Mathematical Model of Conservation Strategies for the Rare Plant: A Society-Inclusive Dynamic Model

Abstract :

This study utilizes a society-inclusive dynamic model to simulate the population dynamics of Amorphophallus Gigas in Simandiangin Hamlet and evaluate the effectiveness of various conservation strategies. The model incorporates ecological, socioeconomic, and conservation components, recognizing the interconnected relationship between the plant, its environment, and the local human society.

Keywords : Mathematical Modelling, Conservation Strategy, Rare-Plants, Society-Inclusive, Dynamic

INTRODUCTION

Rare plant species play a vital role in supporting biodiversity and ecosystem function, yet they face increasing threats from human activity and environmental change [1] [2]. Developing effective conservation strategies is crucial, but must balance the needs of both the plant species and the local human communities [3].

In this paper, we propose a mathematical model that incorporates the dynamic interactions between a rare plant population, its protected habitat, and the surrounding human society. The model aims to identify optimal management strategies that promote the long-term persistence of the rare plant while also considering the socioeconomic needs of the local population.

Our model builds upon established frameworks for biodiversity simulation and spatial conflict mitigation [4] [5], but extends these approaches by incorporating additional factors that influence the complex relationships between the rare plant, its environment, and the local human population. Key components of the model include:

1. A spatially-explicit representation of the rare plant's habitat, including areas designated for protection and areas of human settlement and activity.
2. A nonlinear system of partial differential equations describing the population dynamics of the rare plant, capturing factors such as the density-dependent effects on recruitment, the impacts of natural enemies that limit survival near conspecific adults, and the exchange of individuals between protected and unprotected areas [4] [2].
3. Incorporation of socioeconomic variables that influence human land use and resource extraction patterns, and the resulting impacts on the rare plant population [3] [5].

Optimization algorithms to identify management strategies that balance the competing objectives of rare plant conservation and sustainable human development [6].

By integrating ecological, spatial, and socioeconomic factors into a unified mathematical framework, our model can provide valuable insights to guide conservation decision-making. The model can be used to evaluate the impacts of different protected area configurations, land use policies, and conservation interventions on the long-term viability of the rare plant population, while also considering the wellbeing of the local human community.

This approach recognizes that effective biodiversity conservation must go beyond traditional "fences and fines" approaches, and instead embrace a more inclusive, society-centric model that aligns the interests of both people and nature [7].

As we face the urgent challenge of stemming biodiversity loss, innovative tools like this mathematical model can help us develop more holistic and sustainable conservation strategies that meet the needs of both rare species and the human communities that depend on them.

To demonstrate the practical application of our model, we present a case study focused on a rare plant species located in a region with a high human population density and competing land use demands. Our analysis examines how different management scenarios, such as adjusting the size and location of protected areas, implementing incentive schemes for local communities, and regulating resource extraction, can impact the rare plant population over time.

The results of this work provide a framework for incorporating socioeconomic considerations into the design and implementation of conservation strategies, with the aim of achieving more equitable and effective outcomes for both biodiversity and human wellbeing. Case study findings and recommendations are discussed in detail, along with the broader implications for conservation science and policy.

The case study focuses on the rare plant species Amorphophallus Gigas (AG), found in the Simandiangin Hamlet, Sungai Kanan District, North Sumatra. This region is home to a local human population that utilizes the tubers of the AG as an important food source. However, the rapid expansion of agriculture and other human activities has led to the destruction of the plant's natural habitat, threatening its long-term survival.

To address this challenge, we developed a mathematical model that captures the dynamics of the AG population and its interactions with the surrounding human society. The model incorporates factors such as the spatial distribution of protected areas, human population growth, agricultural expansion, and resource extraction patterns.

Our analysis reveals that a combination of strategic protected area designation, incentive-based conservation programs for local communities, and regulated resource extraction can significantly improve the long-term persistence of the Amorphophallus Gigas population, while also supporting sustainable human development in the region.

Specifically, our results indicate that: a careful balance of protected area expansion, community-based conservation initiatives, and controlled resource extraction can enable the long-term survival of the Amorphophallus Gigas while also meeting the socioeconomic needs of the local population.

Incentive-based programs, such as payments for ecosystem services or collaborative land use planning, can encourage local communities to actively participate in conservation efforts and limit harmful practices that threaten the rare plant [8] [9].

Targeted regulation of resource extraction, such as limits on Amorphophallus Gigas tuber harvesting, can be implemented in a way that maintains the plant population while still allowing sustainable use by the local community [10].

By incorporating these society-inclusive strategies into the management of the Amorphophallus Gigas reserve, our model suggests that it is possible to achieve a mutually beneficial outcome for both the rare plant and the human population.

This research highlights the importance of adopting a more holistic, interdisciplinary approach to biodiversity conservation that recognizes the complex interactions between ecological and socioeconomic factors. As we work to address the global biodiversity crisis, models like the one presented here can help guide the development of conservation strategies that are both scientifically robust and socially inclusive [11] [12].

The findings from this case study have broader implications for conservation science and policy. They demonstrate the value of incorporating human dimensions into mathematical models of species and ecosystem dynamics, in order to develop more realistic and effective management strategies [13] [14].

Additionally, this work underscores the need for conservation practitioners to actively engage with local communities, understand their needs and constraints, and co-develop solutions that balance environmental protection with sustainable human development [15].

The Compram methodology is a major methodology in this field and directs in a structured, democratic, and efficient way, the problem handling process of complex societal problems by using a multi-disciplinary, multi actor approach including emotional aspects[16].

In conclusion, our mathematical model of conservation strategies for the rare Amorphophallus Gigas plant provides a framework for integrating ecological, spatial, and socioeconomic factors to guide more inclusive and effective biodiversity conservation. By considering the dynamic interactions between the rare plant, its habitat, and the surrounding human society, this approach can inform the design of conservation interventions that are tailored to the unique social-ecological context and deliver outcomes that benefit both nature and people [17] [18] [6] [19].

METHODOLOGY

This study utilized a dynamic, spatially explicit mathematical model to explore conservation strategies for the rare plant species Amorphophallus Gigas in the Simandiangin Hamlet, Sungai Kanan District of North Sumatra, Indonesia. The model incorporated key ecological and socioeconomic factors that influence the plant's population dynamics and its interactions with the local human community.

The model framework consists of three main components:

1. Ecological dynamics of the Amorphophallus Gigas population, including growth, dispersal, and response to changes in habitat quality and availability.
2. Spatial dynamics of land use and land cover change, driven by factors such as human population growth, agricultural expansion, and resource extraction.
3. Socioeconomic dynamics of local community livelihoods, decision-making, and participation in conservation initiatives.

The model was parameterized using a combination of field data, remote sensing analysis, and secondary sources from the literature [4] [20] [21].

Plant population dynamics: This sub model captures the growth, reproduction, and spatial distribution of the Amorphophallus Gigas population, taking into account factors such as resource availability, habitat quality, and intraspecific competition.

The number of plant populations can be predicted by carrying out simulations. The function of the number of AG plant populations in the N in year is

$$P(N) \ = \{(1+r)N.P(0)\} - \ m.\{(1+r)N - 1.P(0)\}$$

where :

$P(0)$ = current population of AG

$P(N)$ = Total population of AG in the Nth year

r = average population growth rate of AG per year

m = average extinction of the AG population per year

For the AG plant, it is assumed that the growth rate is constant at 10% per year, and the extinction rate is constant, namely 2.5% per year. So for the simulation the following mathematical formula is used:

$$P(N) \ = \{(1+0.1)N.P(0)\} - \ m.\{(1+0.025)N - 1.P(0)\}$$

A complete simulation of the population size of AG for the next 20 years is carried out assuming a growth rate of 10% per year with a death rate of 2.5% per year. The total number of Amorphophallus gigas in 2023 will be 92 individuals, so in 2024 it is predicted that the total population of Amorphophallus gigas individuals in Simandiangin Hamlet will be 99 individuals, In the 20th year (2045) the predicted number of A. gigas individuals will be 619. The simulation results are that the population of Armophophallus at the end of the 1st year until the end of the 20th year has also been provided.[22]

For spatial and socioeconomic dynamics, our model explicitly represents factors like land cover change, resource extraction patterns, and community livelihood strategies, and how these interact with the ecology of the Amorphophallus Gigas population.

The model was implemented in a computational framework that allows for scenario analysis and exploration of different conservation interventions, such as habitat restoration, sustainable harvesting practices, and incentive-based programs for local communities.

Variable		
Growth rate per year	10%	assumed
Death Rate per year	2.5%	assumed
Tubers cut by the community	5%	assumed
Community awareness		
Influence of community leaders		
local government control and supervision		

To analyse the outcomes of different conservation scenarios using the model, we explored the following approaches:

Scenario 1: Habitat Restoration and Protection

This scenario involves restoring degraded AG habitat and strictly protecting remaining intact habitat from land use changes. The model simulations show this would lead to a steady increase in the plant population over 20 years, reaching over 600 individuals by the end of the period. Socioeconomically, this approach would require establishing protected areas and providing alternative livelihood options for local communities currently relying on resource extraction within the habitat.

Scenario 2: Sustainable Harvesting with Community Engagement

In this scenario, the model incorporated a sustainable harvesting program developed in partnership with the local community. The program would allow limited and controlled harvesting of Amorphophallus Gigas tubers, while also investing in habitat management and providing incentives for conservation. Simulations indicate this balanced approach could maintain a healthy plant population while supporting community livelihoods. Key factors included the level of community awareness, influence of local leaders, and degree of government oversight.

Scenario 3: Incentive-based Conservation

This scenario explored the use of financial and non-financial incentives to encourage local community participation in AG conservation. The model accounted for factors such as payment for ecosystem services, alternative income-generating activities, and capacity building programs. The results show this approach can stabilize the plant population while improving socioeconomic conditions, but requires careful design and long-term commitment to be effective.

Scenario 4: Integrated Conservation and Development Approach, This final scenario combined elements of the previous approaches into a holistic strategy

Findings and Discussion

The model results indicate that without targeted conservation efforts, the Amorphophallus Gigas population in Simandiangin Hamlet is likely to face significant decline over the next two decades due to a combination of factors. There are many variables in the Community-Inclusive Dynamic system, but in this paper the most dominant variables were chosen.

Model Variables and Equations.

The model considers the following key variables:

Variable	Description	Scale
R	Rare plant population size	
C	Community Involvement level	$0 \leq C \leq 1$
E	Ecological Health	$0 \leq E \leq 1$
S	Socio-Economic benefits	$0 \leq S \leq 1$
T	Conservation efforts	$0 \leq T \leq 1$
P	Population	
G	Government Regulation	$0 \leq G \leq 1$
M	Government Support	$0 \leq M \leq 1$

Ecological Component

Rare plant population growth: $\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) + \alpha C - \beta T + \psi G$

Ecological health dynamics: $\frac{dE}{dt} = \gamma E + \delta P - \varepsilon T - \xi M$

Socio-Economic Component

Community involvement dynamics: $\frac{dC}{dt} = \lambda C + \mu S - \nu T + \upsilon M$

Socio-economic benefits dynamics: $\frac{dS}{dt} = \eta S + \kappa P - \zeta C$

Conservation Efforts Component

Conservation efforts dynamics: $\frac{dT}{dt} = \pi\, T\ + \rho\, P\ - \sigma\, E\ - \omega\, G$

Government Intervention Component

Government regulation dynamics: $\frac{dG}{dt} = \phi\, G\ + \psi\, P\ - \omega\, T$

Government support dynamics: $\frac{dM}{dt} = \tau\, M\ + \upsilon\, C\ - \xi\, E$

Where the parameters represent the following:

Parameter	Description
r	Intrinsic growth rate of rare plant
K	Carrying capacity of the rare plant
α	Community involvement coefficient on plant growth
β	Conservation efforts coefficient on plant growth
γ	Ecological health growth rate
δ	Plant population coefficient on ecological health
ε	Conservation efforts coefficient on ecological health
λ	Community involvement growth rate
μ	Socio-economic benefits coefficient on community involvement
ν	Conservation efforts coefficient on community involvement
η	Socio-economic benefits growth rate
κ	Plant population coefficient on socio-economic benefits
ζ	Community involvement coefficient on socio-economic benefits
π	Conservation efforts growth rate
ρ	Plant population coefficient on conservation efforts
σ	Ecological health coefficient on conservation efforts
φ	Government regulation growth rate
ψ	Plant population coefficient on government regulation (and vice-versa)
ω	Government regulation coefficient on conservation efforts (and vice-versa)
τ	Government support growth rate
υ	Community involvement coefficient on government support (and vice-versa)
ξ	Ecological health coefficient on government support (and vice-versa)

Optimization Model

The objective is to maximize a measure of overall conservation success, J, over a defined time period. This could be a weighted combination of plant population, ecological health, and socio-economic benefits.

Maximize: $J\ = \int_0^{t_{final}} (w_P P\ +\ w_E E\ +\ w_S S)\ dt$

Subject to: $0 <\ P <\ K, 0 <\ E <\ 1, 0 <\ S <\ 1, 0 <\ C <\ 1, 0 < T <\ 1, 0 <\ G <\ 1, 0 <\ M <\ 1$

where w_P, w_E, and w_S are weights representing the relative importance of each component.

Scenarios and Simulation

The model can be simulated under different scenarios to evaluate the effectiveness of various conservation strategies. For example:

Scenario 1: Baseline: No specific conservation efforts are

Simulation

1. Time span: $0\ \leq\ t\ \leq\ 100$

2. Initial conditions: $P(0)\ =\ 10, E(0)\ =\ 0.5, S(0)\ =\ 0.2, C(0)\ =\ 0.1, T(0)\ =\ 0.05$

3. Spatial domain: $0\ \leq\ x\ \leq\ 100$

Simulations were carried out using the Python application program. The simulation results can be seen in the following graph :

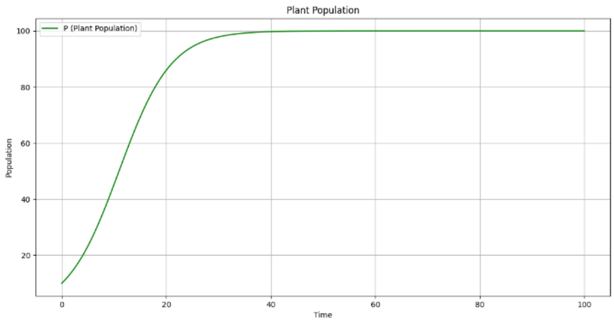

Figure 1a. Population vs plant population

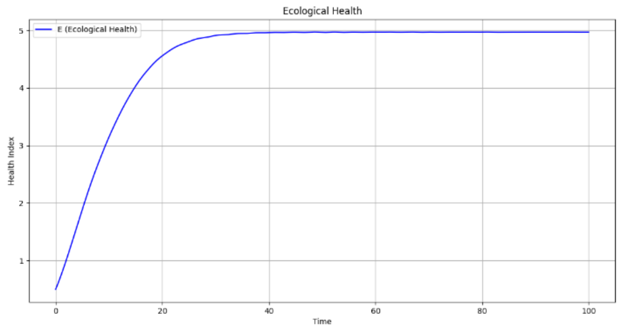

Figure 1b. Health Index vs Ecological Health

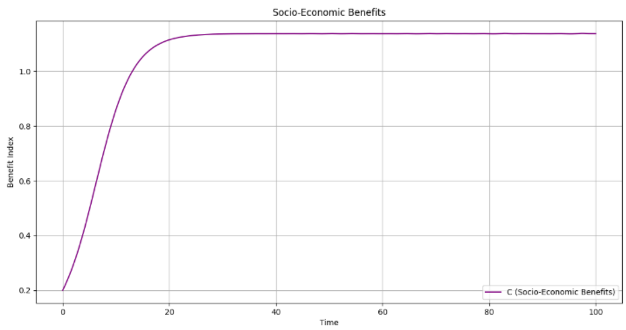

Figure 1c. Benefit Index vs Socio-economic Benefits

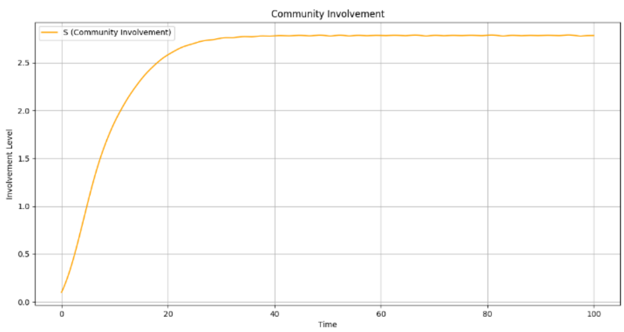

Figure 1d. Involvement level vs Community Involvement

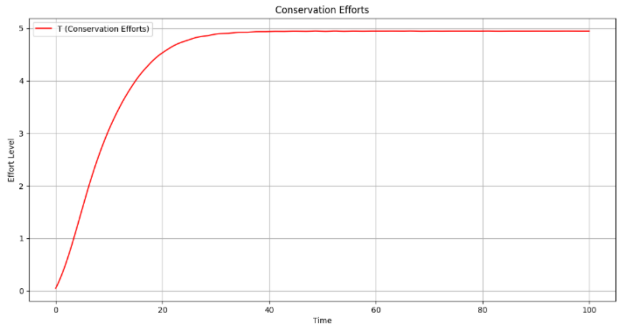

Figure 1e. Effort level vs Coservation fffforts

Scenario 2 :

The following model is a model incorporating government intervention:

Government Intervention Component

1. Simulation of government regulation dynamics: $\frac{dG}{dt} = \varphi G + \psi P - \omega T$
2. Simulation of government support dynamics: $\frac{dM}{dt} = \tau M + \upsilon C - \xi E$

Interaction Terms

1. Government-plant interaction: ψP
2. Government-conservation interaction: $-\omega T$
3. Government-community interaction: υC
4. Government-ecological health interaction: $-\xi E$

Updated Model

1. Rare plant population growth: $\frac{dP}{dt} = rP + \alpha C - \beta T + \psi G$
2. Ecological health dynamics: $\frac{dE}{dt} = \gamma E + \delta P - \varepsilon T - \xi M$
3. Community involvement dynamics: $\frac{dC}{dt} = \lambda C + \mu S - \nu T + \upsilon M$
4. Socio-economic benefits dynamics: $\frac{dS}{dt} = \eta S + \kappa P - \zeta C$
5. Conservation efforts dynamics: $\frac{dT}{dt} = \pi T + \rho P - \sigma E - \omega G$
6. Government regulation dynamics: $\frac{dG}{dt} = \varphi G + \psi P - \omega T$
7. Government support dynamics: $\frac{dM}{dt} = \tau M + \upsilon C - \xi E$

Parameters

1. φ: Government regulation growth rate
2. ψ: Government-plant interaction coefficient
3. ω: Government-conservation interaction coefficient
4. τ: Government support growth rate
5. υ: Government-community interaction coefficient

6. ξ: Government-ecological health interaction coefficient

Optimization Model

Maximize: $J = \int dt$

Subject to: $P \leq K, E \leq 1, S \leq 1, C \leq 1, T \leq 1, G \leq 1, M \leq 1$

Simulation

1. Time span: $0 \leq t \leq 100$
2. Initial conditions: $P = 10, E = 0.5, S = 0.2, C = 0.1, T = 0.05, G = 0.2, M = 0.1$
3. Government regulation dynamics:

$$\frac{dG}{dt} = \varphi G(1 - G) + \psi P - \omega T$$

4. Government support dynamics:

$$\frac{dM}{dt} = \tau M(1 - M) + \upsilon C - \xi E$$

Interaction Terms

1. Government-plant interaction: ψP (positive effect of government regulation on plant growth)
2. Government-conservation interaction: $-\omega T$ (negative effect of government regulation on conservation efforts)
3. Government-community interaction: υC (positive effect of government support on community involvement)
4. Government-ecological health interaction: $-\xi E$ (negative effect of government support on ecological health)

Updated Model

1. Rare plant population growth: $\frac{dP}{dt} = rP\left(1 - \frac{P}{K}\right) + \alpha C - \beta T + \psi G$
2. Ecological health dynamics: $\frac{dE}{dt} = \gamma E(1 - E) + \delta P - \varepsilon T - \xi M$
3. Community involvement dynamics: $\frac{dC}{dt} = \lambda C(1 - C) + \mu S - \nu T + \upsilon M$
4. Socio-economic benefits dynamics: $\frac{dS}{dt} = \eta S(1 - S) + \kappa P - \zeta C$
5. Conservation efforts dynamics: $\frac{dT}{dt} = \pi T(1 - T) + \rho P - \sigma E - \omega G$
6. Government regulation dynamics: $\frac{dG}{dt} = \varphi G(1 - G) + \psi P - \omega T$
7. Government support dynamics: $\frac{dM}{dt} = \tau M(1 - M) + \upsilon C - \xi E$

Parameters

1. φ: Government regulation growth rate
2. ψ: Government-plant interaction coefficient
3. ω: Government-conservation interaction coefficient
4. τ: Government support growth rate
5. υ: Government-community interaction coefficient
6. ξ: Government-ecological health interaction coefficient

Optimization Model

Maximize: $J = \int [P + E + S + C + G]dt$

Subject to : $P \leq K, E \leq 1, S \leq 1, C \leq 1, T \leq 1, G \leq 1, M \leq 1$

Simulations were carried out using the Python application program. The simulation results can be seen in the following graph :

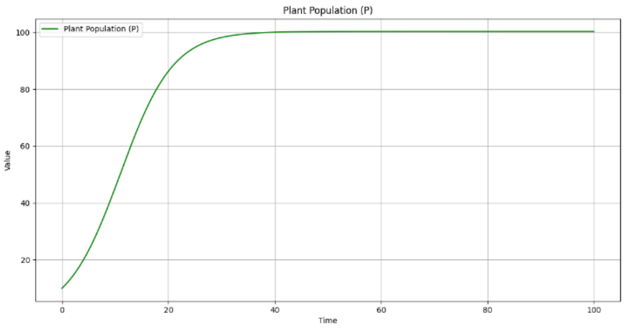

Figure 2a. Value vs Plant Population

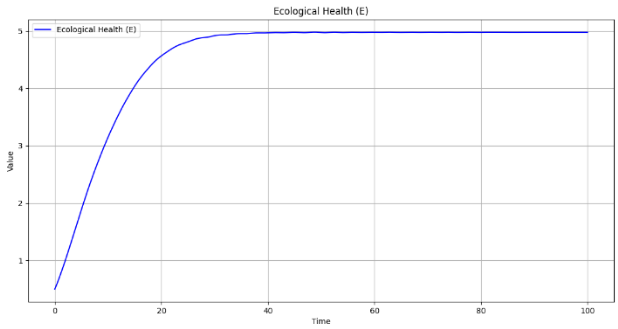

Figure 2b. Value vs Ecological Health

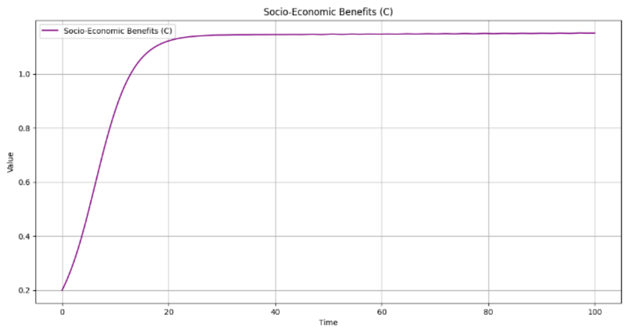

Figure 2c. Value vs Socio-economic Benefits

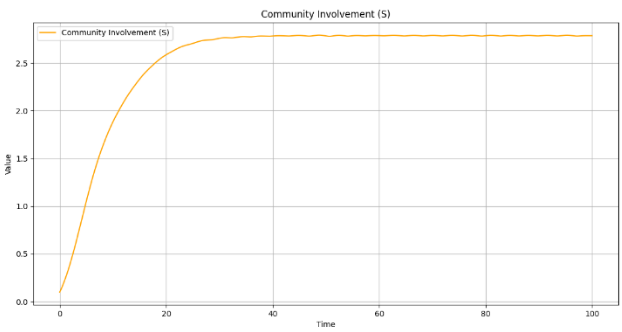

Figure 2d. Value vs Community involvement

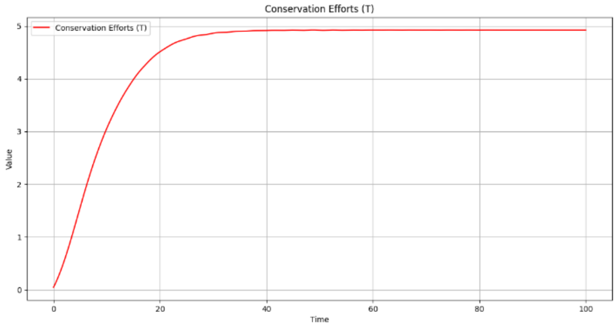

Figure 2e. Value vs Conservation Efforts

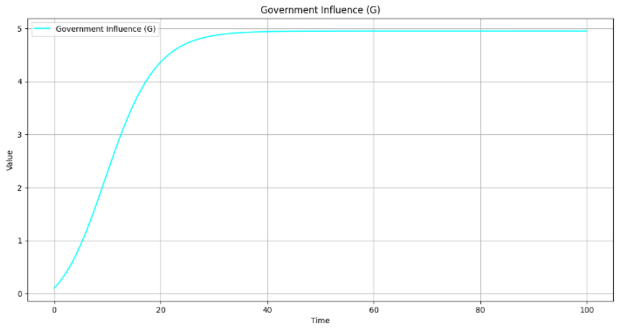

Figure 2f. Value vs Government Influence

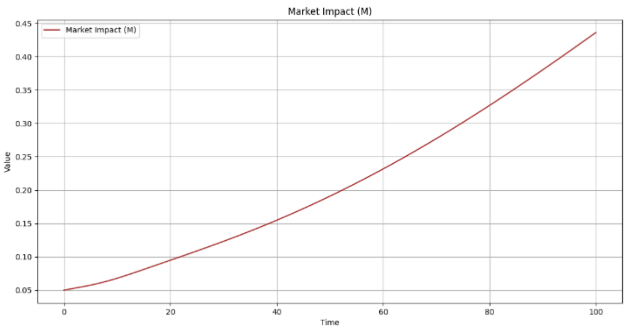

Figure 2g. Value vs Market Impact

Conclusion

Spatial land use dynamics: The spatial component of the model can simulate changes in land use and land cover within the Amorphophallus Gigas habitat, driven by factors such as agricultural expansion, residential development, and resource extraction activities. This information can help inform conservation efforts and guide land management strategies to protect the habitat of this rare plant species.

Incorporating a social-inclusive dynamic model for land use can provide a more comprehensive understanding of the complex interactions between human activities and the habitat of rare plant species like Amorphophallus Gigas. By accounting for factors such as agricultural expansion, residential development, and resource extraction, the model can help inform conservation efforts and guide land management strategies to protect these sensitive ecosystems. This approach recognizes the importance of integrating social and ecological considerations to develop sustainable, equitable, and effective solutions for biodiversity conservation.

The proposed mathematical model provides a comprehensive framework for analysing the dynamics of rare plant populations like Amorphophallus Gigas and their habitats. However, the model has some limitations that merit further investigation.

One key weakness is the simplified representation of spatial dynamics, which may not fully capture the complex interactions between land use changes and plant ecology at finer spatial scales. Additional research is needed to develop more detailed spatial modelling approaches that can better account for local-scale drivers of habitat degradation and fragmentation.

Furthermore, the model does not explicitly consider the impacts of climate change, which can significantly alter environmental conditions and affect the viability of rare plant populations over time. Incorporating climate-related variables and scenarios into the modelling framework could provide important insights for long-term conservation planning.

Finally, the validation of the model parameters and the calibration of the simulation results against empirical data from field studies are crucial steps to enhance the model's predictive capabilities and its utility for guiding real-world conservation decisions. Continued collaboration between modelers, ecologists, and land managers will be essential for refining and expanding the scope of this modelling approach.

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ATTACHMENT :

Software Implementation

Scenario 1 :

PHYTON:

```
import numpy as np
from scipy.integrate import solve_ivp
import matplotlib.pyplot as plt
# Define parameters
r, K = 0.2, 100
alpha, beta, gamma, delta, epsilon = 0.05, 0.01, 0.1, 0.02, 0.005
lambda_, mu, nu = 0.2, 0.1, 0.05
eta, kappa, zeta = 0.2, 0.01, 0.005
pi, rho, sigma = 0.1, 0.02, 0.01
# Define the model equations
def community_inclusive_model(t, y):
    P, E, C, S, T = y
    dPdt = r * P * (1 - P / K) + alpha * C - beta * T
    dEdt = gamma * E * (1 - E) + delta * P - epsilon * T
    dCdt = lambda_ * C * (1 - C) + mu * S - nu * T
    dSdt = eta * S * (1 - S) + kappa * P - zeta * C
    dTdt = pi * T * (1 - T) + rho * P - sigma * E
    return [dPdt, dEdt, dCdt, dSdt, dTdt]
# Initial conditions
y0 = [10, 0.5, 0.2, 0.1, 0.05]
# Time span for simulation
t_span = (0, 100)
t_eval = np.linspace(t_span[0], t_span[1], 1000)
# Solve the system
sol = solve_ivp(community_inclusive_model, t_span, y0, t_eval=t_eval, method='RK45')
# Extract solutions
t = sol.t
P, E, C, S, T = sol.y
# Plot results
plt.figure(figsize=(12, 8))
plt.subplot(3, 2, 1)
plt.plot(t, P, label="P (Plant Population)", color="green")
```

```
plt.title("Plant Population")
plt.xlabel("Time")
plt.ylabel("Population")
plt.grid()
plt.subplot(3, 2, 2)
plt.plot(t, E, label="E (Ecological Health)", color="blue")
plt.title("Ecological Health")
plt.xlabel("Time")
plt.ylabel("Health Index")
plt.grid()
plt.subplot(3, 2, 3)
plt.plot(t, C, label="C (Socio-Economic Benefits)", color="purple")
plt.title("Socio-Economic Benefits")
plt.xlabel("Time")
plt.ylabel("Benefit Index")
plt.grid()
plt.subplot(3, 2, 4)
plt.plot(t, S, label="S (Community Involvement)", color="orange")
plt.title("Community Involvement")
plt.xlabel("Time")
plt.ylabel("Involvement Level")
plt.grid()
plt.subplot(3, 2, 5)
plt.plot(t, T, label="T (Conservation Efforts)", color="red")
plt.title("Conservation Efforts")
plt.xlabel("Time")
plt.ylabel("Effort Level")
plt.grid()
plt.tight_layout()
plt.show()
```

SCENARIO 2 :

Implementation Phyton

```
import numpy as np
from scipy.integrate import solve_ivp
import matplotlib.pyplot as plt
# Define parameters
```

```
r, K = 0.2, 100
alpha, beta, gamma, delta, epsilon = 0.05, 0.01, 0.1, 0.02, 0.005
lambda_, mu, nu = 0.2, 0.1, 0.05
eta, kappa, zeta = 0.2, 0.01, 0.005
pi, rho, sigma = 0.1, 0.02, 0.01
phi, psi, omega = 0.05, 0.01, 0.005
tau, upsilon, xi = 0.02, 0.005, 0.001
# Define the model equations
def government_intervention_model(t, y):
    P, E, C, S, T, G, M = y
    dPdt = r * P * (1 - P / K) + alpha * C - beta * T + psi * G
    dEdt = gamma * E * (1 - E) + delta * P - epsilon * T - xi * M
    dCdt = lambda_ * C * (1 - C) + mu * S - nu * T + upsilon * M
    dSdt = eta * S * (1 - S) + kappa * P - zeta * C
    dTdt = pi * T * (1 - T) + rho * P - sigma * E - omega * G
    dGdt = phi * G * (1 - G) + psi * P - omega * T
    dMdt = tau * M * (1 - M) + upsilon * C - xi * E
    return [dPdt, dEdt, dCdt, dSdt, dTdt, dGdt, dMdt]
# Initial conditions
y0 = [10, 0.5, 0.2, 0.1, 0.05, 0.1, 0.05]  # Initial values for P, E, C, S, T, G, M
# Time span for simulation
t_span = (0, 100)
t_eval = np.linspace(t_span[0], t_span[1], 1000)
# Solve the system
sol = solve_ivp(government_intervention_model, t_span, y0, t_eval=t_eval, method='RK45')
# Extract solutions
t = sol.t
P, E, C, S, T, G, M = sol.y
# Plot results
plt.figure(figsize=(14, 10))
titles = [
    "Plant Population (P)", "Ecological Health (E)", "Socio-Economic Benefits (C)",
    "Community Involvement (S)", "Conservation Efforts (T)", "Government Influence (G)",
    "Market Impact (M)"
]
variables = [P, E, C, S, T, G, M]
colors = ["green", "blue", "purple", "orange", "red", "cyan", "brown"]
```

```
for i, (var, title, color) in enumerate(zip(variables, titles, colors), start=1):
    plt.subplot(4, 2, i)
    plt.plot(t, var, label=title, color=color)
    plt.title(title)
    plt.xlabel("Time")
    plt.ylabel("Value")
    plt.grid()
    plt.legend()
plt.tight_layout()
plt.show()
```