Snake war

🟩 Abstract

Snake Wars: Learning from Nature's Metaphors
This article presents a metaphorical model rooted in nature —snakes, rats, and rice— to expose the dangers of short-term, symptom-based decisions. Snake poaching may seem like an easy solution for income, but it unravels the delicate interdependence of ecosystems, leading to agricultural collapse and food insecurity. These dynamics are not exclusive to nature: they mirror patterns in business and public policy, where decisions often target visible symptoms while ignoring deeper, latent structures. The "Snake Wars" metaphor helps reveal how policies built on short-term metrics can undermine long-term sustainability. This metaphor can also be applied to complex business systems where the invisible drivers of failure are rarely addressed. We advocate for the use of systemic thinking and simulation as tools to uncover root causes and shift decision-making toward sustainable futures.

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System dynamics; innovation adoption; systems thinking; public policy; simulation; ecological balance; economic welfare; latent structures.

(Adapted from Saeed et. al. 2016)

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🟩 Introduction

We often make decisions within visible (manifest) structures —what we can measure, see, or control— without realizing that the real drivers of systemic behavior lie beneath the surface. In ecosystems, as in organizations, removing a key predator like the snake can lead to unintended consequences: overpopulation of prey, collapse of production, and systemic failure. This article presents the "Snake Wars" metaphor, not just as an ecological tale, but as a learning tool for business and policy design.

Our current approaches to problem-solving focus on what’s easy to measure —outputs, shortfalls, activity levels— rather than understanding the invisible structures that generate those outcomes. These hidden structures, rich in interdependencies and feedback loops, are rarely addressed because they are intangible, slow-moving, and difficult to quantify. Yet they are the root of long-term system behavior.

By simulating the dynamics between snakes, rats, and rice, we expose the dangers of short-term gain at the cost of systemic resilience. We argue that this metaphor applies far beyond rural agriculture: it holds lessons for decision-makers in any system —from governments to businesses— who must shift from reactive, symptomatic solutions to deep, systemic change.

🌾🐍🐀 Seeing the System Before Simulating It: A Picture That Speaks for Itself

A simple image can reveal the complexity of a system better than a thousand explanations. In the opening diagram, we observe a deeply interconnected natural cycle: snakes regulate rats, and rats, in turn, threaten rice crops. However, faced with the lure of immediate profit, snake poaching is introduced as a source of income, along with the sale of rice. At first glance, it appears to be a profitable solution. But upon closer inspection, a destructive pattern emerges: as the snake population declines, rats grow uncontrollably, ravaging crops—and ultimately, everyone loses—the farmer, the ecosystem, and the local economy. This image needs no words to raise awareness: it reveals how, by making decisions based on short-term visible gains, we dismantle the invisible structures that sustain our survival.

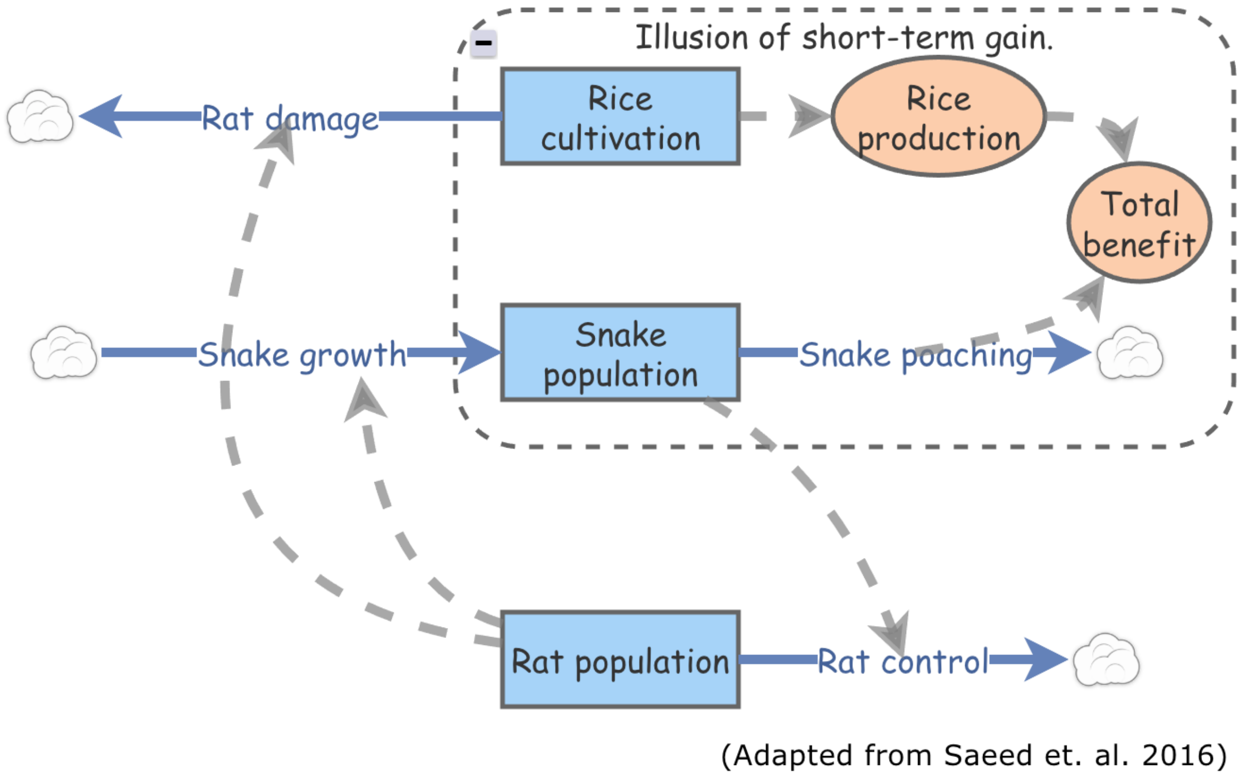


Figure 1 "Where some see rice and snakes as easy profits, the system sees balance. Break that balance, and you harvest collapse."

Seeing the system before simulating it: a picture that speaks for itself
The interaction between snakes, rats, and rice reveals how a single isolated action—like snake poaching—can throw the entire ecosystem off balance, leading to both economic and environmental losses. This image captures the essence of the problem that inspired the model.

📖 Modeling Through Storytelling: Making Systemic Logic Visible

To make the underlying logic of our simulation model clear and accessible, we will walk through each of its four sectors using **storytelling**. This narrative approach allows us to bring to life the structure of stocks, flows, and feedback loops in a way that resonates beyond technical language. By following the journey of snakes, rats, rice fields, and human decisions, we uncover how small actions ripple through an interconnected system—shaping its long-term outcomes. Let's begin with the first sector: the predator-prey relationship between snakes and rats.

📌 Modeling Best Practice Note

Model Normalization: Testing the Base Equilibrium
A good practice in simulation modeling is to **normalize the model**, which means that **when no policies are active and there are no external disturbances**, the system should remain in equilibrium. That is, the stock values should remain constant.

This ensures the mathematical consistency of the model and provides a reliable baseline for analyzing the impact of various policies.

🐍🐀 Sector 1: Predator-Prey Dynamics — Snakes vs. Rats

In this first sector, we model the natural control mechanism between snakes and rats—a classic predator-prey system. Snakes depend on rats as a primary food source, while rats reproduce quickly and can become a plague if left unchecked. When snake populations are healthy, they help regulate rat numbers, keeping the ecosystem in balance. However, when snakes are removed—due to poaching or other human interventions—the rat population grows rapidly, creating cascading consequences for agriculture and human settlements.
This dynamic is represented by a **balancing (negative feedback) loop**:

- As **rat population increases**, it provides more food for snakes.
- More food allows the **snake population to grow**, through natural reproduction.
- As **snakes increase**, they consume more rats.
- This **reduces the rat population**, completing the balancing cycle.

But this balance is fragile. If humans interfere—by poaching snakes or disrupting habitats—the loop is broken. Rats proliferate, leading to crop destruction, food scarcity, and economic losses.

This predator-prey dynamic sets the foundation for understanding why **preserving interdependent species** is crucial for sustainability, not just for conservation but also for economic resilience.

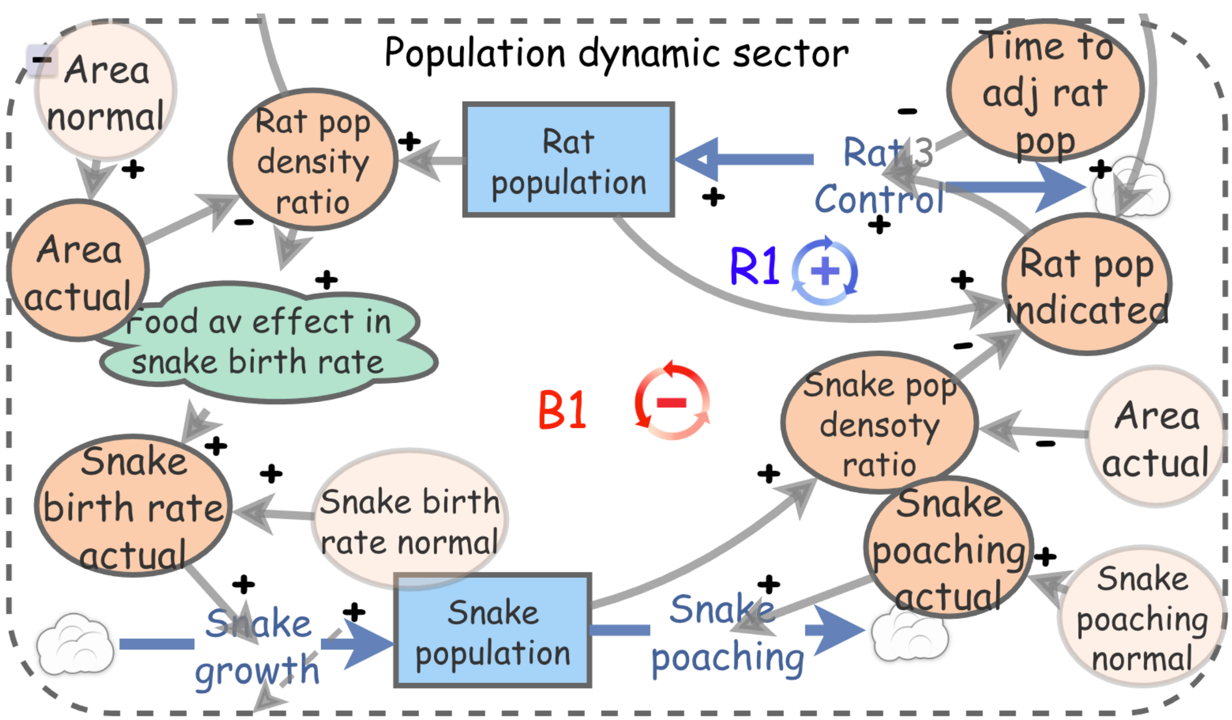


Figure 2: The natural balance between snakes and rats: when snakes disappear, rats explode and the ecosystem collapses.

🐀 Rat Population

- **Name:** Rat Population
- **Initial Value:** 500
- **Unit of Measure:** Rats
- **Allows Negative Values:** ✓ *Allow negatives*
- **Type:** *Stock (Accumulator)*

📝 **Description:**
This stock represents the total rat population in the ecosystem. Rats have a high reproduction rate and feed primarily on cultivated rice, making them a direct threat to food security. Their population increases through natural births and decreases due to predation by snakes. Keeping this population in check is essential for maintaining the balance and stability of the system.

🐍 Snake Population

- **Name:** Snake Population
- **Initial Value:** 10
- **Unit of Measure:** Snakes
- **Allows Negative Values:** ✓ *Allow negatives*
- **Type:** *Stock (Accumulator)*

📝 **Description:**
This stock represents the total number of snakes in the ecosystem. Snakes play a vital role as natural predators of rats. Their population increases when food (rats) is plentiful and declines due to natural death or human actions like poaching. Maintaining a healthy snake population is essential to keeping the rat population under control and ensuring ecological balance. When this balance is disrupted, cascading consequences can follow—harming agriculture, economic resilience, and the long-term sustainability of the system.

🐀 Rat pop density ratio

- **Name:** Rat Population Density Ratio
- **Type:** Auxiliary Variable
- **Formula:**
  ([Rat Population] / [Current Area]) / (Fix([Rat Population]) / Fix([Current Area]))
- **Unit of Measure:** Unitless / Dimensionless

📝 **Description:**
This variable represents the **normalized rat population density**, adjusted so that its value is exactly **1** at the beginning of the simulation, assuming no policies are applied. The Fix() function captures the initial values of the variables to ensure a stable baseline ratio between rat population and area. This normalization technique is considered good modeling practice, as it

confirms that the system is balanced before any interventions are introduced. Because it is a relative ratio, it has no physical units and is categorized as *unitless* or *dimensionless*.

🐍 Food av effect in snake birth rate

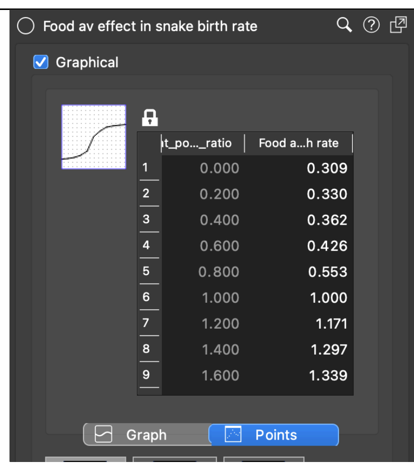
- **Name:** Food Availability Effect on Snake Birth Rate
- **Type:** *Converter* Variable
- **Formula:**
  A **nonlinear function** built using a **data table** that maps X-values (ranging from 0 to 2, based on *Rat Population Density Ratio*) to Y-values representing the effect on snake birth rate.
- **Unit of Measure:** Unitless / Dimensionless

📝 **Description:**

This variable models the **nonlinear relationship** between rat population density and its impact on the birth rate of snakes. The function is defined through a **curve of tabulated points**, with the X-axis ranging from 0 to 2 (input from *Rat Population Density Ratio*), and the Y-axis returning a proportional effect on the snake birth rate.
When the input value does not exactly match a data point on the curve, the model applies **interpolation** to estimate the value between points, ensuring the function provides results across the full range.

Since *Rat Population Density Ratio* equals 1 at the start of the simulation (in the absence of policy interventions), this function should also return **1**, maintaining a normalized and balanced system response. This variable has **no physical units**, as it represents a relative effect.

Figure 3: Non-linear graphical function.



	t_po..._ratio	Food a...h rate
1	0.000	0.309
2	0.200	0.330
3	0.400	0.362
4	0.600	0.426
5	0.800	0.553
6	1.000	1.000
7	1.200	1.171
8	1.400	1.297
9	1.600	1.339

Figure 4: Function data.

Note:

Two data points are missing from the nonlinear function:

1.8 corresponds to 1.36
2.0 corresponds to 1.381

🐍 Snake birth rate actual

- **Name:** Current Snake Birth Rate
- **Type:** Auxiliary Variable
- **Formula:**
  [Snake birth rate normal] * [Food av effect in snake birth rate]
- **Unit of Measure:** 1/Month (1/Months)

📝 **Description:**
This variable represents the **current snake birth rate**, dynamically adjusted based on the availability of food (rats). It is calculated by multiplying the snake's normal birth rate (Snake birth rate normal) by the nonlinear effect caused by the rat population density (Food av effect in snake birth rate).
Thus, when food is scarce (fewer rats), the birth rate decreases; when food is abundant, the birth rate increases proportionally.
This adjusted value is then used to calculate the **snake births flow**, allowing the model to realistically reflect how predator-prey dynamics influence snake reproduction.

🐍 Snake growth

- **Name:** Snake Population Growth
- **Type:** *Flow*
- **Formula:**
  [Snake population] * [Snake birth rate actual]
- **Unit of Measure:** Snakes/Month (Snakes/Months)

📝 **Description:**
This flow represents the **number of snakes born each month**. It is calculated by multiplying the current snake population (Snake population) by the adjusted birth rate (Snake birth rate actual).
It is the inflow that **increases the snake stock**, and it varies depending on food availability (rats), which affects the birth rate.
This component illustrates how the ecosystem reacts to natural conditions, especially within the predator-prey feedback loop.
🔎 **Technical validation note:**
In a normalized simulation —with no policies or disturbances applied— this flow should match the outflow or death rate of snakes, ensuring that the **snake stock remains in equilibrium**. This condition is essential for validating the model's mathematical integrity.

🌾 Area actual

- **Full Name:** Current Rice Cultivation Area
- **Type:** Auxiliary Variable

- **Formula:**
  [Area normal]
- **Unit of Measure:** Hectares (Ha)

📝 **Description:**
This variable represents the **current area dedicated to rice cultivation**, measured in hectares.
By default, it equals the value of [Area normal], which is defined in the **policy sector**, and can be adjusted there to simulate scenarios such as reduction, expansion, or recovery of agricultural land.
It plays a key role in calculating **rat population density** and in assessing the effects of policy interventions on agricultural productivity and ecological balance.

🐍 Snake poaching actual

- **Full Name:** Current Snake Poaching Rate
- **Type:** Auxiliary Variable
- **Formula:**
  [Snake poaching normal]
- **Unit of Measure:** 1/Month (1/Months)

📝 **Description:**
This variable represents the **current rate of snake poaching**, expressed as a monthly proportion.
Its value is directly inherited from [Snake poaching normal], which is defined in the **policy sector** and can be modified to simulate various levels of human pressure on the snake population.
Poaching has a direct impact on reducing snake numbers, disrupting the predator-prey balance and triggering indirect consequences for agriculture and the local economy.

💀🐍 Snake poaching

- **Full Name:** Snake Poaching
- **Type:** *Flow*
- **Formula:**
  [Snake population] * [Snake poaching actual]
- **Unit of Measure:** Snakes/Month (Snakes/Months)

📝 **Description:**
This flow represents the number of snakes that die per month as a result of poaching. It is calculated by multiplying the current snake population by the **current poaching rate** (Snake poaching actual.

This outflow reduces the stock of snakes and directly disrupts the predator-prey cycle. Increased poaching can lead to uncontrolled rat proliferation, damaging crops and destabilizing the ecosystem.

🧮🐀 Rat pop indicated

- **Full Name:** Indicated Rat Population
- **Type:** *Auxiliary variable*
- **Formula:**
  ([Rice density ratio] / [Snake pop density ratio]) * Fix([Rat population])
- **Unit of Measure:** Rats

📝 **Description:**
This variable estimates the reference value for the rat population based on food availability (rice) and predator pressure (snakes).
It is **directly proportional** to the **Rice density ratio** (more food means more rats) and **inversely proportional** to the **Snake pop density ratio** (more predators mean fewer rats).
To maintain model consistency, this value is **normalized using the initial rat population**, obtained through the Fix([Rat population]) function. This ensures that the model remains in equilibrium when no policies are applied.
This variable is used to update the net flow of rats (growth or decline) within the predator-prey dynamic.

⏳🐀 Time to adj rat pop

- **Full Name:** Time to Adjust Rat Population
- **Type:** *Auxiliary variable*
- **Initial Value:** 1
- **Unit of Measure:** Months

📝 **Description:**
This parameter defines the **adjustment time** required for the rat population to move toward its indicated value (**Rat pop indicated**) in the predator-prey cycle. It serves as a **response delay** in the system, reflecting how quickly the population reacts to changes in food availability or predation pressure.
A value of 1 month means the system attempts to reach the indicated population level within one month, enabling a dynamic but manageable response.

🐀⚖️ Rat Control

- **Full Name:** Rat Population Control Flow
- **Type:** *Flow*
- **Formula:** -([Rat pop indicated] - [Rat population]) / [Time to adj rat pop]

- **Units of Measure:** Rats/Months
- **Allows Negative Values:** ✔ Yes (bidirectional flow)

📝 **Description:**

Rat Control adjusts the rat population stock by regulating the **net inflow or outflow** of rats, based on the difference between the desired value (**Rat pop indicated**) and the actual **Rat population**.

- When the desired value is **higher**, the flow is **negative**, adding rats to the stock.
- When the desired value is **lower**, the flow is **positive**, removing rats from the stock.

The negative sign ensures correct directional adjustment.
This bidirectional flow is essential for maintaining ecosystem balance based on predator-prey pressure and food availability.

🌾 Sector 2: Production — Rice cultivation under ecological pressure

In this second sector, we focus on rice cultivation as the central economic activity in the system. Rice is not only a vital food source for the population but also a key indicator of stability and regional well-being.

The logic of this sector is deeply linked to the predator-prey dynamics explored in the first sector. When the rat population grows unchecked—due to the absence of snakes—crop yields suffer significantly. This loss in agricultural output is one of the first visible symptoms of ecological imbalance, directly affecting food security and the local economy.
The model captures this relationship through a causal chain in which:

- Higher rat density leads to lower rice production.
- Lower rice production increases socioeconomic stress.
- This connection justifies the need for systemic policies that address both pest control and the preservation of natural predators.

Thus, the production sector acts as a **thermometer of systemic impact**, reflecting in its outcomes the indirect consequences of ecological disruption.

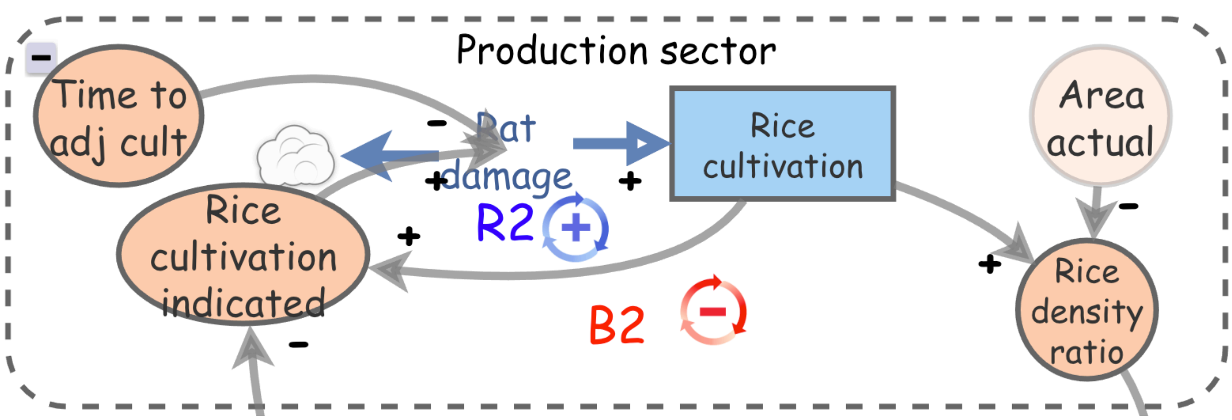


Figure 5: Rice production as a mirror of ecological balance.

The image illustrates how agricultural yield reacts to rat pressure when the natural balance is disrupted. A threatened crop is not only an ecological problem, but also a sign of an emerging food and economic crisis.

Rice cultivation

Type:Stock (Accumulator)
Initial Value:100
Units of Measure:Rice tons
Description:
The Rice cultivation stock represents the accumulated amount of cultivated rice in the system, measured in tons. This variable is essential for assessing both economic welfare and ecosystem health, as rice serves a dual purpose: food security and ecological balance.
Its initial value is normalized to **100 tons** as a baseline for system equilibrium at the start of the simulation. From this point, the stock's value may increase or decrease depending on the dynamics of the system (e.g., rat infestations or increased cultivation area) and the policies applied.
This stock **allows negative values** (Yes), which is necessary to model scenarios where the system collapses and rice cultivation is completely lost. While negative rice values are not physically realistic, allowing them in the model helps signal structural breakdowns or severe policy failures, thus supporting the interpretation of extreme outcomes.

Rice cultivation indicated

- **Full Name:** Indicated Rice Cultivation
- **Type:** *Auxiliary variable*
- **Formula:** (1 / [Rat pop density ratio]) * Fix([Rice cultivation])
- **Units of Measure:** Rice tons

Description:
Rice cultivation indicated represents the expected or desired level of rice cultivation, based on the current pressure exerted by rat population density.

- It is **inversely proportional** to **Rat pop density ratio**: as rat density increases, the indicated level of rice cultivation decreases.
- It uses the Fix function to anchor the calculation to the **initial value** of **Rice cultivation**, maintaining a reference for equilibrium.

This variable helps the system dynamically adjust rice production in response to ecological imbalance caused by predator-prey dynamics, and it informs the adjustment flow defined in the next step of the model.

Time to adj cult (Rice cultivation adjustment time)

Type: Auxiliary variable

Initial value: 1
Units: Months

📝 **Description:**
Represents the time it takes for the rice cultivation stock to adjust in response to system conditions, particularly to rat population pressure.
Purpose: Functions as a delay or damping parameter to avoid abrupt fluctuations in the [Rice cultivation] variable. It helps stabilize the model in response to changes in rat density.

🐀🌾 Rat damage

Type: Flow
Formula: Rat damage= -([Rice cultivation indicated]-[Rice cultivation])/[Time to adj cult]
Units: Rice tons/Months

📝 **Description:**
This flow represents the net impact of rat activity on the cultivated rice stock ([Rice cultivation]).
The difference between [Rice cultivation indicated] (the desired or expected level of rice cultivation adjusted by rat pressure) and [Rice cultivation] (the current stock) determines how much rice should be added to or removed from the stock to restore equilibrium.
The negative sign ensures bidirectional behavior:

- If [Rice cultivation indicated] > [Rice cultivation], the flow is negative → stock increases (crop recovery).
- If [Rice cultivation indicated] < [Rice cultivation], the flow is positive → stock decreases (rat-induced damage).

The parameter [Time to adj cult] controls the speed of adjustment, reflecting how quickly the system reacts to ecological disturbances.

🌾📏 Rice density ratio

Type: Auxiliary variable
Formula: ([Rice cultivation]/[Area actual])*(1/(Fix([Rice cultivation])/Fix([Area actual])))
Units: Unitless or dimensionless

📝 **Description:**
This variable calculates the adjusted or normalized density of rice cultivation. It is obtained by dividing the current level of rice cultivation ([Rice cultivation]) by the actual planting area ([Area actual]) and then normalizing it against the system's initial condition using the Fix function, which captures the initial value of each variable.
The goal of this normalization is to ensure that, **when no policies are applied**, the variable returns a value of **1**, indicating a baseline or equilibrium state in the system. This makes it easier to detect the effects of policies or disturbances throughout the simulation.

Balancing Dance: How Nature Regulates Itself

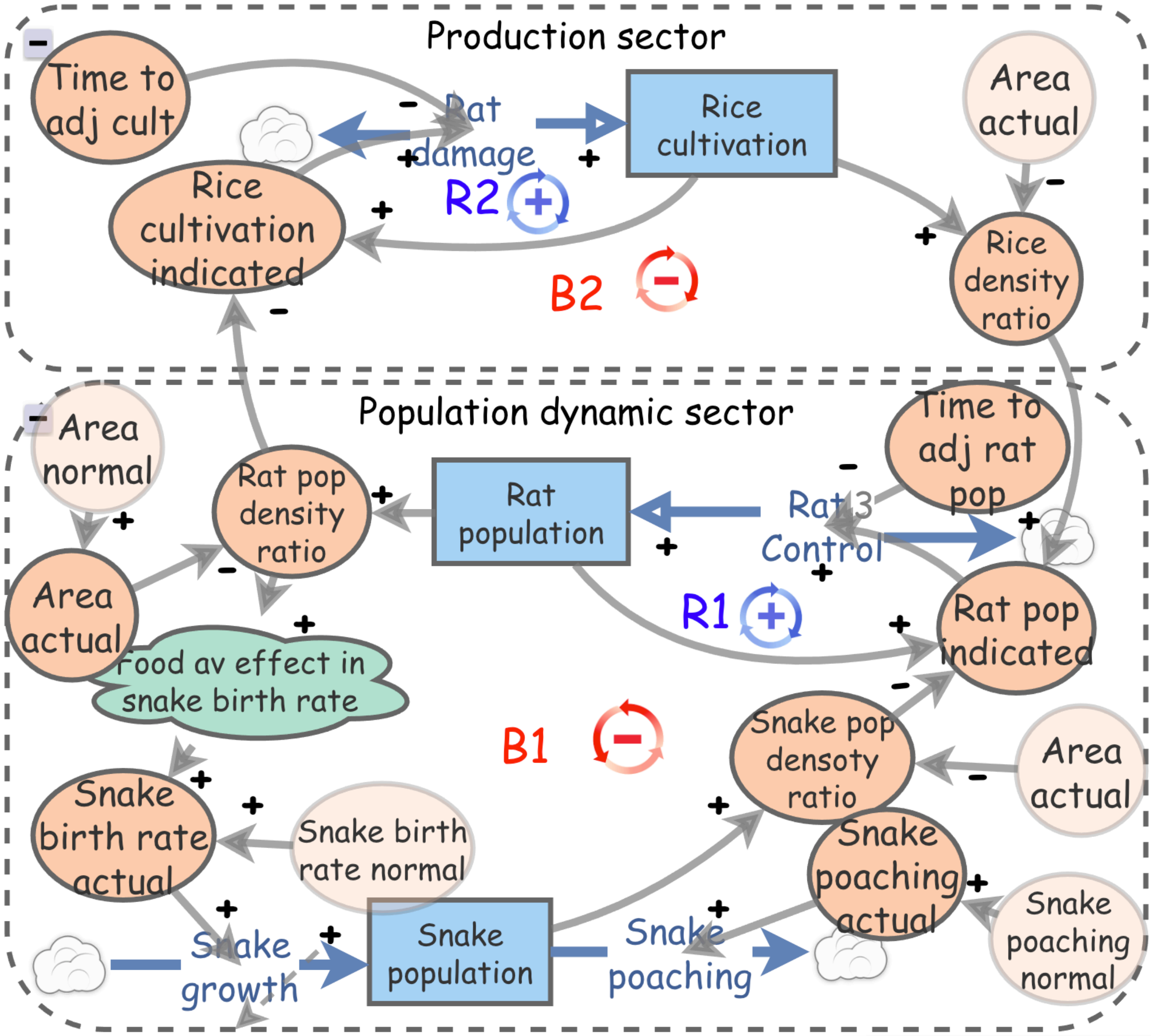


Figure 6: Two interconnected balancing loops: a dance between rats, snakes, and rice.

The model integrates two balancing feedback loops that regulate system behavior:

1. **Rat control loop (B1):**
   Higher snake density leads to more rat predation. As the rat population decreases, its impact on rice drops, guiding the system back toward equilibrium.
2. **Rice protection loop (B2):**
   As rat damage increases, rice cultivation decreases. This lowers food availability for rats, reducing their population and thus damage, closing the loop.

Both loops operate simultaneously to **sustain ecosystem stability**.

🧠⚖️ Policy Sector: Human interventions and unintended consequences

This sector models human decisions that deliberately alter the natural dynamics of the system. It includes key variables such as the intensity of snake poaching and the allocation of land for rice cultivation, enabling the simulation of different policy scenarios. This area reveals how small changes in policy parameters can produce major effects on ecological and economic cycles. It serves as a sandbox for testing sustainable or harmful interventions, exposing side effects that often remain hidden in the short term.

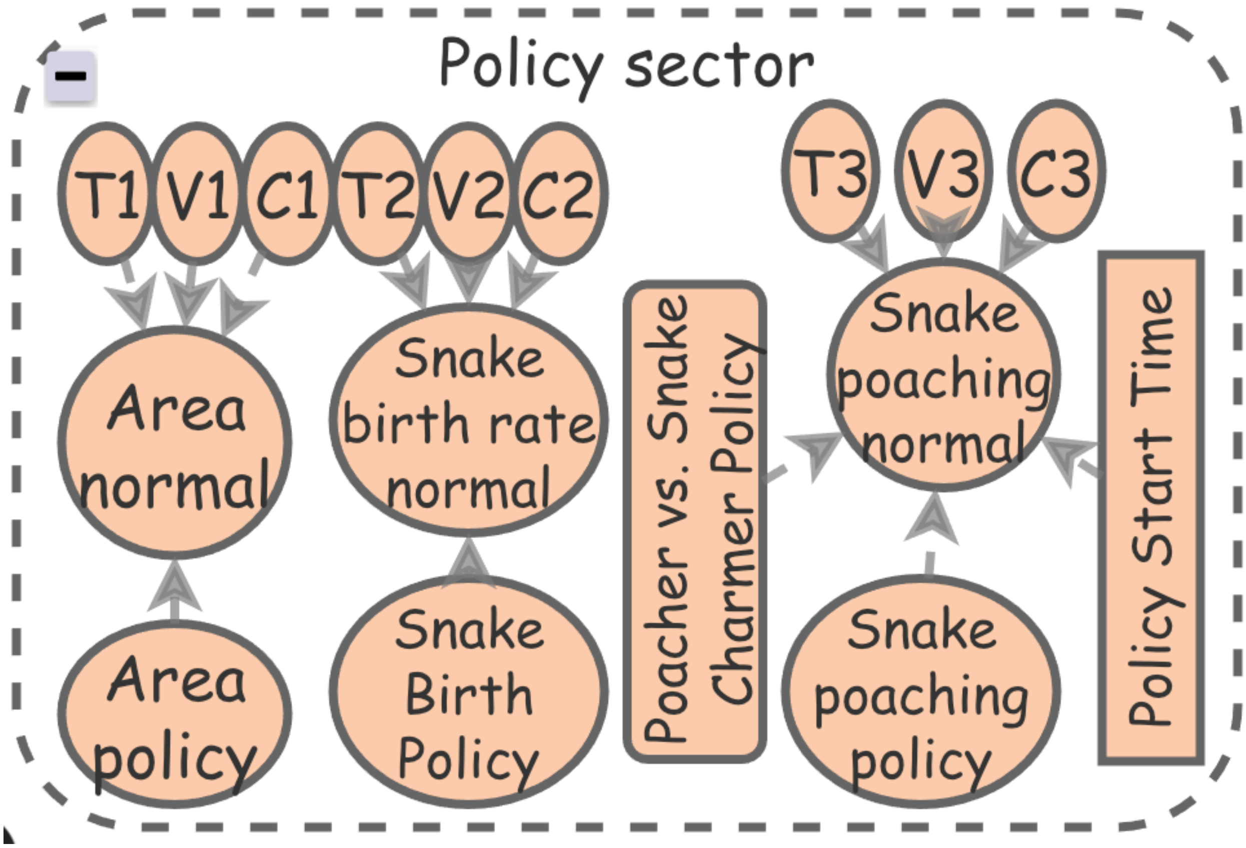


Figure 7: Policy Sector – Designing human interventions

The diagram displays decision variables that alter land use and the intensity of snake poaching. This sector provides a crucial interface for testing policy scenarios, showing how our actions can strengthen or disrupt the system's natural cycles.

📌 Variable: Area normal

Unidad: Hectáreas (Ha)
Sector: Políticas / Policies

📝 Description

The variable **Area normal** defines the baseline value of the rice cultivation area and integrates a policy mechanism that can adjust this value based on user intervention. It is computed as:
[V1] * (1 + ifthenelse([Area policy], 1, 0) * STEP([T1], [C1]/100))

- **V1**: Initial cultivation area when no policy is applied. Default: **1000 Ha**
- **Area policy**: Boolean switch (*State* type) (true/false) to activate the policy.
- **T1**: Simulation time at which the policy becomes active. Value: **5 Months**
- **C1**: Desired percentage change in area. Value: **20** (unitless, i.e., 20%)
- **STEP([T1], [C1]/100)**: Step function that introduces the change after time T1.

When the policy is activated (Area policy = true), from month 5 onward the cultivation area increases by 20%, moving from 1000 to 1200 Ha. This has systemic implications for the rice-rat-snake interaction model and allows us to simulate agricultural policy scenarios.

📌 Variable: Snake birth rate normal

Unidad: 1/Months
Sector: Policies

📝 Description

The variable **Snake birth rate normal** defines the baseline birth rate of snakes. It includes a policy mechanism that can increase or decrease this rate at a specific point in the simulation. The formula is:
[V2] * (1 + ifthenelse([Snake Birth Policy], 1, 0) * STEP([T2], [C2]/100))

- **V2**: Base snake birth rate. Value: **0.1 (1/Months)**
- **Snake Birth Policy**: Boolean variable (*State* type) (true/false) to activate the policy. Value: false
- **T2**: Time at which the policy takes effect. Value: **5 Months**
- **C2**: Percentage change to be applied. Value: **20** (unitless)
- **STEP([T2], [C2]/100)**: Step function that triggers the change after time T2.

If the policy is activated (**Snake Birth Policy = true**), from month 5 onward the snake birth rate increases by 20%, from 0.1 to 0.12 (1/Months). This simulates interventions such as habitat restoration or captive breeding and directly impacts predator-prey dynamics in the model.

📌 Variable: Snake poaching normal

Unit: 1/Months
Sector: Policies

📝 Description

The variable **Snake poaching normal** represents the rate at which snakes are poached. Two distinct policy mechanisms can affect this variable:

1. **Direct Snake Poaching Control Policy**, activated by **Snake poaching policy**.
2. **Poacher Replacement by Snake Charmers Policy**, triggered by **Poacher vs. Snake Charmer Policy**.

The governing formula is:

```
IF ( [Poacher vs. Snake Charmer Policy] = false ) THEN
  [V3] * (1 + ifthenelse([Snake poaching policy], 1, 0) * STEP([T3], [C3]/100))
ELSE
  IF (Time() <= [Policy Start Time]) THEN
    [V3] * (1 + ifthenelse([Snake poaching policy], 1, 0) * STEP([T3], [C3]/100))
  ELSE
    [V3] * (1 + ifthenelse([Poacher vs. Snake Charmer Policy], 1, 0) * STEP([Policy Start Time], (-
[C3])/100))
  END IF
END IF
```

📌 Variables and values involved:

- **V3** = base poaching rate: **0.1 (1/Months)**
- **C3** = percentage change: **20** (unitless)
- **T3** = start of the first policy: **5 Months**
- **Policy Start Time** = start of second policy: **35 Months**
- **Snake poaching policy:** Boolean variable (*State* type) (true/false) to activate the policy. Value: false
- **Snake Charmer Policy:** Boolean variable (*State* type) (true/false) to activate the policy. Value: true

This structure enables a two-phase policy approach: a **direct intervention**, followed by a **transformational shift** to more sustainable practices that decrease snake poaching.
🔁 Logical explanation:
• Before 35 months, if the Poacher vs. Snake Charmer Policy = false, the traditional policy is used, which increases poaching by 20% if enabled.
• After 35 months, if the charmer policy is enabled (Poacher vs. Snake Charmer Policy = true), then poaching is reduced by 20%, using a negative value of change (%), simulated with (-[C3])/100.
This allows for the simulation of a gradual paradigm shift, where hunting is first regulated and then replaced with an alternative solution (charmers), which reduces pressure on snake populations in a more sustainable way.

🧭 Sector 4: Performance Indicators

🌱 Purpose of the Section

This section is designed to **simplify the interpretation of the model's results** by using two key performance indicators plotted on a coordinate system:

- **X-axis**: Economic Welfare
- **Y-axis**: Ecosystem Health

This two-dimensional framework allows users to assess the system's performance at any point in time, helping identify whether the outcomes are sustainable, unsustainable, or indicative of system failure.

📊 Key Indicators

1. **Economic Welfare** (X-axis):
   Reflects the economic well-being of the population or community. This indicator may include variables like rice production, income levels, or economic stability derived from human-ecosystem coexistence.
2. **Ecosystem Health** (Y-axis):
   Measures the condition or integrity of the ecosystem. It can be based on variables like the population balance of key species (snakes, rats), biodiversity, and the natural control of pests.

🟩🟥🟨 Performance Zones

Based on the values of the two indicators, the system's state can be interpreted through the following zones:

Zone	Description	Interpretation
🟩 **Sustainable Zone**	High levels of both economic welfare and ecosystem health.	The system has reached a sustainable balance where policies support both economic and environmental goals.
🟨 **Unsustainable Zone**	One of the indicators is underperforming.	The system is unbalanced—either the economy thrives at the environment's expense, or conservation efforts hinder economic well-being. Policy adjustments are needed.
🟥 **System Failure Zone**	Low levels in both indicators.	The system has collapsed. The implemented strategies have failed economically and environmentally. A fundamental redesign of the approach is required.

🎯 Usefulness of This Sector

This sector allows users to:

- **Track the direction of the system** as the simulation progresses.
- **Compare different policy scenarios** and their impacts.

- **Communicate insights clearly and visually** to decision-makers, students, or non-expert audiences.

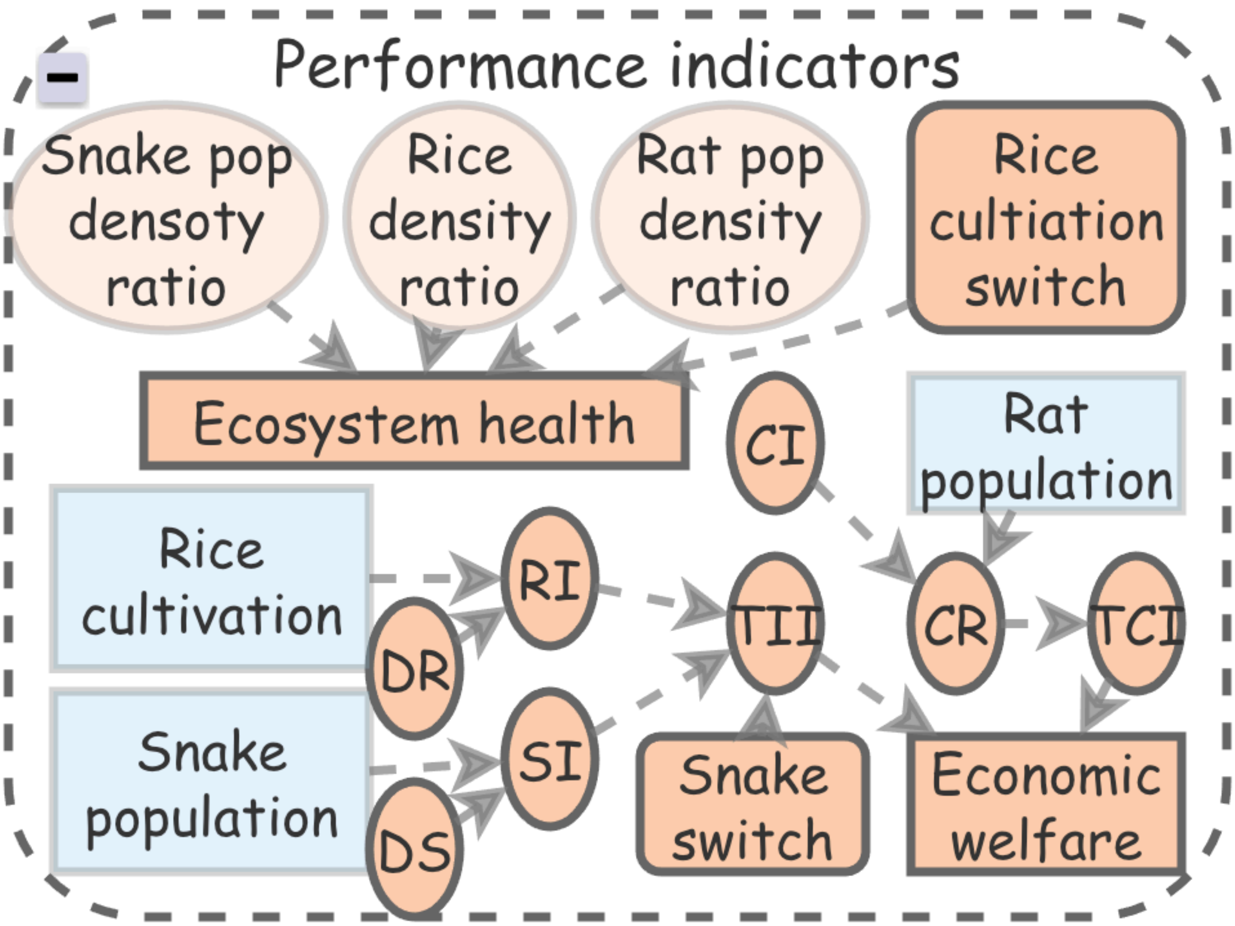


Figure 8: Performance Indicator Sector – Economic Welfare vs. Ecosystem Health.

This diagram provides a visual summary of the model's outcomes by plotting system performance along two axes: Economic Welfare (X-axis) and Ecosystem Health (Y-axis). The quadrant layout categorizes results into three zones: Sustainable (green), Unsustainable (yellow), and System Failure (red), facilitating quick assessment of the impact of policies and system dynamics.

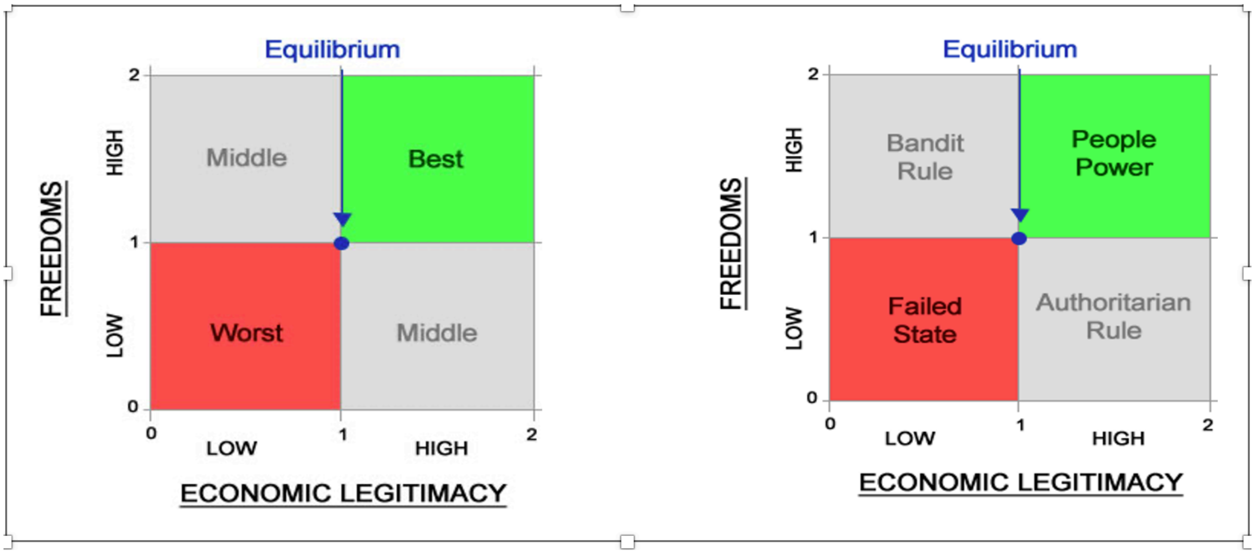


Figure 9: The Systemic Outcomes Magic Quadrant.

The image shows the three key performance zones of the system: in green, the **Sustainable Zone**, where economic and ecological balance is achieved; in yellow, the **Unsustainable Zone**, where one dimension dominates and endangers the system; and in red, the **Failed State Zone**, where both economic welfare and ecosystem health collapse.

Performance Indicator: Ecosystem Health

Type: Auxiliary variable
Units: Dimensionless (no units)
The [Rice cultivation switch] component is defined as (state) and initialized as true, it has no dimensions.
Formula:

([Snake Pop Density Ratio] + [Rice Density Ratio] * ifthenelse([Rice Cultivation Switch], 1, 0)) / ([Rat Pop Density Ratio] * (1 + ifthenelse([Rice Cultivation Switch], 1, 0)))

📝 **Description:**
This indicator represents the systemic health of the ecosystem by comparing the density of beneficial components (snakes and, optionally, rice) to the density of a harmful component (rats). When the variable **[Rice Cultivation Switch]** is set to true, the indicator incorporates rice density in the numerator, acknowledging its ecological and economic role. To maintain the balance of the formula when two elements are in the numerator, the denominator is scaled by 2, using the expression *(1 + ifthenelse([Rice Cultivation Switch], 1, 0))*.
When **[Rice Cultivation Switch]** is false, only snake population density is considered in the numerator, and the denominator remains unadjusted. The resulting value is a dimensionless ratio:

- **Values > 1** suggest a healthy ecosystem.

- **Values < 1** indicate ecological degradation or imbalance.

To ensure consistency and model normalization, the initial value of the indicator (before any policy intervention) is set to **1**, meaning the system starts in a balanced state under normal conditions.

Performance Indicator: Economic Welfare

Type: Auxiliary variable
Units: Dimensionless (no units)
Main formula:

Economic welfare = [TII] / [TCI]
Description:
This indicator evaluates the economic health of the system by calculating the ratio between **Total Income Index ([TII])** and **Total Cost Index ([TCI])**, both normalized to ensure unitless and comparable results.
The interpretation is as follows:

- **Greater than 1** → the system is economically healthy and generating positive returns.
- **Equal to 1** → the system is at a neutral economic state (baseline, before any policy intervention).
- **Less than 1** → indicates economic deterioration or risk.

The model is calibrated so that at the **start of the simulation**, before any policies are implemented, this indicator should yield a value of **1**, aligning with the normalization criteria for comparability.

Calculation of Total Income Index ([TII])

Formula:

[TII] = (([RI]/Fix([RI])) + (([SI]/Fix([SI])) * ifthenelse([Snake switch],1,0))) / (1 + ifthenelse([Snake switch],1,0))
Components:

- **[RI] = [Rice cultivation] * [DR]**
  Income from rice cultivation
  - [DR] = 10 USD per ton of rice
  - Units: US Dollars
- **[SI] = [Snake population] * [DS]**
  Income from snake-derived products and byproducts
  - [DS] = 50 USD per snake
  - Units: US Dollars
- **[Snake switch]**: A boolean (true/false) state variable initialized as true. It controls whether snake-related revenues are included in the income calculation. It also plays a role in the normalization denominator.

Interpretation:

- If Snake switch = false, only rice income is considered.
- If Snake switch = true, both rice and snake incomes are included, and the denominator is adjusted to reflect two income sources for correct normalization.
- The result of [TII] is **dimensionless**.

Calculation of Total Cost Index ([TCI])

Formula:

[TCI] = [CR] / Fix([CR])

Where:

- **[CR] = [Rat population] * [CI]**
  Total cost associated with rat presence (e.g., damage, control)
  - [CI] = 5 USD per rat
  - Units: US Dollars

Output:

- [TCI] is also **dimensionless**, and under baseline (pre-policy) conditions, it is equal to 1.

Brief Descriptions of Economic Model Variables

- **[TII] – Total Income Index**
  A dimensionless index that combines normalized income from both rice cultivation and snake-related products. It adjusts based on the value of the Snake switch.
- **[TCI] – Total Cost Index**
  A dimensionless index representing the total normalized costs derived from the rat population.
- **[RI] – Rice Income**
  Total revenue from rice cultivation, calculated as the quantity of rice produced multiplied by the price per ton.
- **[SI] – Snake Income**
  Total revenue from the sale of snakes and their byproducts, based on snake population and price per unit.
- **[DR] – Dollar per Rice Ton**
  Unit price of rice. Constant value: **10 USD/ton**.
- **[DS] – Dollar per Snake**
  Unit price for each snake or its byproducts. Constant value: **50 USD/snake**.
- **[CR] – Cost by Rats**
  Total cost resulting from the rat population. It is the product of rat population and the unit cost per rat.
- **[CI] – Cost per Rat**
  Estimated cost associated with each rat. Constant value: **5 USD/rat**.
- **[Snake switch] – Snake Revenue Inclusion Switch**
  A Boolean variable (true or false) that determines whether snake-related income is

included in the economic indicator. It also controls normalization logic at the start of the simulation.

🇬🇧 Concise Descriptions (English)

- **Economic Welfare**
  A dimensionless indicator that evaluates the balance between normalized total income and normalized total cost. Values above 1 indicate a healthy economy; values below 1 signal economic stress.
- **Ecosystem Health**
  A dimensionless indicator that compares the density of beneficial species (snakes and optionally rice) to the density of harmful species (rats). Values above 1 represent a resilient ecosystem; values below 1 suggest ecological imbalance.

📋 Bilingual Table – Economic Model Variables

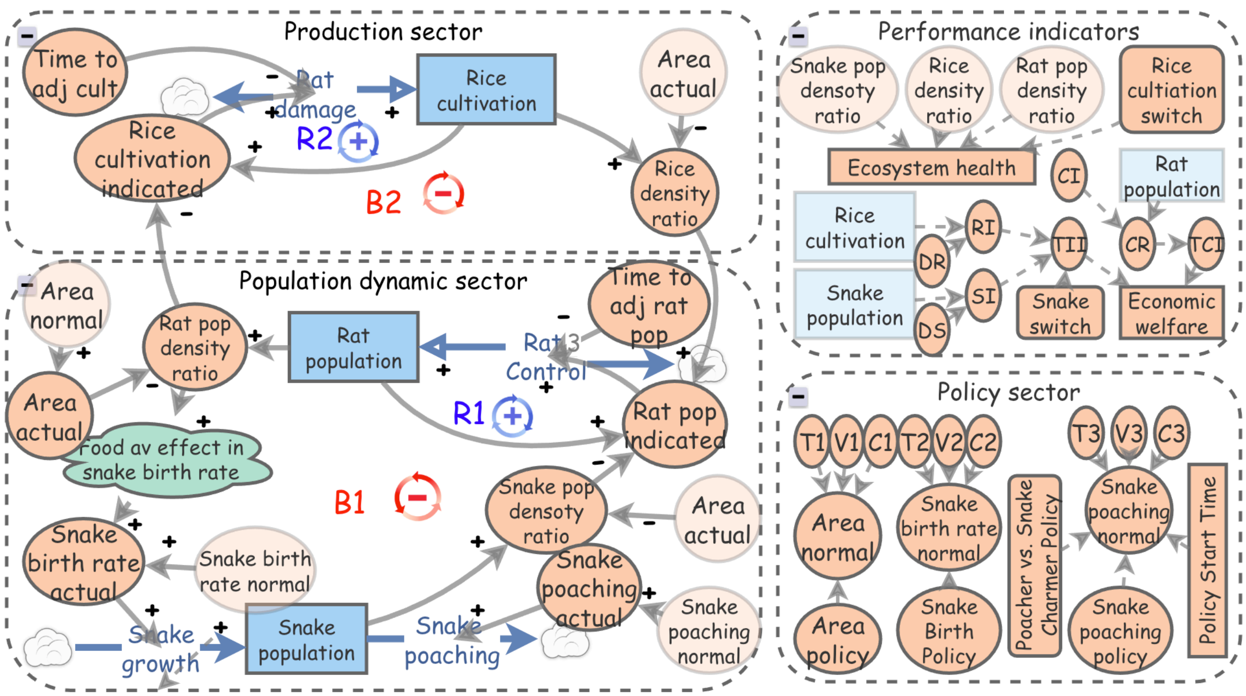
Variable	Description (English)	Descripción (Español)
[TII]	Total Income Index (normalized, dimensionless)	Índice de ingresos totales (normalizado, sin unidades)
[TCI]	Total Cost Index (normalized, dimensionless)	Índice de costos totales (normalizado, sin unidades)
[RI]	Rice Income = [Rice cultivation] × [DR]	Ingreso por arroz = [Cultivo de arroz] × [DR]
[SI]	Snake Income = [Snake population] × [DS]	Ingreso por serpientes = [Población de serpientes] × [DS]
[DR]	Price per ton of rice (10 USD/ton)	Precio por tonelada de arroz (10 USD/tonelada)
[DS]	Price per snake (50 USD/snake)	Precio por serpiente (50 USD/serpiente)
[CR]	Cost from rats = [Rat population] × [CI]	Costos por ratas = [Población de ratas] × [CI]
[CI]	Unit cost per rat (5 USD/rat)	Costo unitario por rata (5 USD/rata)
[Snake switch]	Includes snake income in total revenue (true/false)	Incluye ingresos de serpientes en el total (true/false)

System Dynamics Model for Ecosystem Management and Public Policy

The image displays the complete model, composed of four interconnected sectors:

1. **Biological Ecosystem**, which simulates the dynamics among rats, snakes, and rice cultivation.
2. **Production and Economy**, representing the income and expenses resulting from ecosystem-related activities.
3. **Public Policies**, where interventions can be activated or deactivated to influence system behavior.
4. **Performance Indicators**, which summarize the model's outcomes in two key dimensions: *ecosystem health* and *economic welfare*.

This model provides an integrated view to assess how ecosystem actors interact and how policy decisions impact sustainability and balance.



(Adapted from Saeed et. al. 2016)

Figure 10 Integrated model: natural cycles, economy, policies, and outcomes in one diagram.

Complete system dynamics model for ecosystem management and public policy. It displays the four interconnected sectors: biological ecosystem, economy and production, public policies, and performance indicators. This integration enables analysis of the impact of different decisions on the system's sustainability.

Between Poaching and Charm: The Intervention Dilemma

In this section, we analyze the graphical results of the **Snake War** model across different scenarios, each defined by the activation or inaction of specific policies. The available policies are:

1. **Snake Poaching Policy:** has its own dedicated start-time parameter.
2. **Snake Birth Policy:** uses a separate start-time setting.
3. **Area Policy:** also comes with an independent activation time.
4. **Poacher vs Snake Charmer Policy:** is triggered by the global Policy start time variable.

This structure allows us to evaluate the impact of strategic decisions on the system's dynamic behavior. Through these scenarios, we identify patterns, transitions, and critical points that influence ecosystem sustainability and regional economic well-being.

🧩 Graphical Results Analysis: Insights for Systemic Decision-Making

Graph types and interpretation overview
To evaluate the impact of different policies applied to the *Snake War* model, we analyze four types of graphs per scenario. These represent critical relationships within the system and highlight key dynamics emerging from policy decisions. The graph types are:

1. **Rice cultivation vs. Rat population**
   This shows how rat pressure directly affects agricultural productivity.
2. **Performance indicators: Economic welfare vs. Ecosystem health**
   This graph summarizes system behavior into two strategic dimensions:
   - **Economic welfare**
   - **Ecosystem health**

   The plot is divided into **four zones**:
   - 🔷 **Upper-right (blue): Sustainable outcome** (high welfare, high ecosystem health)
   - 🔻 **Lower-left (red): Failed state** (economic and environmental collapse)
   - 🔶 **Upper-left / lower-right (yellow): Unsustainable outcomes** (sacrificing one dimension for the other)

   This format helps **simplify interpretation** and supports clear communication of policy consequences.
3. **Rice cultivation vs. Snake population**
   Illustrates how biological control through snakes indirectly supports agriculture by regulating rat populations.

4. **Snake population vs. Rat population**
   A classic **predator-prey** relationship graph, showing potential cycles, equilibria, or collapse based on interactions.

All four graphs will be presented **together in a single table per scenario**, accompanied by an **integrated caption** and a **concise narrative summary** linking the results to real-world decision making — especially in business contexts where short-term gains often compete with long-term sustainability.

🐍 Scenario 1: No Policies Applied

Scenario description:

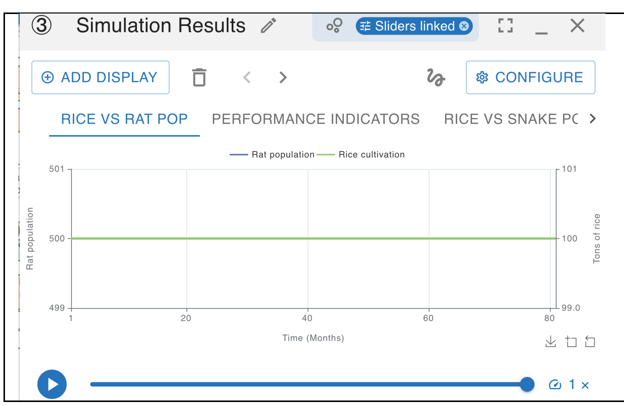
In this first scenario, no policy is activated throughout the entire simulation. The system remains in a stable state, which is intentional, as the model was designed using a **normalization technique**—meaning initial values and rates were calibrated to produce dynamic equilibrium.

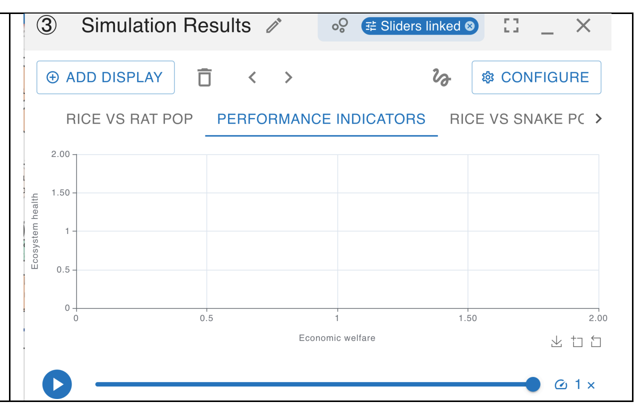
Graphical result:

All stocks and flows remain constant over time. There are no oscillations or upward/downward trends. This behavior serves as a baseline or **reference scenario** against which the effects of future policy interventions can be compared.

Interpretation:

This scenario shows that, in the absence of intervention, the system experiences neither crisis nor improvement. The stability arises from a natural balance among births, deaths, harvesting, and predation, and reveals that any disruption will come from external decisions—that is, from the activation of policies.





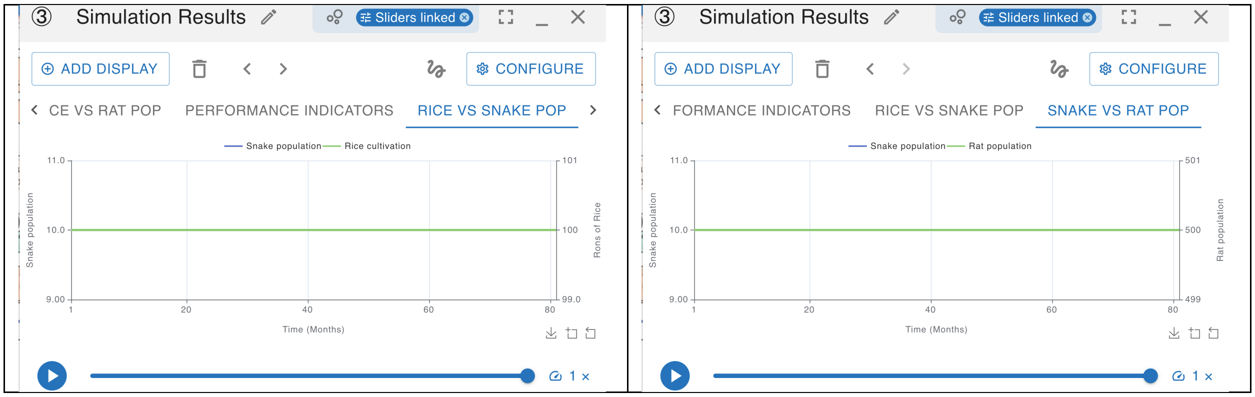


Figure 11: Systemic impact of policies on the snake-rat-rice dynamics: four key graphical perspectives.

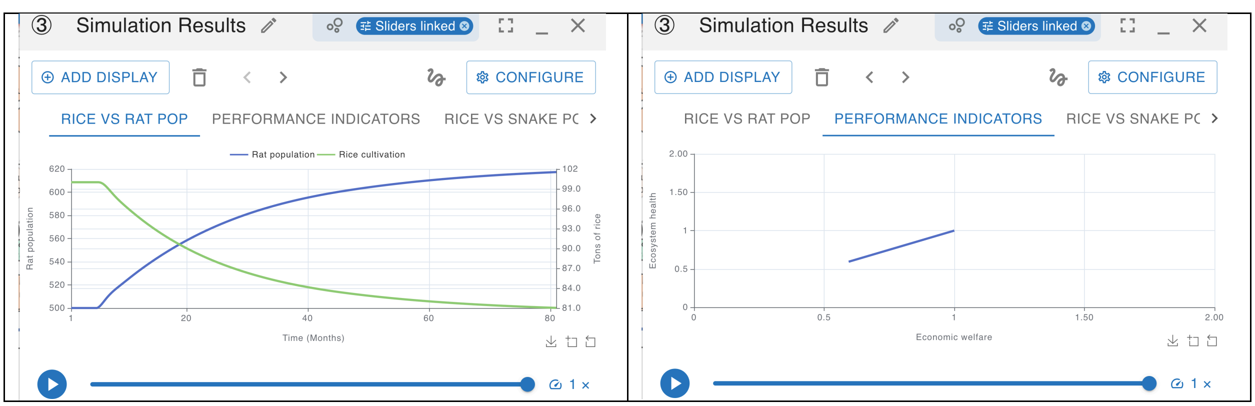
Each scenario is analyzed through four visualizations: (1) rice cultivation vs. rat population, (2) economic welfare vs. ecosystem health, (3) rice cultivation vs. snake population, and (4) snake population vs. rat population. These graphs reveal how policies influence productivity, biological control, and long-term sustainability.

🐍 Scenario 2: Snake Poaching Policy Activation

Snake Poaching Policy applied at month 5 with 20% intensity

🧩 Stage description:

In this scenario, a snake poaching policy is implemented in month 5, reducing the snake population by 20%. This disrupts the ecological balance by removing the natural control over rats. The result is a rapid collapse in rice cultivation, an explosion in the rat population, and a significant decline in both economic and environmental performance indicators.



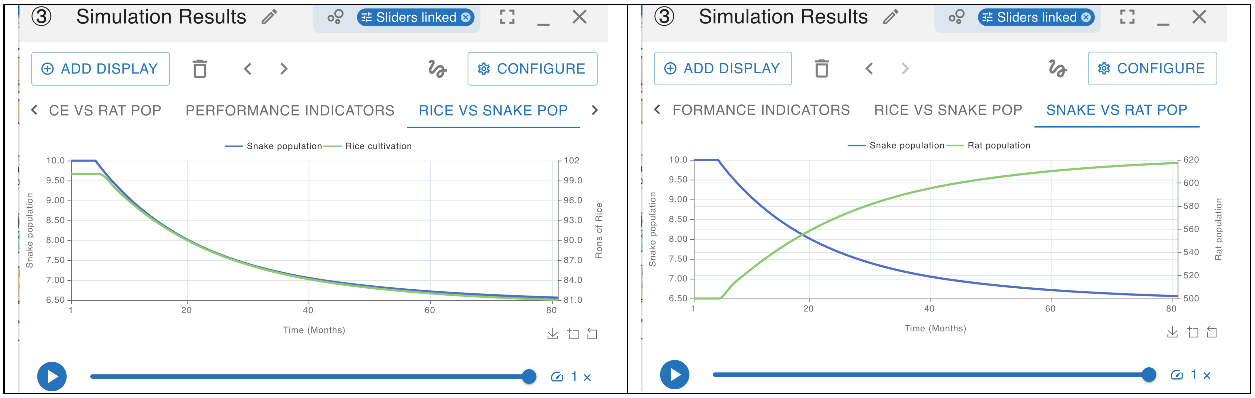


Figure 12: System collapse due to non-systemic intervention: impacts of snake poaching.

The graphs show how removing key predators (snakes) leads to rat overgrowth, declining rice yields, and a multidimensional crisis that ends in the system's Failed State quadrant.

Graphical Summary of Scenario 2: Activating Snake Poaching Policy at Month 5 (20%)

Graph Type	Description
1. Rice cultivation vs Rat population	Rice production drops dramatically as rat population surges without natural predators.
2. Performance indicators	Both **Economic Welfare** and **Ecosystem Health** fall into the lower-left quadrant, indicating a failed state.
3. Rice cultivation vs Snake population	Both rice and snake populations collapse — showing systemic degradation.
4. Snake population vs Rat population	

Business Lessons

Scenario 2 illustrates the dangers of **short-sighted, non-systemic decisions**. Several real-world business analogies mirror these patterns:

Business analogies:

1. **Firing key departments to cut costs**
   Removing essential "predator" functions like QA, R&D, or compliance might unleash internal issues—errors, inefficiencies, or cultural decay—that were previously under control.
2. **Removing checks and balances**
   Companies removing internal audits or soft governance to streamline operations often end up facing larger chaos, reputational damage, or regulatory penalties.

3. **Cutting preventive maintenance or cybersecurity**
   Savings from avoiding preventive measures can cause catastrophic failures later, much like ecological collapse due to predator removal.
4. **Dismantling strategic partnerships**
   Eliminating valuable intermediaries, alliances, or trusted vendors may destabilize distribution or customer service, allowing competitors to thrive.

🔥 Scenario 3: Expanding Without Transformation Accelerates Collapse

📘 Section Description:

In this scenario, two policies are activated simultaneously in month 5:

- **Snake Poaching Policy** at 20%
- **Area Policy**, expanding the rice cultivation area by 20%.

The intention to increase production by enlarging the cultivated land fails disastrously. The linear logic —more land means more rice— ignores the systemic dynamics of the ecosystem. The elimination of snakes disrupts ecological balance and allows the rat population to grow unchecked, devastating the new crops. As a result, the system collapses even faster than in the previous scenario.

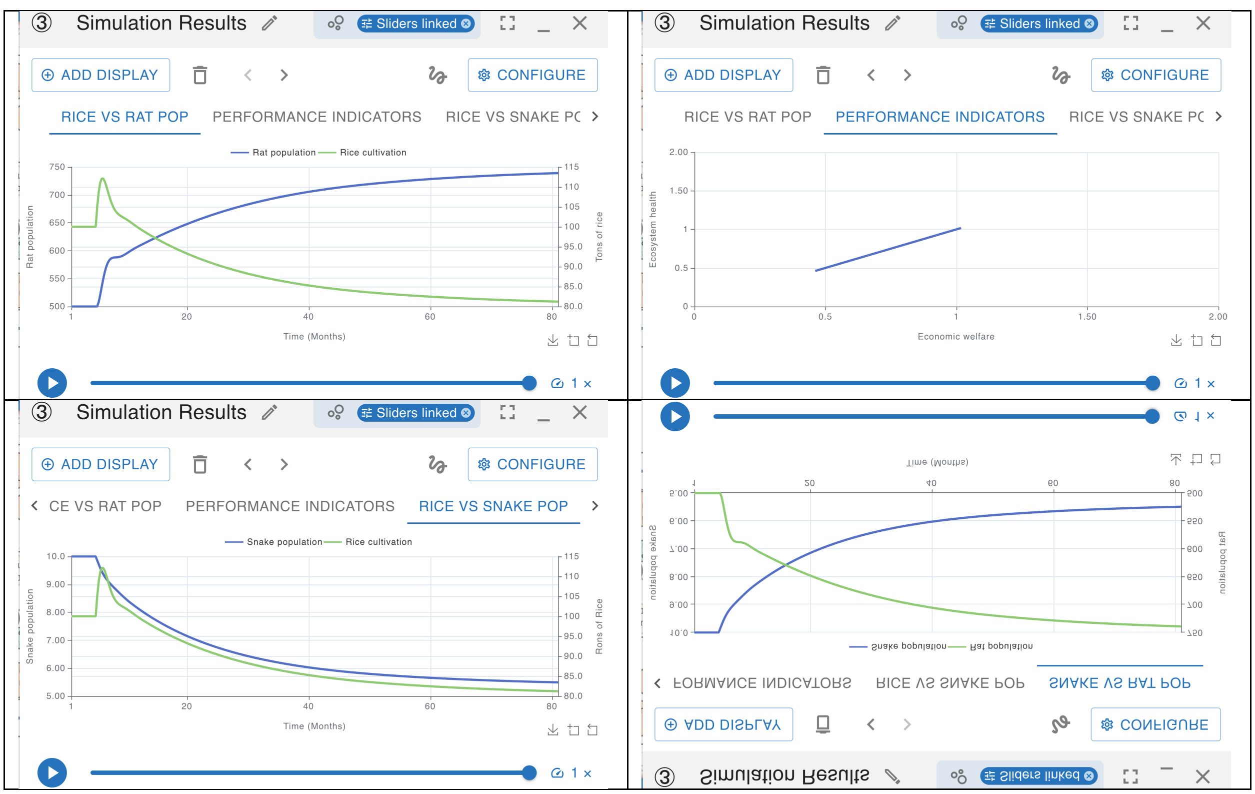


Figure 13: More area, no structural control, faster collapse.

This scenario illustrates how tackling visible symptoms (e.g., planting more land) without addressing underlying structural causes —such as predator-prey balance— can worsen outcomes. Instead of solving the problem, it accelerates collapse.

📊 Graphical Summary Table – Scenario 3

Activated Policies:

- **Snake Poaching Policy:** active in month 5 at 20%
- **Area Policy:** active in month 5 at 20%

No.	Graph	Observed Behavior Description	Systemic Interpretation
1	**Rice cultivation vs rat population**	Rice cultivation declines while rat population grows	Expanding area without controlling rats worsens the issue instead of solving it
2	**Performance indicators**	Both economic and ecological indicators fall sharply	Superficial policy mix accelerates systemic collapse towards a failed state
3	**Rice cultivation vs snake population**	Both rice production and snake population decline	Poaching removes natural predators; the larger area cannot compensate for structural failure
4	**Snake population vs rat population**	Snake population collapses while rat population surges	The system loses balance: natural pest control is severely weakened

🏢 Business Example – Connecting to Reality:

In the business world, this is like a company facing low profitability deciding to **expand by opening more branches or increasing production**, without solving structural issues like **operational inefficiencies, poor customer service, or a weak value proposition**. The result: **higher costs, loss of control, and faster bankruptcy**.

Realistic example:
A restaurant chain known for poor service and quality opens more locations, thinking volume will fix their finances. But more dissatisfied customers amplify the problem, damage the brand, and speed up the business's collapse.

Increasing rice area by 20% did not boost yields; rat numbers continued to rise. By tackling only the visible symptom—more hectares—without addressing the underlying structure, the problem worsens and the system collapses even faster.

🐍 Scenario 4 – Snake Charmers: The System Reaches the Sustainable Zone

Scenario Description:

This scenario activates two policies:

- **Snake Poaching Policy** at 20% in **month 5**, as seen in earlier scenarios. This initially causes system deterioration.
- **Poacher vs Snake Charmer Policy**, activated in **month 35** using the variable **Policy Start Time**. This second policy changes the behavior of actors, reducing poaching through structural, social, or economic incentives.

After the intervention of **snake charmers**, the system gradually recovers and stabilizes. The performance indicators show a clear and sustained improvement.

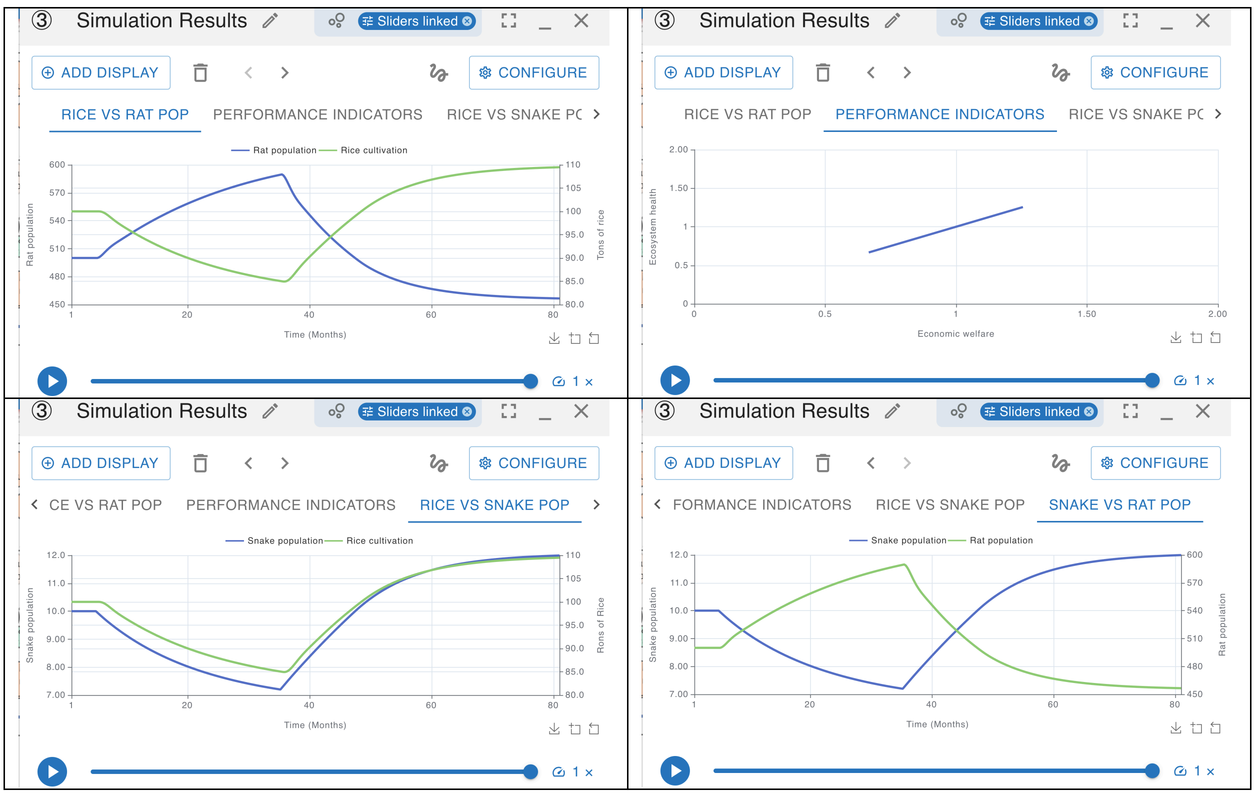


Figure 14: Del colapso a la sustentabilidad: los encantadores de serpientes restauran el equilibrio del sistema, a pesar de la caza furtiva persistente.

📊 Expanded Summary Table – Scenario 4

Snake Poaching (20%) from Month 5 + Snake Charmer Policy from Month 35
This scenario reveals a turning point in system behavior. Between **months 5 and 35**, the system collapses into a **failing state**, with declining rice production, exploding rat populations, and critical ecological damage due to ongoing poaching. However, starting in **month 35**, the implementation of the **Snake Charmer Policy** triggers a systemic shift.
Despite continued poaching (perhaps reflecting the persistence of illegal practices in real life), the **transformative role of snake charmers**—acting as cultural agents or structural incentives—leads to **stabilization and recovery** across all key indicators. The result is a system that evolves toward **long-term sustainability**.

No.	Graph	Observed Behavior	Systemic Interpretation
1	**Rice cultivation vs rat population**	**From month 5–35:** rice drops, rats flourish → **After month 35:** rice stabilizes, rats decline	Initial ecological collapse reverses with predator restoration and better systemic balance
2	**Performance indicators**	**From month 5–35:** system falls into failing quadrant → **After month 35:** moves to top-right	Structural change leads to balance between economy and ecology—the sustainable zone is reached
3	**Rice vs snake population**	Snakes recover, rice production improves post month 35	Controlled predator presence restores agricultural resilience without destabilizing the system
4	**Snake vs rat population**	Snake population increases; rats are effectively controlled	Predator-prey cycle is reestablished, crucial for long-term food and ecosystem stability

🌐 Connection to the Business World:

This case study illustrates the transformative power of systems thinking to uncover and address the root causes of complex problems. Acting only on visible symptoms—like expanding operations, increasing investment, or reacting to crises—may bring short-term relief but rarely leads to lasting solutions. True sustainability arises when organizations reshape the underlying structures and hidden policies that drive systemic behavior.

The "Snake Charmer" intervention serves as a powerful metaphor for business: in the face of market instability, productivity issues, or organizational conflict, tackling only the obvious rarely works. Companies that thrive in the long term are those that redesign internal rules, reshape operational cultures, and realign incentive systems—ensuring that economic performance, organizational well-being, and social responsibility move together.

This case reminds leaders and decision-makers that real change doesn't come from firefighting, but from illuminating and redesigning the terrain that fuels the fire in the first place.

Conclusion

This case study highlights the transformative power of systems thinking to uncover and tackle the deep, often invisible roots of complex problems. Intervening only on visible symptoms—such as expanding farmland or reacting to poaching—leads to fragile and short-lived results. True resilience and sustainability emerge only when we redesign the underlying structures and latent policies that drive system behavior.

The "Snake Charmer" intervention serves as a compelling metaphor for intelligent, culturally informed structural change—an approach capable of restoring balance and generating enduring prosperity, even amidst persistent social or behavioral constraints. It reminds us that long-term solutions demand more than action: they require insight, alignment, and systemic vision.

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