effect of density and sex ratio on gonad development and spawning in the crayfish *Procambarus llamasii*. *Aquaculture*, 236(1-4), 331-339. <https://doi.org/10.1016/j.aquaculture.2004.02.031>
- Cerón-Ortiz, AN., Ángeles Monroy, M.Á., Limón Mendoza, MA., & León Escamilla, JA. (2019). Impact of the sex ratio in the breeding aspects of the crayfish *Cambarellus montezumae*. *Hidrobiológica*, 29(2), 53-62.
- Cerón-Ortiz, AN., Moctezuma-Reséndiz, O., Ángeles-Monroy, M.Á., Montufar-Serrano, E., & León-Escamilla, JA. (2015). Efecto interactivo del alimento y la calidad de agua en el crecimiento y sobrevivencia de postlarvas de acocil de río *Cambarellus montezumae*. *Revista Mexicana de Biodiversidad*, 86(1), 131-142. <https://doi.org/10.7550/rmb.4850>

- FAO–United Nations Food and Agriculture Organization (2018). El estado mundial de la pesca y la acuicultura 2018. Cumplir los objetivos de desarrollo sostenible. <http://www.fao.org/3/I9540ES/i9540es.pdf>
- FAO–United Nations Food and Agriculture Organization (2024). El estado mundial de la pesca y la acuicultura 2018. La transformación azul en acción. <https://doi.org/10.4060/cd0683es>
- Gallardo-Pineda, Y., Rodríguez-Serna, M., Carmona-Osalde, C., & Blancas-Arroyo, G. (2015). Efecto de la temperatura sobre el crecimiento, supervivencia y reproducción de juveniles de *Cambarellus patzcuarensis*. *AquaTIC*, 42, 17-27.
- García-Padilla, G. M. (2014). Aspectos sobre el crecimiento y reproducción del acocil *Cambarellus montezumae* (Saussure, 1857). Un análisis ecofisiológico. [Tesis de Maestría, Universidad Nacional Autónoma de México]. <https://repositorio.unam.mx/contenidos/443470>
- Gowland Sainz, M. F. (2018). Biología de la reproducción en la centolla *Lithodes santolla* del Canal Beagle: apareamiento y limitación espermática. Universidad de Buenos Aires.
- Gutiérrez-Yurrita, P. J., & Morales-Ortíz, A. (2002). Ecophysiological races of *Cambarellus* spp (Cambaridae) in Querétaro, Central México: the beginning of a new species. *Freshwater Crayfish*, 13, 187-197.
- Hernández, P., & Palma, S. (2003). Fecundidad, volumen del huevo y rendimiento reproductivo de cinco especies de porcelánidos intermareales del norte de Chile (Decapoda, Porcellanidae). *Investigaciones Marinas*, 37(2), 35-46. <https://www.redalyc.org/articulo.oa?id=45631204>
- Latournerié Cervera, J. R., Nacif Osorio, Y., Cárdenas Vázquez, R. de J., & Romero Jarero, J. (2006). Crecimiento, producción y eficiencias de energía de crías de acocil *Cambarellus montezumae* (Saussure) alimentadas con detritus de *Egeria densa*. *REDVET. Revista Electrónica de Veterinaria*, 7(12), 1-11. <https://www.redalyc.org/pdf/636/63612664016.pdf>
- Lizárraga-Cubedo, H. A., Pierce, G. J., & Santos, M. B. (2008). Reproduction of Crustaceans in Relation to Fisheries. In: Reproductive Biology of Crustaceans, pp. 169-222.
- Moctezuma, A. (1996). Bases biológicas y técnicas para el cultivo del acocil. In Bases biológicas y técnicas para el cultivo del acocil *Cambarellus montezumae*. [Tesis de Maestría, Universidad Colima].
- Montemayor Leal, J., Mendoza Alfaro, R., Aguilera González, C., & Rodríguez Almaraz, G. (2010). Influencia de la alimentación sobre la reproducción y crecimiento del acocil regio (*Procambarus regiomontanus*), especie en peligro de extinción. *Ciencia UANL*, 13(3), 276-286. <https://www.redalyc.org/pdf/402/40215495010.pdf>
- Norzagaray Campos, M., Muñoz Sevilla, P., Sánchez Velasco, L., Capurro Filograsso, L., & Llánes Cárdenas, O. (2012). Acuicultura: estado actual y retos de la investigación en México. *AquaTIC: Revista Electrónica de Acuicultura*, 37, 20-25. <http://revistaaquatic.com/ojs/index.php/aquatic/article/view/119>
- Pérez-Rodríguez, J. C. (2017). Biología reproductiva (Calidad espermática y regeneración del espermátforo) del langostino de río *Macrobrachium americanum* alimentado con diferentes dietas [Tesis de Maestría, Instituto Politécnico Nacional].
- Piferrer, F. (2009). Determinación y diferenciación sexual en los peces. In: La Reproducción de los peces: aspectos básicos y sus aplicaciones en acuicultura. Observatorio Español de Acuicultura, pp. 249–336.
- Platas-Rosado, DE, & Vilaboa-Arróniz, J. (2014). La acuicultura mexicana: potencialidad, retos y áreas de oportunidad. *Revista Mexicana de Agronegocios*, 35, 1065-1071. <http://www.redalyc.org/articulo.oa?id=14131676015>
- Rodríguez-Serna, M., & Carmona-Osalde, C. (2002). Balance energético del Acocil *Cambarellus montezumae* (Saussure) (Crustacea: Astacidae: Cambaride) pérdida de energía en la tasa metabólica. *Universidad y Ciencia*, 18(36), 128-134. <https://www.redalyc.org/pdf/154/15403604.pdf>
- Rojas, Y., Alvarez, F., & Villalobos, J. L. (2002). Morphological Variation in the Crayfish *Cambarellus montezumae* (Decapoda: Cambaridae). In: Modern Approaches to the Study of Crustacea. Springer US, pp. 311-317. https://doi.org/10.1007/978-1-4615-0761-1_43
- Thieman, W. J., & Palladino, M. A. (2010). Biotecnología acuática. In: Introducción a la biotecnología (Segunda Ed.) Editorial Pearson, pp. 231–259.
- Yeh, H. S., & Rouse, D. B. (1995). Effects of Water Temperature, Density, and Sex Ratio on the Spawning Rate of Red Claw Crayfish *Cherax quadricarinatus* (von Martens). *Journal of the World Aquaculture Society*, 26(2), 160-164. <https://doi.org/10.1111/j.1749-7345.1995.tb00239.x>