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# Dynamics of commercial size interval populations of female redclaw crayfish (*Cherax quadricarinatus*) reared in gravel-lined ponds: A stochastic approach

José Naranjo-Páramo, Alfredo Hernández-Llamas, Mayra Vargas-Mendieta, Laurence Mercier, Humberto Villarreal*

*BioHelis, Innovation and Technology Park, Northwest Biological Research Center (CIBNOR), Calle Instituto Politécnico Nacional # 195, La Paz B.C.S. 23096, Mexico*

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ABSTRACT

The objective of the present study was to establish the impact of monosex-female redclaw crayfish (*Cherax quadricarinatus*) culture in gravel-lined ponds, by using a stochastic approach to analyze production dynamics for the 40–60 g, 61–90 g and > 90 g commercial-size intervals. After growing female redclaw crayfish 17 weeks in 2500 $m^2$ gravel-lined ponds stocked at 6 females $m^{-2}$, mean final weight was 80.53 ± 0.70 g, survival was 76.2 ± 1.7% and FCR was 0.82 ± 0.10. Overall, yields averaged 0.26 t $ha^{-1}$, 2.12 t $ha^{-1}$ and 0.99 t $ha^{-1}$, respectively, for the 40–60 g, 61–90 g and > 90 g size intervals. This resulted in a mean total biomass of 3.39 t $ha^{-1}$ and a commercial biomass of 3.3 t $ha^{-1}$. Values of the coefficient of variation of total commercial biomass indicated a maximum certainty in production after 10 weeks, when percentages of recruitment of the 40–60 g and 61–90 g size intervals were similar. The contribution of the > 90 g size interval was negligible, and the total composition of the commercial population was more homogeneous. The sensitivity analysis showed consistency of the simulation model. After 10 weeks, variability of the commercial biomass is particularly influenced by the rate at which mean individual weight ($w_{t.}$) changes from its initial value to its final value ($k$). In contrast, after 17 weeks the variability of $k$ was not relevant in determining the variance of commercial biomass, because the influence of $k$ progressively diminishes as the final weight of crayfish is approached.

Results from the Monte Carlo simulation indicated that, when increasing sample size from one pond to 100 ponds, variability in production forecasts was reduced 89.8%.

The present study demonstrates the feasibility of monosex-female redclaw crayfish culture in gravel-lined ponds. It also shows that the stochastic approach used to analyze production dynamics for the 40–60 g, 61–90 g and > 90 g commercial-size intervals is an important tool to evaluate the impact of size classes on total production and commercial yields. According to our results, we recommend an initial stocking density of 6 organisms $m^{-2}$ for commercial monosex grow-out of females in gravel-lined ponds.

## 1. Introduction

The redclaw, *Cherax quadricarinatus*, is a species with adequate characteristics for cultivation. Jones (1995), Masser and Rouse (1997), and Villarreal (2000) indicated that the species tolerates temperatures from 5 to 32 °C, with an optimum at 26–28 °C. Cortés-Jacinto et al. (2004) and Saoud et al. (2012), among others, reported a nutritional requirement of crude protein and lipids for grow-out ranging from 20 to 30% and 5–10%, respectively. Rapid growth, tolerance to wide variations in water quality and adaptability to intensification make the redclaw crayfish suitable for commercial production (Anson and Rouse, 1994; Naranjo and Villarreal, 2002; Villarreal, 2000). Jones (1990) indicated that the species could reach 100 g in 240 days, depending on density. Table 1 shows a selected group of growth studies for *C. quadricarinatus* at different sizes and stocking densities. Naranjo-Páramo et al. (2004), in particular, evaluated the effect of different densities for the juvenile phase in commercial gravel-lined ponds, obtaining growth rates from 1.7 to 2.4 g $week^{-1}$. More recently, Nuñez-Amao et al. (2016) showed that intensification is possible for male and female redclaw culture, using doubled the stocking densities compared to those reported by Soowannayan et al. (2015), and generating growth rates of 2 g $week^{-1}$ with yields up to 2600 kg $ha^{-1}$ for females. Nevertheless, size heterogeneity could still become an issue for commercial size production of females, as the price of redclaw crayfish is dependent on individual weight (Stevenson et al., 2013). Hutchings and Villarreal (1996) proposed a management strategy for redclaw cultivation incorporating a mixed-sex nursery stage to 20 g, followed by a monosex grow-out, since males grow faster and attain a larger size than

* Corresponding author.
*E-mail address:* humberto04@cibnor.mx (H. Villarreal).

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**Table 1**
Selected growth studies for *C. quadricarinatus* at different sizes and stocking densities.

| Size (g) | Density (Org $m^{-2}$) | Reported by |
|---|---|---|
| 2.9[a] | 0.75 | Karplus et al. (1995) |
| 3 | 15 | Hutchings and Villarreal (1996) |
| 25 | 6 | Hutchings and Villarreal (1996) |
| 3.2 | 1, 3 and 5 | Pinto and Rouse (1996) |
| 1.05 | 5.5 | Sagi et al. (1997) |
| 42 | 1 | Sagi et al. (1997) |
| 4.6–17.01 | 3, 9 and 15 | Jones and Ruscoe (2000) |
| 7.1[b] | 20 | Karplus et al. (2001) |
| 1.3 | 5, 6, 8, 11 and 20 | Naranjo-Páramo et al. (2004) |
| 8.1 | 1.2, 1.8, and 2.4 | Webster et al. (2004) |
| 9.6 | 4 and 6 | Rodgers et al. (2006) |
| 1.5 | 4 | Soowannayan et al. (2015) |
| 2.5 | 15 | Nuñez-Amao et al. (2016) |
| 20 | 6 | Nuñez-Amao et al. (2016) |
| 30 | 1, 2, 5 and 6 | Present study |

[a] Polyculture.
[b] Intensive polyculture.

females (Curtis and Jones, 1995; Karplus et al., 1995). Rodgers et al. (2006) demonstrated the benefit of monosex male-only culture of redclaw crayfish as opposed to female-only or mixed-sex culture. Bioenergetically, males channel more of their energy towards somatic growth rather than reproduction (Rodríguez-González et al., 2009). Soowannayan et al. (2015) indicated that females stop growing when they reach maturity, due to the development of gonads, so they are harvested to reduce size heterogeneity, allowing males to grow to 100 g in 240 days. This reported lack of female growth for the species could represent a problem in terms of farm profitability. Nevertheless, Curtis and Jones (1995) have indicated that, in the absence of males, reproductive output of females is greatly diminished, potentially resulting in faster growth rates.

To our knowledge, modeling size heterogeneity of crayfish has only been addressed by Nuñez-Amao et al. (2016), who studied dynamics of the intensive commercial production of redclaw crayfish, in 2500 $m^2$ (25 × 100 m) earthen ponds lined with a 0.5-mm HDPE membrane. In the current study, we used a stochastic model to evaluate culture in 2500 $m^2$ earthen ponds lined with gravel. This is the proper mathematical method for analysis whenever random variability is being considered in the treatment of biological processes (Batschelet, 1971). Stochastic models are useful tools for decision making when uncertain and risky events are involved (Clemen and Reilly, 2014), such as production dynamics. The model was calibrated using production data from a commercial farm in Ecuador, to determine the adequacy of the model as a prediction tool.

The objective of the present study was to establish the impact of monosex-female redclaw crayfish (*Cherax quadricarinatus*) culture in gravel-lined ponds by using a stochastic approach to analyze the production dynamics for the 40–60 g, 61–90 g and > 90 g commercial-size intervals.

## 2. Material and methods

### 2.1. Experimental conditions

Grow-out trials were conducted in eight gravel-lined ponds (2500 $m^2$ each, 100 × 25 m) in a commercial farm near Churute, Province of Guayas, Ecuador. Two types of shelters were used for crayfish protection in each pond: 250 bundles made of 10 1 $m^{-2}$ synthetic mesh sheets, with a pore size diameter of 5 mm, were placed around the perimeter of the ponds; and baked clay bricks (25 × 15 × 12 cm) with four orifices (diameter = 6 cm). The synthetic weave provides shade and shelter, and increases surface area as a substrate for biofloc accumulation, thus facilitating grazing by the crayfish. The bricks were distributed homogeneously over the pond bottom to offer the equivalent of 100% hiding places to the crayfish population.

Freshwater from a well was used to fill ponds to 1.3 m depth. Water was exchanged at 5% daily. Inorganic fertilizer (Nutrilake®, 3:1 nitrogen:superphosphate; 6 kg $ha^{-1}$) was initially used to stimulate natural productivity, and when water transparency exceeded 45 cm. Aeration was supplied continuously with a 1-HP paddlewheel aerator (Hangzhou Ocean Industry Co., Hangzhou, China) in each pond.

Female redclaw (31.1 ± 1.08 g) were obtained by harvesting nursery ponds after roughly 90 days (Naranjo-Páramo et al., 2004), and stocked in duplicate gravel-lined grow-out ponds at four stocking densities: 1, 2, 5, and 6 individuals $m^{-2}$. Individual weight was recorded weekly, from random samples of 60 crayfish per pond, using a digital balance (Ohaus®, Parsippany, NJ; ± 0.01 g). Final survival and biomass were calculated at the end of the trial (119 days).

A commercial pellet feed for crayfish (Rangen-Balrosario, Guayaquil, Ecuador, (28% crude protein, 5% total lipids) was offered once a day (5:00 pm) following Naranjo-Páramo et al. (2004). Feed was scattered by hand following a relationship between crayfish weight and feed rate (as % of biomass) (Table 2). The food conversion ratio (FCR) was established as the total feed ministered divided by the total harvested biomass (kg).

Temperature (T), dissolved oxygen (DO), and pH were measured daily using a multiparameter YSI Professional Plus probe (YSI Incorporated, Yellow Springs, Ohio, USA). Data was obtained at 70 cm of pond depth. Turbidity was measured using a Secchi disk. The dissolved oxygen sensor was calibrated preparing 8 g of $Na_2SO_3$ diluted in 500 mL of distilled water. After 60 min, the sensor was immersed in the solution for a 0 mg $L^{-1}$ calibration. After rinsing, the second point was obtained in water-saturated air. Calibration for the pH sensor was accomplished with pH 7 and pH 10 buffers provided by YSI. Water samples were taken weekly to measure dissolved ammonia, nitrate and nitrite using an optical DRELL 2000 spectrophotometer (HACH®, Loveland, Colorado, USA) following methodologies described by the manufacturer. Ammonia determination is based on the indophenol method, where ammonia reacts with alkaline salicylate in the presence of chlorine to form a green-blue indophenol complex. Equipment calibration for ammonia used a stock solution with 3.82 g of $NHCl_4$, dried at 105 °C, in ammonia-free reagent water, and diluted to 1 L, where 1 mL = 1 mg NH3-N. Standard solutions 1/10, 1/100, 1/1000 were prepared by dilution in water and read at 690 nm. Nitrate is first reduced to nitrite, using a zinc-based solution. Nitrite is then determined by reaction with sulphanilic acid in the presence of N-(1-naphthyl)-ethylene diamine to form a reddish dye. A standard curve was done using dilutions of a solution of 200 µM $NaNO_2$ and read at 540 nm absorbance. For all nutrient tests, resulting color intensity is directly proportional to concentration. In addition, hardness (as calcium carbonate), alkalinity (as calcium carbonate), phosphate, iron and copper were occasionally assayed from incoming water. Hardness determination was done using Eriochrome Black T indicator [1-(1-hydroxy-2-naphthylazo)-6-nitro-2-naphthol-4-sulfonic acid] and titration with $Na_2EDTA$ (ethylenediaminetetraacetic acid, disodium salt) solution.

**Table 2**
Relationship between crayfish weight and feed rate (as % percentage of biomass).

| Feed rate (% biomass) | Redclaw weight (g) |
|---|---|
| 0.80 | 31.1–46.5 |
| 0.75 | 46.6–50.5 |
| 0.70 | 50.6–56.5 |
| 0.65 | 56.6–73.5 |
| 0.65 | 73.6–100.0 |
| 0.50 | > 100 |