Estimating the impact of COVID-19 pandemic on alternative semi-intensive shrimp (*Penaeus vannamei*) production schedules in Mexico: a stochastic bioeconomic approach

Javier M. J. Ruiz-Velazco¹,² · Margarita Estrada-Perez² · Nallely Estrada-Perez¹ · Alfredo Hernández-Llamas³

Received: 8 February 2022 / Accepted: 27 July 2022 / Published online: 6 August 2022
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2022

Abstract
This study uses a stochastic bioeconomic approach to estimate the COVID-19 pandemic economic impact on shrimp farming in Mexico. Seeding-harvesting schedules — March–June, May–August, and August–November — were analyzed using shrimp prices and production costs corresponding to 2017–2019 (pre-pandemic) and 2020 (pandemic). The analyses estimated net revenue varied within 597.97–2758.88 USD$ ha⁻¹ and 1262.40–1701.32 USD$ ha⁻¹ under the pre-pandemic and pandemic scenarios, respectively. Significant decreases (38%) were estimated in net revenue values in March–June and May–August under the pandemic scenario. However, probability distributions estimated that uncertainty on the expected net revenues was not affected by the pandemic conditions, and the probability of losing was null or negligible in all the cases. Unfavorable conditions under the pandemic also required significantly higher break-even production for March–June (25.7%) and May–August (28.5%) schedules. The cost of post-larvae was the most important economic factor influencing net revenue. To conclude, although the operating conditions during the pandemic were conducive to worsening the economic outcome, no evidence still exists that uncertainty and economic risk increased compared with pre-pandemic conditions.

Keywords COVID-19 pandemic · Stochastic bioeconomics · Shrimp production · Economic risk

Introduction
COVID-19 pandemic (from now on, “pandemic”) has been causing major problems worldwide and significant damage to the global economy. The seafood sector, like most industries, has to deal with a negative outlook on demand and several obstacles in supply
Global shrimp and salmon production was expected to be the most affected by the pandemic (FAO and Eclac, 2020).

Several reports have been prepared regarding how the pandemic has affected aquaculture activities worldwide. Kakoolaki et al (2020) estimated its potential socio-economic effects on the world shrimp aquaculture sector during its early stages. Waiho et al. (2020) evaluated the pandemic impact on Malaysia aquaculture sector and discussed the potential effectiveness of the coping strategies implemented. The pandemic impact in Bangladesh was assessed by Rafiquzzaman (2020). Islam et al. (2021) discussed the case of Bangladesh to suggest a set of immediate and long-term changes to policy and plans to recover aquaculture and fishery sectors from the pandemic. Lebel et al. (2021) studied the effects of public health responses to the pandemic on aquaculture farmers in the Mekong Region. A sectoral assessment of the pandemic impact on aquaculture in India was conducted by Kumaran et al. (2021). Akter and Khan (2021) showed shrimp farming as a case study of the pandemic economic impacts on southwestern Bangladesh.

According to Betanzo-Torres (2020), fish farmers and seafood traders in Mexico reported that sales during Easter week (April 5–11, 2020) were down 60% compared with the previous year and relatively low prices due to low demand and tourism activity shutdown. Martínez-Cordero et al. (2020) surveyed tilapia producers in Mexico, indicating that most of the farmers scheduled harvesting on Easter and Easter week during the pandemic, but sales dropped 50% on average, and tilapia prices decreased about 15–17% due to the confinement.

The reports mentioned above have been prepared based on surveys of the regional or sectoral impact of the pandemic on aquaculture, but estimations of the quantitative economic impact caused at the individual farms level have remained unaddressed. This study focuses on assessing such impact on the typical shrimp production of farmers operating in the state of Nayarit, Mexico, which, together with the states of Sinaloa and Sonora, constitute the most important shrimp producers in Mexican aquaculture CONAPESCA Comisión Nacional de Acuicultura y Pesca (2018). A bioeconomic approach was used for evaluating the pandemic impact from a detailed dynamical perspective rather than an overall static description.

The stock model presented by Ruiz-Velazco et al. (2013) and Estrada-Pérez et al. (2015) was used to analyze the seeding-harvesting schedules: March–June, May–August, and August–November. Surveys among shrimp farmers, post-larvae hatchery managers, and feed manufacturers were conducted to update production costs and shrimp prices before (2017, 2018, and 2019) and during (2020) the COVID-19 pandemic. In addition, stochastic elements were incorporated into the analyses to account for the uncertainty and economic risk involved in the expected outcomes.

To our knowledge, no such study has been previously conducted and reported in the literature.

**Materials and methods**

**Database**

Primary production data from semi-intensive shrimp farms were used for stock model calibration as described by Ruiz-Velazco et al. (2013) and Estrada-Pérez et al. (2015). Table 1 summarizes the mean values of the general operating conditions.
Stock model

The model proposed by Ruiz-Velazco et al. (2013) predicts shrimp biomass as a function of time as the product of shrimp individual mean weight and surviving shrimp population. The following equation in the model by these authors serves to predict shrimp growth:

\[ w_t = w_i + \left( w_f - w_i \right) \left( \frac{1 - k^t}{1 - k^h} \right)^3 \]  

(1)

where \( w_t \) is the mean individual weight predicted after \( t \) time units; \( w_i \) is initial weight; \( w_f \) is final weight; \( k \) is a growth coefficient; and \( h \) is the number of time units at harvest time.

On the other hand, the authors use the negative exponential equation to calculate surviving shrimp population (\( n_t \)):

\[ n_t = n_0 e^{-zt} \]  

(2)

where \( n_0 \) is initial population and \( z \) is the instantaneous mortality rate.

Multiple regression equations and stochastic elements

Using multiple regression analyses, Ruiz-Velazco et al. (2013) established relationships between the stock model parameters and water quality and management. This investigation incorporates the residual errors obtained from those analyses as stochastic elements in the bioeconomic model. Table 2 shows the equations and error distributions obtained from the analyses.

The multiple linear regression procedure available in Stata 17 (Stata Corp, College Station, TX) was used for the analyses, which deals automatically with multicollinearity according to the methods described by Rencher (2002). Tests for violation of linear regression assumptions available in Stata 17 indicated data adequacy.

### Table 1
Mean (± standard deviation) values of rearing conditions and production variables of semi-intensive shrimp *Penaeus vannamei* farming during alternative seeding-harvesting schedules

| Variable                        | Schedule                     |
|---------------------------------|------------------------------|
|                                 | March–June                   | May–August                   | August–November              |
| Temperature (°C)                | 31.02 ± 0.63                 | 31.98 ± 0.15                 | 31.14 ± 0.68                 |
| Dissolved oxygen (mg L\(^{-1}\)) | 4.86 ± 0.75                  | 3.90 ± 0.23                  | 4.33 ± 0.39                  |
| Stocking density (post-larvae m\(^{-2}\)) | 15.07 ± 1.53                | 26.22 ± 5.67                 | 20.14 ± 5.24                 |
| Rearing duration (weeks)        | 10.50 ± 1.10                 | 11.94 ± 1.13                 | 12.86 ± 1.77                 |
| Yield (t ha\(^{-1}\))          | 1.13 ± 0.12                  | 1.80 ± 0.48                  | 1.6 ± 0.37                  |
Feed conversion ratio model

The feed conversion ratio (FCR) showed an increasing linear trend throughout the rearing period, and the linear equation predicted it as a function of time \((t)\) according to:

\[
FCR_t = a + bt
\]  

where \(a\) and \(b\) are regression coefficients whose values are in turn calculated using the multiple regression equation:

\[
a = 1.491087 - 0.0316577 T + \epsilon 5
\]  

and,

\[
b = nml(0.08, 0.02)
\]

where \(T\) is pond water temperature; \(nml\) is the normal distribution with mean and standard deviation within parentheses; and \(\epsilon 5 = nml (0.0, 0.05)\).

Economic model

This model calculates net revenue \((nr, \text{ in USD}\$\) with 19.13 MXN per USD\$ exchange rate) as a function of time \((t)\) according to:

\[
nr_t = i_t - c_t
\]

where income \((i_t)\) is the product of shrimp biomass from the stock model and farm-gate shrimp price, and \(c_t\) are the costs considered for analysis, namely:

\[
c_t = cfeed_t + cfert_t + ce_t + cPL + cpp + cl + cma + cmi + ch
\]

where \(cfeed\) is the cost for feed; \(cfert\) for fertilizer; \(ce\) for energy; \(cPL\) for post-larvae; \(cpp\) for pond preparation; \(cl\) for labor; \(cma\) for maintenance; \(cmi\) for miscellaneous; and \(ch\) for harvesting. The benefit/cost ratio \((B/C)\) was also calculated as: \(B/C_t = i_t / c_t\). Sale shrimp prices and unitary costs were obtained from personal communications (Tables 3, Table 2. Multiple regression equations used to predict the values of the stock model parameters as a function of water quality and management variables. Normal distributions (nml) with zero mean values were used to generate error values (\(\epsilon\)) for parameters and variables. The standard deviations of the distributions are within parentheses. A distribution was fitted to coefficient \(k\) values directly after no significant result was obtained from the corresponding regression analysis.

| Equation | Error distribution |
|----------|-------------------|
| Stock model parameters: | |
| \(w_f = -25.2436 + 0.9678 T + 0.5329 RD + \epsilon 1\) | \(\epsilon 1 = nml (1.39)\) |
| \(k = nml (0.83, 0.06)\) | |
| \(z = 0.0916 - 0.0081 DO + 0.0010 D - 0.0034 RD + \epsilon 2\) | \(\epsilon 2 = nml (0.01)\) |
| Water quality and management variables: | |
| \(T = 0.049 D + 30.36 + \epsilon 3\) | \(\epsilon 3 = nml (0.61)\) |
| \(DO = 6.51 - 0.036 D - 0.1175 RD + \epsilon 4\) | \(\epsilon 4 = nml (0.60)\) |

\(T\) mean pond water temperature, \(RD\) rearing duration, \(DO\) dissolved oxygen, \(D\) stocking density.
The same parameter values of the stock model, regression equations, and FCR model were used for 2017–2019 and 2020.

Random variability in feed and post-larvae unitary costs and shrimp sale prices for the pre-pandemic scenario was incorporated as follows: (1) regression analyses served to determine whether ascending or descending trends existed during the period; (2) when no significant trend was detected ($p \geq 0.05$), cost or price values were pooled, and a Program Evaluation and Review Technique (PERT) distribution was used with the minimum, maximum and most likely parameters estimated from the pooled set values; (3) when a significant trend was determined, a normal error

### Table 3
Shrimp sale price mean values (USD$ kg^{-1}$) used for analyses during pre-pandemic and pandemic scenarios

| Shrimp size (g) | Pre-pandemic | Pandemic |
|----------------|--------------|----------|
| 7              | 3.53         | 3.66     |
| 8              | 3.44         | 3.44     |
| 9              | 3.72         | 3.51     |
| 10             | 3.90         | 3.84     |
| 11             | 4.10         | 3.73     |
| 12             | 4.35         | 3.93     |
| 13             | 4.34         | 4.16     |
| 14             | 4.29         | 4.20     |

Shrimp prices were obtained by personal communications (Encarnación Torres, Productora y Comercializadora de Camarón, J. Rangel Becerra Zepeda, December 2020)

### Table 4
Unitary cost estimates. Shrimp post-larvae and feed costs were the only ones differing among the pre-pandemic and pandemic operating conditions

| Costs                        | Pre-pandemic | Pandemic |
|------------------------------|--------------|----------|
| Post-larvae (USD$ thousand^{-1}$) | 4.50 (pre-pandemic), 5.34 (pandemic) |
| Feed (USD$ kg^{-1}$)         | 0.82 (pre-pandemic), 0.92 (pandemic) |
| Fertilizers (USD$ kg^{-1}$)  | 0.95         |
| Energy (USD$ kwh^{-1}$)      | 0.15         |
| Pond preparation (USD$ ha^{-1} yr^{-1}$) | 115.38 |
| Labor (USD$ ha^{-1} yr^{-1}$) | 2352.00      |
| Maintenance (USD$ ha^{-1} yr^{-1}$) | 481.15 |
| Miscellaneous (USD$ ha^{-1} yr^{-1}$) | 157.31 |
| Harvesting (USD$ shrimp kg^{-1}$) | 0.10         |

Post-larvae and feed prices were obtained by personal communications (Gonzalo Abundis, Policultivos Intensivos de Nayarit, February 2021) (Venancio Torres, Alimentos Balanceados Camaronay, March 2021)
Table 5 Minimum (Min), maximum (Max), and most likely (ML) program evaluation and review technique (PERT) distribution parameter estimates, and error normal distributions (nml: mean, standard deviation) used for stochastic values calculation of feed and post-larvae unitary costs and shrimp sale prices during the pre-pandemic and pandemic scenarios. ML = (6 mean–Min–Max)/4

| Distributions | Prices | Pre-pandemic | | | | | | Pandemic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PERT | NORMAL | PERT | | nml | | | | | | |
| Feed | 0.79 | 0.86 | 0.81 | 0.0045, 0.0005 | 0.82 | 0.94 | 0.93 |
| Post-larvae | | | | | | | | | | | | |
| Shrimp (7 g) | | | | | | | | | | | | |
| M-J | 3.02 | 3.77 | 3.40 | 3.00 | 3.70 | 3.34 |
| M-A | 3.54 | 3.78 | 3.66 | 3.51 | 3.70 | 3.63 |
| A-N | Not available | Not available | | | | |
| Shrimp (8 g) | | | | | | | | | | | | |
| M-J | 3.16 | 3.95 | 3.55 | 3.16 | 3.95 | 3.55 |
| M-A | 3.35 | 3.40 | 3.38 | 3.35 | 3.38 | 3.36 |
| A-N | 3.23 | 3.52 | 3.41 | 3.23 | 3.52 | 3.41 |
| Shrimp (9 g) | | | | | | | | | | | | |
| M-J | 3.16 | 3.95 | 3.59 | 3.46 | 3.65 | 3.55 |
| M-A | 3.71 | 4.39 | 3.97 | 3.24 | 3.55 | 3.40 |
| A-N | 3.43 | 3.73 | 3.62 | 3.50 | 3.66 | 3.59 |
| Shrimp (10 g) | | | | | | | | | | | | |
| M-J | 3.76 | 4.70 | 4.23 | 3.97 | 4.18 | 4.08 |
| M-A | | 3.72, 0.15 | 3.55 | 3.76 | 3.62 |
| A-N | 3.55 | 3.87 | 3.75 | 3.76 | 3.87 | 3.82 |
| Shrimp (11 g) | | | | | | | | | | | | |
| M-J | 3.92 | 4.76 | 4.55 | 3.66 | 3.92 | 3.81 |
| M-A | 3.81 | 4.19 | 4.04 | 3.35 | 3.61 | 3.41 |
| A-N | 3.81, 0.05 | 3.92 | 3.97 | 3.95 |
| Shrimp (12 g) | | | | | | | | | | | | |
| M-J | 4.30 | 5.22 | 4.99 | 3.76 | 4.08 | 3.95 |
| M-A | 3.80 | 4.35 | 4.23 | 3.66 | 3.76 | 3.69 |
| A-N | 3.66 | 4.18 | 3.96 | 4.13 | 4.18 | 4.16 |
| Shrimp (13 g) | | | | | | | | | | | | |
| M-J | 4.30 | 5.21 | 4.99 | 3.92 | 4.18 | 4.05 |
| M-A | 3.96 | 4.35 | 4.20 | 3.96 | 4.35 | 4.20 |
| A-N | 3.71 | 4.18 | 3.93 | 4.18 | 4.29 | 4.23 |
| Shrimp (14 g) | | | | | | | | | | | | |
| M-J | 4.30 | 5.22 | 4.99 | 4.18 | 4.34 | 4.25 |
| M-A | 4.05 | 4.46 | 4.30 | 4.05 | 4.46 | 4.30 |
| A-N | 4.08 | 4.29 | 4.18 | 4.08 | 4.44 | 4.33 |

Post-larvae, feed, and shrimp prices were obtained by personal communications: Gonzalo Abundis, Policultivos Intensivos de Nayarit, February 2021; Venancio Torres, Alimentos Balanceados Camaronay, March 2021; Encarnación Torres, Productora y Comercializadora de Camarón, J. Rangel Becerra Zepeda, December 2020

M-J March–June, M-A May–August, A-N August–November
distribution resulting from the regression analysis was used to add random error values to cost or price (Table 4). Given that the pandemic scenario corresponded to a single year, random variability in prices was incorporated using PERT distributions as described above with the parameters estimated from data costs and prices collected during 2020 (Table 5).

**Stochastic break-even analysis**

The following formula calculates the production yielding break-even situations ($BP$) (Parakin, 1996):

$$BP = FC/(UI − UVC)$$  \hspace{1cm} (8)

where $FC$ are the fixed costs; $UI$ and $UVC$ are the unit income (shrimp price/kg) and unit variable cost/kg of shrimp produced.

**Monte Carlo simulation and statistical and sensitivity analyses**

The bioeconomic model was programmed in Excel 2019, and probability distributions for $nr_p$ and break-even production under the different scenarios were inferred with Monte Carlo simulation using @RISK v.8.1 (Palisade Corp., Ithaca, NY, USA). Following Ayyub (2014), the expected $nr_p$ value measures average return, whereas the standard deviation measures dispersion in $nr_p$, reflecting uncertainty associated with the outcome. According to the author, the coefficient of variation (ratio standard deviation/mean) is thus a measure of uncertainty per unit value of the expected $nr_p$. This study adopts such a coefficient (CV) as an uncertainty indicator. Zar (2010) explains the $t$-test and $Z$-test used in this investigation to determine whether the pandemic situation significantly affected the economic benefits (mean $nr_p$), uncertainty (CV), and break-even production ($BP$) when compared with the pre-pandemic situation, setting significance at $α = 0.05$. On the other hand, the loss probability estimated from the $nr_p$ probability distribution served as an economic risk indicator.

A sensitivity analysis was also conducted to estimate the contribution to uncertainty of the bioeconomic model parameters and water quality variables. This analysis used the multiple regression routine in @Risk 8.1 (Palisade, Ithaca, NY, U.S.A.) with “mapped” regression coefficients indicating the amount $nr_p$ is modified per standard deviation unit of each model parameter, thus contributing to its uncertainty.

**Results**

According to net revenue values, the best harvesting times for the pre-pandemic period were estimated at the end of March–June and May–August schedules (i.e., 11 weeks; Fig. 1). However, during the pandemic period, the best harvesting time was 10 weeks in both schedules (Fig. 1). In August–November schedule, no differences were estimated regarding harvesting time (11 weeks) in both scenarios (Fig. 1). The $B/C$ ratio was maximized simultaneously as $nr_p$, except for May–August and August–November schedules in the pre-pandemic situation.
Figure 2 shows the probability distributions of $nr_t$ values inferred from the Monte Carlo simulation for the three schedules at their best harvesting times under the pre-pandemic and pandemic scenarios. Net revenue varied from 1597.97 to 2758.88 USD$ ha$⁻¹ and from 1262.40 to 1701.32 USD$ ha$⁻¹ under the pre-pandemic and pandemic scenarios. The $t$-test indicated that during the pandemic scenario, significant decreases (38%) were estimated in net revenue values in March–June and May–August schedules. In contrast, no significant differences existed in the August–November schedule between the pre-pandemic and pandemic conditions. On the other hand, the $Z$-test indicated that mean CV values did not vary significantly among the schedules, and the probability of losing was null or negligible in all the cases. The inferred probability distributions for the $B/C$ ratio when its maximum values occurred indicated better results for the pre-pandemic period (1.46–1.69) than those resulting from the pandemic scenario (1.38–1.41).

Table 6 summarizes the results obtained from the inferred probability distributions for $BP$. The pandemic conditions required a significantly higher mean $BP$ for March–June (25.7%) and
May–August (28.5%) schedules, while no significant difference existed for the August–November schedule. Obtaining mean $BP$, however, does not impede the possibility of losing. The probability of loss was very similar in all the cases and slightly varied around 55.8%. The probability distributions showed that to minimize loss probability to 5%, $BP$s 20.7 to 29.5% higher than the mean $BP$ were necessary. Mean $BP$ represented 23.6 to 36.8% of the total mean productive capacity, while the percentage corresponding to the $BP$ required for 5% loss probability ranged from 29.3 to 45.8%. Except for the August–November schedule, the mean total production percentages required for mean $BP$ and 5% loss probability were higher under the pandemic scenario.

Fig. 2 Probability distributions of net revenue for the alternative seeding-harvesting schedules under the pre-pandemic (17–19) and pandemic (20) scenarios. The values corresponding to the dashed lines indicate the 95% probability intervals. Different letters indicate significant differences among the scenarios for each schedule separately. SD standard deviation, CV coefficient of variation, LP loss probability
**Table 6** Stochastic break-even production analysis results for the alternative seeding-harvesting schedules under pre-pandemic and pandemic conditions. Different letters indicate significant differences for each schedule between both conditions.

| Schedule                        | Mean total production (kg ha⁻¹) | Mean BP (kg ha⁻¹) | LP for mean BP (%) | BP for 5% LP (kg ha⁻¹) | MPP-MBP (%) | MPP-5% LP |
|---------------------------------|---------------------------------|-------------------|-------------------|------------------------|-------------|-----------|
| March–June (pre-pandemic)       | 1114.3                          | 326.5a            | 56.6              | 404.1                  | 29.3        | 36.3      |
| March–June (pandemic)           | 1114.3                          | 410.4b            | 54.5              | 495.5                  | 36.8        | 44.5      |
| May–August (pre-pandemic)       | 1794.0                          | 423.2a            | 56.4              | 526.4                  | 23.6        | 29.3      |
| May–August (pandemic)           | 1794.0                          | 543.9b            | 55.7              | 694.0                  | 30.3        | 38.7      |
| August–November (pre-pandemic)  | 1400.2                          | 495.0a            | 56.7              | 641.2                  | 35.4        | 45.8      |
| August–November (pandemic)      | 1400.2                          | 486.1a            | 54.8              | 599.1                  | 34.7        | 42.8      |

*BP* break-even production, *LP* loss probability, *MPP-MBP* mean total production percentage required for mean BP, *MPP-5% LP* mean total production percentage required for 5% LP.
Table 7 Results of the sensitivity analysis of net revenue to the stochastic variability of the bioeconomic model parameters for the alternative seeding-harvesting schedules under pre-pandemic and pandemic scenarios. The values indicate the net revenue/ha change per parameter standard deviation unit.

| Schedules          | March–June | May–August | August–November |
|--------------------|------------|------------|-----------------|
|                    | Pre-pandemic Parameter | Pandemic Parameter | Pre-pandemic Parameter | Pandemic Parameter | Pre-pandemic Parameter | Pandemic Parameter |
| $W_f$              | 423.7      | 344.8      | Z $-575.3$      | Wf $430.5$        | Z $-392.8$           | Z $-417.1$         |
| $Z$                | $-409.0$   | $-307.6$   | $W_f$ $532.8$   | $Z$ $-418.4$      | $W_f$ $376.9$        | $W_f$ $401.4$      |
| $c_{PL}$           | $-224.3$   | $T$ $165.15$ | $aF$ $-284.3$   | $aF$ $-250.5$     | $c_{PL}$ $-224.2$    | $aF$ $-227.6$      |
| $T$                | 198.4      | $aF$ $-156.9$ | $T$ $255.8$     | $T$ $211.4$       | $aF$ $-201.9$        | $T$ $193.2$        |
| $SP$               | 166.5      | $DO$ $124.96$ | $DO$ $234.7$    | $DO$ $170.1$      | $T$ $181.8$          | $DO$ $169.2$       |
| $DO$               | 166.2      | $k$ $-59.82$ | $c_{PL}$ $-225.4$ | $k$ $-131.0$     | $DO$ $160.1$        | $bF$ $-56.8$       |
| $aF$               | $-157.5$   | $SP$ $42.27$ | $c_{feed}$ $-147.4$ | $bF$ $-67.7$     | $SP$ $67.2$          | $k$ $-45.8$        |
| $bF$               | $-40.5$    | $bF$ $-42.10$ | $SP$ $126.5$    | $SP$ $64.9$       | $bF$ $-50.8$         | $c_{feed}$ $-31.2$ |
| $c_{feed}$         | $-20.2$    | $c_{feed}$ $-22.69$ | $bF$ $-68.5$   | $c_{feed}$ $-36.2$ | $k$ $-42.3$          | $c_{PL}$ $-20.1$   |
| $c_{PL}$           | $-16.26$   | $c_{PL}$ $-28.8$ | $c_{feed}$ $-24.3$ | $SP$ $13.8$      | $SP$ $13.8$          | $SP$ $13.8$        |

$W_f$ shrimp final weight, $k$ shrimp growth coefficient, $Z$ shrimp mortality rate, $T$ temperature, $DO$ dissolved oxygen, $aF$ and $bF$ regression coefficients for FCR prediction, $SP$ shrimp sale price, $c_{feed}$ feed cost, $c_{PL}$ post-larvae cost

The sensitivity analysis indicated that shrimp final weight and mortality rate were the main parameters consistently affecting $nr_t$ variability (Table 7). The post-larvae cost was the most notably economic parameter contributing to $nr_t$ variance, while pond water temperature, dissolved oxygen, and feed conversion ratio showed intermediate importance. Shrimp sale prices and feed costs were of lower importance (Table 5).

Discussion

This investigation indicates that the conditions prevailing during the pandemic impaired the economic performance of semi-intensive shrimp production during March–June and May–August 2020. Nonetheless, it is worth noting that despite the worsening economic conditions under the pandemic scenario, the probability of having losses was null or negligible.

Under the pandemic scenario in March–June and May–August 2020, the rearing time when maximum $nr_t$ values were obtained showed that harvesting a week earlier would have been preferable compared with the pre-pandemic scenario 2017–2019. At the end of the production cycles, income diminished during the pandemic because shrimp prices decreased in June (3.7–6.6%) and August (2.4–14.7%) compared with the pre-pandemic operating conditions. In contrast, in the pandemic scenario, shrimp prices rose 7.3–7.8% during November, without affecting when maximum $nr_t$ occurred because higher post-larvae (18.6%) and feed (12.2%) costs compensated for price increases.

The $B/C$ ratio is a relative index that measures the efficiency of gaining per monetary unit invested, while $nr_t$ is an absolute gain indicator, and their maximization may occur at...
different times during the production cycle. Such a case occurred in some pre-pandemic schedules, although the pandemic conditions were conducive to maximizing both indexes simultaneously.

The results showed that the conditions during the pandemic scenario did not lead to higher uncertainty (i.e., higher CV) or economic risk (i.e., loss probability) than the previous operating conditions. Nevertheless, the prevailing conditions during the pandemic impaired net revenues and B/C ratio. Shrimp prices diminished due to decreased demand for farmed shrimp, particularly during the first part of the pandemic (Solano, personal communication, 2021). Rafiquzzaman (2020), Islam et al. (2021), and Lebel et al. (2021) reported similar situations for Bangladesh and the Mekong Region, where the lockdown forced by the pandemic led to consumption and price reduction of aquaculture products. During the pandemic, the low market shrimp price has been deemed the major issue for shrimp farmers in Southwestern Bangladesh (Akter and Khan, 2021). However, this investigation found that during the pandemic, shrimp prices recovered in November and exceeded those observed in the previous years.

Increases in pelleted feed price during the pandemic also contributed to impairing net revenues and B/C ratio mainly due to rises in fishmeal (11.0%, Torres, personal communication, 2021) and fish oil (12.0%, SalmonExpert, 2021) used for manufacturing feed. Feed suppliers have embarked on a strategy to substitute fishmeal with other inputs containing vegetable protein to sustain feed prices and be competitive (Torres, personal communication, 2021). On the other hand, Mexican hatchery broodstock, feed, and live feed used for shrimp post-larvae production are priced in USD$ (Jaime, personal communication, 2021). The exchange rate rose approximately 7.2% during the pandemic, thus significantly increasing post-larvae unitary costs. Lebel et al. (2021) referred that higher input prices adversely impacted aquaculture farms in the Mekong Region during the pandemic.

When break-even production was calculated, the results obtained were consistent with those obtained for nr, and B/C, indicating that the worse conditions occurred in March–June and May–August during the pandemic. Adverse economic conditions resulting from lower shrimp prices and increased post-larvae and feed costs required higher yields to reach break-even situations than the necessary production under the pre-pandemic scenario. However, no significant differences were estimated in break-even production in August–November between both scenarios because, as explained previously, increased shrimp price in November during the pandemic compensated for higher post-larvae and feed costs.

Overall, the sensitivity analysis indicated that the number of parameters contributing significantly to nr variance was higher under the pandemic scenario, resulting in a lower influence of each parameter on nr variance per parameter unit standard deviation than in the pre-pandemic scenario. The parameter relevance was consistent in both scenarios, particularly those strongly or moderately influencing nr variance. Consequently, although the difference in shrimp prices and costs determined the economic outcome in both scenarios, their contributions to uncertainty were of little importance when analyzed within the context of each scenario.

The sensitivity analysis also showed that the most influential economic parameter was post-larvae unitary cost. As mentioned previously, hatcheries producing *Penaeus vannamei* post-larvae in Mexico determine their sale prices based on the exchange rate between the MXN and USD$ since many of their inputs come from abroad and are priced in USD$. Thus, the high sensitivity on nr to stochastic variability of post-larvae cost reflects the uncertainty associated with the exchange rate.

Several sensitivity analyses have previously shown that shrimp sale price is the most important economic factor influencing net revenue (Hernandez-Llamas and
Zarain-Herzberg, 2011; Hernández-Llamas et al., 2013; Moreno-Figueroa et al. 2019; Estrada-Perez et al. 2020; Ruiz-Velazco et al. 2021). High variability in shrimp prices and price grading by size are deemed the leading causes of shrimp price relevance by those authors. However, in this investigation, shrimp price was not the most influential economic parameter because its values were relatively stable from 2017 to 2019 and in 2020, and the differences in price among shrimp sizes were minor.

Conclusion

This study concludes that operating conditions during the COVID-19 pandemic were conducive to worsening the economic performance of semi-intensive farms, particularly during the March–June and May–August schedules. However, in the short term, loss probability was null or negligible, and no evidence existed that uncertainty and economic risk increased compared with the previous farming conditions. Nevertheless, further studies should be conducted to update the pandemic impact.

Acknowledgements

The authors are thankful to people involved in the shrimp farming industry, in particular Gonzalo Abundis (Policultivos Intensivos de Nayarit), Venancio Torres (Alimentos Balanceados Camaron), and Encarnación Torres (Productora y Comercializadora de Camarón, J. Rangel Bercerra Zepeda) for providing valuable economic information before and during the pandemic event. The authors also thank Diana Fischer for English edition.

Author contribution

Margarita Estrada-Perez contributed to the study conception and acquisition of data. Nallely Estrada-Perez and Javier M.J. Ruiz-Velazco prepared and analyzed the primary database, conducted the statistical analysis, programmed and conducted simulations with the stock model, and wrote the first draft. Alfredo Hernandez-Llamas supervised, corrected, and approved the research and wrote the final manuscript.

Data availability

Data cannot be made available because they belong to commercial farmers, and the authors do not have authorization for sharing them.

Declarations

Conflict of interest

The authors declare no competing interests.

References

Akter R, Khan MR (2021) Shrimp farming in Southwestern Bangladesh: a case study of economic impacts during COVID-19. Asian J Med Biol Res 7:273–283. https://doi.org/10.3329/ajmbr.v7i3.56137

Ayyub BM (2014) Risk analysis in engineering and economics. CRC Press, Boca Raton, FL.

Betanzo-Torres EA (2020) El COVID-19 contagia a la acuacultura mexicana. Divulgación Acuícola 52: 8–9

CONAPESCA (2018) Anuario Estadístico de la Acuicultura y Pesca. México: SAGARPA. https://nube.conapesca.gob.mx/sites/cona/dgppe/2018/ANUARIO_2018.pdf

Estrada-Pérez M, Ruiz-Velazco JMJ, Hernandez-Llamas A, Zavala-Leal I (2015) A bio-economic approach to analyze the role of alternative seeding-harvesting schedules, water quality, stoking density and duration of cultivation in semi-intensive production of shrimp in Mexico. LAJAR 43:466–472. https://doi.org/10.3856/vol43-issue3-fulltext-8

Estrada-Perez N, Ruiz-Velazco JMJ, Hernández-Llamas A (2020) Economic risk scenarios for semi-intensive production of Litopenaeus (Penaeus) vannamei shrimp affected by acute hepatopancreatic necrosis disease. Aquac Rep 18:100442. https://doi.org/10.1016/j.aqrep.2020.100442

FAO, ECLAC (2020) Food systems and COVID-19 in Latin America and the Caribbean: impacts and opportunities in fresh food production Bulletin 11. Santiago FAO. https://doi.org/10.4060/cb0501en. Accessed 26 June 2021
Hernández-Llamas A, Ruiz-Velazco JMJ, Gomez-Muñoz VM (2013) Economic risk associated with white spot disease and stochastic variability in economic, zootechnical and water quality parameters for intensive production of Litopenaeus vannamei. Rev Aquac 5:121–131. https://doi.org/10.1111/raq.12008

Hernández-Llamas A, Zarain-Herzberg M (2011) Bioeconomic modeling and risk analysis of raising shrimp Litopenaeus vannamei in floating cages in northwestern Mexico: assessment of hurricane hazard, stochastic variability of shrimp and feed prices, and zootechnical parameters. Aquac 314:261–268. https://doi.org/10.1016/j.aquaculture.2011.02

INFOPESCA (2021) COVID-19: Impacto en el comercio mundial de pescado. https://www.infopesca.org/contenido/covid-19-impacto-en-el-comercio-mundial-de-pescado Accessed 12 September 2021

Islam MM, Khan MI, Barman A (2021) Impact of novel coronavirus pandemic on aquaculture and fisheries in developing countries and sustainable recovery plans: Case of Bangladesh. Mar Policy 131:104611. https://doi.org/10.1016/j.marpol.2021.104611

Kakoolaki S, EbnejatTorab SAM, Ghajari A, Anvar AA, Sepahdari A, Ahari H, Hoseinzadeh H (2020) Socio-economic impacts of Coronavirus (COVID-19) outbreak on world shrimp aquaculture sector. Iran J Aquat Anim Health 6:1–18. https://doi.org/10.29252/ijaah.6.1.1

Kumaran M, Geetha R, Antony J, Kumaraguru Vasagam PK, Anand PR, Ravisankar T, Raymond Jani Angel J, De D, Muralidhmar M, Patil PK, Vijayan K (2021) Prospective impact of Corona virus disease (COVID-19) related lockdown on shrimp aquaculture sector in India — a sectoral assessment. Aquac 531:735922. https://doi.org/10.1016/j.aquaculture.2020.73

Lebel L, Soe KM, Thanh Phuong N, Navy H, Phousavanh P, Jutagate T, Lebel P, Pardthaisong L, Akester M, Lebel B (2021) Impacts of the COVID-19 pandemic response on aquaculture farmers in five countries in the Mekong Region. Aquac Econ Manag 25:298–319. https://doi.org/10.1080/13657305.2021.1946205

Martínez-Cordero J, Campos A, Borrego P, Monroy S, Meza S (2020) Efectos del covid en la acuicultura de tilapia en México. PANORAMA ACUÍCOLA, 50–56 ACUÍCOLA edición 25–4 mayo-junio 2020

Moreno-Figueroa LD, Villarruel-Colmenares H, Naranjo-Páramo J, Vargas- Mendieta M, Mercer L, Casillas-Hernández R, Hernández-Llamas A (2019) Bioeconomic modelling of the intensive production of white-leg shrimp (Litopenaeus vannamei) in a photo heterotrophic hypersaline system, with minimal seawater replacement. Rev in Aquac 11: 685–696. https://doi.org/10.1111/raq.12252

Parkin M (1996) Microeconomía. Addison-WesleyIberoamericana, México DF

Rafiquzzaman SM (2020) Case study on the impact of pandemic COVID-19 in aquaculture with its recommendations. AJPAB 2(2):36–38. https://doi.org/10.34104/ajpab.020.36038

Rencher AA (2002) Method of multivariate analysis, 2nd edn. John Wiley and Sons, New York

Ruiz-Velazco JMJ, González-Romero MA, Estrada-Perez N, Hernandez-Llamas A (2021) Evaluating partial harvesting strategies for whiteleg shrimp Litopenaeus (Penaeus) vannamei semi-intensive commercial production: profitability, uncertainty, and economic risk. Aquac Int 29:1317–1329. https://doi.org/10.1007/s10499-021-00695-5

Ruiz-Velazco JMJ, Estrada-Pérez M, Hernández-Llamas A, Nieto-Navarro JT, Peña-Messina E (2013) Stock model and multivariate analysis for prediction of semi-intensive production of shrimp Litopenaeus vannamei as a function of water quality and management variables: a stochastic approach. Aquacul Eng 56:34–41. https://doi.org/10.1016/j.aquaculture.2013.04.003

SalmonExpert (2021) Producción mundial de harina de pescado aumentó 11% en 2020. https://www.salmonexpert.cl/article/produccion-mundial-de-harina-de-pescado-aument-11-en-2020. Accessed 13 February 2021.

Waiho K, Fazhan H, Ishak SD, Kasan NA, Liew HJ, Norainy MH, Ikhwanduddin M (2020) Potential impacts of COVID-19 on the aquaculture sector of Malaysia and its coping strategies. Aquac Rep 18:100450. https://doi.org/10.1016/j.aqrep.2020.100450

Publisher’s note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.
Authors and Affiliations

Javier M. J. Ruiz-Velazco¹,² · Margarita Estrada-Perez² · Nallely Estrada-Perez¹ · Alfredo Hernández-Llamas³

Javier M. J. Ruiz-Velazco
marcialj@uan.edu.mx

Margarita Estrada-Perez
margaritaestradaperez@gmail.com

Nallely Estrada-Perez
nallely.estrada@uan.edu.mx

¹ Escuela Nacional de Ingeniería Pesquera, Universidad Autónoma de Nayarit, Carretera a los Cocos, Km 12 San Blas, 63740 Bahía de Matanchen Nayarit, Mexico

² Programa de Posgrado en Ciencias Biológico Agropecuarias (CBAP), Universidad Autónoma de Nayarit, Cd. de La Cultura Amado Nervo s/n, 63255 Tepic, Nayarit, Mexico

³ Centro de Investigaciones Biológicas del Noroeste (CIBNOR), Av. Instituto Politécnico Nacional 195, Col. Playa Palo de Sta. Rita, 23096 La Paz, B.C.S, Mexico