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Modeling Competitive Fresh Fruit Bunch Price Dynamics Using A Predator-Prey Industrial Ecology Framework: Evidence from Nagan Raya Aceh

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Abstract: This study develops a logistic predator-prey model to describe the short-term interactions between the market conditions for Fresh Fruit Bunches (FFB) and the competitive activities of Palm Oil Mills (POMs) in Nagan Raya, Aceh. Weekly fresh fruit bunch (FFB) price data from January through April 2025 were used. The calibrated model is able to reproduce the main temporal patterns of the normalized FFB dynamics, indicating that the proposed nonlinear interaction structure provides a reasonable representation of the observed system. The threshold analysis also shows that the POMs's sustainability depends on the balance between the POMs's response to FFB resources and the rate of decline in activity. Transcritical bifurcation provides a useful mathematical interpretation of how changes in competitive responses can shift the system between regimes of non-coexistence and sustained coexistence. These findings suggest that the proposed framework can serve as a mathematical tool for analyzing the interrelated dynamics of resource competition within the local palm oil industry.

Keywords: Fresh Fruit Bunch (FFB); Price Dynamics; Palm Oil Mills; Predator–Prey Model; Industrial Ecology; Competition Intensity

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A. INTRODUCTION

Mathematical modeling has become an indispensable tool for understanding the dynamics of predator-prey interactions. Predator-prey modeling has a long history dating back to the pioneering works of (Kopf & Lotka, 1925) and (Volterra, 1926, 1928). Many recent advances in predator-prey modeling highlight innovative approaches and their contributions to the field of mathematical ecology, where researchers explore various factors influencing these complex dynamics. These models provide insights into complex ecological relationships and aid in the development of effective management strategies. In business ecosystems, for example, predator-prey modeling has been widely applied to understand various forms of competitive relationships between two or more competing species. (Crookes & Blignaut, 2016) used a predator-prey model to simulate dynamics among sectors within the steel industry. (Hung et al., 2017) applied an enhanced Lotka-Volterra model to study competition between convenience-oriented and budget-oriented retail stores in Taiwan by decomposing the data into three components, thereby yielding more efficient estimates. (Dejuán Asenjo & Dejuán-Bitriá, 2018) developed a predator-prey model to explain cycles in a credit-driven economy, where the predator, in this case, is the part of the financial sector that issues credit for non-output transactions. This increases the debt-to-GDP ratio and inflates an economic bubble, which ultimately has a negative impact on the real growth rate (the prey). (Olena Nikolaieva & Yevheniia Bochko, 2019) studied the market share behavior of operating systems using the Lotka-Volterra model and then attempted to predict the market shares for the Android and iOS operating systems using numerical integration. (Edwards et al., 2020) applied the predator-prey relationship to compare the outcomes of predator and prey stocks under conditions of autarky and free trade. They tested some of the modeling results on a case study from the fishing industry. (Montero, 2021) applied the predator-prey model to investigate stock market fluctuations. (Serpa & Steiner, 2022) demonstrate in their paper that the labor market can be modeled using a predator-prey framework, which provides decision-makers with generalized theoretical elements that enable a more accurate and deterministic understanding of the relationship between employers and employees in Brazil. (Raghavendra & Veeresha, 2023) used a modified Lotka-Volterra equation (predator-prey model) to study competition among various compensation mechanisms. Clearly, the Lotka-Volterra model is a reliable method for studying and analyzing two or more competing species.

Although the predator-prey model has been widely applied in the fields of industrial ecology and socioeconomic systems, its application to local agricultural commodity markets remains limited, particularly in regional contexts with limited data. Take, for example, the palm oil industry, where oil palm is the primary crop in Asia, particularly in Southeast Asian countries such as Malaysia, Indonesia, and Thailand. These countries account for 85% of global palm oil production (Iskandar et al., 2018). In these countries, oil palm plantations cover millions of hectares of land and make a significant contribution to their economies. Palm oil is the most widely produced vegetable oil in Asia, accounting for 37% of total vegetable oil production in 2013. The annual growth rate of palm oil production in Asia from 2004 to 2013 was 6.7%, and the main contributors to global palm oil production were Indonesia and Malaysia, which together accounted for an average of 81.7% of total global production during the same period (Oettli et al., 2018). In Indonesia, particularly in regions that depend on natural resources, processing capacity and the availability of raw materials are geographically concentrated. Under such conditions, price formation is driven not only by global market signals but also shaped by local competitive interactions among processing plants. In many palm oil-producing regions, intense competition for fresh fruit bunches (FFB) among mills can lead to short-term price volatility, which affects mill profitability and the well-being of smallholder farmers. Studies have analyzed FFB marketing networks (Alham et al., 2020; Jakfar et al., 2015), price transmission (Tety et al., 2013), and transportation cost efficiency (Herviandinata et al., 2025) for the Aceh and Sumatra regions, demonstrating how competition among market participants is influenced by proximity to mills, infrastructure availability, and transactional relationships. Some of these studies adopt a descriptive or econometric approach, without considering population-based dynamic interactions. Price volatility in the fresh fruit bunch (FFB) market has also been widely discussed in the palm oil industry literature, particularly in relation to the welfare of smallholder farmers (Marzukhi et al., 2021; Sukiyono et al., 2017; Witjaksono et al., 2023), mill productivity or efficiency (Ghulam Kadir et al., 2022; Maskromo et al., 2024), supply chain efficiency (Marimin et al., 2020), regional competitiveness (Pebrianto et al., 2024), and policy mechanisms affecting price transmission (Hatmaja et al., 2023; Nesti et al., 2019). However, most empirical analyses remain static and focus on price determinants rather than the dynamic, endogenous interactions among competing factories. In this paper, we expand upon the existing literature by introducing a nonlinear dynamic framework (the predator-prey model) capable of capturing the feedback mechanisms between supply availability and factory activity.

To capture these dynamic interactions, we adopt an industrial ecology perspective, which views factories and raw material suppliers as interdependent populations within a shared economic ecosystem. Drawing inspiration from ecological predator-prey theory (Bazin et al., 1974; Serrouya et al., 2015; Wootton et al., 2021), competition among mills is conceptualized as consumption pressure on the supply of fresh fruit bunches (FFB), while supply availability regulates mill activity through price mechanisms. This analogy allows for the use of nonlinear dynamic systems (nonlinear behavior) to model feedback loops (interdependence) and adaptive processes within the palm oil industry ecosystem, which are difficult to represent using static or equilibrium-based economic models. Using weekly fresh fruit bunch (FFB) price data from January through April 2025 sourced from palm oil mills in Nagan Raya Regency, Aceh Province, we analyzed the nonlinear dynamics (FFB price competition). This study is expected to provide a quantitative basis for designing policies aimed at maintaining market stability in the regional palm oil industry, particularly in Aceh Province.

B. MATERIALS AND METHOD

1. Data and Study Context

This study focuses on the local industrial ecosystem of palm oil mills operating in Nagan Raya Regency, Aceh Province, Indonesia. This region exhibits a highly competitive purchasing environment, where multiple mills simultaneously set weekly prices for FFB, creating endogenous market dynamics driven by strategic interactions and supply responses. Weekly FFB price data were collected from official price announcements published by the Nagan Raya Plantation Office for the period January–April 2025 (Table 1). The dataset includes: regional average prices, company-specific purchase prices for 8 (eight) active palm oil mills, and weekly price adjustments (increases/decreases/stagnation).

Table 1. Weekly Fresh Fruit Bunch (FFB) Price Data For Nagan Raya

Week	Announcement Date	Price of FFB (Rp/kg)
1	January 6, 2025	2.820
2	January 13, 2025	2.850
3	January 20, 2025	2.875

Week	Announcement Date	Price of FFB (Rp/kg)
4	January 27, 2025	2.930
5	February 3, 2025	2.980
6	February 10, 2025	3.020
7	February 17, 2025	3.000
8	February 24, 2025	2.980
9	March 3, 2025	2.960
10	March 10, 2025	2.910
11	March 17, 2025	2.870
12	March 24, 2025	2.850
13	April 8, 2025	2.880
14	April 14, 2025	2.900
15	April 21, 2025	2.940

2. Logistic Predator–Prey Model

The interaction between competition among palm oil mills (POMs) and the supply of fresh fruit bunches (FFB) is modeled using logistic predator-prey model. The predator-prey terminology represents interaction mechanisms rather than literal biological relationships. The FFB resource index (*F*) represents the local supply/market conditions faced by POMs, while *M* represents the mills' latent competitive activity. An increase in *F* creates favorable conditions for mill activity through βFM. Conversely, intensified mill activity reduces the effective FFB resource state through αFM. Therefore, this model captures a feedback mechanism in which favorable supply conditions stimulate competition among mills, while intensified competition feeds back into the resource/market state. The dynamics system is defined as:

$$\frac{dF}{dt} = rF(1 - F/K) - \alpha FM \quad (1)$$

$$\frac{dM}{dt} = \beta FM - \delta M \quad (2)$$

where:
r : the intrinsic recovery/growth rate of F
K : the effective carrying capacity of the FFB resource index
α : effect of mill activity on F,
β : response of mill activity to F, and
δ : decline/withdrawal rate of mill activity

3. Parameter Estimation and Model Fit

The model parameters were estimated using a nonlinear least-squares approach based on the observed temporal dynamics of the normalized FFB resource index. Unlike previous linear regression formulations, this approach directly estimates the parameters of the nonlinear logistic predator-prey system to ensure consistency between the mathematical formulation and the empirical calibration procedure. The observed FFB prices are converted into a positive normalized resource index *F(t)* using:

$$F_t = 0.1 + 0.9\frac{P_t - P_{\min}}{P_{\max} - P_{\min}} \quad (3)$$

Where P_t denotes the observed weekly FFB price, while P_{min} and P_{max} represent the observed minimum and maximum prices, respectively. A lower bound of *0.1* is introduced to avoid a zero initial condition, since $F = 0$ is an invariant boundary of the model and would prevent the classical interaction term from becoming active. Weekly direct observations of aggregate factory competitive activity are not available for the entire observation period. Therefore, *M(t)* is treated as an index of latent factory competitive activity, rather than as a physical quantity observed directly. To establish a scale for the latent state, the initial condition is normalized to *M(0) = 1*. Thus, the value of *M(t)* should be interpreted as a relative activity index rather than as the number of operating factories, production volume, or the percentage of factories. By defining the model parameters as $\theta = (r, K, \alpha, \beta, \delta)$, the parameter vector was then estimated by minimizing the sum of the squared differences between the observed and simulated F(t) trajectories:

$$\min_{\theta} \sum_{t=1}^{T} [F_{\text{obs}}(t) - F_{\text{sim}}(t; \theta)]^2 \quad (4)$$

subject to positive parameter constraints and the model equations. For each set of candidate parameters, the interrelated ordinary differential equations are numerically integrated over a 15-week observation period using specified initial conditions. The optimization procedure iteratively updates the parameter values to minimize the difference between the observed and simulated *F(t)*. The initial conditions for the resource index are taken from the first normalized observation, while the latent plant activity is initialized at *M(0)=1*. By setting *F(0) = 0.10* and *M(0) = 1*, the model's performance was then evaluated using the root mean square error (*RMSE*) and the coefficient of determination (R^2):

$$RMSE = \sqrt{\frac{1}{T} \sum_{t=1}^{T} (F_{\text{obs},t} - F_{\text{sim},t})^2} \quad (5)$$

and

$$R^2 = 1 - \frac{\sum_{t=1}^{T} (F_{\text{obs},t} - F_{\text{sim},t})^2}{\sum_{t=1}^{T} (F_{\text{obs},t} - \bar{F}_{\text{obs}})^2} \quad (6)$$

Since *M(t)* is not directly observed, the estimated interaction parameters involving *M* particularly a must be interpreted with caution. Normalizing *M(0) = 1* sets the scale of the latent state and allows for numerical calibration, but this is not a direct measure of grinding activity.

C. RESULTS AND DISCUSSION

1. Empirical Dynamics of Weekly FFB Prices

The empirical dataset consists of weekly observations of fresh fruit bunch (FFB) prices reported for Nagan Raya Regency from January through April 2025. The observations reveal substantial short-term variations in FFB prices during the study period, with an initial upward trend followed by a decline and subsequent recovery. This non-monotonic pattern provides an empirical basis for examining the possibility of endogenous adjustments between FFB supply conditions and POMs purchasing activity. Rather than interpreting each weekly price movement as an independent shock, this study treats the observed trajectory as the aggregate result of repeated adjustments within the local palm oil industry ecosystem. As mills compete more intensely for available FFB, purchasing pressure may increase, while tighter raw material availability may subsequently constrain mill operations. The resulting feedback loop provides a plausible mechanism through which short-term fluctuations can arise even in the absence of sustained external shocks. However, the relatively short observation period must be taken into account when interpreting the results. The data from January through April 2025 are sufficient to identify short-term trends and calibrate the proposed dynamic framework, but they should not be interpreted as evidence of a long-term structural price cycle.

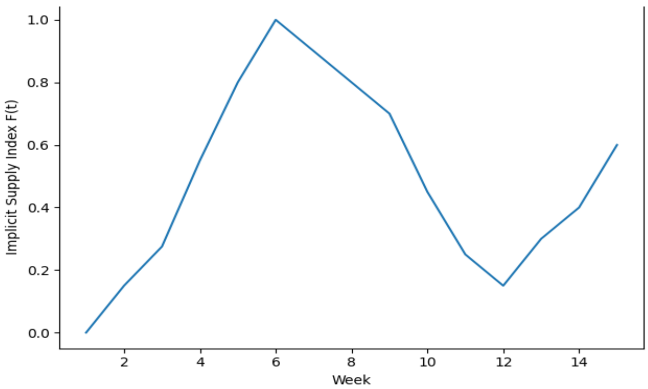

Figure 1. Empirical Dynamics of Weekly FFB Prices

2. Equilibrium Model and Local Stability

From the model: $\begin{matrix} \frac{dF}{dt} = rF\left(1 - \frac{F}{K}\right) - \alpha FM, \\ \frac{dM}{dt} = \beta FM - \delta M. \end{matrix}$, the equilibrium is obtained from $\frac{dF}{dt} = 0$, $\frac{dM}{dt} = 0$.

From the second equation $M(\beta F - \delta) = 0$, so $M = 0$, or $F = \frac{\delta}{\beta}$.

For Equilibrium 1: If $M = 0$, then $F\left(1 - \frac{F}{K}\right) = 0$. Thus, $F = 0$ or $F = K$. Consequently, there are two boundary equilibria: $E_0 = (0, 0)$ or $E_F = (K, 0)$. E_F is interpreted as a resource-only equilibrium, i.e., a condition where the mill activity index is not sustained. For Equilibrium 2 (coexistence); an interior equilibrium where $M > 0$, then $F^* = \frac{\delta}{\beta}$. Substituting into the first equation yields: $rF^*\left(1 - \frac{F^*}{K}\right) - \alpha F^* M^* = 0$.

Since $F^* > 0$, we have $r\left(1 - \frac{F^*}{K}\right) - \alpha M^* = 0$, thus: $M^* = \frac{r}{\alpha}\left(1 - \frac{F^*}{K}\right)$.

With $F^* = \frac{\delta}{\beta}$, we obtain:

$$E^* = \left(\frac{\delta}{\beta}, \frac{r}{\alpha}\left(1 - \frac{\delta}{\beta K}\right)\right) \tag{7}$$

This equilibrium is positive only if $\beta K > \delta$. This will form the basis for the section on threshold and transcritical bifurcation analysis. With the calibration parameters $r = 0.8701$, $K = 1.0302$, $a = 0.00701$, $\beta = 2.9548$, and $\delta = 1.3640$, we obtain: $F^* = \frac{1.3640}{2.9548} = 0.461$, and $M^* = \frac{0.8701}{0.00701}\left(1 - \frac{1.3640}{(2.9548)(1.0302)}\right) \approx 68.50$. Thus: $E^* = (0.4616, 68.50)$. The value 68.50 does not represent the number of factories. Since M is a latent mill competitive activity index normalized such that $M_0 = 1$, this value is on the model's index scale.

Next, for the Jacobian matrix: $J(F, M) = \begin{pmatrix} r - \frac{2rF}{K} - \alpha M & -\alpha F \\ \beta M & \beta F - \delta \end{pmatrix}$. At E^*, since $\beta F^* - \delta = 0$, then: $J(E^*) = \begin{pmatrix} -\frac{r\delta}{\beta K} & -\frac{\alpha\delta}{\beta} \\ \frac{\beta r}{\alpha}\left(1 - \frac{\delta}{\beta K}\right) & 0 \end{pmatrix}$. With the following estimation parameters, then: $J(E^*) = \begin{pmatrix} -0.3899 & -0.00324 \\ 202.36 & 0 \end{pmatrix}$.

Next, regarding local stability, the eigenvalue characteristics obtained are: $\lambda^2 - \text{tr}\,(J^*)\lambda + \det\,(J^*) = 0$. The trace of $\text{tr}\,(J^*) = -\frac{r\delta}{\beta K} < 0$ and the determinant $\det\,(J^*) = r\delta\left(1 - \frac{\delta}{\beta K}\right)$; if $\beta K > \delta$, then $det\,(J^*) > 0$. Since the trace is negative and the determinant is positive, the equilibrium coexistence is locally asymptotically stable. For the calibrated parameters, the eigenvalues are: $\lambda_{1,2} = -0.19494 \pm 0.78550i$. Since $Re(\lambda) < 0$ and the imaginary part is nonzero, then: E^* is a locally asymptotically stable focus. The negative real part of the eigenvalue indicates that disturbances around the coexistence equilibrium decay over time, while the nonzero imaginary part gives rise to an oscillatory component. Therefore, the coexistence equilibrium is a locally asymptotically stable focus, implying damped oscillatory adjustments rather than persistent cycles. In the context of the Nagan Raya palm oil market, this model represents a system in which deviations between FFB resource conditions and competitive mill activity can produce short-term fluctuations, but these fluctuations are expected to diminish as the system approaches its long-term coexistence state.

3. Model Calibration and Temporal Dynamics

Figure 2 presents a temporal comparison between the observed FFB resource index and the trajectory generated by the calibrated logistic predator-prey model. The observed FFB prices were converted into a positive normalized resource index $F(t)$, with values ranging from 0.10 to 1.00 over the 15-week observation period. The model was calibrated by estimating the parameters r, K, a, β, and δ, while the unobserved competitive activity of the mill, $M(t)$, was treated as a latent state variable. The initial condition for the latent activity index was normalized to $M(0) = 1$.

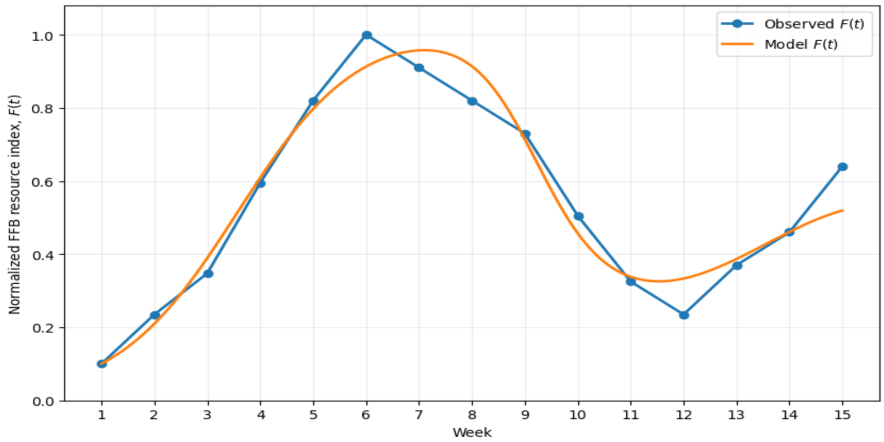

Figure 2. Observed and simulated trajectories of the normalized FFB resource index F(t) during January–April 2025.

As shown in Figure 2, the simulation trajectory captures the main temporal patterns of the observed FFB resource index, including its initial increase, peak around Week 6, subsequent decline, and partial recovery toward the end of the observation period. The calibrated model yields an RMSE of *0.0572* and an R^2 of *0.9535*, indicating a close fit within the sample between the observed and simulated *F(t)*. Therefore, the model provides a reasonable representation of the short-term temporal dynamics of the normalized FFB resource conditions. Nevertheless, the relatively short observation period and the absence of direct observations of *M(t)* imply that these calibration results should be interpreted as evidence of model consistency rather than as validation of out-of-sample predictions. In particular, the state of latent plant activity is inferred from the coupled dynamic system rather than measured directly.

4. Phase-Plane Dynamics

To further investigate the interaction between FFB resource conditions and POMs competitive activity, the calibrated trajectories were examined in the phase space (*F, M*). In the proposed interpretation, *F(t)* represents a normalized index of FFB resource or market conditions, while *M(t)* represents a latent index of POMs competitive activity. The coexistence equilibrium is given by $E^* = \left(\frac{\delta}{\beta}, \frac{r}{\alpha}\left(1 - \frac{\delta}{\beta K}\right)\right)$, which, based on the estimated parameter values, this yields $E^* = (0.4616, 68.50)$. The appropriate linearization has eigenvalues: $\lambda_{1,2} = -0.19494 \pm 0.78550i$, that exhibits a locally asymptotically stable focus.

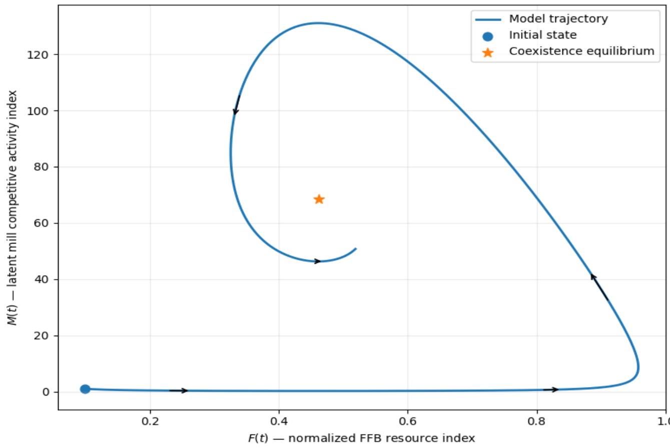

Figure 3. Phase-plane plot of the implicit supply index $F(t)$ and POMs activity index $M(t)$

Figure 3 illustrates the nonlinear interaction between the two states of the model. Starting from the normalized initial conditions $(F_0, M_0) = (0.10, 1)$, the trajectory initially moves toward a higher value of F, while latent POMs activity subsequently increases. As the interaction term aFM becomes stronger, the resource index decreases, followed by a reduction in POMs activity. This results in repetitive motion in the phase space rather than a monotonic adjustment of either state. This trajectory is consistent with the local stability results obtained from the Jacobian analysis. Since the eigenvalues of the coexistence equilibrium have a negative real part and a nonzero imaginary part, perturbations around E^* are expected to decay while exhibiting oscillatory components. Thus, the model predicts a damped oscillatory approach to coexistence in the long-term dynamics of the system. However, it should be emphasized that the 15-week observation window does not allow sufficient time for the simulation trajectory to fully converge to E^*. Therefore, Figure 2 should be interpreted as an illustration of the transient interactions generated by the calibrated model, rather than as direct empirical evidence that the system has reached its theoretical equilibrium.

5. Threshold and Bifurcation Analysis

The existence of a positive coexistence equilibrium depends on the relative strengths of the grinding response and the activity decay. From the second model equation $\dot{M} = M(\beta F - \delta)$, the threshold condition for the persistence of positive grinding activity is obtained as $\mathcal{R} = \frac{\beta K}{\delta}$. A positive coexistence equilibrium exists when $\mathcal{R} > 1$. For the calibrated set of parameters, the threshold value is $\mathcal{R} = \frac{(2.9548)(1.0302)}{1.3640} = 2.2317 > 1$. Therefore, the system is estimated to be in the coexistence regime. The critical value of the grinding response parameter is $\beta_c = \frac{\delta}{K} = 1.3240$. At $\beta = \beta_c$, the positive equilibrium satisfies $M^* = 0$, and coincides with the boundary equilibrium $E_F = (K, 0)$, indicating a transcritical bifurcation.

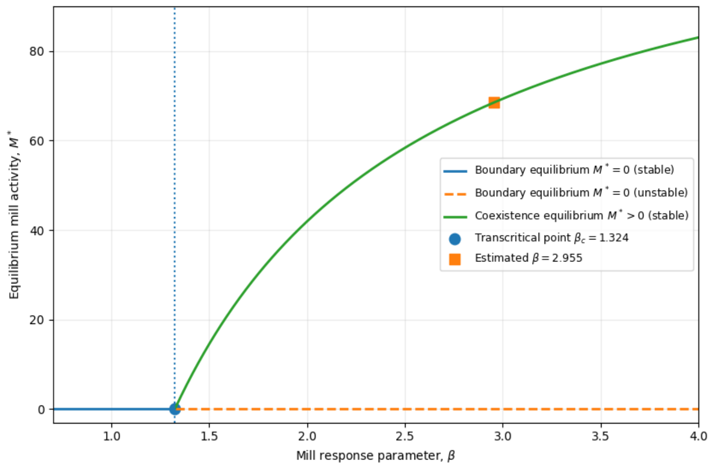

Figure 4. Transcritical bifurcation diagram of the equilibrium POMs activity (M^*) with respect to POMs response parameter β

Figure 4 shows the bifurcation structure of the equilibrium grinding activity as the response parameter β varies. For $\beta < \beta_c$, no positive coexistence equilibrium exists, and the only relevant equilibrium at the boundary is $M^* = 0$. At the critical value $\beta_c = 1.3240$, the boundary equilibrium and the positive coexistence branch intersect. For $\beta > \beta_c$, a positive equilibrium $M^* > 0$, emerges and increases with β, consistent with the coexistence regime predicted by the model. The estimated value of $\beta = 2.9548$, lies well above the critical threshold, yielding $\mathcal{R} = 2.231$. Therefore, under the calibrated parameter regime, the model predicts the persistence of the competitive POMs activity state rather than its disappearance. Mathematically, the transition at $\mathcal{R} = 1$ represents a transcritical bifurcation that separates the non-coexistence and positive coexistence regimes.

6. Sensitivity Analysis

A sensitivity analysis was conducted to measure the influence of model parameters on threshold quantities and positive coexistence equilibrium. Since the available dataset consists of only 15 weekly observations and the competitive activity of plant $M(t)$ is treated as a latent state, a normalized forward sensitivity analysis was adopted instead of a sampling-based global sensitivity method. This approach provides an analytically interpretable assessment of parameter effects while avoiding overinterpretation of the small calibration sample. The threshold quantity is defined as $\mathcal{R} = \frac{\beta K}{\delta}$. The normalized sensitivity indices are: $S_K^{\mathcal{R}} = 1$, $S_\beta^{\mathcal{R}} = 1$, and $S_\delta^{\mathcal{R}} = -1$, while $S_r^{\mathcal{R}} = S_\alpha^{\mathcal{R}} = 0$.

Therefore, the persistence threshold is equally and positively sensitive to the effective FFB capacity K and POMs response parameter β, while the activity decay parameter δ has an equally strong negative effect. The parameters r and a do not directly influence the threshold conditions. The coexistence equilibrium of the FFB resource index is $\mathcal{R} = \frac{\beta K}{\delta}$. Normalized sensitivity: $S_p^{F^*} = \frac{p}{F^*}\frac{\partial F^*}{\partial p}$. Since: $\frac{\partial F^*}{\partial \beta} = -\frac{\delta}{\beta^2} = -\frac{F^*}{\beta}$, and $\frac{\partial F^*}{\partial \delta} = \frac{1}{\beta} = \frac{F^*}{\delta}$, then: $S_\beta^{F^*} = -1$ and $S_\delta^{F^*} = +1$. Meanwhile: $S_r^{F^*} = S_K^{F^*} = S_\alpha^{F^*} = 0$, so, an increase in β reduces the balanced FFB resource index, while an increase in δ increases it. From an economic/industrial perspective, β can be interpreted as the mill's response to the availability of FFB, while δ represents the rate of activity withdrawal or decline.

For the equilibrium of the plant's competitive activities, $M^* = \frac{r}{\alpha}\left(1 - \frac{\delta}{\beta K}\right)$; the normalized sensitivities are: $S_r^{M^*} = 1$, $S_\alpha^{M^*} = -1$; $S_K^{M^*} = S_\beta^{M^*} \approx 0.812$; and $S_\delta^{M^*} \approx -0.812$. Therefore, the plant's equilibrium activity is most directly influenced by the intrinsic recovery parameter r and the competitive pressure parameter α, each of which has unit elasticity in absolute terms. The parameters K and β also increase equilibrium activity, while δ decreases it.

Table 2. Normalized Sensitivity Indices of $\mathcal{R}$, F*, and M*

Parameter	$\mathcal{R}$	F*	M*
r	0	0	+1.000
K	+1.000	0	+0.812
α	0	0	−1.000
β	+1.000	−1.000	+0.812
δ	−1.000	+1.000	−0.812

D. CONCLUSIONS AND SUGGESTIONS

This study develops a logistic predator-prey model to describe the short-term interactions between the market conditions for Fresh Fruit Bunches (FFB) and the competitive activities of POMs in Nagan Raya, Aceh. The calibrated model is able to reproduce the main temporal patterns of the normalized FFB dynamics, indicating that the proposed nonlinear interaction structure provides a reasonable representation of the observed system. Further equilibrium and stability analyses show that the calibrated system supports a locally asymptotically stable state of coexistence with damped oscillatory dynamics. Bifurcation analysis identifies a critical threshold separating the non-coexistence and positive coexistence regimes, providing a mathematical criterion for assessing the persistence of POMs competitive activity. These findings suggest that the proposed framework can serve as a mathematical tool for analyzing the interrelated dynamics of resource competition within the local palm oil industry. However, the results are based on a short observation period of 15 weeks and a latent representation of POMs activity. Future studies should incorporate longer time series and direct POMs-level activity data to improve parameter identification, model validation, and predictive capabilities.

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