

Conservation

Survival, growth and sexual dimorphism of the land crab *Cardisoma guanhum* under semi-controlled captive conditions

Supervivencia, crecimiento y dimorfismo sexual del cangrejo terrestre Cardisoma guanhum en condiciones semicontroladas de cautiverio

Karla Verónica Santana-Aguayo, Carlos Iván Pérez-Rostro *,
Martha Patricia Hernández-Vergara

Instituto Tecnológico de Boca del Río, División de Estudios de Posgrado e Investigación, Laboratorio de Mejoramiento Genético y Producción Acuicola, Km. 12 Carretera Veracruz–Córdoba, 94290 Boca del Río, Veracruz, Mexico

*Corresponding author: ivandna02@hotmail.com (C.I. Pérez-Rostro)

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Abstract

This study evaluated the survival, growth, and reproductive performance of *Cardisoma guanhum* maintained for 12 months under semi-controlled conditions. A total of 341 adult crabs were collected from mangrove habitats and housed in a naturalized enclosure equipped with buried PVC shelters, freshwater and saltwater basins, and automated sprinklers to maintain humidity. Crabs were fed a plant-based diet supplemented with tilapia muscle and monitored monthly. Final survival reached 76%, and 68.6% of females became ovigerous, supporting the species' reproductive viability under captive conditions. Morphometric growth was recorded in 170 intact individuals. Notably, carapace width increased by approximately 1 mm/month despite the near absence of visible molting, particularly among smaller crabs (< 100 g), which gained over 150% in total weight. Seasonal patterns were detected, with greater somatic gains in warmer months. No significant differences were observed between sexes overall, although some interactions were noted in specific morphometric traits. These findings suggest the potential occurrence of hypertrophic tissue expansion or mineral recycling in the absence of ecdysis, which merits further investigation. This study provides the first long-term physiological baseline for *C. guanhum* under ex-situ conditions and supports its potential use in conservation and aquaculture programs.

Keywords: Terrestrial crustaceans; *Ex-situ* conservation; Reproductive biology; Captive management

Resumen

Este estudio evaluó la supervivencia, el crecimiento y el desempeño reproductivo de *Cardisoma guanhum* durante 12 meses en condiciones semicontroladas. Se recolectaron 341 cangrejos adultos en manglares y se mantuvieron en un recinto naturalizado con refugios de PVC enterrados, estanques de agua dulce y salada, y

rociadores automatizados para mantener la humedad. Los organismos fueron alimentados con una dieta vegetal suplementada con músculo de tilapia y monitoreados mensualmente. La supervivencia final fue de 76 y 68.6% de las hembras se volvieron ovígeras, evidenciando viabilidad reproductiva en cautiverio. Se registró crecimiento morfométrico en 170 individuos con apéndices intactos; el ancho del caparazón aumentó aproximadamente 1 mm por mes, pese a la casi ausencia de mudas visibles. Los organismos más pequeños (< 100 g) incrementaron su peso en más de 150%. Se observaron patrones estacionales, con mayores ganancias somáticas en meses cálidos. No se detectaron diferencias significativas entre sexos, salvo algunas interacciones en rasgos específicos. Los resultados sugieren posibles mecanismos de expansión tisular o reciclaje mineral sin muda. Este estudio aporta una línea base fisiológica a largo plazo y respalda el potencial de la especie para conservación y acuicultura.

Palabras clave: Crustáceos terrestres; Conservación *ex-situ*; Biología reproductiva; Manejo en cautiverio

Introduction

Coastal ecosystems provide critical services for biodiversity, food production, and human livelihoods. However, increasing anthropogenic pressures—including urban expansion, agriculture, and coastal infrastructure—have led to widespread loss and degradation of mangroves and wetlands (Alvarez & Briquets, 1983). This environmental decline directly threatens terrestrial crab species of the family Gecarcinidae, including *Cardisoma guanhumi*, a large land crab distributed from Florida to Brazil (Anger, 2013; Botelho et al., 2001).

Cardisoma guanhumi plays a key ecological role in mangrove ecosystems as a detritivore and sediment bioturbator. Its burrowing behavior enhances sediment oxygenation and stimulates microbial decomposition, contributing to nutrient cycling and substrate balance (Kristensen, 2008). Economically, it is highly valued in several Caribbean countries for its large chelipeds and meat content (Watson-Zink, 2021). In Mexico, although *C. guanhumi* is not currently listed under NOM-059 as endangered (Semarnat, 2020), its inclusion in local management programs reflects growing concern over population decline, and has been subject to seasonal fishing bans in regions such as Veracruz (Semarnat, 2020). Despite its ecological and commercial relevance, scientific knowledge on *C. guanhumi* is still limited, especially under captive conditions. Most available studies on *C. guanhumi* are over 2 decades old and focus primarily on natural history and reproductive cycles, with very limited data on captive performance or aquaculture potential (Diele et al., 2005; Smith & Smith, 2001).

Given the ongoing degradation of coastal habitats and the absence of recent biological data, understanding the growth and reproductive performance of *C. guanhumi* in captivity is essential. This study aimed to evaluate the feasibility of maintaining this species under semi-controlled conditions, describing seasonal growth patterns and reproductive output. The findings provide

foundational data for conservation strategies and offer the first long-term evidence of physiological plasticity in captivity, supporting future aquaculture development for this native land crab. Such species are vital for coastal productivity and food web integrity (Gifford, 1963).

Materials and methods

The experiment was conducted at the Aquaculture Genetics and Production Laboratory of the Instituto Tecnológico de Boca del Río (ITBOCA), Veracruz, Mexico. A total of 341 adult specimens of *C. guanhumi* (132 males and 209 females; cephalothorax width > 50 mm) were manually collected during July and August 2022 from mangrove habitats along the Boca del Río-Antón Lizardo-Alvarado corridor (19°03'08" N, 96°00'27" W). Collection was performed under environmental authorization in compliance with national regulations and with minimal handling stress. Ovigerous females were excluded to avoid interference with growth and reproductive monitoring. Crabs were weighed (165.11 ± 50.19 g) and measured (CW: 6.80 ± 0.81 cm; CL: 5.06 ± 0.79 cm) before transport in 60-L plastic containers (15 individuals per container) to the laboratory facilities.

Crabs were maintained for 12 months in a semi-controlled, custom-built habitat designed to simulate key structural and microclimatic features of their natural environment. The enclosure measured 7 × 6 m, delimited by concrete perimeter walls 1.2 m high, and was installed directly over natural soil. A 30-cm-deep layer of fine sand was distributed across the entire area to allow natural burrowing behavior.

Eighty cylindrical PVC shelters, ranging from 2.5" to 6" in diameter, were buried diagonally into the substrate. Each tube was partially exposed at one end and fully embedded at the other, mimicking natural burrow structures and providing refuge. These shelters were distributed evenly across the enclosure. A young red mangrove (*Rhizophora* sp.) tree was planted at the

center of the habitat to provide shading and promote environmental heterogeneity.

Two shallow basins were integrated at ground level to simulate aquatic access points: one freshwater basin (0.80 × 0.40 m) and one saltwater basin (0.60 × 0.50 m). These allowed the crabs to access both water types to mimic the species' natural osmoregulatory behavior. The enclosure was protected with plastic mesh netting to prevent escapes and exclude predators.

A sprinkler system powered by a ½ HP submersible pump was installed to automatically maintain ambient humidity at $70 \pm 10\%$ and simulate rainfall events. This system operated intermittently throughout the day, creating a microclimatic regime resembling that of natural coastal mangroves. Environmental parameters including temperature and salinity were monitored daily using a YSI 556 multiparameter probe. Crabs were stocked at low density ($< 1.0 \text{ ind/m}^2$) to minimize territorial stress and promote natural behavior. A 5-day acclimation period was provided before experimental measurements commenced. The layout of the semi-controlled habitat and individual crab marking strategy are illustrated (Fig. 1).

Crabs were fed ad libitum with a rotating mixture of fruits and vegetables, supplied daily. Each individual

received approximately 30–40 g/day of plant matter, including chopped papaya (10 g), mango (8 g), banana (5 g), coconut (3 g), watermelon (5 g), pumpkin (5 g), radish (2 g), and carrot (2 g), provided in alternating combinations to ensure dietary variety and stimulate natural foraging behavior.

In addition, each crab was offered 5 g of fresh tilapia (*Oreochromis* sp.) muscle every 2 days as a source of animal protein. All food items were weighed prior to distribution using a digital scale, and uneaten remnants were removed within 24 hours to prevent microbial proliferation and maintain substrate hygiene. Feeding was performed in the early morning to take advantage of natural crab activity rhythms. Food was distributed uniformly across the enclosure to reduce competition and ensure equal access among individuals.

A total of 170 crabs that retained all appendages throughout the experiment were selected for monthly morphometric monitoring. Each individual was permanently identified by engraving a unique mark on the dorsal carapace using a Dremel® rotary tool, a method shown to be effective and non-lethal for individual identification in crustaceans, followed by a dot of red nail polish to facilitate visual recognition during handling.

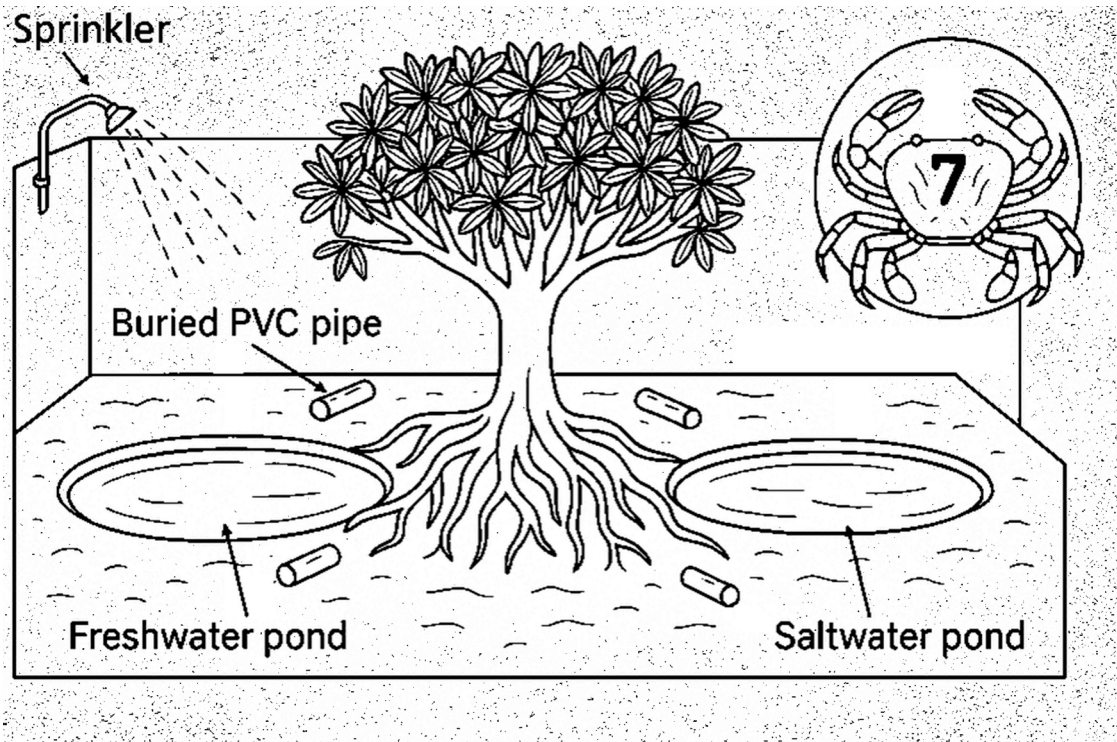


Figure 1. Experimental enclosure for *Cardisoma guanhumii* under semi-controlled conditions. The system included a central mangrove tree, freshwater and saltwater basins embedded at ground level, diagonally buried PVC pipes for shelter, and overhead sprinklers to maintain humidity. Inset: dorsal view of a marked crab with engraved ID and red nail polish.

Nine morphometric parameters were recorded: total weight (TW), cephalothorax width (CW), cephalothorax length (CL), and bilateral measurements of the chelipeds, including: chelae (RCh, LCh), carpi (RCa, LCa), and meri (RM, LM). All linear dimensions were measured to the nearest 0.01 cm using a digital caliper (Autotec™), and weight was recorded to the nearest 2 g using an Ohaus Scout Pro SPU2001 electronic scale. Measurements were conducted at 30-day intervals for a total of 12 months. Handling was performed with care to minimize stress and avoid damage to limbs or exoskeleton. Data were logged immediately into individual digital records for subsequent statistical analysis. All measurements were performed by a single trained observer to reduce operator error.

Survival was assessed as the proportion of live individuals at the end of the 12-month experimental period relative to the initial number of crabs introduced into the habitat ($n = 341$). Daily inspections were conducted to detect mortalities, which were immediately removed to prevent deterioration and potential contamination of the enclosure. Causes of mortality were not determined but monitored for frequency to identify potential trends.

Reproductive activity was evaluated based on the presence of ovigerous females. Identification was performed by visual inspection of the ventral abdomen to detect external egg masses attached to the pleopods. Females were not handled unnecessarily to avoid detachment or disturbance of egg clutches. The number of ovigerous females was recorded seasonally, and reproductive peaks were determined based on their frequency during each sampling period. Although no copulation events were directly observed, the appearance of ovigerous females was interpreted as evidence of successful mating or possible sperm storage, as reported in other decapods. No interventions (e.g., hormone induction) were performed to stimulate reproduction.

Statistical analysis

Only crabs that retained all appendages throughout the entire experimental period ($n = 170$) were included in the statistical analyses. Data were first tested for normality using the Kolmogorov-Smirnov and Lilliefors tests, and for homogeneity of variances using Levene's test. Sex-related differences across all morphometric variables were analyzed using one-way multivariate analysis of variance (MANOVA). To evaluate the effects of season and sex on specific traits, a two-way ANOVA was conducted for each morphometric variable independently. When significant differences were detected, Tukey's HSD post hoc test was applied to identify specific group differences. Additionally, to assess growth performance by initial body size, crabs were grouped into 4 weight classes (0-99

g, 100-199 g, 200-299 g, > 300 g), and a two-way ANOVA (sex \times weight class) was performed. Statistical analyses were performed using Statistica version 7.0 (StatSoft Inc., Tulsa, OK, USA), and differences were considered statistically significant at $p < 0.05$. Statistical procedures followed standard biometric methodology (Sokal & Rohlf, 2003).

Results

Cardisoma guanhum was successfully maintained for 12 consecutive months in the semi-controlled habitat, showing a final survival rate of 76.25%. Males exhibited slightly higher survival than females. These values are comparable to those reported in similar experimental setups for other land or semi-terrestrial brachyurans, such as *Gecarcinus lateralis* and *Ucides cordatus*, where survival ranged between 70-85% under laboratory or mesocosm conditions (Greenaway, 2003; Hartnoll, 1982). However, published data on long-term captive maintenance of *C. guanhum* remain scarce, with most available studies limited to short observational trials or reproductive monitoring under field conditions (Gifford, 1963; Shinozaki-Mendes et al., 2013). Sex-specific survival percentages are presented in Table 1.

Ovigerous females were recorded in all seasons, with the highest occurrence observed during summer and early autumn. A total of 68.6% of the females became ovigerous at least once throughout the year, consistent with historical accounts of reproductive periodicity in this species. Although no copulation events were directly observed during the trial, the consistent appearance of externally egg-bearing females suggests that successful mating occurred prior to or during the initial weeks of captivity. This observation supports the hypothesis of sperm storage capacity in *C. guanhum*, a reproductive trait widely documented in decapod crustaceans and associated with multiple spawning events and temporal reproductive flexibility (Bauer, 1986; Taissoun, 1974).

On average, *C. guanhum* exhibited a monthly morphometric gain of approximately 1 mm in cephalothorax width under captive conditions, despite the absence of molting in all but one individual. All morphometric variables showed significant seasonal increases over the 12-month period. The most pronounced gains occurred in cephalothorax width (CW) and total weight (TW), with maximum values recorded during spring and summer. These seasonal trends are illustrated in Figure 2. Two-way ANOVA indicated a significant effect of weight class on TW gain ($p < 0.001$), but no effect of sex ($p > 0.05$) nor sex \times weight class interaction. Crabs in the lowest weight class (0-99 g) showed the highest relative

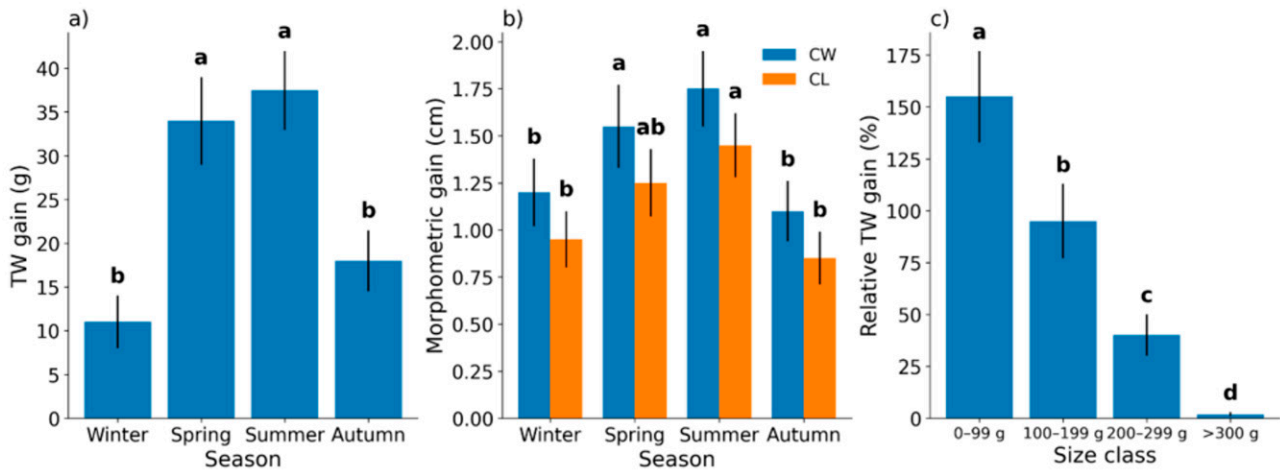


Figure 2. Seasonal and size-class growth patterns of *Cardisoma guanhumii* after 12 months in captivity. a, Total weight (TW) gain by season; b, cephalothorax width (CW) and length (CL) growth by season; c, relative TW gain by initial weight class. Bars represent mean \pm standard deviation ($n = 170$). Different superscript letters denote significant differences (Tukey's HSD, $p < 0.05$).

TW gain ($> 150\%$), whereas those above 300 g gained less than 3% (Fig. 2). Multivariate analysis of variance (MANOVA) did not detect overall differences between sexes across the 9 morphometric variables. However, a significant interaction was found for cephalothorax length (CL) between sex and season ($p = 0.02$).

Discussion

The relatively high survival rate can be attributed to the design of the artificial habitat, which included multiple buried shelters, regulated humidity through simulated rainfall, access to both freshwater and saltwater, and low stocking density. These conditions have been recognized as critical factors for terrestrial crab survival under controlled environments (Herreid, 1963; Oliveira et al., 2020), likely contributing to reduced stress, enhanced shelter availability, and overall behavioral stability.

Importantly, no signs of cannibalism or excessive agonistic behavior were observed during the experimental period. This contrasts with other decapods in captivity where confinement and competition for space often lead to significant mortality, as reported by Bauer (1986) and Fox (1975). The lack of mortality peaks during the reproductive season also suggests that the species can tolerate environmental manipulation and semi-controlled conditions without major physiological stress.

To our knowledge, this is one of the first experimental reports documenting long-term survival of *C. guanhumii* under captive conditions with ecological elements resembling natural mangrove habitats. Previous studies

Table 1

Summary of survival by sex in *Cardisoma guanhumii* after 12 months under semi-controlled conditions.

Sex	Initial number	Final number	Survival (%)
Male	132	106	80.3
Female	209	154	73.7
Combined	341	260	76.25

No statistical comparisons were performed, as crabs were maintained in a single habitat. However, survival rates by sex are reported for descriptive purposes.

on this species have primarily been limited to short-term reproductive monitoring or natural history observations (Hartnoll, 1982; Smith & Smith, 2001).

The reproductive performance observed under semi-controlled conditions confirms that *C. guanhumii* is capable of adapting its reproductive cycle to artificial environments with minimal intervention. The presence of mangrove vegetation, natural soil substrate, and controlled humidity may have played a key role in maintaining environmental cues necessary for ovarian development and spawning behavior, as shown in studies on similar species (Mariappan et al., 2000; Silva & Oshiro, 2002). Unlike studies performed under purely laboratory conditions, where reproductive inhibition is common in terrestrial crabs, this setup offered a more ecologically relevant habitat, favoring reproductive success. The relatively high frequency of ovigerous females obtained without hormonal induction

or photoperiod manipulation highlights the potential of *C. guanhumi* for captive broodstock development. Given the limited number of experimental studies on reproductive ecology in this species, these findings contribute novel evidence for its suitability in aquaculture and conservation-based culture systems.

The observed growth pattern in *C. guanhumi* under captive conditions may reflect a typical crustacean molting mechanism, in which the inner layer of the old exoskeleton is reabsorbed prior to ecdysis and a new cuticle is secreted and later calcified. This process allows size increase while maintaining structural stability of the carapace in adults. The reabsorption of calcium and other minerals, and their temporary storage in gastroliths or the hepatopancreas, has been well documented in decapods (Chang, 1995; Greenaway, 1985; Skinner, 1985), and is particularly relevant in land crabs due to limited environmental calcium availability.

Although somatic growth in decapod crustaceans is typically associated with molting events, the sustained morphometric increases observed in this study, in the apparent absence of clearly detectable ecdysis, may reflect subtle molting events, mineral recycling dynamics, or cuticular remodeling processes not externally observed. Similar mechanisms have been discussed in other decapods under stable environmental conditions (Chang, 1995; Greenaway, 1985; Skinner, 1985).

This physiological flexibility may represent an adaptive response of semi-terrestrial crabs to fluctuating environmental constraints (Anger, 2013; Zimmer et al., 2019). Further studies incorporating histological and endocrine approaches would help clarify the mechanisms underlying the morphometric patterns recorded here (Hartnoll, 2001). Similar sex-based morphometric assessments have been conducted in other brachyurans such as *Menippe mercenaria*, where cheliped development is linked to territorial behavior and reproductive strategies (Bauer, 1986; Savage & Sullivan, 1978).

Cardisoma guanhumi can be maintained under semi-controlled conditions with high survival and reproductive performance. The sustained morphometric growth recorded during the study provides a baseline for understanding its physiological responses in captivity and supports its potential for ex situ conservation and aquaculture applications.

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