M A T H L I N E
JURNAL MATEMATIKA DAN PENDIDIKAN MATEMATIKA
ISSN 2502-5872 (Print)
ISSN 2622-3627 (Elektronik)

This is an open access article under the CC BY-SA license

Volume 11 Number 4, November 2026, 907-920

MATHEMATICAL MODEL FOR ANALYZING DEGRADATION OF MANGROVE FORESTS IN LANGSA

Ulya Nabilla[1*], Novianda[2], Mawarni[3], Fitri Rezky Hamzani[4], Shevira Agustri Maulana[5], Adellia Helena[6], Amelia[7], Nurviana[8], Fairus[9], Riezky Purnama Sari[10]
[1,3,4,5,6,7,8,9,10] Mathematics Department, Universitas Samudra, Aceh, Indonesia
[2] Industrial Engineering Department, Universitas Samudra, Aceh, Indonesia

*Correspondence: ulya.nabilla@unsam.ac.id

Received 23 February 2026; Revised 24 July 2026; Accepted 25 August 2026

ABSTRACT

The mangrove forest area in Kota Langsa declined from 8,000 ha in 2022 to 6,172.42 ha in 2023 due to natural processes and human activities, particularly population growth and aquaculture expansion. This research develops a predator–prey mathematical model based on a system of differential equations to describe the interactions among mangrove forest area, human population, and aquaculture pond area. The objectives are to construct the model, analyze the stability of its equilibrium points, and investigate the system dynamics. The model was developed using data from Desa Kuala Langsa and analyzed by equilibrium point analysis, Jacobian matrix, eigenvalue analysis, and numerical simulations through Maple. The resulting model is given by $\frac{dH}{dt} = \propto \left(1 - \frac{H}{B}\right) H - \tau PH - \eta TH$; $\frac{dP}{dt} = \tau\delta PH - \mu P + \beta \left(1 - \frac{P}{A}\right) P$; $\frac{dT}{dt} = \eta\theta TH - \omega T$. The proposed model has six equilibrium points, consisting of five asymptotically stable equilibrium points and one unstable equilibrium point. Numerical simulations indicate that population growth increases pressure on the mangrove ecosystem, resulting in a decline in the mangrove forest area, which subsequently reduces the aquaculture pond area. The results demonstrated that mangrove forest degradation in Kota Langsa is strongly influenced by the interactions between ecological factors and human activities. The proposed model provides a mathematical framework for analyzing these interactions and may be extended in future research by incorporating management interventions or conservation policies.

Keywords: Mathematical Model, Differential, Equilibrium, Stability, Mangrove.

How to Cite: Nabilla, U., Novianda, N., Mawarni, M., Hamzani, F. R., Maulana, S. A., Helena, A., Amelia, A., Nurviana, N., Fairus, F., & Sari, R. P. (2026). Mathematical Model for Analyzing Degradation of Mangrove Forests in Langsa. *Mathline: Jurnal Matematika dan Pendidikan Matematika, 11*(4), 907-920. http://doi.org/10.31943/mathline.v11i4.1122

PRELIMINARY

Indonesia possesses one of the largest mangrove forest ecosystems in the world (Khairunnisa et al., 2020), covering approximately 3,364,080 ha (Nurbaya, 2021). Kota Langsa, Provinsi Aceh, is one of the regions with extensive mangrove forests, stretching across the districts of Langsa Timur, Langsa Barat, and Langsa Lama. Hanafiah (2022) reported that the mangrove forest area reached approximately 8,000 ha. However, the area

declined to 6,172.42 ha in 2023 (Badan Pusat Statistik Kota Langsa, 2024). Furthermore, Purba et al. (2023) reported that 6.275 ha of mangrove forest were classified as slightly degraded, while 0.346 ha were categorized as severely degraded. This reduction in mangrove forest area indicates the occurrence of mangrove forest degradation in Kota Langsa.

Previous research has shown that mangrove degradation was driven by both natural processes and anthropogenic activities. Iswahyudi et al. (2019) identified illegal logging, pollution, and the conversion of mangrove forests into aquaculture ponds and residential areas as the primary causes of mangrove ecosystem degradation in Kota Langsa. Similarly, Wakhidah et al. (2022) reported that the conversion of mangrove forests into aquaculture ponds is one of the major factors contributing to ecosystem degradation. Susilawati et al. (2018) further emphasized that increasing human activities, particularly the conversion of mangrove forests into residential areas, can suppress the growth of mangrove forests.

Mathematical models have been widely employed to investigate the dynamics of mangrove forest degradation. Nugraheni et al. (2019) demonstrated that increasing populations of proboscis monkeys and the expansion of aquaculture ponds contributed to the reduction of mangrove forest area. In the same year, Mohamad et al. (2019) showed that although the human population declined toward extinction and mangrove forest resources increased, uncontrolled industrialization could still lead to forest extinction, particularly when accompanied by uncontrollable forest fires. Furthermore, Wakhidah et al. (2022) developed a mathematical model showing that mangrove forests, proboscis monkey populations, and aquaculture ponds could coexist under the influence of time delay.

Based on the review of previous research, no mathematical model has been developed specifically to analyze mangrove forest degradation in Kota Langsa by integrating population growth and aquaculture pond expansion as the primary drivers of degradation. Therefore, this research develops a mathematical model based on a system of differential equations using a predator-prey approach to represent the interactions among mangrove forest area, human population, and aquaculture pond area. In addition to investigating the existence and stability of the model's equilibrium points, the dynamic behavior of the system is examined through numerical simulations using real data from Desa Kuala Langsa.

Accordingly, the objectives of this research are: 1. To develop a mathematical model of mangrove forest degradation by incorporating the effects of population growth

and aquaculture pond expansion. 2. To analyze the stability of the equilibrium points of the proposed model. 3. To investigate the dynamic behavior of the mangrove forest degradation model.

METHODS

This research was conducted in Desa Kuala Langsa, Kota Langsa. According to Purba et al. (2023), this area has experienced extensive mangrove forest degradation. The spatial distribution of mangrove ecosystem degradation in Desa Kuala Langsa is presented in Figure 1.

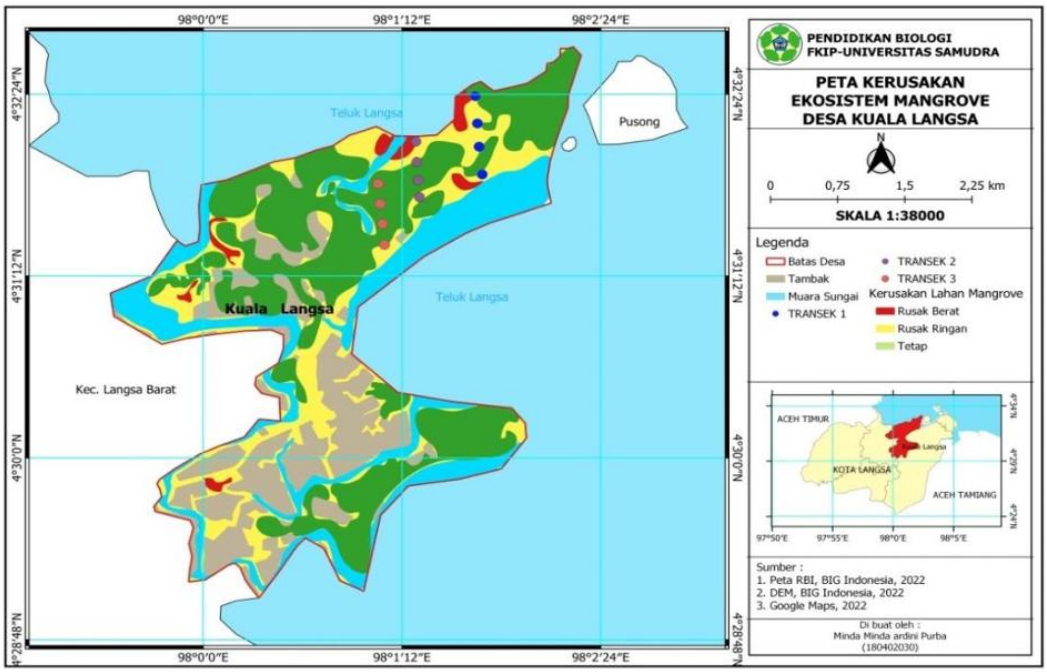


Figure 1. Map of the Mangrove Ecosystem in Desa Kuala Langsa (Source : Best Journal : Biology Education Science and Technology)

The data used in this research consisted of mangrove forest area, aquaculture pond area, and human population. Data on mangrove forest area were obtained from Rahmadi et al. (2022), aquaculture pond area data were provided by Dinas Komunikasi dan Informatika, and population data were obtained from Kantor Geuchik Kuala Langsa.

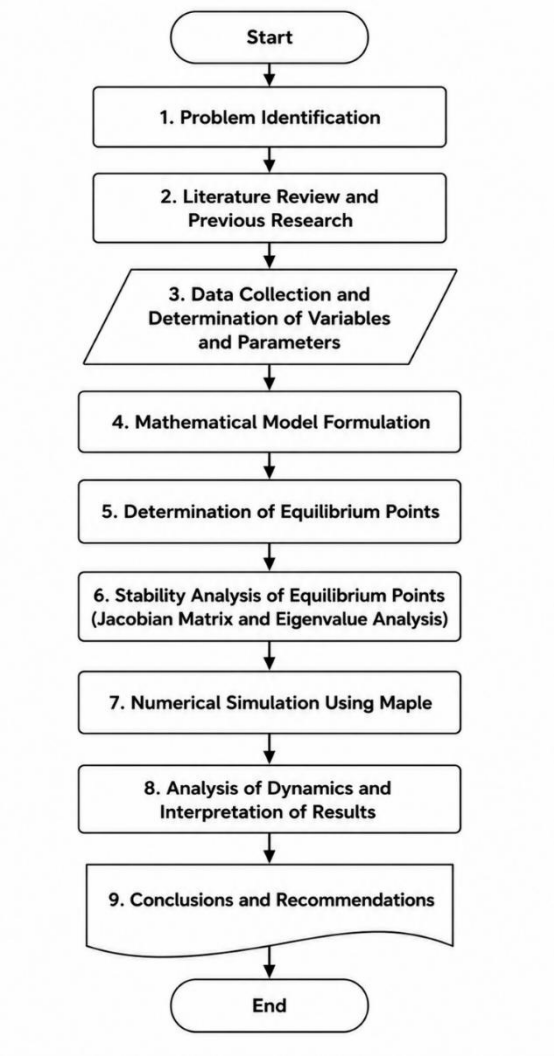


Figure 2. Research Flowchart

The research procedure began with the identification of mangrove forest degradation problems in Kota Langsa through a literature review and data collection. The collected data were used to determine the model variables and parameters, followed by the construction of a mathematical model based on a system of differential equations using a predator-prey approach. The proposed model was then analyzed by determining its equilibrium points and investigating their stability through Jacobian matrix and eigenvalue analyses. To describe the system of dynamic behavior, numerical simulations were performed using Maple software. The simulation results were subsequently analyzed and interpreted to explain the interactions among mangrove forests, human populations, and aquaculture ponds, leading to conclusions consistent with the objectives of the research.

1. *Predator-Prey* Mathematical Model Approach

The problem-solving approach applied in this research was the *predator-prey* mathematical model approach. This approach involved a system of differential equations.

According to (Hadi et al., 2019), differential equations are equations that contain or involve derivatives or differentials of unknown functions.

Kartono (2012) stated that the general form of a differential equation is as follows.

$$\begin{aligned}\frac{dx_1}{dt} &= f_1(x_1, x_2, \dots, x_n, t)\\ \frac{dx_2}{dt} &= f_2(x_1, x_2, \dots, x_n, t)\\ &\vdots\\ \frac{dx_n}{dt} &= f_n(x_1, x_2, \dots, x_n, t)\end{aligned} \quad (1)$$

Where $x_1, x_2, \dots, x_n$ are independent variables and$t$ is dependent variable, such that $x_1 = x_1(t), x_2 = x_2(t), \dots, x_n = x_n(t)$, with $\frac{dx_n}{dt}$ being the derivative of the function x_n with respect to t.

(Mohamad et al., 2019) added that this mathematical model approach used several compartments. The compartments used in this research are the mangrove forest population, the human population, and the pond area.(Nugraheni et al., 2019) state that dynamic analysis in mathematical modeling includes determining and analyzing equilibrium points, determining and analyzing the stability of the system of equations, and inputting data and performing numerical analysis in the system of equations.

2. Equilibrium Point

This analysis aimed to determine the fixed point at which equation 1 reaches equilibrium. Equilibrium in this context refers to the condition where there is no significant change in the system variables over time. Munandar (2017) stated that the equilibrium point obtained by finding the solution to equation 1 when $(x_1, x_2, \dots, x_n) = 0$. To find this solution, equation 1 is stated as follows.

$$\begin{aligned}y_1 &= a_{11}x_1(t) + a_{12}x_2(t) + \cdots + a_{1n}x_n(t)\\ y_2 &= a_{21}x_1(t) + a_{22}x_2(t) + \cdots + a_{2n}x_n(t)\\ &\vdots\\ y_n &= a_{n1}x_1(t) + a_{n2}x_2(t) + \cdots + a_{nn}x_n(t)\end{aligned} \quad (2)$$

Equation 2 can be expressed in matrix form as follows.

$$\begin{pmatrix}y_1\\ y_2\\ \vdots\\ y_n\end{pmatrix} = \begin{pmatrix}a_{11} & a_{12} & a_{1n}\\ a_{21} & a_{22} & a_{2n}\\ \vdots & \ddots & \vdots\\ a_{n1} & a_{n2} & a_{nn}\end{pmatrix}\begin{pmatrix}x_1\\ x_2\\ \vdots\\ x_n\end{pmatrix} \quad (3)$$

Next, we obtain equation 4.

$$(\bar{A} - I)x(t) = 0 \quad (4)$$

Assuming $(\bar{A} - I)$it is not singular, it is obtained $x(t)$as the equilibrium point of thesystem. If λ it is the eigenvalue of equation 4, then the following general solution form is obtained.

$$x(t) = c_1\lambda_1^n v_1 + c_2\lambda_2^n v_2 + \cdots + c_k\lambda_k^n v_k \quad (5)$$

Where c_i is a constant and v_i is an eigenvector corresponding to the eigenvalue λ_i for $i = 1,2, \ldots, k$ (Elaydi, 2005) .

3. Stability of Equilibrium Point

To analyze the stability of the equilibrium point, the model was linearized around the equilibrium point, and the eigenvalues of the resulting Jacobian matrix were analyzed. Eigenvalues with negative real parts indicate stability, while eigenvalues with positive real parts indicate instability.

According to (Maknun, 2019), one way to analyze stability was to use the Routh-Hurwitz criterion. For example, given the characteristic equation,

$$\lambda^n + A_1\lambda^n + \cdots + A_{n-1}\lambda^n + A_n = 0 \quad (6)$$

With A_n is a real number coefficient $n = 1, 2, \ldots$ and its characteristic equation is a zero-forming polynomial that has a negative real part with $A_1 > 0, A_2 > 0, \ldots, A_n > 0$. Based on the equation above, $n$the Routh-Hurwitz matrix (H_k) is obtained which is defined as follows.

$$H_k = \begin{bmatrix} A_{11} & 1 & 0 & \cdots & 0 \\ A_{21} & A_{22} & 1 & 0 & \vdots \\ \vdots & \vdots & \vdots & 1 & \vdots \\ A_{n1} & A_{n2} & A_{n3} & \cdots & 1 \end{bmatrix} \quad (7)$$

The stability of a fixed point has three behaviors, namely stable, unstable, and saddle. Furthermore, (Maknun, 2019)stated that a fixed point x^* of a system is said to be stable if each real eigenvalue is negative and each component of the complex eigenvalue, its real part is less than or equal to zero. A fixed point x^* of a system is said to be unstable if each real eigenvalue is positive and each component of the complex eigenvalue, its real part is greater than zero. A fixed point x^* of a system is said to be saddle if the product of two real eigenvalues is negative.

RESULT AND DISCUSSION

1. Model Construction

At this step, several assumptions, variables, and parameters were established to construct a mathematical model in the form of a system of differential equations.

The assumptions adopted in this research were as follows: the growth of the mangrove forest is limited by the environmental carrying capacity, and the growth of the human population is limited by the environmental carrying capacity.

The variables and parameters used in this research are presented in Tables 1 and 2, respectively.

Table 1. Research Variables

Variables	Information	Mark	Data Sources
H	Mangrove forest area	811.04 Ha	(Rahmadi et al., 2022)
P	Human population	2,289 people	(Dinas Komunikasi dan Informatika, 2023)
T	Aquaculture pond area	100 Ha	Field survey in Desa Kuala Langsa

Table 2. Research Parameters

Parameters	Information	Mark	Data Sources
α	Intrinsic growth rate of the mangrove forest	$\frac{1.8}{year}$	Assumption
β	Intrinsic growth rate of the human population	$\frac{0.3}{year}$	(Mohamad et al., 2019)
τ	Mangrove degradation coefficient due to human activities	$\frac{0.001}{people \times year}$	Assumption
δ	Mangrove utilization rate by the human population	0.005	Assumption
η	Aquaculture expansion coefficient associated with mangrove availability	$\frac{0.002}{Ha \times year}$	(Nugraheni et al., 2019)
μ	Natural mortality rate of the human population	$\frac{0.01}{year}$	Assumption
θ	Conversion rate of mangrove forests into aquaculture ponds	0.8	Assumption
ω	Degradation rate of aquaculture ponds due to declining land quality	$\frac{0.5}{year}$	(Nugraheni et al., 2019)
A	Environmental carrying capacity for the human population	$\frac{Total\ area\ of\ Kuala\ Langsa \times f_{suit} population}{Land\ area\ requirement/person} \approx \frac{154{,}500m^2 \times 1}{\frac{32.31m^2}{people}} \approx 4{,}782\ people$	Calculated from field data
B	Environmental carrying capacity for the mangrove forest	$1{,}000\ Ha$	Assumption

Based on the phenomena that occurred and supported by assumptions, variables, and research parameters, the model conducted in this research was illustrated as in Figure 3.

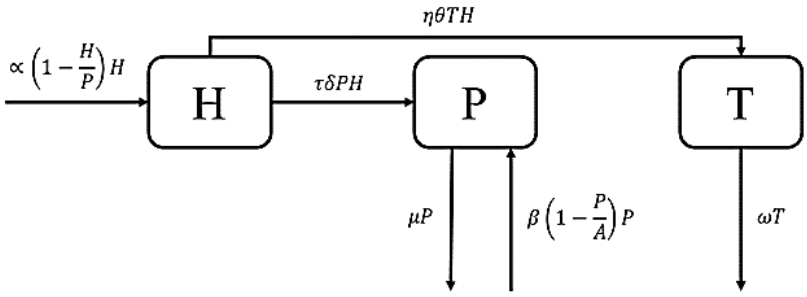


Figure 3. Mangrove Forest Degradation Model

Based on the diagram in Figure 3, a mathematical model is obtained in the form of a system of differential equations as follows.

$$\frac{dH}{dt} = \propto \left(1-\frac{H}{B}\right)H - \tau PH - \eta TH$$
$$\frac{dP}{dt} = \tau\delta PH - \mu P - \beta\left(1-\frac{P}{A}\right)P$$
$$\frac{dT}{dt} = \eta\theta TH - \omega T \quad (8)$$

2. Equilibrium Point Analysis

This analysis aimed to determine the fixed point or equilibrium point when the model or equation 8 reaches equilibrium. Equilibrium in this context refers to the condition where there is no significant change in the system variables over time. To obtain the equilibrium point, equation 8 is transformed into a matrix. The matrix is then solved when the matrix equals 0. Using *the Maple software*, six equilibrium points are obtained from equation 8, namely:

$$\{H=0,P=0,T=0\};\left\{H=0,P=\frac{A(\beta-\mu)}{\beta},T=0\right\};\{H=B,P=0,T=0\};\left\{H=\frac{\omega}{\eta\theta},P=0,T=\frac{\alpha(B\eta\theta-\omega)}{B\eta^2\theta}\right\};\left\{H=\frac{\omega}{\eta\theta},P=0,T=\frac{\alpha(B\eta\theta-\omega)}{B\eta^2\theta}\right\};\left\{H=\frac{\omega}{\eta\theta},P=\frac{A(\beta\eta\theta+\delta\omega\tau-\eta\mu\theta)}{\beta\eta\theta},T=-\frac{AB\beta\eta\tau\theta+AB\delta\omega\tau^2-AB\eta\mu\tau\theta-B\alpha\beta\eta\theta+\alpha\beta\omega}{\beta\eta^2\theta B}\right\};\text{serta}\quad\left\{H=-\frac{B(A\beta\tau-A\mu\tau-\alpha\beta)}{AB\delta\tau^2+\alpha\beta},P=\frac{A\alpha(B\delta\tau+\beta-\mu)}{AB\delta\tau^2+\alpha\beta},T=0\right\} \quad (9)$$

3. Stability Analysis

Stability analysis was required to determine whether the obtained equilibrium points were stable or not. This analysis involved linearizing the model around the equilibrium point and analyzing the eigenvalues of the resulting Jacobian matrix. The eigenvalues obtained from equation 9 were as follows.

a. At the first equilibrium point, $\{H=0,P=0,T=0\}$, the eigenvalues obtained were $\{-\omega,\beta-\mu,\alpha\}$. This situation was unstable because there was $\alpha>0$ were alleviated.

b. At the second equilibrium point, $\left\{H = 0, P = \frac{A(\beta-\mu)}{\beta}, T = 0\right\}$, the eigenvalues obtained were $\left\{-\omega, -\beta + \mu, -\frac{A\beta\tau - A\mu\tau - \alpha\beta}{\beta}\right\}$. This condition was locally asymptotically stable if $\beta > \mu$ and $A\tau(\beta - \mu) > \alpha\beta$ were alleviated.

c. At the third equilibrium point, $\{H = B, P = 0, T = 0\}$, the eigenvalues obtained were $\{B\eta\theta - \omega, B\delta\tau + \beta - \mu, -\alpha\}$. This condition was locally asymptotically stable if $B\eta\theta < \omega$ and $B\delta\tau + \beta < \mu$ were alleviated.

d. At the fourth equilibrium point, $\left\{H = \frac{\omega}{\eta\theta}, P = 0, T = \frac{\alpha(B\eta\theta-\omega)}{\eta^2\theta B}\right\}$, the eigenvalues obtained were $\left\{\beta - \mu + \frac{\omega\delta\tau}{\eta\theta}, \frac{\omega\left(-\alpha+\sqrt{\alpha^2+4B\alpha\eta\theta-4B^2\alpha\eta^2\theta^2}\right)}{2B\eta\theta}, \frac{\omega\left(-\alpha-\sqrt{\alpha^2+4B\alpha\eta\theta-4B^2\alpha\eta^2\theta^2}\right)}{2B\eta\theta}\right\}$. This condition was locally asymptotically stable if $\beta + \frac{\omega\delta\tau}{\eta\theta} < \mu$ and $\alpha > \sqrt{\alpha^2 + 4B\alpha\eta\theta - 4B^2\alpha\eta^2\theta^2}$ were alleviated.

e. At the fifth equilibrium point, $\{H = \frac{\omega}{\eta\theta}, P = \frac{A(\beta\eta\theta+\delta\omega\tau-\eta\mu\theta)}{\beta\eta\theta}, T = \frac{\alpha\beta\eta\theta - A(\beta\eta\tau\theta+\delta\omega\tau^2-\eta\mu\tau\theta) - \frac{\omega\alpha\beta}{B}}{\beta\eta^2\theta}\}$, the eigenvalues obtained were so long that they are not included in this article. The stability analysis was performed using the Routh-Hurwitz criterion. The characteristic polynomial equation was $\lambda^3 + a_1\lambda^2 + a_2\lambda + a_3 = 0$. This condition was locally asymptotically stable if $a_1 > 0, a_2 > 0, a_3 > 0, a_1a_2 > a_3$.

f. At the sixth equilibrium point, $\{H = -\frac{B(A\beta\tau - A\mu\tau - \alpha\beta)}{AB\delta\tau^2+\alpha\beta}, P = \frac{A\alpha(B\delta\tau+\beta-\mu)}{AB\delta\tau^2+\alpha\beta}, T = 0\}$, the eigenvalue was also obtained, which was so long that it is not included in this article. As with the fifth equilibrium point, this stability analysis also uses the Routh-Hurwitz criterion. The characteristic polynomial equation was $\lambda^3 + b_1\lambda^2 + b_2\lambda + b_3 = 0$. This condition was locally asymptotically stable if $b_1 > 0, b_2 > 0, b_3 > 0, b_1b_2 > b_3$.

4. Numerical Simulation and Results Interpretation

At this step, numerical simulations were performed using the variables and parameters presented in Tables 1 and 2. The simulation results were illustrated using graphs of the mangrove forest area, the aquaculture pond area, and the human population.

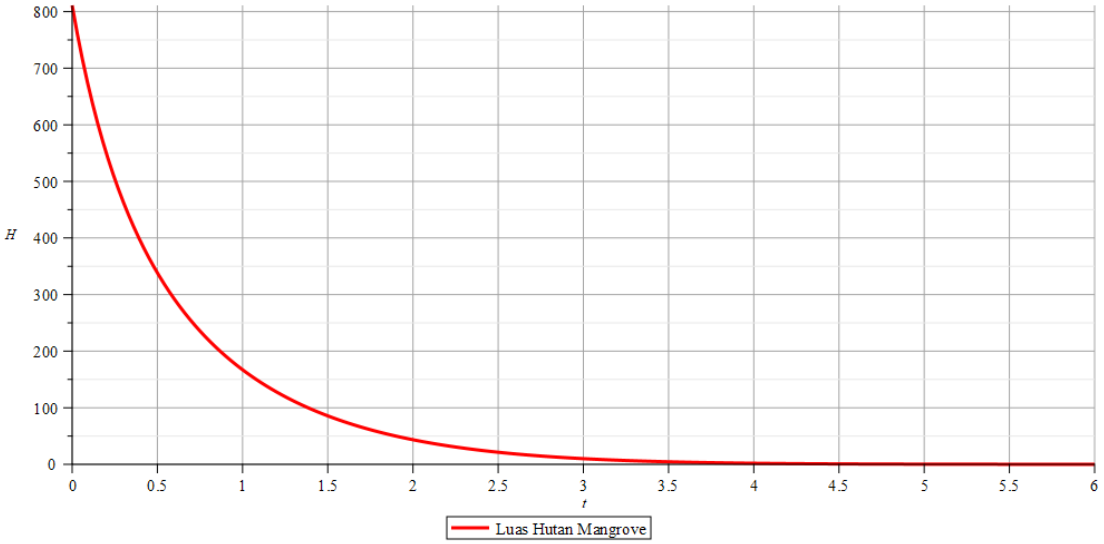


Figure 4. Numerical Simulation of Mangrove Forest Area

Figure 4 shows that the area of mangrove forest decreased significantly from an initial level of 811.04 ha to nearly zero during the simulation period. The decline was particularly sharp from the beginning of the year until the second year. This indicated that the rate of mangrove loss due to human activity and land conversion to fishponds exceeded the natural regeneration capacity. In the second to fourth years, the rate of decline began to slow, indicated by a gradually flattening curve. Furthermore, in the fourth year and beyond, the area of the mangrove forest approached a relatively constant level near zero. This is because there is less area left to degrade, but the area of mangrove forest is never completely depleted or reaches 0.

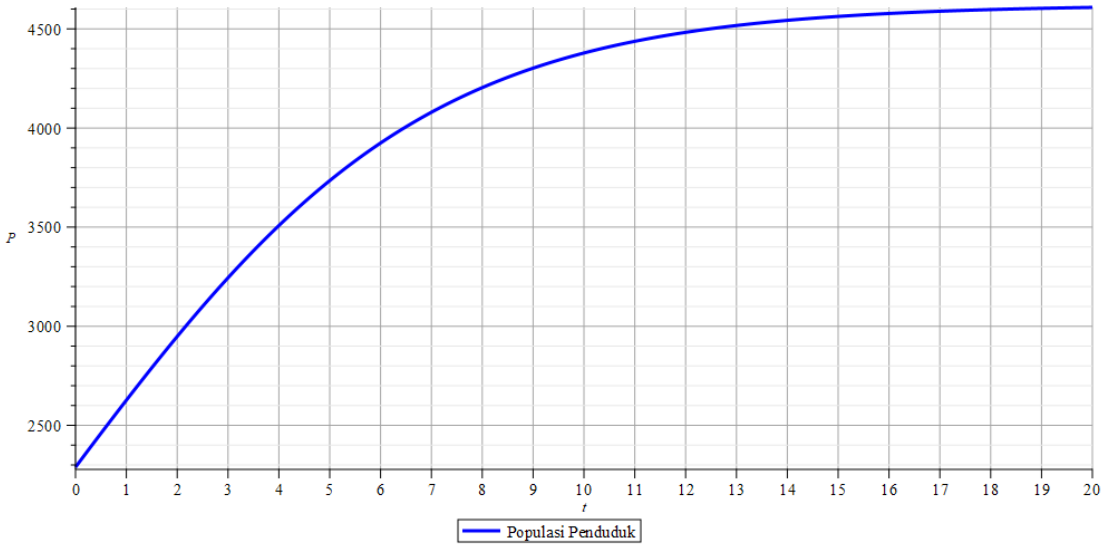


Figure 5. Numerical Simulation of Human Population

Figure 5 shows that the population increased from an initial level of approximately 2,289 people to a point approaching the environmental carrying capacity of 4,782 people. From

the start of the simulation through the eighth year, population growth was relatively rapid, as the availability of resources and space remained sufficient. Between the eighth and fourteenth years, growth began to slow due to the limiting influence of the environmental carrying capacity. Subsequently, from the fourteenth year onwards, the population size tended to stabilize at around 4,782, indicating that the population had neared its carrying capacity. This demonstrates that the population does not grow indefinitely but reaches an equilibrium where birth rates and population increases are balanced by limiting factors. Nevertheless, the growing population has the potential to increase pressure on the mangrove area—driven by the rising demand for residential land, the utilization of coastal resources, and economic activities—thereby indirectly accelerating the degradation of the mangrove ecosystem.

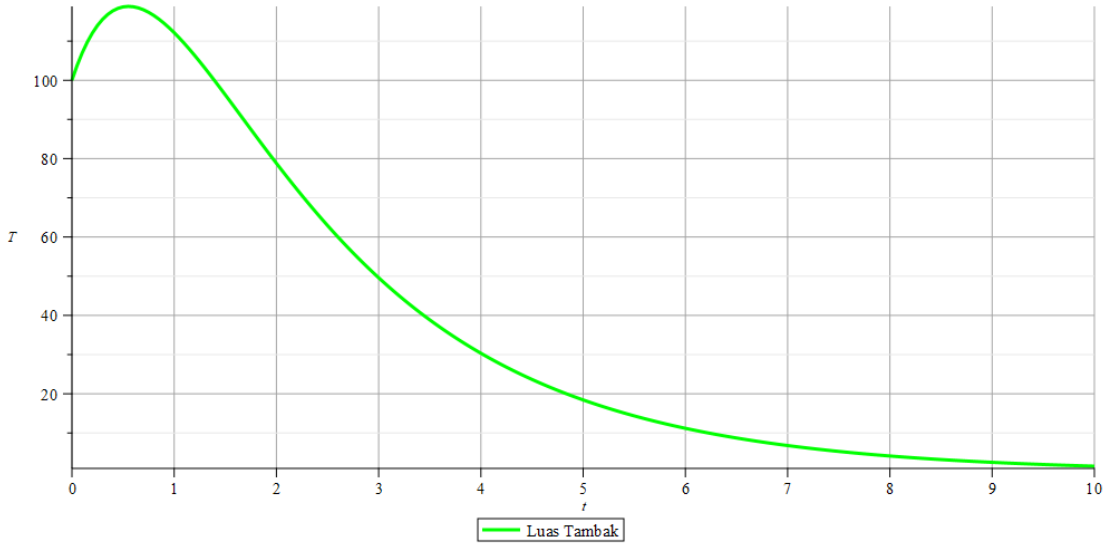


Figure 6. Numerical Simulation of Aquaculture Pond Area

Figure 6 shows that the pond area, initially 100 hectares, increased to a maximum of approximately 117 hectares by the middle of the period. Following this peak, the pond area declined sharply leading up to the fourth year, dropping to around 30 hectares. From the fourth year onwards, the rate of decline slowed, and the pond area gradually approached zero. This indicates that the conversion of mangrove areas into ponds continued until the midpoint of the period, facilitated by the availability of mangrove land. However, as the remaining mangrove area dwindled, the pond area also decreased, eventually approaching a state where no pond activity remained. These results demonstrate a strong interdependence between the sustainability of pond operations and the presence of mangrove forests; consequently, the exploitation of mangroves undermines the sustainability of the pond aquaculture sector itself.

CONCLUSION

Based on the results of the analysis in this research, the following conclusions were obtained.

1. A predator–prey mathematical model involving three variables, namely the mangrove forest area, human population, and aquaculture pond area, was successfully developed $\frac{dH}{dt} = \propto \left(1 - \frac{H}{B}\right) H - \tau PH - \eta TH$; $\frac{dP}{dt} = \tau\delta PH - \mu P - \beta\left(1 - \frac{P}{A}\right) P$; $\frac{dT}{dt} = \eta\theta TH - \omega T$ under the assumption that the growth of the mangrove forest and the human population is constrained by environmental carrying capacity.
2. Stability analysis revealed that the proposed model possesses one unstable equilibrium point and five asymptotically stable equilibrium points. The system converges to an asymptotically stable equilibrium when the stability conditions are alleviated.
3. Numerical simulations indicate that population growth increases pressure on the mangrove ecosystem, resulting in a reduction in mangrove forest area. The decline in mangrove forests subsequently leads to a decrease in the aquaculture pond area. The model used in this research was a predator-prey model involving three variables: mangrove forest area, human population, and pond area.

The proposed model effectively describes the dynamics of mangrove forest degradation. Future research may improve the model by incorporating management interventions or conservation policies.

ACKNOWLEDGMENT

The researchers would like to thank the Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) of Universitas Samudra for funding this research through the expert assistant research project, with funding sources from the 2025 Unsam DIPA. The researchers would also like to express their appreciation to all parties who have contributed to the completion of this research.

DECLARATIONS

Author Contribution : Author 1: Conceptualization, Methodology, Writing - Original Draft, Supervision.
Author 2: Project Administration.

Author 3: Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, and Writing - Review & Editing.
Author 4: Data Curation and Resources.
Author 5: Conceptualization, Investigation, Formal Analysis, Validation, and Writing - Review & Editing.
Author 6: Data Curation and Resources.
Author 7: Visualization.
Author 8: Visualization.
Author 9: Review & Editing.
Author 10: Review & Editing.

Funding Statement : This research was funded by Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Universitas Samudra, through the DIPA Universitas Samudra 2024.

Conflict of Interest : The authors declare no conflict of interest.

Additional Information : Additional information is available from the corresponding author upon reasonable request.

REFERENCES

Badan Pusat Statistik Kota Langsa. (2024). *Kota Langsa dalam Angka Tahun 2024*. BPS Kota Langsa.

Dinas Komunikasi dan Informatika. Tabel Rekapitulasi Penduduk Per Semester II Tahun 2023 di Kota Langsa. Kota Langsa: Diskominfo; 2023.

Elaydi, S. (Ed.). (2005). *An Introduction to Difference Equations* (Third Edition). Springer Science+Business Media, Inc.

Hadi, A. N., Djauhari, E., Supriatna, A. K., & Johansyah, M. D. (2019). Teknik Penentuan Solusi Sistem Persamaan Diferensial Linear Non-Homogen Orde Satu. *Jurnal Matematika*, *18*(1), 2598–8980.

Hanafiah, J. (2022). *Hijaunya Hutan Mangrove Kuala Langsa*. https://www.mongabay.co.id/2022/08/27/foto-hijaunya-hutan-mangrove-kuala-langsa/

Iswahyudi, I., Kusmana, C., Hidayat, A., & Noorachmat, B. P. (2019). Evaluasi Kesesuaian Lahan untuk Rehabilitasi Hutan Mangrove Kota Langsa Aceh. *Jurnal Matematika Sains Dan Teknologi*, *20*(1), 45–56.

Kartono. (2012). *Persamaan Diferensial Biasa*. Graha Ilmu.

Khairunnisa, C., Thamrin, E., & Prayogo, H. (2020). Keanekaragaman Jenis Vegetasi Mangrove di Desa Dusun Besar Kecamatan Pulau Maya Kabupaten Kayong Utara. *Jurnal Hutan Lestari*, *8*(2), 325–336.

Maknun, M. (2019). *Analisis Dinamik Model Matematika Interaksi Host-Parasitoid*. Universitas Islam Negeri Maulana Malik Ibrahim.

Mohamad, R., Rauf, Moh. D. A., & Lakisa, N. (2019). Model Matematika Kerusakan Hutan dengan Memperhatikan Faktor Industri dan Kebakaran. *Euler: Jurnal Ilmiah Matematika, Sains Dan Teknologi*, *7*(1), 6–14.

Munandar, A. (2017). *Analisis Konsistensi dan Kestabilan Model Dinamik Diskret pada Masalah Predator-Prey dengan Fungsi Respon Ratio Dependent dan Pemanenan pada Predator*. Universitas Islam Negeri Maulana Malik Ibrahim.

Nugraheni, K., Burhan, M. J. I., Pancahayani, S., & Azka, M. (2019). Stability Analysis of Mangrove Forest Resource Depletion Models Due To The Opening of Fish Pond Land. *Journal of Physics: Conference Series*, *1277*(1), 1–8.

Nurbaya, S. (2021). *Peta Mangrove Nasional Tahun 20221*.

Purba, M. A., Elfrida, & Nursamsu. (2023). Pemetaan Kerusakan Ekosistem Mangrove Akibat Aktivitas Masyarakat Di Desa Kuala Langsa Kecamatan Langsa Barat. *Best Journal: Biology Education Science and Technology*, *6*(1), 379–385.

Rahmadi MT, Yuniastuti E, Hakim MA, Suciani A. Pemetaan Distribusi Mangrove Menggunakan Citra Sentinel-2A: Studi Kasus Kota Langsa. Jambura Geoscience Review. 2021;4(1):1–10.

Susilawati, N. G. K., Toknok, B., & Korja, I. N. (2018). Faktor Penyebab Kerusakan Hutan Mangrove di Desa Buranga Kecamatan Ampibabo Kabupaten Parigi Moutong. *ForestSains*, *15*(2), 91–99.

Wakhidah, U. U. S., Nugraheni, K., & Winarni, W. (2022). Analysis of Mangrove Forest Resource Depletion Models due to The Opening of Fish Pond Land with Time Delay. *Jurnal Ilmu Dasar*, *23*(1), 65–74.