Aquacultural Engineering 70 (2016) 56–62

Contents lists available at ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aqua-online

# Deterministic and stochastic models for analysis of partial harvesting strategies and improvement of intensive commercial production of whiteleg shrimp (*Litopenaeus vannamei*)

Alicia Estrada-Pérez[a], Javier M.J. Ruiz-Velazco[a,b], Alfredo Hernández-Llamas[c,*], Iram Zavala-Leal[a,b], Leonardo Martínez-Cárdenas[a,b]

[a] *Programa de Posgrado en Ciencias Biológico Agropecuarias (CBAP), Universidad Autónoma de Nayarit, Cd. de La Cultura Amado Nervo s/n, Tepic 63255, NAY, Mexico*
[b] *Escuela Nacional de Ingeniería Pesquera, Universidad Autónoma de Nayarit, Bahía de Matanchén Km 12, Carretera a los Cocos, San Blas 63740, NAY, Mexico*
[c] *Centro de Investigaciones Biológicas del Noroeste (CIBNOR), Av. Instituto Politécnico Nacional, 195 Col. Playa Palo de Sta. Rita Sur, La Paz 23096, BCS, Mexico*

ARTICLE INFO

*Article history:*
Received 7 July 2015
Received in revised form
24 September 2015
Accepted 30 November 2015
Available online 4 December 2015

*Keywords:*
Partial harvesting
Shrimp
Modeling production

ABSTRACT

Partial harvesting is an alternative for managing cash flow of aquaculture farms. We use deterministic and stochastic models to analyze zootechnical, water quality and management factors influencing intensive production of shrimp when incorporating partial harvesting strategies. Data from a commercial farm in the State of Nayarit, Mexico were used for modeling. The main factors affecting shrimp production and its variability were: final weight and growth rate of shrimp, water temperature, pond size, length of daily aeration, and the time when the first partial harvest is conducted. Using the largest pond size (4.0 ha), minimum length of aeration (7.5 h), and first harvesting at 8.5 weeks resulted in a minimum total harvest of 2690 kg ha$^{-1}$ (partial and final harvests of 643, 269, 1075, and 703 kg ha$^{-1}$). Using the smallest pond size (1.0 ha), maximum length of aeration (7.9 h), and first harvesting at 11.5 weeks resulted in a maximum total harvest of 3524 kg ha$^{-1}$ (partial and final harvests of 1111, 234, 997, and 1182 kg ha$^{-1}$). The increase in shrimp production from improved management was 31%. The stochastic model showed that increasing farm size from 1 to 40 ha diminished the variability of shrimp production by 84.0%, meaning a reduction of 2.2% per hectare as size increased. Sensitivity analysis indicated that, overall, final weight of shrimp and length of aeration are the most important factors determining production. The models can be used to determine, in future research, the optimum harvesting strategy, using a bioeconomic approach.


## 1. Introduction

Cash flow problems lead to more aquaculture business failures than any other problem (Engle, 2010). Partial harvesting is a strategy for managing cash flow of aquaculture farms. Selling off part of the inventory reduces stocking densities on the farm, resulting in faster growth of the remaining fish and greater turnover of the crop. Revenue from selling off a portion of the crop and the higher turnover of the crop often improves cash flow and reduces cash deficits (Engle, 2010).

Despite the relevance that this practice entails from an economic perspective, the number of studies analyzing the advantages and management of partial harvesting is relatively scarce. Forsberg (1999), using a bioeconomic approach, determined that it is more profitable to size-grade salmon prior to harvest compared to harvesting a batch of fish with similar size distribution to that of the standing stock. Brummett (2002) compared three typical partial harvesting systems and an unharvested control for tilapia in terms of gross yield and observed that significantly higher yields were obtained in ponds that were partly harvested by hook and line. Yu and Leung (2006) used impulsive control theory to develop a partial harvesting model capable of addressing discrete and another partial harvesting strategies for shrimp. Yu et al. (2009) developed a model of partial harvesting of shrimp, using the network-flow approach.

* Corresponding author. Tel.: +52 612 123 8416; fax: +52 612 125 3625.
*E-mail address:* ahllamas04@cibnor.mx (A. Hernández-Llamas).

http://dx.doi.org/10.1016/j.aquaeng.2015.11.003
0144-8609/

Partial harvesting in shrimp farms in Mexico is a common practice and, according to FIRA (2009), at least three strategies are used. One focuses on increasing yields by stocking at high densities and partly harvesting 12–18 g shrimp. This practice thins the shrimp stock in ponds, allowing final harvests of medium and large shrimp. This strategy brings liquidity, but the price of early harvested shrimp is low. A second strategy seeks large shrimp size by using low stocking densities and carrying out one or two partial harvests of 16–18 g shrimp, which leads to large shrimp (>30 g) at final harvest. A third strategy is a combination of the previous ones, obtaining intermediate yields. Monitoring shrimp prices is emphasized under this last strategy.

Hernandez-Llamas and Zarain-Herzberg (2011) used a bioeconomic model to analyze shrimp production raised in floating cages in northwestern Mexico, and determined that partial harvesting provided higher revenue compared to a one-time harvest. Apart from that study, there are no antecedents of investigations analyzing partial harvests of shrimp in Mexico.

The principal objective of this investigation was to analyze the zootechnical, water quality and management factors influencing intensive shrimp production incorporating partial harvesting strategies. For this, we developed deterministic and stochastic models that were calibrated with primary data from an intensive commercial shrimp farm operating in the state of Nayarit, Mexico. The production models from this study are intended to be used as a part of a bioeconomic model in future research for definition of the management strategies that, not only maximize biological production, but economic performance as well.

## 2. Materials and methods

### 2.1. Data survey

Data from a commercial intensive shrimp farm in the State of Nayarit were used. There were 29 cases (ponds) operating during summer at a stocking density of 30 post-larvae $m^{-2}$ for 19 weeks, and conducting three partial harvests. The database allowed us analyzing the following variables for each pond: mean weight of shrimp, survival, mean pond water temperature, mean dissolved oxygen content, mean length of daily aeration (length of aeration, hereafter), time when each of the three partial harvests was done, and percentage of the stock that was taken at each harvest. The mean, minimum and maximum values of these variables are shown in Table 1, together with the dates and mean weight of shrimp at each partial harvest.

### 2.2. Deterministic model

A deterministic stock model was used to calculate shrimp biomass ($b_t$), as a function of time ($t$):

$$b_t = w_t n_t \tag{1}$$

where $w_t$ is the mean weight of shrimp and $n_t$ is the number of surviving shrimp at time $t$.

The growth curve proposed by Ruiz-Velazco et al. (2010) was used to calculate $w_t$:

$$w_t = w_i + \left(w_f - w_i\right)\left(\frac{1-k^t}{1-k^h}\right)^3 \tag{2}$$

where $w_i$ is the initial weight, $w_f$ is final weight, $k$ is the rate at which $w_t$ changes from its initial value to its final value, $t$ is the number of time units for which $w_t$ is calculateed (such as 5 if $w_t$ is calculateed for five weeks), and $h$ is the number of time units at final harvest.

To calculate $n_t$, survival was conceptualized as a series of successive events involving, for every partial harvest, two phases. During the first phase, survival is calculated until the first partial harvest, thereafter, survival is calculated for a second phase until the next partial harvest. This second phase becomes, in turn, the first phase of the next event involving the next partial harvest. Survival is calculated in this way until the final harvest. As a consequence, the analysis included four phases over the course of production: the initial phase previous to the first partial harvest, and three more immediately after the first, second and third partial harvests. These phases will be named phase 1, phase 2, phase 3, and phase 4, meaning that they correspond to the periods previous to partial harvests 1, 2, and 3, and the final harvest.

To model these events, the diphasic model proposed by Ruiz-Velazco et al. (2014) was used. According with the authors, the general form of the survival equation (Gulland, 1969) used for each phase is:

$$n_t = N_0 \exp(-zt) \tag{3}$$

where $n_t$ is the number of live shrimp at time $t$, $N_0$ is the initial number of shrimp, and $z$ is the instantaneous rate of mortality.

If $F_1(t)$ and $F_2(t)$ are the algebraic expressions of the general survival model corresponding to the two phases of survival, we have:

$$F_1(t) = N_{0,1} \exp(-z_1 t) \tag{4}$$

**Table 1**
Mean, minimum and maximum values of the variables in the database used for analysis, together with dates and means weight of shrimp at each partial harvest.

| Variable | Mean | Minimum | Maximum |
|---|---|---|---|
| Weight of shrimp (g) | 18.6 | 14.9 | 22.9 |
| Water temperature (°C) | 32.6 | 31.5 | 33.3 |
| Dissolve oxygen (mg $L^{-1}$) | 6.5 | 5.4 | 7.3 |
| Pond size (ha) | 2.4 | 1.0 | 4.0 |
| Length of aeration (h) | 7.7 | 7.5 | 7.9 |
| Time of first partial harvest (weeks) | 9.5 | 8.5 | 11.5 |
| Time of second partial harvest (weeks) | 13 | 12.5 | 13.5 |
| Time of third partial harvest (week) | 15.5 | 14.5 | 17.5 |
| First partial harvest of standing stock (%) | 23.43 | 19.0 | 28.0 |
| Second partial harvest of standing stock (%) | 16.84 | 7.0 | 27.0 |
| Third partial harvest of standing stock (%) | 22.09 | 15.0 | 29.0 |
| Date of first partial harvest (day/month) | | 20/Aug. | 10/Sept. |
| Date of second partial harvest (day/month) | | 17/Sept. | 24/Sept. |
| Date of third partial harvest (day/month) | | 01/Oct. | 22/Oct. |
| Weight of shrimp at first partial harvest (g) | 10.36 | 8.2 | 13.1 |
| Weight of shrimp at second partial harvest (g) | 14 | 12.6 | 15.1 |
| Weight of shrimp at third partial harvest (g) | 16 | 14.2 | 18 |