INFLUENCE OF ALEVINAGE TIME IN THE OPTIMIZATION OF TAMBAQUI BIOMASS PRODUCTION IN SEMI-INTENSIVE FISH FARMING IN THE NORTHERN REGION OF AMAZONAS

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ABSTRACT

Objective: To evaluate the weight mix for the market obtained with variation in the pre-fixed fingerlings time, for the cultivation of tambaqui (Colossoma macropomum) in a semi-dug tank.

Theoretical framework: The parameters evaluated regarding resources are, the tanks, each of which has its own capacity, its own state variable, which includes fish biomass, growth function and mortality rate. And identifying potential alternatives and making better decisions that optimize biomass production are important, but that take into account the reduction of its environmental impact.

Method: The model incorporates two types of input variables. The discrete event variable, which comprises the number of fish in each batch, the number of tanks available, the time between the arrival of fingerlings in the system and the frequency of classification by weight for the market. The second refers to the continuous time variable, involving the weight of the fish, dissolved oxygen (DO) available to the fish, and feed consumption.

Results and conclusions: The analysis showed that the decision variables are the quantities of fish, with the premise of final weight of 0.5 kg, 1 kg and 2 kg which are related to the hatching time pre-fixed at entry as “30, 40, 50, 60, 70, 80, 90, 100 days” in phase I, results in the optimization of production, target weight for the market as a function of time, in layout scenarios of 5 and 10 tanks, with the premise of harvesting in both, with Mix weight with 0.5kg, 1kg and 0.5kg, 1kg, 2kg to maximize net profit. Considering that the transition between growth phases is a stochastic process, which satisfies the Markov property. It was possible to define the balance between the input and output of the system.

Research implications: The study is of great relevance, as it describes a sequential queue through the growth phases in relation to time, capable of determining the optimization of production with weight mix to maximize net profit.

Originality/value: The research reveals that it is possible to use queuing theory analyzes in stochastic processes, evaluating the transition between time phases, which satisfies the Markov property.

Keywords: Optimization of Production, Markov Property, Colossoma Macropomum, Economic Performance.

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INFLUÊNCIA DO TEMPO DE ALEVINAGEM NA OTIMIZAÇÃO DA PRODUÇÃO DE BIOMASSA DO TAMBAQUI EM PISCICULTURA SEMI-INTENSIVA NA REGIÃO NORTE DO AMAZONAS

RESUMO

Objetivo: Avaliar o mix de peso para o mercado obtido com a variação no tempo de alevinagem pré-fixado, para o cultivo de tambaqui (Colossoma macropomum) em tanque semiescavado.

Referencial teórico: Os parâmetros avaliados referente os recursos são, os tanques cada um dos quais têm sua própria capacidade, sua própria variável de estado, onde compreende a biomassa de peixe, a função de crescimento e taxa de mortalidade. E identificar potenciais alternativas e tomada de melhor decisão, que otimize a produção de biomassa são importantes, mas que leve em consideração a redução do seu impacto ambiental.

Método: O modelo incorpora dois tipos de variáveis de entrada. A variável de evento discreto, que compreende o número de peixes em cada lote, o número de tanques disponível, o tempo entre a chegada de alevinos no sistema e a frequência de classificação por peso para o mercado. A segunda refere-se a variável de tempo contínuo, envolvendo o peso do peixe, oxigênio dissolvido (OD) disponível para o peixe, e o consumo de ração.

Resultados e conclusões: A análise mostrou que as variáveis de decisão são as quantidades de peixes, com premissa de peso final de 0,5kg, 1 kg e 2 kg que relacionados ao tempo de alevinagem pré-fixados na entrada em “30, 40, 50, 60, 70, 80, 90, 100 dias” na fase I, resulte na otimização da produção, peso alvo para o mercado em função do tempo, em cenários layout de 5 e 10 tanques, com premissa de despesca em ambos, com mix de peso com 0,5 kg, 1 kg e 0,5 kg, 1 kg, 2 kg para maximizar o lucro líquido. Considerando que a transição entre as fases de crescimento um processo estocástico, que satisfaz a propriedade de Markov. Foi possível definir o equilíbrio entre a entrada e saída do sistema.

Implicações da pesquisa: O estudo é de grande relevância, pois descreve uma fila sequencial através das fases de crescimento em relação ao tempo, capaz de determinar a otimização da produção com mix de peso para maximiza o lucro líquido.

Originalidade/valor: A pesquisa revela que é possível utilizar análises da teoria das filas em processos estocásticos, avaliando a transição entre as fases do tempo, que satisfaz a propriedade de Markov.

Palavras-chave: Otimização da Produção, Propriedade de Markov, Colossoma Macropomum, Desempenho Econômico.

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1 INTRODUCTION

Faced with climate change, the maximum potential in aquaculture fish production should be established, as an alternative supply in view of future impacts, in the fishing production patterns due to stock depletion, by shifting reduced production with species moving to new habitats (ISAAC & RUFFINO, 1996; FREITAS et al. 2007; CHEUNG et al. 2009a, b; COSTA et al. 2013; CAMPOS et al. 2015) or as a result of changes in marine net primary production (BRP ANDER, 2007; CHEUNG et al. 2009b). The need for strategies in the planning that improve aquaculture production to supply this essential source of proteins, essential amino acids and minerals, especially in countries with food deficit and low income (EASTERLING, 2007; RICE & GARCIA, 2011; FAO, 2012). And by identifying potential alternatives and better decision-making, optimizing biomass production is important, but taking into consideration the reduction of its environmental impact (NAYLOR et al. 2009).
In our study, the premise was to evaluate scenarios with discrete times prefixed in the nursery, which would result in a higher profitability in the expenditure with target weight mix for the market, for the cultivation of tambaqui (*Colossoma macropomum*) in semi-excavated tank. For being one of the production systems of aquaculture widely used in semi-intensive fish farming in the North Region of Amazonas, in which fish farmers have developed initially on a small scale (IZEL & MELO, 2004; GOMES & SILVA, 2009; CAVERO et al., 2009). And they need inherent responses to the interactions between the decision variables and biological factors of the species.

2 THEORETICAL FRAME

There are considerable literature related to biomass management in aquaculture, with simulated results using different management tools, which allow comparing different layout scenarios under a wide set of conditions (BJORNDAL, 1988; FORSBERG, 1999; ERNST et al. 2000; BJORNDAL et al. 2004). In general, solutions to optimization problems are often solved through operational research (OP) tools. Where important constraints must be considered in the planning and management of this activity (SUMMERFELT et al. 1993; CACHO, 1997). Aiming at efficient use of resources, reduce costs as well as assess the duration of the production cycle, balancing the flow in the queue system, formed in the transition of the phases in the tanks with the growth time of the fish considered as a time-varying Markov process (FORSBERG, 1999; WINSTON, 2004; SUMMERFELT et al. 2009; HALACHMI, 2012). And its optimization involve variables related to: biology of the species that will determine the time horizon between the phases of fish growth in the tank; external variables (temperatures, dissolved oxygen (OD), prices, costs); and mainly decision variables (spending strategies and intake batches of fry). The evaluation of the restrictions of the fish farming system, modes of operation and local conditions allow to achieve better results of profit on investment (BJORNDAL, 1988; FORSBERG, 1999; HALACHMI et al. 2005; HALACHMI, 2007; HERNANDEZ, 2007; CRAVEIRO et al. 2019).

The optimization model, in fish farming, many strategic and operational decisions can be optimized through mathematical modeling that forms the basis of the methodology of operational research (OSMAN & LAPORTE, 1996; BLUM & ROLI, 2003). For Pidd (1992) modeling and simulation of production systems, it is a process of creating and experimenting with mathematical and logical models of a physical system. Where the model is actually a set of hypotheses about how the system works. With assumptions expressed by mathematical, logical and symbolic relationships between entities or objects of interest in the system. And it can be used to evaluate a number of different hypothetical scenarios related to the real system, performing the simulation, either manually or by computer. The result of the simulation allows for generating favorable combinations, for a better forecast of the operational characteristics of the real system.

3 METHOD

To quantify the basic parameters for entry of the model, the zootechnical data were collected in the farm Ecology Pescado, located in Km 11 of the Bank Extension - Highway AM 010 Km 127, municipality of Rio Preto da Eva, near Manaus - Amazonas, Brazil. During three growing semesters that extended from April/2012 to November/2013 and repeated from August/2022 to July/2023 post pandemic, and encompassed the growth phases between nursery and fattening. Initially, the fry had between 1.5 and 2.0 g, arranged in two batches of 19,200 fish. And fed with commercial feed with 36% crude protein at 5% of the biomass. This stage
was called phase I - hatching and lasted 50 days. After this phase, distributed in equal parts, sequentially in eight fattening ponds and fed with commercial feed with 28% crude protein at 3% of the biomass, with total expenditure after 100 days defined as phase II. The tanks with a standardized area of 3,200 m² and a 1.5 m depth. On the farm, the current turnover was aimed at meeting the demand for refrigerators, which prefer fish expended with a weight of 0.5 kg. Based on the actual situation, designed tank layout scenarios were simulated, with the limit biomass capacity defined by the availability of dissolved oxygen (OD) for the fish in the tank. Food management and control of the physico-chemical parameters of water followed literature recommendations (ARAÚJO-LIMA & GOULDING, 1998; KUBITZA, 2000; IZEL & MELO, 2004; CAVERO et al. 2009; GOMES & SILVA, 2009; ROSAS et al. 2023). The calculation of the suggested time that the fish remains in each growth phase in the tank, this as described by Halachmi, (2007) in system with recirculation in aquaculture (RAS), and will be demonstrated in the result.

The tambaqui (Colossoma macropomum, Cuvier 1818) fish of the order Characiformes, belonging to the family Serrasalmidae (GERY, 1977; MIRANDE, 2010) and native to the Amazon and Orinoco rivers and their tributaries. It is the main native species cultivated in Brazil and in some Latin American countries, for having good zootechnical qualities (GRAEF, 1995; GOULDING & CARVALHO, 1982; SAINT-PAUL, 1986; SOUSA & FREITAS, 2010).

The economic assessment was adapted according to the methodology proposed by Silva et al. (2003), in which only the partial operating cost (COP) is considered, defined as the value spent on feed and fry, salary, energy and maintenance, including depreciation per tank, with a horizon of fifteen years of operation time. And gross income (GR) obtained from the sale of live fish (in natura) at the place of production, obtaining the partial net profit. For simulation analysis of the net profit of layout 5 and 10 tank scenarios, according to CRAVEIRO et al. (2019), formulated in spreadsheet, the results were demonstrated in scatter chart, in Statistica 10 software (StatSoft, 2010).

Conceptualizing system of queuing batches of fish with prefixed hatching time, initially for the planning of expenses, as a function of the optimal production mix, were considered two scenarios, following the methodology described by Halachmi (2007) in system with recirculation in aquaculture (RAS) that determines the period in the successive phases of growth. In our study, scenario 1A corresponds to a real situation (Figure 1) and allowed to estimate the growth curve in weight, using non-linear estimation, with the Quasi-Newton algorithm, in Statistica 10 software (StatSoft, 20210). The estimated growth curve by weight for tambaqui was according to equation $y = (6950.79) \times [1 - \exp ^{(-1.18094) \times x}]^3$ for the growing period.
Influence of Alevinage Time in the Optimization of Tambaqui Biomass Production in Semi-Intensive Fish Farming in the Northern Region of Amazonas

Figure 1. Scenario 1A: corresponding real situation in a transition diagram '2, 8 layout' in commercial scale semi-excavated tank in the interior of the Amazon. Where it represents the arrival of the batch of fish passing through the initial growth in phase I - hatching and the departure rate for phase II - fattening. Si is the amount of time spent expected by a fish in growth phase i.

Source: Self-authored.

Scenario 1B consists of the simulation of a stochastic process, using weight values, estimated by the growth curve in weight for the tambaqui. That according to the species growth function, it is possible to estimate the probability of an individual's weight in a series of transitions between the nursery phase t₀ and fattening phase t₁ for a given future time, i.e. optimal weight for expenditure. In our model, the premise was to meet market demands as a function of time, average weight 0.5kg, 1kg and 2kg for refrigerators, supermarkets and trade fairs respectively. The feed consumption was proportional to the feed conversion rate, corresponding to each weight in 1:1; 1.2:1 and 1.6:1 given obtained from the farm administration and will be a restriction used in the calculation of the economic evaluation.

To obtain tractable computation, assume that the stochastic process satisfies the Markov property, with simulated batch flow transition, describing a sequential queue through the growth phases in the semi-excavated tanks. In that dynamic process characteristics are governed by probability theory, able to define a set of states that can achieve and describe the criteria of their transition. In which time is a linear measure through which the system moves. Thus, when a batch of fish or entity grows to its predetermined size, it releases the tank or resource, and proceeds to the next stage. At the end of each growth phase, a batch is divided, so that the fish begin with a weight corresponding to the smallest biomass until reaching its limit in each successive phase. To this end, scenarios were simulated with pre-fixed alveinage times of 30; 40; 50; 60; 70; 80; 90 and 100 days only in phase I. seeking better balance of the fish arrival batch in the system given by λ and its output in the expenditure by µ, considering that the time in the aleveinage phase does not influence the profit generated in the expenditure, in relation to the total time of the production cycle.

Combined with this production strategy, modifications are considered in the area of the nursery tank in the proportions of 1.5x, 2x, 2.5x. Where lots of fish begin cultivation in the nursery phase and remain at a discrete point in time until the limit of the biomass capacity of the system, which is defined by the availability of dissolved oxygen (OD) for the fish (BRAUM & JUNK, 1982; PAULY & HOPKINS, 1983; SAINT-PAUL, 1984; PREIN, 1987; VAL & ALMEIDA-VAL, 1995; ARANA, 2006). The batches are then transferred to the next stages of cultivation, characterizing the production cycle as a system of rows of the M/M/1 Markovian type, i.e. single channel row and multiple stages (LAW & KELTON, 2000; KLEIJNEN et al. 2005), which is feasible for the calculation of the balance between the successive stages of fish.
growth (HALACHMI, 2007; 2012). In which were designed two scenarios of 5 and 10 tanks for simulation analysis, so defined, small and large fish farmer respectively. As shown in the layout scenario with 5 tanks (Figure 2), being 1 for nursery and 4 for fattening, and which should be understood, that for the transition in phases III and IV will be used two tanks only in these phases of fattening, since a number of possible combinations of scenarios for expenditure can be obtained.

Figure 2. Represents scenario 1B, a transition diagram '1, 4, 2, 2 layout' in semi-excavated tank. Where \( \lambda \) represents the batch entry of fry into the system, through phase I, and the departure rates for fattening phases II, III and IV. Si is the amount of time spent expected by a fish in growth phase i.

Source: own authorship.

Note that in this example, only two tanks are occupied in phase III and IV in relation to the cycle time, allowing entry of a new batch of fish, according to the strategy adopted for phase I. The surplus quantity of fish being placed at the market disposal.

The formulation of the number calculation in days in each phase in the system, with the composition of several semi-excavated tanks in the farm as layout shown in figure 1. It will be used as the basis to formulate new scenarios for simulation analysis with 5 and 10 tank layout, and application of the calculations in our model, with an input and output rate are equal in each tank, so scenario 1B (figure 2) can be balanced to obtain \( \lambda \) optimal for a queue system with transitions between the growth phases, suggested as general formula (Eq. (1)). Where the expectation of the time the fish takes to grow during a production cycle in the tank can be represented by the hope E(S) being S a controlled environment for the fish to grow. Following the methodology described by Halachmi (2007), the arrival batches of fish in the system given by \( \lambda \) and exit at the expense by \( \mu \) describing a Poisson and Exponential distribution respectively. And its main approach to solving probabilistic planning problems is through its modeling as a Markovian process (HOWARD, 1960; BONET & GEFFNER, 2005; KLEIJNEN et al. 2005). That hypotheses are made that the selection of the best action can be taken knowing only the current state of the agent and the environment is completely observable (PUTERMAN, 1994; JACOBY et al. 2012). The tank utilization at 100% is obtained when \( \rho = \lambda / \mu = 1 \) with this, we can establish in the model a balance between the batch input of fry arriving at the system equal to or close to its output \( \mu \lambda = 1 \) assuming that:

\[
E(S) = 1/\mu = 1/\lambda \tag{1}
\]

For the number of parts in which a lot of fish is divided (P), and the number of tanks excavated (c) in a growing phase where:

\[
\rho = (\lambda / \mu) \cdot P/c \tag{2}
\]
Replacing $\rho = 1$, means to achieve 100% tank utilization we have:

$$1 / \mu = (1 / \lambda . c / P) \quad (3)$$

Substituting $S = (1/\mu)$, where $S$ is the expected time that a fish spends in growth phase $i$, yields:

$$Si = (1/\lambda . ci / i Pi) \quad (4)$$

$$Si = 1/(\lambda Pi/ci) = ci / (\lambda Pi) \quad (5)$$

Where:

$Si$ is the period in growth phase $i$, $ci$ is the expected number of tank excavated in growth phase $i$, $Pi$ is the number of parts in which a lot of fish is divided, since it enters growth phase $i$, in general this category division is known as event classification and ordering. In our case, the lot with $N_1 = 19200$ in phase I is divided into smaller parts, for phase II, forming $P$ sublots, that is, four lots of $N_2 = 4800$ fish each, and the real number in categories was $P_2 = 2$ will be shown in the results.

In general, the full growing period $\Sigma Si$ is known, and depend on the biological characteristics of the cultivated species and local conditions in the growing system, such as water quality, temperature, oxygen, feeding, and management, where:

$$\Sigma Si = \Sigma (1/\lambda . ci / Pi) \rightarrow \Sigma \Sigma [Si = 1/\lambda$$

$$\rightarrow 1/\lambda = \Sigma Si / \Sigma (ci/[Pi]) \quad (6)$$

$$\Sigma Si = \Sigma (ci / (\lambda Pi)) \rightarrow 1/\lambda = \Sigma Si / \Sigma (ci/Pi) \quad (7)$$

For a projected annual turnover, $T$ (ton per year) obtained by:

$$T = \lambda . Nf . Bf = (\Sigma (ci/[Pi]) / \Sigma Si) \cdot Nf \cdot Bf \quad (8)$$

Where:

$\lambda$ (lots per year) is the entry and exit rates, resulting from the number of lots of fish leaving per year, $Nf$ (fish) is the number of fish in a lot at the time of market, and $Bf$ (kg) is the final weight of the fish. For the given optimization problem:

$$\max T = \max(\Sigma (ci/[Pi]) / \Sigma Si) \cdot Nf \cdot Bf \quad (9)$$

Subject to restrictions where:

$\Sigma ci =$ number of excavated tanks that can fit in a given farm space.

$Di =$ Permitted fish biomass density at the end of the growth phase of any $i$, defined in the calculation by the availability of dissolved oxygen (OD) for the fish in the tank. In the present study considered 5 mg/l OD.

$$\Sigma Si \leq \text{total growth period in all phases} \quad (10)$$

$$Bi = \text{Balevino} + Ct\Sigma Si,$$ where:

Initial fish biomass body weight is dependent on the rate of growth $Ct$ and time in the $\Sigma Si$ system.

$$ci = \lambda . Yes. \ [Pi], \text{number of growing crop tanks } i \quad (\text{from Eq. (4)})}
The decision parameters were in this case: c1, c2, c3, c4, S1, S2, S3, S4, P3, P4, N, λ.

The model of optimization in our study, the parameters evaluated concerning the resources are: the tanks each of which have its own capacity, its own state variable, which involve the fish biomass, the tanks each of which has its own capacity and mortality rate. The model incorporates two types of input variables. The Discrete Event Variable, which comprises the number of fish in each lot, the number of tanks available, the time between the arrival of fry in the system and the frequency of classification by weight for the market. The second refers to the continuous time variable, which involves fish weight, available OD for fish and feed consumption. In which the decision variables are the quantities of fish of 0.5 kg, 1 kg and 2 kg, which related to the time of nursing prefixed in phase I, result in the optimization of the target weight mix for market as a function of time, in layout scenarios for 5 and 10 tanks for simulation analysis, with expense premise in both with target weight mix of 0.5 kg, 1 kg and 0.5 kg, 1 kg, 2 kg with the aim of optimizing the production of tambaqui biomass in semi-excavated tank, which maximizes the profit.

According to tambaqui biology, growth by weight is achieved in the expected period, assuming for simulation that a batch of fish with a final target weight of 0.5 kg in phase II, are expended after 150 days of production, and present a normal distribution, with constant coefficient of variation during the whole period of growth. Following the same procedure for a batch of fish with a final target weight of 1 kg in stage III and a batch with a final target weight of 2 kg in stage IV, has its expense after previous period with 60 days and 120 days respectively. The layout scenarios with 10 tanks, are proportional in quantity to the layout scenarios with 5 tanks. And different pre-fixed alveinage times (30; 40; 50; 60; 70; 80; 90 and 100 days) were formulated in phase I for analysis and simulation of production in the system, since a number of possible combinations of target weight mix for expenditure can be obtained.

With the balancing of the system of queuing lots of fish in the tanks according to time, it is possible to define different classification criteria for decision making, in the management of planning for expenditure with target weight for the market, or forecast for a business plan of a new project (BJORNDAL et al. 2004; LLORENTE & LUNA, 2014; CRAVEIRO et al. 2019). The optimization result was obtained with simulation analysis of the scenarios, according to the following assumptions:
(i) the complete cycle in tambaqui fish farming shall be from nursery to overhead, taking into account multiple production cycles per tank.
(ii) The time horizon is divided into periods comprising the growth phases in the tanks, in which the external variables (temperature, OD, price, cost) and decision expense strategies and fish lot entry) variables can be considered constant, starting from the stabilization of the expenditure process. The results presented refer to a time horizon of one year, with production time stabilized from Stages III and IV.
(iii) considers the immediate expenditure of the predetermined fraction of biomass limit in the tank at the end of each phase, the quantity of fish with weight corresponding to the lowest biomass remaining until it reaches its limit in each successive phase.
(iv) consider batches of fish with homogeneous weight distribution.
(v) Prices considered for simulation are independent of demand. In our study, it was R$ 4.00/kg; R$ 5.00/kg; R$ 6.50/kg for fish weighing 0.5 kg; 1 kg and 2 kg respectively.

4 RESULTS AND DISCUSSIONS

For the calculation of the suggested number in days for each growth phase in the tank, it was based on the management strategy to optimize biomass production by determining the
distribution of the decision variable over the time horizon as a result of Table 1, to maximize profit. Thus, the balance between the successive phases of fish growth was based on the initial calculation suggesting the number of days a given batch of fish remains in each phase, replacing in the general case, for several tanks in each layout, in the Eqs. (4) and (7), obtained the numerical values as was done for the layout '1, 4, 2, 2' (fig.2), with period of total growth of tambaqui $\sum S_i = 330$ days. With the number of cultivation tanks $c_1 = 1; c_2 = 4; c_3 = 2; c_4 = 2$; and the number of sublots formed from a lot $P_1 = 1; P_2 = 2; P_3 = 1; P_4 = 1; P_4 = 1$ we obtain:

Eq. 7 $\rightarrow$ $1/\lambda = 330/ (1/1+4/2+2/1+2/1) = 47$ days.

Eq. 4 $\rightarrow$ $S_1 = 1/\lambda \times c_i/P_i = 47 \times 1/1 = 47$ days.

$S_{II} = 1/\lambda \times c_i/P_i = 47 \times 4/2 = 94$ days.

$S_{III} = 1/\lambda \times c_i/P_i = 47 \times 2/1 = 94$ days.

$S_{IV} = 1/\lambda \times c_i/P_i = 47 \times 2/1 = 94$ days.

To Eq. (7) with three variables, where $c$, the number of tanks excavated and $P$, the number of sublots formed from a lot, considered managerial parameters in the farm. And "S" is a controlled environment for fish, considering the growing period, a biological variable that depends on a variety of conditions such as water quality, temperature, oxygen, feeding, and management. With the calculation shown above, optimal $\lambda$ and $S_i$ ensure that the entire system will be balanced considerably.

In this case, the total time was $\sum S_i = 330$ days for tambaqui to reach the final market weight, that is, the sum of the waiting times in each phase of fish growth. The calculation of the optimal number of days in each growth phase is suggested, but should be understood by the manager as a decision parameter to balance the production flow in the queue system. Note that scenario 1A was subdivided giving rise to scenario 1B initially formulated with 1 (one) nursery tank and 4 (four) fattening tanks to facilitate understanding of the calculations.

The fish batch queuing system as a function of the different nursery times in phase I, with the waiting time of stable state in each growth phase for the fish, previously calculated from the biological characteristic of the species. For tambaqui the total waiting time was $\sum S_i = 330$ days. This calculation served as the basis to balance the production flow and establish strategic planning, simulating successive expenses, varying the pre-fixed hatching time in 30; 40; 50; 60; 70; 80; 90 and 100 days only in phase I. According to the premise defined target weight mix for the market with 0.5 kg, 1 kg and 0.5 kg, 1 kg, 2 kg. The simulated scenarios in electronic spreadsheet were computed for layout 5 tanks, in which were compared their production obtained with the weight mix, in relation to the scenario 1A (real) practiced on the farm. Prices considered for simulation are independent of demand. In our study, it was R$ 4.00/kg; R$ 5.00/kg; R$ 6.50/kg for fish weighing 0.5 kg; 1 kg and 2 kg respectively. The annual volume of biomass production per tank is limited by the availability of OD for fish under optimal conditions. The state of the production cycle stabilized from phase III and IV. Forming a sequence that repeats itself at a certain future time. These values are considered to optimize the production of tambaqui biomass in a semi-excavated tank. And their respective net profits with respect to the different nursery times are shown in table 1. The simulation of the layout scenarios with 10 tanks, were proportional in quantity with respect to the respective prefixed times for alevinagem of the layout scenarios with 5 tanks, and the values used as partial operational cost parameters (COP) are presented in table 2.
Table 1. Net profit in relation to the different nursery times of tambaqui

<table>
<thead>
<tr>
<th>Time alevin n.</th>
<th>NO tank</th>
<th>NO expenditure</th>
<th>Target Weight sale (kg)</th>
<th>Production / year (kg)</th>
<th>RB (R$)</th>
<th>COP (R$)</th>
<th>Profit* (R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>5</td>
<td>2</td>
<td>2,880</td>
<td>30</td>
<td>115</td>
<td>200.00</td>
<td>101 140.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 / 1</td>
<td>9600 / 19200</td>
<td>134 400.00</td>
<td>91 309.80</td>
<td>43 090.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 / 1 / 2</td>
<td>2400/10800/1200</td>
<td>141 600.00</td>
<td>100 679.40</td>
<td>40 920.60</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>5</td>
<td>2</td>
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<td>9600 / 19200</td>
<td>134 400.00</td>
<td>91 309.80</td>
<td>47 325.60</td>
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<tr>
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<td>0.5 / 1 / 2</td>
<td>2400/10800/1200</td>
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<td>100 679.40</td>
<td>40 920.60</td>
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<td>134 400.00</td>
<td>87 074.40</td>
<td>47 325.60</td>
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<td>0.5 / 1 / 2</td>
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<td>100 679.40</td>
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<td>100 679.40</td>
<td>40 920.60</td>
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<td>14400 / 19200</td>
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<td>0.5 / 1 / 2</td>
<td>2400/10800/1200</td>
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<td>100 679.40</td>
<td>40 920.60</td>
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<td>230</td>
<td>400.00</td>
<td>147 220.20</td>
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<td></td>
<td>0.5 / 1</td>
<td>14400 / 28800</td>
<td>201 600.00</td>
<td>109 434.60</td>
<td>92 165.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 / 1 / 2</td>
<td>10800/18000/7200</td>
<td>180 000.00</td>
<td>104 519.40</td>
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<td>100</td>
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<td>162 580.20</td>
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<td></td>
<td>0.5 / 1</td>
<td>14400 / 28800</td>
<td>201 600.00</td>
<td>105 199.20</td>
<td>96 400.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.5 / 1 / 2</td>
<td>10800/18000/7200</td>
<td>180 000.00</td>
<td>100 284.00</td>
<td>79 716.00</td>
<td></td>
</tr>
</tbody>
</table>

* Profit generated considering only the production time, with the stabilization of the system that will be from phase III and IV.

Source: Self-authored.
The economic evaluation considered the partial operating cost (COP), defined as the value spent on feed and fry, salary, energy and maintenance, including the depreciation per tank (see Table 2), discounted from the gross income (RB) referring to the sale of live fish (in natura) at the production site, for layout scenarios with 5 and 10 strokes.

### Table 2. Partial operating cost (COP) of production biomass also in semi-excavated tank

<table>
<thead>
<tr>
<th>1. Fixed Costs</th>
<th>unit</th>
<th>5 tanks</th>
<th>10 tanks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depreciation of facilities and infrastructure / tank (R$)</td>
<td>Month</td>
<td>264.14</td>
<td>215.40</td>
</tr>
<tr>
<td>Electric power / maintenance and others (R$)</td>
<td>Month</td>
<td>1 248.25</td>
<td>1 248.25</td>
</tr>
<tr>
<td>Labor and Charges</td>
<td>Month</td>
<td>2 679.20</td>
<td>4 018.80</td>
</tr>
<tr>
<td>Labor (70% MOD) (R$)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. Variable costs</th>
<th></th>
<th>80.00</th>
<th>80.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alevinos (R$)</td>
<td>thousand</td>
<td>80.00</td>
<td>80.00</td>
</tr>
<tr>
<td>Ration 28% Raw Protein (R$)</td>
<td>R$/kg</td>
<td>1.44</td>
<td>1.44</td>
</tr>
<tr>
<td>Consumption single weight CAA = 1:1</td>
<td>R$</td>
<td>27 648.00</td>
<td>55 296.00</td>
</tr>
<tr>
<td>Mix Consumption - 2 AAC = 1.2:1</td>
<td>R$</td>
<td>30 412.80</td>
<td>60 825.60</td>
</tr>
<tr>
<td>Mix Consumption - 3 AAC = 1.6:1</td>
<td>R$</td>
<td>33 177.60</td>
<td>66 355.20</td>
</tr>
</tbody>
</table>

1MOD = Labor with salary (R $ 788,00) with charges (70%) being 1 in charge for 5 attacks; and 1 in charge for 10 tanks. 2FAC = apparent dietary conversion (1:1 is kg ration for each kg biomass).

If the problem for the fish farmer is in determining the expenditure in time that maximizes the profit obtained from the sale of the product. The simulation response can assist in better decision making. With the results demonstrated, production planning may opt for an annual turnover, which maximizes profit when the target weight mix in the outflow rate expense given by $1/\mu$ enters into equilibrium with a certain pre-fixed hatching time, with input rate given by $1/\lambda$. And comparing the situation 1A (real) with the optimized result of the mix obtained with 0.5 kg, 1 kg and 0.5 kg, 1 kg, 2 kg were observed points of higher profitability, as seen in Figures 3 and 4.
Influence of Alevinage Time in the Optimization of Tambaqui Biomass Production in Semi-Intensive Fish Farming in the Northern Region of Amazonas

Figure 3. It represents the optimization of the Profit obtained in relation to different nursery times, and compares two production expense strategies of tambaqui with target weight for the market: 0.5 kg, and 0.5 kg, 1 kg.
Source: Self-authored.

Figure 4. It represents the optimization of the Profit obtained in relation to different nursery times, and compares two production spending strategies of tambaqui with target weight for the market: 0.5 kg, 1 kg and 0.5 kg, 1 kg, 2 kg.
Source: Self-authored.

The criterion of the number of fish in the successive growth phases for the semi-excavated tanks in this study, each with a volume of 4800 m³ (40x80x1.5m). The respiration rate of the species Colossoma macropomum is known at 250 mgO₂/kg/h. And it was used as a parameter in the calculation of the maximum biomass as a function of time, it is determined by the criterion: stocking density by the availability of OD for the fish in the tank at each growth stage. Observing the influence exerted by the increase in the quantity of fish in the environment, causes reduction of OD to a critical level 3 mg/l for tambaqui species figure 5 (VAL & ALMEIDA-VAL, 1995; GOMES et al. 2006). The mortality rate was 1% in each tank, the average water temperature of the collected semi-excavated tanks was between 28.03ºC to...

Table 3 shows the parameters used in the calculation for production planning by tank, and is an important constraint. And it should be used by the management of the farm to balance the production flow in the system of semi-excavated tanks, in the successive phases of growth. With the biomass limitation of 2400 kg per tank, it is shown in the last column \((7200000/250)/12=2400\text{kg}\). It is possible to change the proportions in 1.5x, 2x, and 2.5x only in the area of the tank of the nursery phase, allowing to be used as a strategy, in transferring fish with weight advanced in relation to the time of equilibrium in the growing system, that is, \(1/\mu = 1/\lambda\).

<table>
<thead>
<tr>
<th>Volume (m³)</th>
<th>Liters</th>
<th>OD (mg/L)</th>
<th>Total OD</th>
<th>% OD consumption</th>
<th>OD for fish</th>
<th>Consumption mgOD/kg Biomass/hr</th>
<th>Period (h)</th>
<th>Capac. Biomass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4,800</td>
<td>4800000</td>
<td>5</td>
<td>24000000</td>
<td>70.0</td>
<td>7200000</td>
<td>250</td>
<td>12</td>
<td>2,400</td>
</tr>
<tr>
<td>7,200</td>
<td>7200000</td>
<td>5</td>
<td>36000000</td>
<td>70.0</td>
<td>10800000</td>
<td>250</td>
<td>12</td>
<td>3,600</td>
</tr>
<tr>
<td>9,600</td>
<td>9600000</td>
<td>5</td>
<td>48000000</td>
<td>70.0</td>
<td>14400000</td>
<td>250</td>
<td>12</td>
<td>4,800</td>
</tr>
<tr>
<td>12,000</td>
<td>1200000</td>
<td>5</td>
<td>60000000</td>
<td>70.0</td>
<td>18000000</td>
<td>250</td>
<td>12</td>
<td>6,000</td>
</tr>
</tbody>
</table>

Source: Self-authored.

With the composition of several tanks semi-excavated on the farm according to layout '1, 4, 2, 2' (figure 2), a batch of fish with density \(D = 19200\) as suggestion changing by 2.5x the area of the nursery tank, a fish can remain in the tank phase I until reaching biomass capacity by the availability of OD with weight 312 g (6000 kg/19200 fish = 312 g/fish). Then transferred to the next phases. Attention, the mortality rate of 1% in each phase was not considered in the above calculation. Thus, in our study the mortality rate adds up to 4%, the purchase of fry was...
Influence of Alevinage Time in the Optimization of Tambaqui Biomass Production in Semi-Intensive Fish Farming in the Northern Region of Amazonas

increased by a factor of 1.04 that corresponds to 768 units to compensate for the loss of fish in the production cycle.

The estimation of the growth curve in weight of tambaqui in semi-intensive fish farming, with optimal growth period, at the end of each phase, suggests moving a lot of fish or spending it to the market as a result obtained by Eq. (4) In our study the calculated time was 47, 141, 235 and 330 days, obtaining a classification of the fish in relation to the time (fish age) with target weight estimated by the growth curve in tambaqui weight (figure 7) equation y = (6950.79) × [1-\exp(1.18094 × x)]³ projecting fish with average weight 0.080 kg, 0.487 kg, 1.08 kg, 2.15 (2) Obtaining the criterion of moving 47 days and 0.080 kg in time from phase I to phase II, moving 141 days and 0.487 kg in time from phase II to phase III, moving 235 days and 1.08 kg in time from phase III to phase IV of that phase with 330 days and 2.15 kg. Based on this example, time values were adjusted in each phase.

Figure 6. Growth curve in tambaqui weight (Colossoma macropomum), in semi-intensive fish farming, commercial scale. Recorded research data of three cycles and 100 samples per total experimental unit 6 tanks, in the interior of the Amazon.

Weight x time (days/year): 0.38 = 150 days, 0.64 = 210 days, 0.90 = 330 days.
Source: adapted from GOMES & SILVA, 2009

The aquaculture production system represents a dynamic system of discrete events, and one that needs planning capable of balancing production constraints and product cost that may vary over time, depending on the technology employed, fish growth, feeding, management practices, and other factors, to satisfy market requirements (FORSBERG, 1999). In our study, where the decision variables were, the quantity of fish of 0.5kg, 1 kg and 2 kg that related to the nursery time prefixed in phase I. It resulted in the optimization of the target weight mix for the market as a function of time, simulated in layout scenarios for 5 and 10 tanks, with the premise of expenditure on both with target weight mix of 0.5 kg, 1 kg and 0.5 kg, 1 kg, 2 kg with the aim of optimizing the production of biomass of tambaqui in semi-excavated tank, to maximize profit. For Cacho (1997), expenditure planning has a greater impact on the cash flow of the fish farming enterprise, as well as the allocation of limited production resources such as feed, fry, labor, working capital and environmental resources. For Llorente & Luna (2014), the lack of competitiveness of many aquaculture enterprises is not about technical and biological aspects, but arises from the difficulty of managing the production process and economic decision-making.
The ceaseless demand for production, and the increased competition in the tambaqui market, has led fish farmers to practice expenses in period with short cycle, obtaining fish with average weight 0.5 kg to meet refrigerators. Resulting in a reduction of operating margins and affecting their profitability. It is important to note that according to Schmittou (1993) efficient production does not mean the maximum weight that can be produced, but rather the weight to be produced with the best feed conversion index in the shortest possible time period, and with a final weight accepted by the consumer market. However, decision management and crop strategies can be planned according to economic constraints and market demand (e.g. fish size or spending time). Respecting the limit stocking density by the availability of OD for the fish in the tank at each growth stage. Maintaining control over successive phases of tambaqui growth during cycles, avoiding reduction of OD to a critical level 3 mg/l in the tank (VAL & ALMEIDA-VAL, 1995; GOMES et al. 2006).

The control of the time that should last each growth phase to produce a batch of fish more efficiently is important. Following the methodology used by Halachmi (2007) in aquaculture recirculation system (RAS), it was possible to establish the calculation of the suggested time of the number of days a lot of fish remains at a certain stage. However, the optimal number of days in each growth phase is suggested, but should be understood by the manager as a decision parameter to balance the production flow in the queue system (CRAVEIRO et al. 2019). Also, taking into consideration the cultivated species and the target weight strategy for the market, as in our study for tambaqui, the time horizon was deducted by the growth curve (Figure 6). The final weight in each phase was similar to that obtained by Izel & Melo (2004); Gomes & Silva (2009); Cavero et al. (2009).

The range of optimization problems in aquaculture is very wide, resulting from a significant number of species, modes of operation and local conditions. However, few studies have focused on marine cages for Atlantic salmon production (FORSBERG, 1999; HERNANDEZ et al. 2007), aquaculture recirculation system applying queuing theory (RAS; HALACHMI, 2007; HALACHMI, 2012), dynamic models based on differential equation (HERNANDEZ et al. 2003) or Markov process (SPARRE, 1977; FORSBERG, 1996) and optimal control of system constraints such as temperature (HERNANDEZ et al. 2007). However, the results presented in this work, with simulation for layout scenarios with 5 and 10 attacks on commercial scale, with time prefixed in the alevinagem for tambaqui species, can assist in better decision making in the planning of the target weight for expenditure. For Llorente & Luna, (2014) the maximum amount of fish lot production can be obtained at the expense of different weights. Where lots that produce larger fish arrive to obtain proportional operating profits, due to their higher market value. With the results shown in figures 4 and 5, where optimal points are observed in the target weight mix for the market seen in table 1. The profit generated from the variation of the prefixed times in phase I was only considering the production time, with the stabilization of the system given from phase III and IV. Since the waiting time in the phases prior to these, they happen simultaneously in the period of stabilization of the system. Suggesting production planning with a focus on annual turnover, which maximizes profit, depending on the size of the fish farming enterprise. Note that points that maximize profit are obtained with weight mix of 0.5 kg, 1 kg and 0.5 kg, 1 kg, 2 kg for the fry time of 80 and 90, representing higher profitability in the system compared to that obtained in scenario 1A (real).
Figure 7. Profitability efficiency in the production of tambaqui in semi-excavated tank comparing the time of nursery in relation to the weight mix for the market.

Partial net profit.
Source: Self-authored.

Figure 7 shows that the efficiency in the production of tambaqui biomass, which shows greater profitability, is when the planning is directed towards the spending with the product mix, with different weights for the market. This result is strategic for the management of the number of cycles from the stabilization of the expenditure system, as well as for the consumption of feed that directly influences production costs, and can improve incentive policies and adaptation to environmental standards, since higher productivity per unit can be achieved (COSTELLO et al. 2008; GUTIERREZ et al. 2011; MENEGON et al. 2023). For Naylor et al. (2009) to ensure that aquaculture continues to grow in a sustainable way, they will be the main limitations for the sustainability of world fish production.

5 CONCLUSIONS

This study analyzed the results obtained in the expenditure of target weight mix, for the species tambaqui in semi-excavated tank on a commercial scale, submitted to the variation of the time prefixed in the nursery phase. Aimed at optimizing biomass production, to maximize profit. The simulation of the layout scenarios with 5 and 10 tank, predicts a situation of perfect balance, disease-free, technical failure, which can result in loss of the production batch. The assumption considered for analysis and simulation was that the time in the nursery phase does not influence the profit, in relation to the total time of the production cycle. The results showed that the best profitability, is obtained in the weight mix expenditure when the exit time comes into balance with the nursery time with 80 and 90 days. However, other studies may bring better solutions, since gaps (time gaps) have been identified between the successive phases of fish growth in the tank, and it is an alternative research that improves the performance of the tambaqui’s biomass production. In order to include gaps and considering the continuous time horizon, studies and a more general model of optimization are already being constructed.
ACKNOWLEDGMENTS

To FAPEAM for the grant of the scholarship as decision Nº 188/2013 - doctoral scholarship, referring to the Notice N. 005/2013 - RH-INTERIORIZATION - Continuous Flow.

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