Mammoth Game II - Doomed by Density

Abstract

Doomed by Density is the second chapter in the Mammoth Game series. This systems model introduces a new balancing feedback loop driven by population density. As mammoths multiply, competition, disease transmission, and resource depletion intensify, leading to a sharp rise in mortality. This model highlights the paradox of growth: the very success of a species can trigger its collapse. By simulating these dynamics, we explore the systemic limits to expansion and the unintended consequences of exceeding ecological thresholds.

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Keywords
population dynamics, births, deaths, mammoths, dynamic system, basic model, systems thinking, online simulation, active learning.

Table of contents:

Table of figures:

Introduction

Why do some species collapse after thriving? In *Doomed by Density*, we take the foundational dynamics of the original Mammoth Game—birth and death feedback loops—and add a crucial new element: population density. With more mammoths packed into the same space, territorial conflicts increase, diseases spread faster, and food becomes scarce. These density-driven pressures form a balancing loop that accelerates mortality as the population grows. Through this model, we uncover the systemic behaviors that transform abundance into threat, showing how internal feedback—not external predators—can be the main driver of extinction.

MODEL REGISTRATION

This section defines the core metadata of the model, including the title, a brief description, and key tags. These elements help **identify, classify, and share the model** within the online simulator, enabling its use in **educational settings, collaborative analysis, and documentation processes**. Properly setting this information is essential to promote open access, reuse, and understanding by other users.

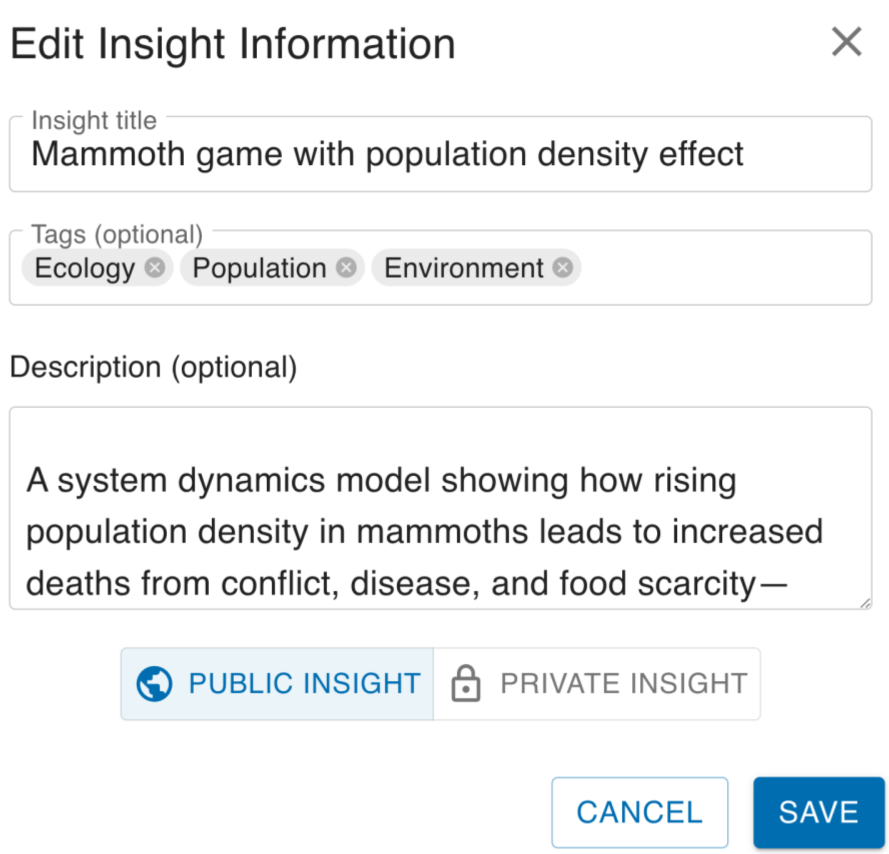


Figure 1: Model registration for "Mammoth Game".

✅ Title

Mammoth Game II - Doomed by Density

✅ Tags sugeridos *(en ambos idiomas)*:

#población #mamuts #simulación #modeloBásico #sistemasDinámicos #nacimientos #muertes #educación #introductorio #modelado #pensamiento Sistémico #simulación Online	#population #mammoths #simulation #basicModel #dynamicSystems #births #deaths #education #introductory #modeling #systemsThinking #onlineSimulation

📝 Model short description

A system dynamics model showing how rising population density in mammoths leads to increased deaths from conflict, disease, and food scarcity—revealing how internal limits can trigger collapse—or slow down growth—as seen in other phenomena where expansion seems endless, like money or power.

MODEL SETTINGS

This section establishes the foundational rules for how time flows and how calculations are performed in the simulation. It sets parameters such as the simulation's starting point, duration, and time resolution. It also includes computational details like the chosen integration method and the granularity of updates. These settings are essential to ensure consistent results and to adapt the model's behavior to the desired analytical or educational context.

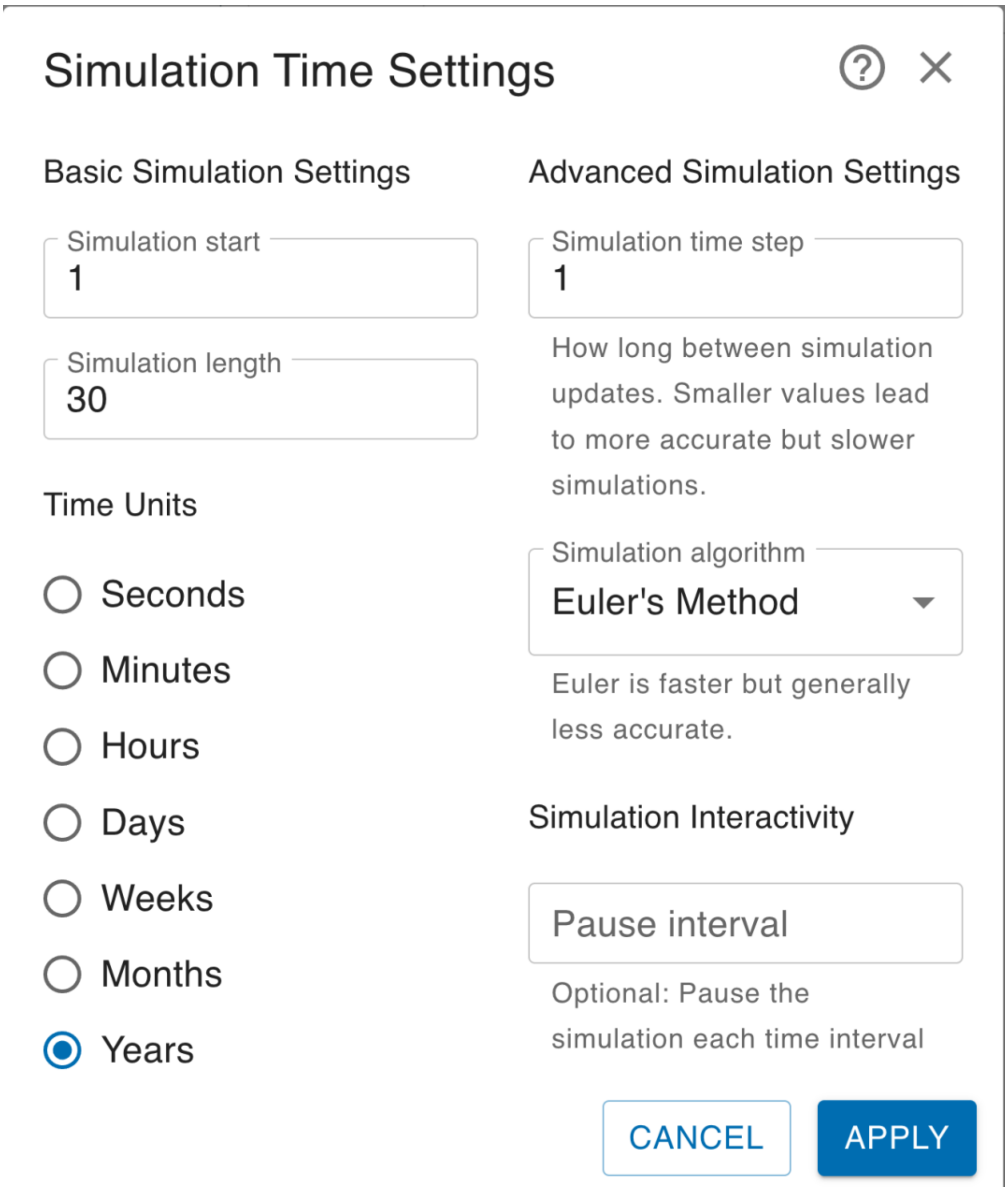


Figure 2: Simulation settings for the "Mammoth Game" model

Causal Loop Diagram (CLD)

This section presents the Causal Loop Diagram (CLD), which maps the feedback structure underlying the model. Through reinforcing and balancing loops, it illustrates how population dynamics, birth and death rates, and population density interact to shape the system's behavior over time. The CLD provides a high-level, qualitative view that helps uncover systemic patterns before diving into the quantitative simulation model.

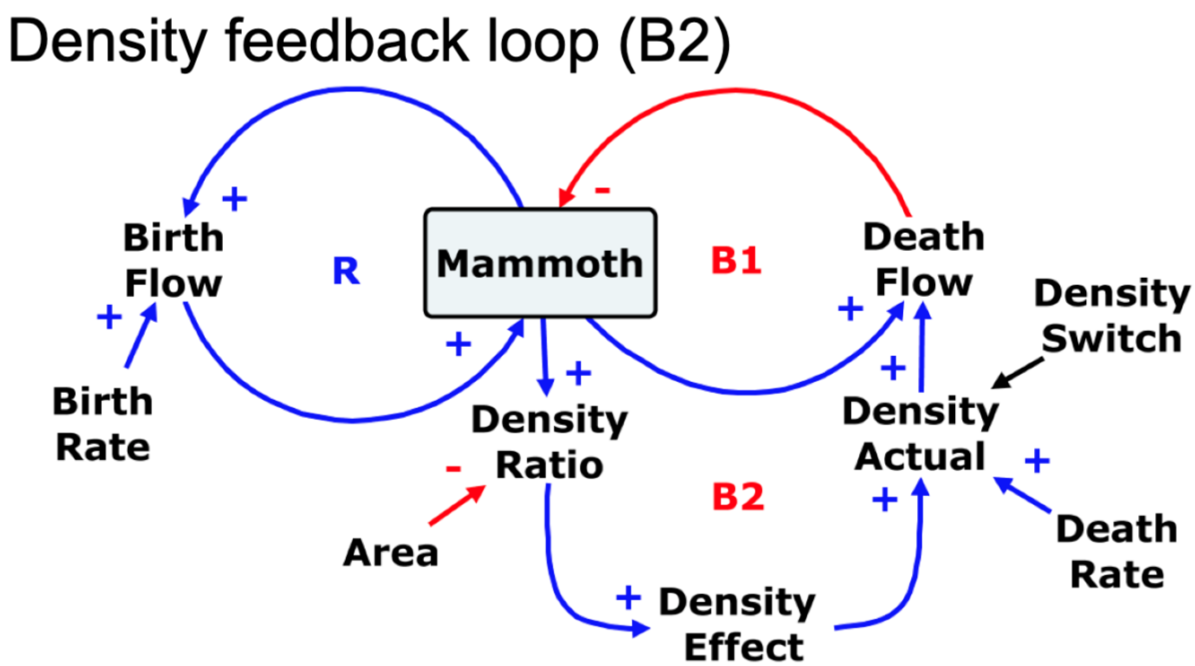


Figure 3: Causal Loop Diagram (CLD) of the model. It highlights reinforcing and balancing loops involved in mammoth population dynamics.

Model Structure: From Loops to Simulation

This section presents the stock and flow structure that translates the feedback loops identified in the CLD into a working simulation model. It defines the key components—stocks, flows, variables, and connectors—that represent how mammoth population grows and declines over time. The structure makes explicit the mechanisms of births, deaths, and density-driven constraints, enabling experimentation and policy testing within a dynamic environment.

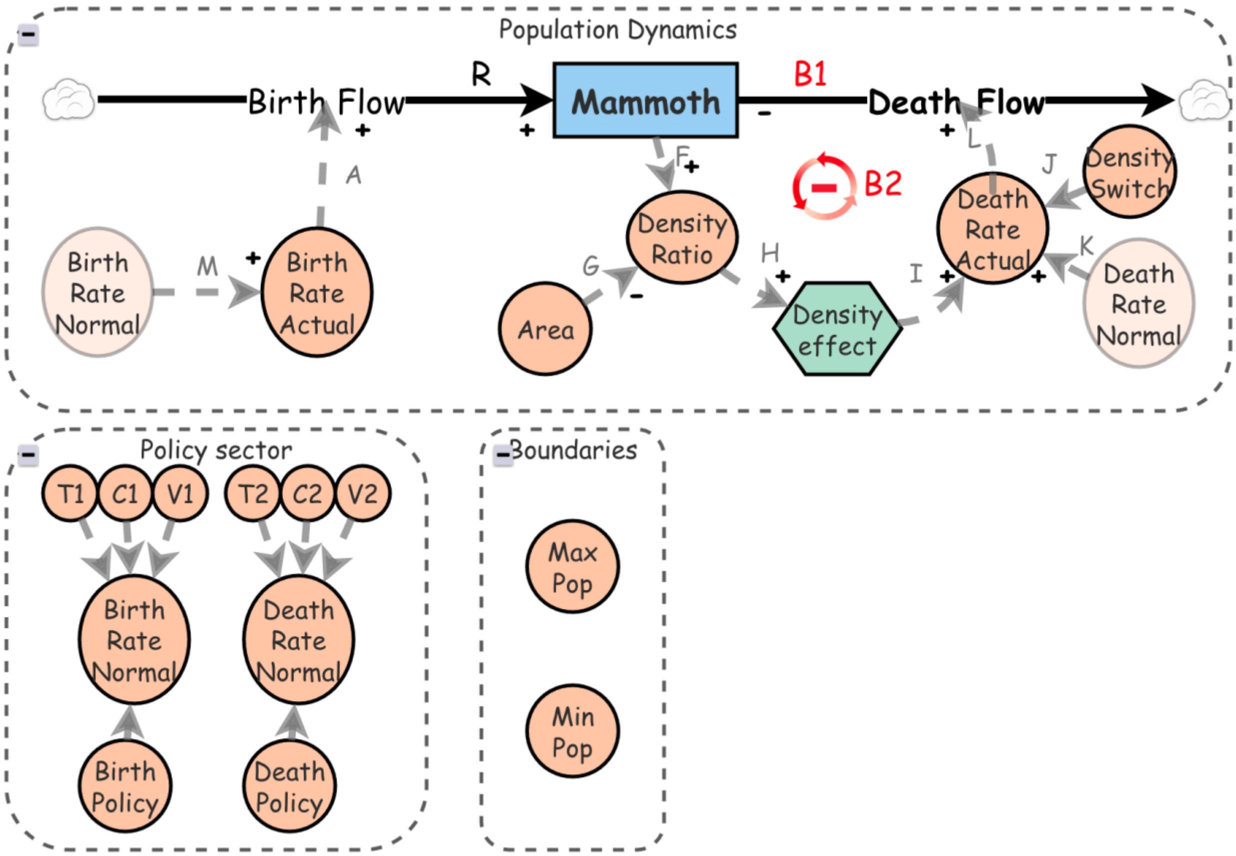


Figure 4: Stock and flow structure of the Mammoth Game II model, integrating birth, death, and density-driven feedback loops.

Policy Sector: Designing Interventions and Control Parameters

This section documents the key variables in the **Policy Sector**, which enables strategic interventions within the model. These variables serve as control mechanisms that modify the system's natural behavior over time, allowing for the exploration of scenarios with or without policy actions. By activating these policies, core parameters—such as birth or death rates—can be altered from a specific time point onward, simulating actions like conservation programs, species control, or habitat restoration. This flexible structure allows these effects to be connected to other model sectors through **ghost variables**, channeling their impact into the dynamic variables they influence.

Inserting Primitives into the Model

To begin building the model, the user places the cursor in the center of the canvas (workspace) where the diagram will be displayed. Right-clicking opens a contextual menu that allows the selection and insertion of various **primitives**—the basic building blocks of simulation models. These include:

- **Stocks:** Accumulators representing quantities or populations, such as mammoths.
- **Auxiliary Variables:** Elements that compute intermediate values based on other variables (e.g., change rates).
- **Converters:** Components that transform or scale values (e.g., from percentage to absolute values).
- **States (Checkboxes):** Switches used to enable or disable conditions or policies during the simulation.
- **Text box:** Text containers used to annotate, title, or explain elements of the model directly on the canvas.
- **Picture:** Inserted images to enhance visual understanding, provide context, or decorate the model.
- **Interactive buttons:** Buttons that perform specific actions such as resetting or pausing the simulation.

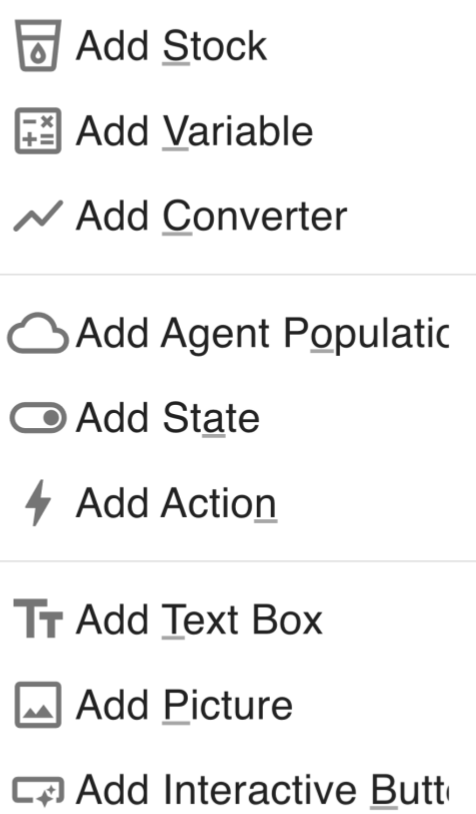


Figure 5: Contextual menu for inserting primitives into the canvas.

Right-clicking on the workspace displays a dialog box that allows the user to insert the model's fundamental elements, including stocks, flows, auxiliary variables, converters, interactive states (checkboxes), text boxes, images, and interactive buttons. This feature supports both the visual and functional construction of the model.

📌 Variable: Birth Rate Normal

Unit: 1/Year
Sector: Policies
📝 **Description**:
The variable **Birth Rate Normal** defines the baseline birth rate for the modeled species (e.g., mammoths or Deer). It includes an intervention policy mechanism that allows this rate to be modified from a specific point in time.

The formula used is:

[V1] * (1 + ifthenelse([Birth Policy], 1, 0) * STEP([T1], [C1]/100))

V1: Base birth rate. Value: 0.2 (1/Month)
Birth Policy: Boolean variable (*State* type) that activates or deactivates the policy. Initial value: *false*
T1: Time at which the policy takes effect. Value: 5 Year
C1: Percentage change to apply. Value: 40 (unitless)
STEP([T1], [C1]/100): Step function that triggers the change from month 5 onward.
If the policy is activated (**Birth Policy = true**), starting in month 5 the birth rate increases by 40%, from 0.2 to 0.28 (1/Month). This simulates interventions such as habitat restoration, genetic enhancement, or assisted reproduction, and their impact on population dynamics.
💡 Note:
By convention, the name **Birth Rate Normal** is used to indicate that this variable should be linked via a *Ghost* in the **Population Dynamics** sector, specifically to the variable **Birth Rate Actual**. This modular design allows for easy integration of additional effects influencing the actual birth rate, such as predator-prey interactions, food availability, or population stress. For instance, to incorporate the effect of a predator, one can simply multiply **Birth Rate Normal** by an additional factor representing that influence. This strategy promotes scalability and flexibility for future model development.

📌 Variable: Death Rate Normal

Unit: 1/Year
Sector: Policies
📝 **Description**:
The variable **Death Rate Normal** defines the baseline death rate for the modeled species (e.g.,

mammoths or snakes). It incorporates a policy mechanism that allows this rate to be adjusted from a specific point in time. The formula is as follows:

[V2] * (1 + ifthenelse([Death Policy], 1, 0) * STEP([T2], [C2]/100))

- **V2**: Base death rate. Value: 0.20 (1/Year)
- **Death Policy**: Boolean variable (*State* type) that activates or deactivates the policy. Initial value: *false*
- **T2**: Time at which the policy takes effect. Value: 5 Years
- **C2**: Percentage change to apply. Value: 20 (unitless)
- **STEP([T2], [C2]/100)**: Step function that triggers the change from year 5 onward.

If the policy is activated (**Death Policy = true**), from year 5 onward the death rate increases by 20%, going from 0.20 to 0.24 (1/Year). This allows the model to simulate interventions such as increased hunting, environmental stress, disease outbreaks, or population control strategies, and their impact on population dynamics.

💡 **Note**:

By convention, the variable **Death Rate Normal** is designed to be linked via a *Ghost* to the **Death Rate Actual** variable in the **Population Dynamics** sector. The latter already includes a preliminary calculation of the density-dependent mortality effect, based on the normal value defined here. This modular setup allows the model to grow over time by incorporating additional interactions, such as predator-prey dynamics, food availability (e.g., grasslands), or other ecological or anthropogenic factors. This strategy ensures scalability and flexibility for the future development of the model.

Sector: Population Dynamics

This sector captures the core structure of the model: the dynamic behavior of the mammoth population over time. It includes population *stocks*, birth and death flows, and the integration of policies and ecological effects. This is where the impact of external conditions and decisions on population growth, stabilization, or collapse is revealed.

Primitive: Stock - Mammoth

- Stock name: **Mammoth**
- Unit of measure: **Mammoths**
- Initial value: **80000**
- Value slider:
  - Show slider: ✅ Disabled
- Short description:

Represents the accumulated population of mammoths in the ecosystem. This value can be adjusted to explore different starting scenarios and analyze their impact on the system's dynamics.

Primitive: Variable –Birth Rate Actual

Variable: Birth Rate Actual
Unit: 1/Year
Formula: [Birth Rate Normal]
Sector: Population Dynamics
📝 Description:
The Birth Rate Actual variable represents the effective birth rate used in the model. Initially, it equals Birth Rate Normal, but it is designed as the central connection point for all future effects on birth dynamics—such as predator-prey interactions, food availability (pasture management), population stress, and any environmental or policy-driven modifications.
💡 Note:
Birth Rate Actual serves as a modular coupling node. All future effects impacting population growth should be funneled through this variable, altering its value via multiplicative or additive factors. This ensures a clean, scalable model structure that facilitates future development and integration of complex dynamics.

Primitive: Flow –Birth Flow

- **Flow name: Birth Flow**
- **Type: Flow**

- **Formula[Mammoth]*[Birth Rate Actual]**
- **Unit of measure: Mammoths/Year**
- **Short description:**

This flow represents the number of mammoths born each year, calculated as the product of the current mammoth population and the birth rate. It feeds directly into the *Mammoth* stock and models natural population growth.

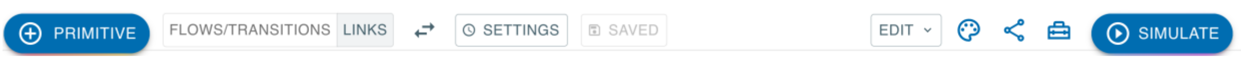


Figure 6: Top canvas menu to activate flows, draw links, and change their direction.

How to add flows to the model (in English)

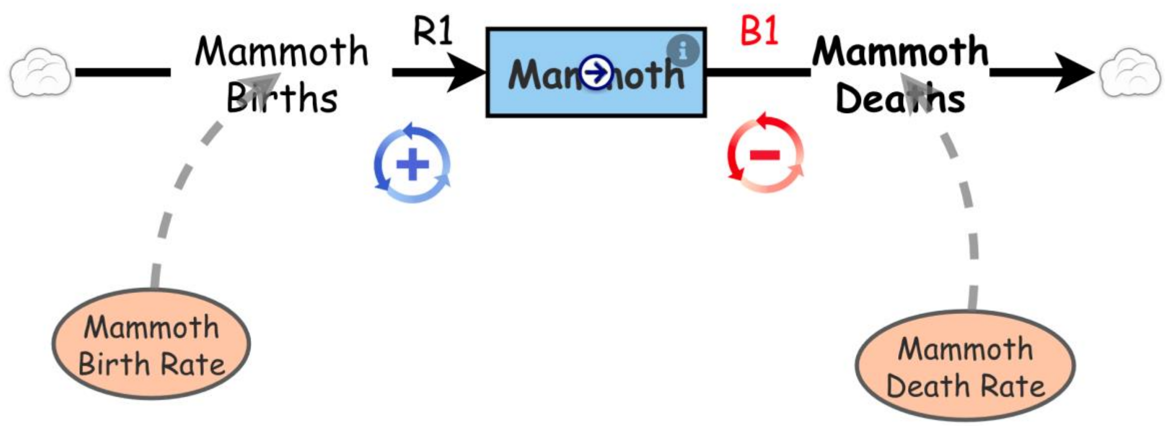


Figure 7: How to draw flows from a stock by enabling "Flows" mode and dragging from the stock's center circle.

It is important to note that **flows** are not an independent type of primitive like stocks, variables, or converters. Instead, flows are integrated directly into the diagram using tools from the menu.

To add a flow to the model:

1. Go to the top of the *canvas* and select the **Flows** option.
2. A small **white circle** will appear inside the rectangle representing a stock.
3. Place your cursor on that circle, **click and drag with the mouse** in any direction from the stock's border.
4. When you release the mouse, the flow will be added to the model.

To **change the direction** of the flow (e.g., inflow or outflow), select the **arrows icon** located on the right side of the top menu.

This process helps build clear population dynamics, such as mammoth births and deaths, which directly modify the population stock.

🔄 *When and how to define a biflow?*

Sometimes, a flow may represent both inflows and outflows depending on model conditions. These are called **bidirectional flows**.
To allow a flow to take negative values (i.e., to subtract from the stock), you must **uncheck** the **“Only positive rate”** option located on the right side of the canvas.
This enables the flow direction to change during the simulation, making the model better suited to represent reversible or compensatory processes.

Variable: Area

Value: 600000 (Acres)
Unit: Acres
Sector: Population Dynamics
📝 **Description:**
The **Area** variable defines the total land area available to the modeled population (e.g., mammoths). It represents the spatial limits of the ecosystem and can influence future calculations involving population density, carrying capacity, food availability, or territory defense.
💡 **Note:**
Although currently used as a constant, **Area** is ready to be linked with future policies or events such as habitat expansion, conservation efforts, or land fragmentation. This makes it a flexible foundation for incorporating spatial dynamics into the model.

Variable: Density Ratio

Unit: dimensionless (unitless)
Sector: Population Dynamics
📝 **Description:**
The **Density Ratio** variable captures the current population density relative to its initial baseline at the start of the simulation. It uses a normalized formula to track proportional changes in habitat density over time. The formula is:

([Mammoth] / [Area]) / (Fix([Mammoth]) / Fix([Area]))

- [Mammoth]: current stock of mammoths
- [Area]: available land area (in acres)
- Fix(): function that returns the initial value of a variable at simulation start.

This setup ensures that at time zero (when no policies are active and no changes have occurred), **Density Ratio** equals **1** by design. Any deviation from 1 reflects a relative increase or decrease in habitat density as the system evolves.
💡 **Note:**
This normalized ratio can drive future modules such as environmental pressure, overcrowding effects, resource competition, or adaptive policy triggers. Its modular structure makes it ideal for scalable and flexible model expansion.

Variable: Density Effect

Unit: dimensionless
Sector: Population Dynamics
Type: Nonlinear Converter (Graph)
📝 **Description**:
The Density Effect variable captures the relative impact of population density on mammoth mortality. It is defined as a nonlinear function of the Density Ratio, allowing the model to reflect how density-driven stress, competition for resources, or exposure to threats can influence death rates.
The function is specified through a graph that translates the Density Ratio into a multiplicative factor applied to the Death Rate Actual. A value greater than 1 indicates increased mortality due to higher density, while a value below 1 indicates more favorable survival conditions.
📊 **Graph**:

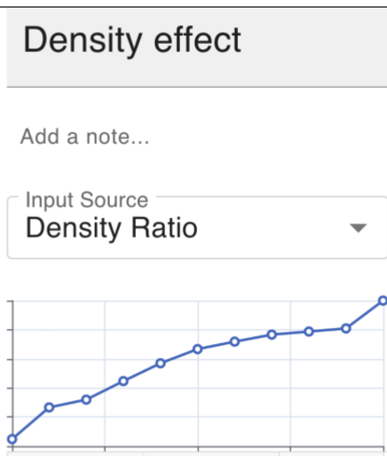


Figure 8: Nonlinear effect of population density on mammoth mortality rate.

Density ratio	Density effect
0	0.072
0.2	0.399
0.4	0.479
0.6	0.67
0.8	0.854
1	1
1.2	1.077
1.4	1.149
1.6	1.181
1.8	1.213
2	1.5

💡 **Note**:
This modular design supports future extensions to incorporate other density-dependent effects, such as carrying capacity, territory management, or ecological shifts.

Variable: Density Switch

Type: *State*
Unit: *Boolean (true/false)*
Sector: Population Dynamics
📝 Description:
The **Density Switch** is a *State*-type primitive that acts as a toggle to determine whether the effect of population density should be included in the calculation of the **Death Rate Actual** for mammoths. Its initial value is set to false, meaning that, by default, density effects are not considered, and mortality is calculated solely based on the baseline or normal death rate.

When the value is switched to true, the **Density Effect**—a nonlinear function—is activated. This function modulates the death rate depending on the ratio of the mammoth population to the available area, capturing ecological self-regulation dynamics such as overpopulation, environmental stress, or resource scarcity.

Activating this policy allows the model to simulate and compare scenarios with and without natural population regulation, enhancing its realism and supporting the analysis of habitat management interventions.

📌 Variable: Death Rate Actual

Unit: 1/Year
Sector: Population Dynamics
📝 **Description:**
Death Rate Actual represents the effective mortality rate in the model. Its base value is *Death Rate Normal*, but the formula includes a conditional mechanism using the boolean *Density Switch* to apply or ignore the effect of population density.
The formula is:

ifThenElse([Density Switch], [Death Rate Normal] * [Density effect], [Death Rate Normal])

- When *Density Switch* is **true**, a density-based adjustment (*Density effect*) modifies the mortality rate.
- When **false**, the rate remains constant at its normal value.

This structure allows the model to simulate more realistic ecological conditions, such as stress due to overcrowding or limited resources. It also prepares the variable to incorporate future effects like predation or food scarcity.

📌 Flow: Death Flow

Unit: Mammoths/Year
Sector: Population Dynamics
📝 **Description (ENGLISH):**
Death Flow represents the number of mammoths dying per year. It is calculated by multiplying the current population size (*Mammoth*) by the effective death rate (*Death Rate Actual*), which may include effects like density dependence or activated policy interventions.
Formula:

[Mammoth] * [Death Rate Actual]
This flow removes individuals from the population stock and allows the model to track how environmental or policy changes affect survival.

📌 Variable: Max Pop

Unit: Mammoths

Value: 165,000 mammoths
Sector: Population Dynamics
📝 Description:
Max Pop defines a fixed reference value to represent the upper limit of the mammoth population in model graphs. Its sole purpose is visual: it helps visually compare the current population size with a maximum theoretical threshold, facilitating the analysis of carrying capacity or potential growth.

📌 Variable: Min Pop

Unit: Mammoths
Sector: Population Dynamics
Value: 75,000 mammoths
📝 **Description:**
Min Pop represents a minimum reference value for display in the model's graphs. It acts as a visual lower bound in mammoth population charts, helping to identify significant drops relative to a theoretical or desired threshold.

Complete Mammoth Game Model

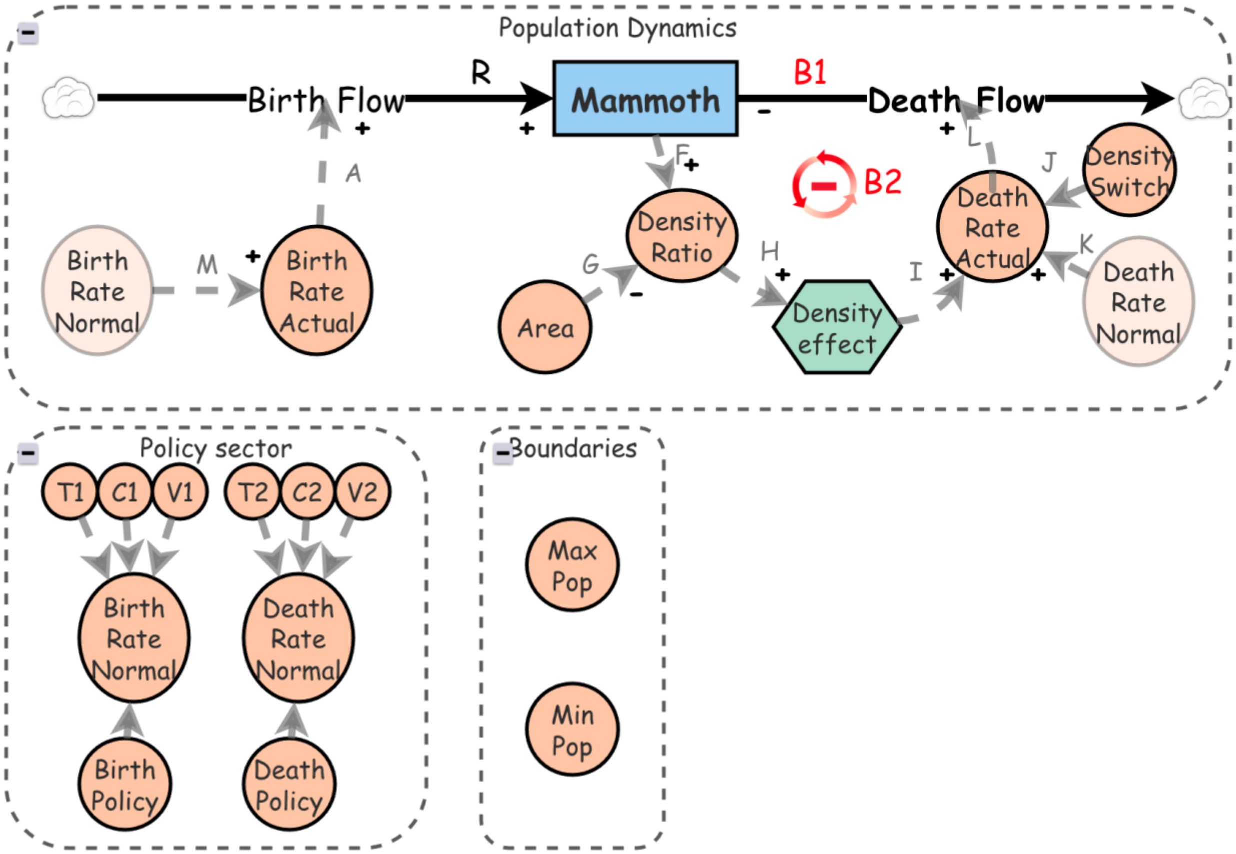


Figure 9: Full view of the complete model with components, links, and visual customization.

Model Results Section

General Introduction

This model includes three possible policies that can be activated to explore intervention scenarios affecting mammoth population dynamics:

- **Birth Policy**: increases the birth rate from a specific point in time.
- **Death Policy**: modifies the death rate (either increasing or decreasing it) from a specific point in time.
- **Density Switch**: enables a density-dependent mortality adjustment mechanism.

Each policy can be independently turned on or off, allowing exploration of their individual and combined effects. The following sections present different scenarios based on specific policy combinations.

Scenario 1: No Intervention — Steady State

Description:
In this scenario, none of the available policies are activated. That is, the simulation represents a natural, unmanaged environment where population dynamics depend solely on the default birth and death rates.

The outcome is a steady state: the mammoth population remains constant over time. This serves as a baseline for evaluating the impact of future policy-driven scenarios.

Figure 10: Baseline scenario: stable mammoth population dynamics without intervention.

Scenario 2 – *Birth Policy* Activation

In this scenario, only the policy called *Birth Policy* is activated. This intervention increases the normal birth rate by 40%, starting from year 5 of the simulation. Since the death rate remains unchanged and no density effects are applied, the result is exponential growth of the mammoth population.

This scenario shows how a favorable intervention—such as assisted reproduction, habitat enhancement, or active protection—can trigger a rapid growth dynamic if other system variables are not balanced.

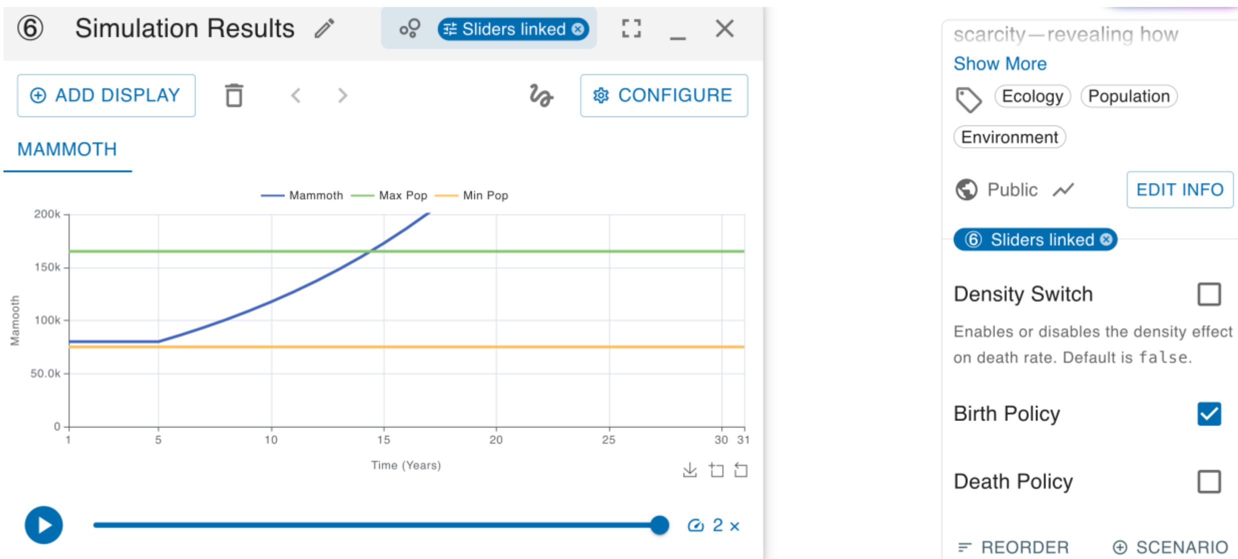


Figure 11: Chart for Scenario 2: Birth Policy activated, increasing the birth rate by 40%. Exponential growth of the mammoth population is observed.

Scenario 3 – Combined Activation of *Birth Policy* and *Density Switch*

In this scenario, two policies are activated simultaneously: *Birth Policy* and *Density Switch*. The first increases the birth rate by 40% starting in year 5, while the second enables the population density effect on the death rate.

At first, the mammoth population grows rapidly, as in the previous scenario. However, as density increases, a **balancing loop** kicks in: the density effect raises the death rate, gradually slowing down the exponential growth. Eventually, the population reaches a new equilibrium, stabilizing at a plateau without further intervention.

This emergent behavior is essential for understanding dynamics in other complex systems like businesses or ecosystems. What if a company grows rapidly, but factors like market saturation, resource depletion, or operational overload trigger a similar effect? Models like this help us anticipate and plan more wisely.

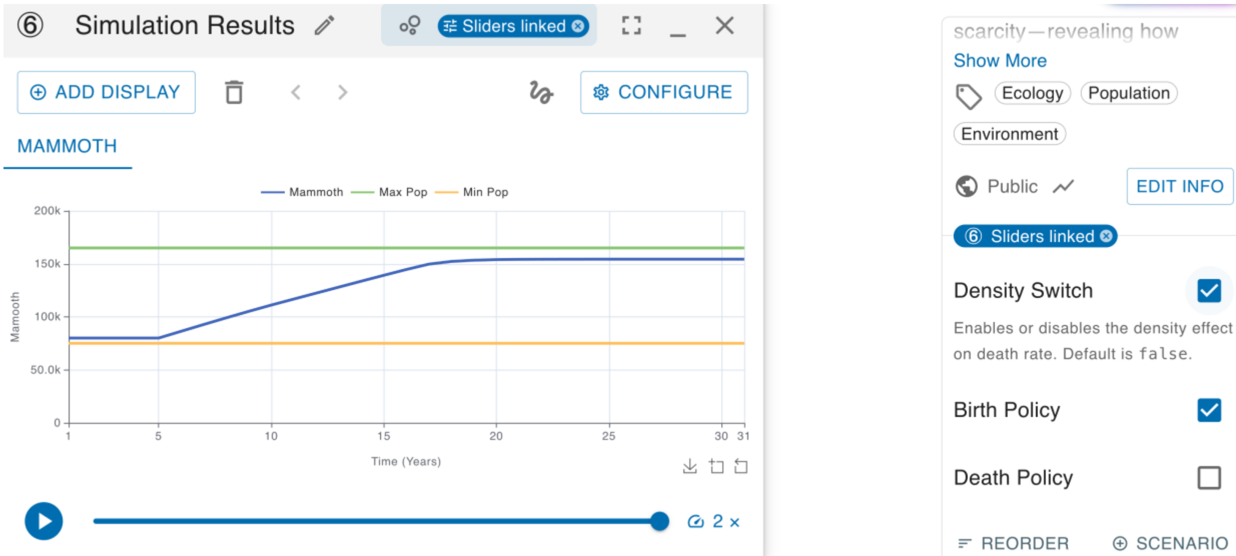


Figure 12: Chart for Scenario 3: Combined activation of Birth Policy and Density Switch. The density effect slows exponential growth and stabilizes the mammoth population.

📘 Scenario 4 – Full Activation: *Birth Policy*, *Density Switch*, and *Death Policy*

In this final scenario, all three policies are activated simultaneously:

- **Birth Policy** increases the birth rate by 40% starting in year 5.
- **Density Switch** enables the density effect, raising the death rate as population increases.
- **Death Policy** applies an additional increase to the death rate, also starting in year 5.

The result is an **almost complete halt in population growth**. Although the birth policy pushes for growth, the combined effects of density and the additional death policy strongly counterbalance that push. The population barely increases before stabilizing at a much lower equilibrium.

This scenario demonstrates how **multiple simultaneous interventions can lead to nonlinear and counterintuitive outcomes**. In business or public policy, applying too many corrective measures at once may prevent progress instead of promoting it.

Figure 13: Chart for Scenario 4: Full policy activation. Population growth is almost completely halted due to the combined effects of density and increased death rate.

General Reflection on the Scenarios

The four scenarios demonstrate how **management or public policies** can produce dramatically different outcomes depending on their design, timing, and combinations.

- In **Scenario 1**, with no interventions, the system remains **stable**, reaching a natural balance.
- In **Scenario 2**, activating only the birth policy leads to **exponential growth**, ignoring limits and long-term sustainability.
- In **Scenario 3**, the initial growth from the birth increase is curbed by **population density effects**, introducing a **balancing feedback loop** that stabilizes the system more realistically.
- Finally, **Scenario 4** shows how combining all policies can become **overly restrictive**, essentially halting population growth.

This analysis highlights a key lesson from systems thinking:

A system's behavior emerges from the structures, feedback loops, and policies within it.

Designing isolated interventions without accounting for their interactions can be just as risky as not acting at all. Instead, understanding **feedback dynamics** enables more effective and sustainable policy design.

Simulations like this provide a virtual lab to test the consequences of decisions before applying them in the real world. In fields like business, ecology, or public health, grasping systemic behavior can mean the difference between long-term success and unexpected collapse.

📌 What if we applied these lessons to our organizations or governments? How would our approach change if we saw systems as living networks, not linear machines?

Chart/Table Configuration

Charts in the simulation environment can be fully customized. Users can define axis scales (left and right), label them, set minimum and maximum limits, choose which variables to plot, and even change the chart type—such as time series, scatter plot, or others—depending on the nature of the analysis. This flexibility allows for a clearer interpretation of model dynamics under different policy scenarios.

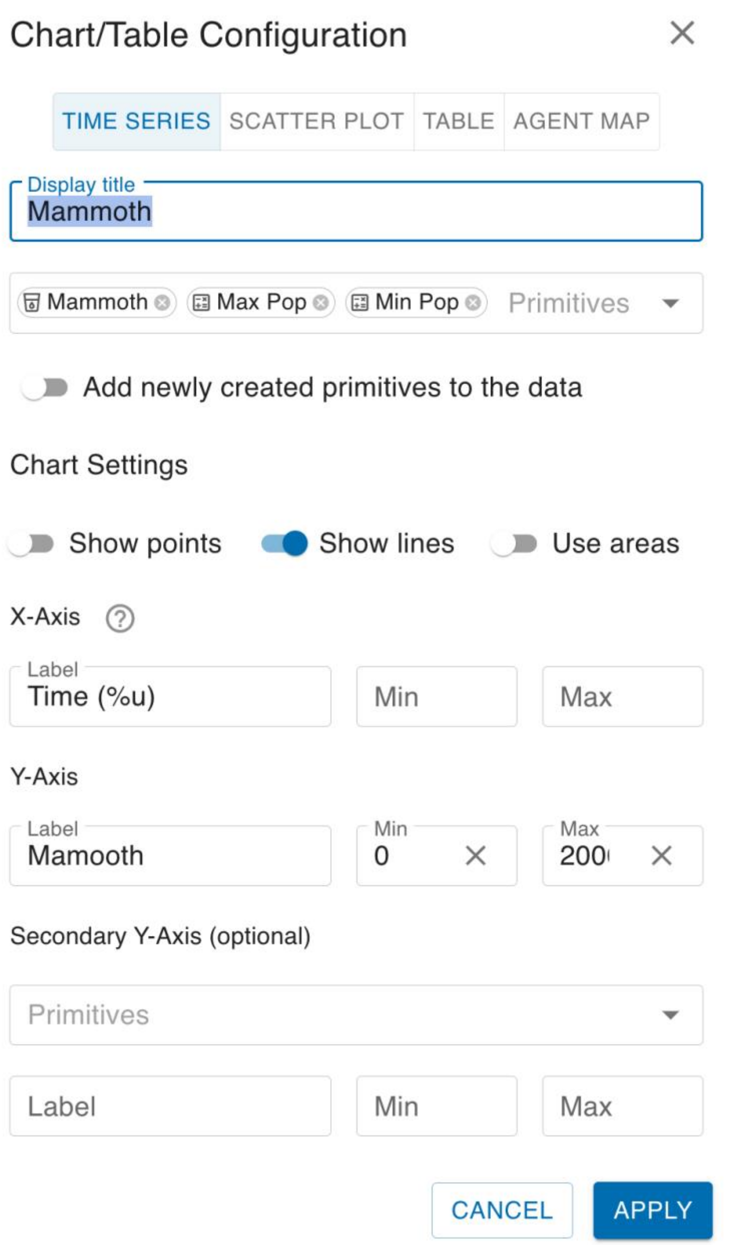
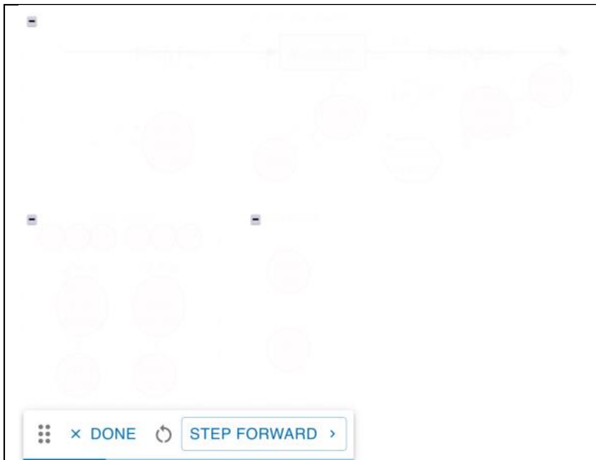
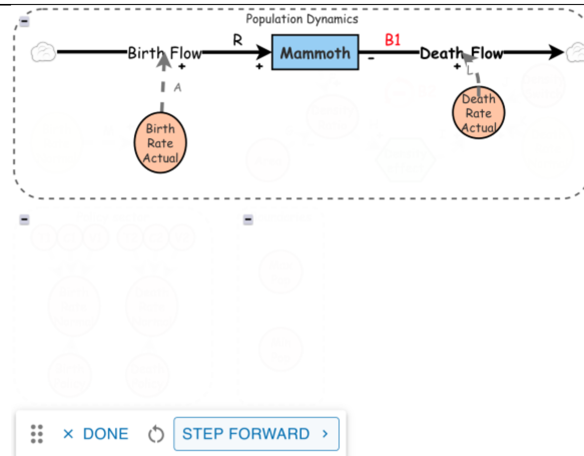
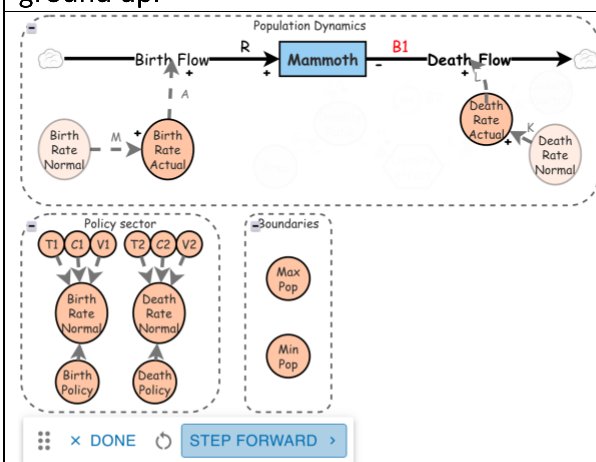
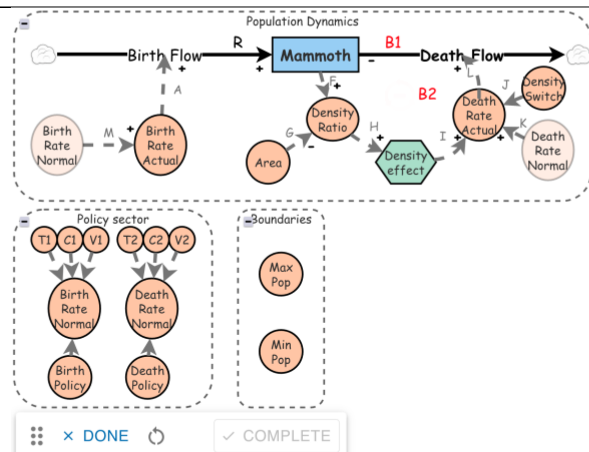


Figure 14: Custom chart settings to visualize population dynamics and policy effects over time.

🕮 Model Storytelling

This tour shows how policies—such as encouraging births or reducing deaths—interact with invisible structures like population density to define the fate of a species. The fictional mammoth rebirth reminds us that acting isn't enough: we must understand the structure. A lesson applicable to our organizations, communities, and governments.*Table 1: ▨ Complete storytelling in four steps — from mammoth stock to growth and control loops.*

 *Figure 15: : ▱ Step 1: "Clean Slate: The Starting Point"* We begin with a blank canvas, ready to build a story of population evolution from the ground up.	 *Figure 16: ▨ Step 2: "Basic Dynamics: Births, Deaths, and Population"* We model the core flows of change—birth and death shape the growth of the system.
 *Figure 17: ▱ Step 3: "Policies and Limits: The Power to Intervene"* We add policy decisions and boundaries to observe their influence on population dynamics.	 *Figure 18: ▨ Step 4: "Density Effect: The Hidden Feedback"* We integrate how population density regulates the system, unveiling the role of balancing feedback loops.

Conclusion

The model presented shows how the population dynamics of a species —in this case, the mammoth— can change drastically depending on the policies applied and their interaction with system structures such as density and environmental limits. From exponential growth to sustainable equilibrium or even complete stagnation, the different scenarios allow us to visualize the consequences of our decisions in complex systems.

💡 **Integrated Reflection:** In real life —whether in ecosystems, businesses, communities, or countries— policy decisions do not operate in a vacuum. It is their interaction with the structure of the system that determines their true impact. This model not only explains **what** happens, but also **why** it happens and **how** we might intervene more effectively.

By integrating systems thinking and dynamic simulation, we learn to look beyond symptoms and act on deeper causes. This approach is not only useful in ecology; it also sheds light on how to transform organizations, prevent crises, or design sustainable strategies. In an interdependent world, **understanding systems is not an option — it's a strategic necessity.**

References

The Mammoth Game:
The Shape of Change
The text of
Lesson 3: The Mammoth Game
From the books
The Shape of Change
and
The Shape of Change: Stocks and Flows
By Rob Quaden and Alan Ticotsky
With Debra Lyneis
Illustrated by Nathan Walker
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