BB512 - Instructor Resources

Owen R. Jones (Course Coordinator)

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This website and other course materials

This website contains resources for instructors in BB512.

We may not do ALL of these exercises, but you are welcome to do ones we miss in your own time.

Software

We will use Excel and R/RStudio during this course.

Excel

I expect you will already have Excel installed, so there is not much to say here.

Be aware that Excel differs depending on the language it is localised in. For example, Danish vs. English. This means that some of the commands might differ between version. See here for examples.

R and RStudio

R and RStudio are two separate pieces of software. RStudio is a user-friendly interface to talk to R, it cannot work if you have not got R installed. So, when you install these two programs, install R first, then RStudio.

Already have them installed? I strongly recommend to update to the latest versions of R, which you can download here and RStudio Desktop, which you can find here.

(PART) Evolution by Natural Selection

The Blind Watchmaker

Introduction

This exercise simulates evolutionary processes using an algorithm inspired by *The Blind Watchmaker*. Students will observe how random mutations and selection pressure shape the evolution of a target phrase from an initial random string. By altering parameters of selection and phrase length, students will explore the balance between randomness (mutation) and determinism (selection) in evolutionary processes. This exercise provides insight into natural selection and highlights the filtering nature of natural selection.

Key concepts

- **Random Mutation**: Each generation introduces random changes (mutations) in the string.
- **Selection Pressure**: When active, selection favours letters that match the target phrase, simulating the process of natural selection.
- **Stochasticity vs Determinism**: Evolution combines random mutations and deterministic selection, resulting in gradual adaptation toward a specific goal (in this case, a predefined phrase).

Learning outcomes

- Greater understanding of adaptive evolution via natural selection.
- Understanding that random change does NOT result in disorder, if paired with selection.
- Use of R for exploring biological phenomenon.

Activity Overview

Time: 30 minutes

1. **Introduction (5-10 min)**: Explain the activity, including the basic concepts of natural selection.

2. **Loading RStudio, Script setup (5 min)**: Students load RStudio, create a new script and paste the exercise script into it.
3. **Main Activity (15 min)**: Students may use their own phrase, they should use the script and then answer the questions.
4. **Discussion and Wrap-Up (5-10 min)**: Run through the questions and answers. Reflect on how the simulation demonstrates key concepts of selection, adaptation, and evolution.

Instructions for facilitating

Code Setup

1. **Preparation**: Ensure students have R and RStudio installed. If needed, provide assistance with installation or setting up the R environment.
2. **Running the Code**: Students open a new R script, paste the provided code, and save it.
    - Explain that the simulation uses random letter generation to mimic mutations, and selection fixes correct letters over time, just as beneficial traits are selected in nature.
3. **Modifying Parameters**: Have students edit parameters like `phrase`, `nGenerations`, and `selection`, observing the effects.

Key Observation

- When **selection is ON**, the phrase gradually becomes more similar to the target, showing how selection can direct random mutations toward a specific outcome.
- When **selection is OFF**, the output remains random, illustrating that random changes without selection do not lead to order or meaningful results.

Questions and model answers

Question 1: What happens if selection is turned OFF? - Without selection, mutations accumulate randomly without any guidance, resulting in no directional progress toward the target phrase.

Question 2: Does the number of generations affect whether the target phrase is reached? - Yes, more generations allow more opportunities for mutations and selection to work, increasing the chances of reaching the target phrase, but there is no absolute guarantee.

Question 3: Does the speed of reaching the target phrase depend on the length of the phrase? - Yes, longer phrases require more steps to match each letter, meaning the process takes more time and generations due to the greater complexity.

Question 4: How does this simulation differ from real natural selection? - Real natural selection is not driven by a specific goal. It is shaped by environmental pressures and the organisms' fitness relative to their surroundings, rather than aiming for a specific outcome like in this simulation.

Teaching Tips

1. **Clarify the Role of Selection**: Emphasise that selection drives the evolutionary process toward the target, while random mutations provide the variation necessary for evolution.
2. **R Programming Guidance**: Assist students in modifying parameters like mutation rate, number of generations, and selection to observe different outcomes.
3. **Link to Real Evolution**: Discuss how real-world evolution is more complex and involves multiple factors such as genetic drift, environmental changes, and does not have a predetermined goal like the target phrase.

Common Pitfalls to Watch For

- **Misunderstanding Selection**: Students might think that selection always chooses perfect sequences. Clarify that selection favours the closest match, not necessarily perfection.
- **R Script Issues**: Ensure students accurately modify the code to adjust parameters like the mutation rate and number of generations.
- **Misinterpretation of the Target Concept**: Make sure students understand that real natural selection does not work toward a fixed outcome like in this simulation.

Bug Hunt Camouflage (NetLogo)

Introduction

This exercise demonstrates adaptive evolution and natural selection using a predator-prey simulation in NetLogo. Students take on the role of a predator (a bird) and hunt bugs to observe how the bug population evolves in response to selective pressures. The key concept is the relationship between camouflage and predator efficiency, mirroring real-world natural selection.

Key Concepts

- **Natural Selection**: The process where individuals with traits better suited to the environment survive and reproduce, passing those traits to the next generation.
- **Adaptive Evolution**: Changes in populations over time that enhance survival and reproduction in a given environment.
- **Selection Pressure**: The environmental factors that influence which individuals survive and reproduce.
- **Heritability**: A measure of the fraction of phenotype that can be attributed to genetic variation.

Learning Outcomes

- Understanding adaptive evolution via natural selection.
- Understanding how fitness depends on the environment.
- Understanding the terms adaptation, selection, selection pressure, heritability.

Activity Overview

Time: 45 minutes

1. **Introduction (5 min)**: Explain the activity, including the basic concepts of natural selection and camouflage.
2. **Simulation Setup (5-10 min)**: Students log into NetLogo and load the Bug Hunt Camouflage model.
3. **Main Activity (25 min)**: Students play the role of a predator, hunting bugs and observing how the bug population evolves over time. Students pause and analyse the graphs to assess hunting efficiency and bug color evolution.
4. **Discussion and Wrap-Up (5-10 min)**: Reflect on how the simulation demonstrates key concepts of selection, adaptation, and evolution.

Instructions for Facilitating

Simulation Setup

1. Guide students to open NetLogo and find the “Bug Hunt Camouflage” model.
    - **Tip**: If using UCloud, ensure students are familiar with the platform steps outlined in the task description.
2. Explain the interface: sliders control population and mutation rates, while the graphs provide real-time feedback on bug traits and hunting efficiency.

Running the Simulation

- Students begin by adjusting the population sise to 30 bugs using the “carrying-capacity” slider.
- Students click “set up”, then start the simulation with “Go”. They then hunt bugs by clicking on them. Encourage them to hunt quickly to avoid bias in their selection process.
- Students observe how their hunting impacts the bug population, paying attention to changes in color traits (hue, saturation, brightness) and hunting efficiency (the slope of the graph showing number of bugs caught) over time.
- After 5 minutes of hunting, students should pause the simulation and examine the graphs.
    1. **Bugs Caught vs. Time**: Steep slopes indicate high hunting efficiency.
    2. **Color Distribution**: This will show the shift in color traits due to selective pressures from hunting.
- Encourage students to reflect on how the bug population becomes better adapted to their environment over successive generations.

- After about 10 minutes, get them to pause (by pressing “Go”) and change the background picture.

Questions & Model Answers

1. What happens to the average color of the bug population with time as you hunt?
Over time, the average color of the bug population tends to shift towards colors that blend in better with the environment. As you hunt, bugs with less effective camouflage are caught more easily, while those that are harder to spot survive and pass on their traits to their offspring. This results in a gradual change in the population’s average color.

2. What happens to your hunting efficiency?
Initially, hunting efficiency is high, as the bugs are easy to spot. However, as the population evolves and the bugs’ colors become better camouflaged with the environment, hunting efficiency decreases. This reflects natural selection, where better-adapted individuals (bugs) are harder to catch.

3. Would you say that the bug population becomes worse or better adapted to their environment?
The bug population becomes better adapted to their environment. As selective pressure is applied (through predation), bugs with colors that offer better camouflage survive and reproduce, increasing the frequency of these adaptive traits in the population.

4. Can you explain how this happens?
This is a result of natural selection. Bugs with colors that provide better camouflage have a higher chance of survival because they are harder to detect by predators. These surviving bugs reproduce, passing on their coloration traits to their offspring. Over generations, the population’s coloration shifts to match the environment better, increasing the population’s overall fitness in that habitat.

5. After simulating in one environment (e.g. poppy field) for a few minutes, pause then switch to another environment. Are the bugs now well- or poorly-adapted to their new environment?
When the environment is changed, the bugs are usually poorly adapted to the new environment initially. The traits that made them well-camouflaged in the previous environment may now stand out, making them more visible to predators. This change highlights the importance of the environment in determining what traits are beneficial for survival.

6. Do the genotypes of individuals change (e.g., with individual age)?
No, the genotypes of individual bugs do not change as they age. The genotypes are fixed at birth and are inherited from their parents. However, the population’s genotype distribution can change over time due to natural selection favoring certain traits (such as better camouflage) and through mutations in the offspring.

7. Increasing the “max-mutation-step” makes bug offspring less like their parents. How do you think this will influence the speed of adaptation of the bugs?

Increasing the mutation step introduces greater genetic variability into the population. This can speed up adaptation by providing more opportunities for new beneficial traits to arise. However, it can also produce non-adaptive traits that may decrease the fitness of individuals. The overall effect on adaptation speed will depend on how many of the mutations are beneficial in the given environment.

Teaching Tips

- **Concept Reinforcement**: Frequently remind students of the evolutionary principles at play. Point out how the simulation reflects real-world dynamics, such as how organisms evolve to evade predators or increase predation efficiency.
- **Model Flexibility**: Depending on student progress, you may encourage them to modify other sliders (e.g., mutation rate) to explore more complex evolutionary dynamics.
- **Connecting Theory to Simulation**: Help students relate their observations in the simulation to theoretical principles, such as the definition of evolution as "change in heritable traits over generations."

Common Pitfalls

- **Misinterpreting Graphs**: Students may struggle to understand the relationship between color changes and hunting efficiency. Emphasise that selection pressure favors bugs that are harder to see, and this trait is passed on to future generations.
- **Technical Issues with NetLogo**: Ensure students are comfortable with the UCloud setup or have downloaded NetLogo in advance.

Additional Resources

- Read more about the model here: NetLogo Bug Hunt Camouflage.

(PART) Population Growth Models

Geometric growth

Introduction

This exercise explores the geometric growth model in discrete time steps, focusing on how different values of λ affect population dynamics. It aims to develop students' understanding of growth models, the effects of log transformations, and the limitations of simple models.

Key Concepts

- Geometric growth assumes constant λ, leading to exponential growth or decline.
- Plotting log-transformed population sizes allows easier visualisation of trends.
- Limitations of the model include the assumption of infinite resources and lack of environmental constraints.

Learning outcomes

- Competence in using Excel formulae for mathematical modeling.
- Understanding the the parameters of exponential/geometric growth.
- Competence in using mathematical models in Excel to strengthen own understanding of biological processes.
- Awareness of rearranging of mathematical formulae to produce different forms of models.
- Knowing that the slope of the $ln(N_t)$ vs. t relationship can tell you about population growth rate (it is $ln(\lambda)$).

Activity Overview

Time: 40-45 minutes

1. **Introduction (5 min)**: Explain the activity, including the basic concepts of geometric growth

2. **Main Activity (25 min)**: Students complete the Excel sheet and answer the questions provided.
3. **Discussion and Wrap-Up (5-10 min)**: Run throught the questions and discuss answers.

Instructions for Facilitating

Excel Setup

1. **Download File**: Ensure students have downloaded the provided Excel file `GeometricGrowth.xlsx`.
2. **Initial Setup**:
   - Start with an initial population size (N_0) of 10 and a growth rate (λ) of 1.1.
   - Use Excel formulas to calculate population size at each time step from $t = 1$ to $t = 20$.
   - Example formula: `=B8*$F$8`, where `B8` is the population at time `t` and `$F$8` is the growth rate λ.
3. **Creating Charts**:
   - Plot the population size against time using an x-y scatterplot.
   - Create a second plot using the natural logarithm of population size (`LN()`) on the y-axis.

Key Observations

- **Plot Comparison**: The linear plot will show exponential (curved) growth, while the log-transformed plot should display a straight line, where the slope represents $ln(\lambda)$.
- **Altering λ**: As students experiment with different values for λ (e.g., 0.8, 1, 1.2), they will observe changes in the steepness of the population growth curve. A λ of 1 results in no population growth, while λ values below 1 indicate population decline.
- **Trendline Slope**: Adding a trendline to the log-transformed graph and determining its slope will give $ln(\lambda)$. Students can use this slope to compute λ using the Excel function `EXP()`.

Geometric Series Calculation

- **Geometric Series Formula**: Introduce students to the geometric series formula, $N_t = N_0\lambda^t$. This formula provides a shortcut to calculate population size at any given time without stepping through each time point manually.
- **Application**: Use this formula to calculate population size for $t = 5$ and compare it to earlier manual calculations. Then extend it to predict population size after a large number of generations (e.g., $t = 900$).

- **Where does that equation come from?**

As a starting point, consider this equation: $N_{t+1} = \lambda N_t$.

If we want to calculate N_{t+2}, we would need to plug in N_{t+1} instead of N_t: $N_{t+2} = \lambda N_{t+1}$,

and, since we know that $N_{t+1} = \lambda N_t$,: $N_{t+2} = \lambda\lambda N_t$.

Similarly, if we wanted to calculate N_{t+2}, we'd end up with: $N_{t+3} = \lambda\lambda\lambda N_t$.

This can be simplified by raising λ to a suitable power, and using the starting population at time = 0, N_0:

eqn. 9. $N_t = \lambda^t N_0$.

This should be familiar to those of you that did (or remember!) the concept of geometric series which you have likely covered in earlier maths classes.

Questions & Model Answers

1. How does the population size change with time for different values of λ?

The growth rate λ drives the population's exponential increase or decrease.

- For $\lambda > 1$, the population size increases exponentially.
- For $\lambda = 1$, the population size remains constant.
- For $\lambda < 1$, the population size decreases exponentially.

2. Why is it useful to plot log-transformed population size?

Log-transformations linearise exponential relationships. Therefore, the transformation converts the exponential growth trajectory into a straight line allowing for easier interpretation of the growth rate, as the slope corresponds to $\log(\lambda)$. You can get the λ value by taking the exponential of $\log(\lambda)$ (in Excel `=EXP()`).

3. What are the limitations of the geometric growth model? - The model assumes infinite resources, no competition, or environmental constraints, making it unrealistic for real-world populations. Real-world populations face density-dependent factors and environmental stochasticity, which the geometric model does not account for.

4. What would happen if we introduced a carrying capacity to this model? - The population would follow a logistic growth model, where growth slows as the population nears the carrying capacity.

Teaching Tips:

- **Reinforce Mathematical Understanding**: Emphasize how rearranging and transforming formulas, such as logarithmic transformations, are useful tools for interpreting population growth models.

- **Visual Learning**: Encourage students to compare the linear and log-transformed plots side by side to see how exponential growth behaves differently in each case.
- **Connect to Ecology**: When discussing real-world applications, introduce concepts like carrying capacity and logistic growth to contrast with geometric growth. -. **Model limitations**: Engage students in discussions about how the model could be adapted to account for real-world variables like environmental factors or density dependence.

Additional Resources

- **Excel Tutorial**: If students are unfamiliar with Excel's log transformation and trendline features, provide a walkthrough. They should use natural log (`=LN`).

Estimating Population Growth Rate

Introduction

This exercise allows students to work with real population data to estimate the population growth rate (λ) by applying log transformation and linear regression in Excel. It reinforces concepts of geometric growth, exponential growth, and practical skills in data analysis using Excel. Students will learn how to interpret log-transformed data, calculate the growth rate, and understand model assumptions and real-world factors that may affect population growth.

Key Concepts

- **Exponential Growth**: Populations grow by a constant rate (λ) each time step, leading to exponential growth. Log-transforming the data linearizes this relationship.
- **Log Transformation**: Applying $\log_e$ to population size makes it possible to fit a linear model to exponential growth data. The slope of this line gives $\log(\lambda)$, and exponentiating this value yields λ, the population growth rate.
- **Limitations of the Model**: The exercise uses a geometric growth model, which assumes a constant growth rate. Real-world populations often deviate from this due to environmental variability, competition, and other factors.

Learning outcomes

- Competence in using Excel formulae for data transformation and regression analysis.
- Understanding the role of λ in population growth and its estimation through log-transformed data.
- Competence in applying mathematical models in Excel to analyse real biological data.

- Awareness of how log transformations can linearise exponential growth data for easier interpretation.
- Knowing that the slope of the $ln(N)$ vs. time relationship represents $ln(\lambda)$ and can be used to estimate population growth rate.

Activity Overview

Time: 20 minutes

- 1-2 minutes: Introduce the exercise
- 2-3 minutes: Students read the exercise introduction and instructions.
- 10 minutes: Students do the exercise. Check on them as you walk around the class.
- 5 minutes: Wrap up and go through answers to questions.

Instructions for Facilitating

Step 1: Download and Open the Data

1. Ensure students download the provided Excel file `EstimatingGrowth.xlsx`.
2. Once students open the file, explain that the dataset contains population sizes recorded annually over 25 years.

Step 2: Plot the Population Size Over Time

- In Excel, have students create an x-y scatter plot of **population size** N_t against **time** (Year).
- Ensure students correctly label the axes and choose an appropriate chart type.

Step 3: Log-Transform the Population Size

1. Guide students to create a new column for the **natural logarithm** of the population size by using the Excel formula `=LN(cell)` where `cell` refers to the population size at a specific time step.
2. Students should then create a second scatter plot using the **log-transformed population size** on the y-axis and **time** on the x-axis.

Step 4: Fit a Linear Regression Model

1. In the log-transformed scatter plot, students will add a **linear trendline**.
    - Right-click on the data points and select “Add Trendline.”
    - Choose “Linear” and check the box for “Display Equation on Chart.”
2. Explain that the **slope** of the trendline represents $\log(\lambda)$.

Step 5: Calculate λ

- Once students have the slope from the trendline, they will calculate λ using the formula $\lambda = e^{\text{slope}}$, which can be done in Excel with the formula `=EXP(cell)`.

Questions & Model Answers

1. Interpret the Plot: What does the log-transformed plot of population size over time tell you about the population's growth trend? Does the population appear to grow exponentially?

- The log-transformed plot should show a straight line if the population is growing exponentially, because the natural logarithm of an exponentially growing population will linearize the exponential curve. A positively sloped line indicates growth, a flat line suggests stability, and a negatively sloped line indicates population decline.

Estimate Growth Rate: What is the estimated population growth rate (λ) based on your linear regression analysis?

- The slope of the regression line from the log-transformed plot corresponds to $\log(\lambda)$. To find λ, students one can exponentiate the slope: $\lambda = e^{\text{slope}}$.
- Example: If the slope of the regression line is 0.086, then $\lambda = e^{0.086} \approx 1.09$, meaning the population grows by approximately 9% per year.

Model Assumptions: What assumptions does this model make about population growth? Discuss any potential real-world factors that might affect the accuracy of your estimate for λ.

- The model assumes that population growth follows a constant rate (λ) over time, without any external influences such as migration, resource limitations, or environmental changes. In the real world, population growth rates can fluctuate due to factors such as weather, food availability, disease, or human intervention.
- Other factors, like density dependence (competition for resources), may also affect the accuracy of the model. The geometric model does not account for a carrying capacity, which limits population growth in real ecosystems.

Teaching Tips:

1. **Ensure Students Understand Log Transformations**: Emphasize why log transformation linearises the exponential growth model, making it easier to interpret the population's growth trend. A short explanation of the mathematics behind this is helpful. Explain that exponential

growth is linear in log space because $\log(N_t) = \log(N_0) + t\log(\lambda)$, which is analagous to the standard equation for a straight line $y = ax \times b$.

2. **Excel Skills**: Ensure students know how to use Excel for log transformations (`LN` function), plot data, add trendlines, and display the regression equation on their charts. Consider providing a walkthrough if they are not familiar with Excel's plotting tools.

3. **Discuss Model Assumptions**: Encourage students to critically think about the assumptions behind geometric growth models. A good discussion could involve real-world examples where the assumptions break down, such as predator-prey dynamics, food shortages, or disease outbreaks.

4. **Data Quality and Measurement Error**: Highlight how measurement error or random fluctuations can influence data analysis. If measurement noise was introduced in the exercise, this can be a good opportunity to discuss the impact of imperfect data on the accuracy of the estimated growth rate.

5. **Comparing to Year-over-Year Estimates**: Have students compare the growth rate they estimate from the regression model to a simple year-over-year ratio estimate of population growth. Discuss why these values might differ, particularly in the presence of noise or irregularities in the data.

Common Pitfalls

- **Confusion with Log Transformation**: Students may not understand why log transformation creates a straight line from exponential data.
- **Exponentiating the Slope**: Remind students that the slope of the regression line represents $\log(\lambda)$, and they need to calculate $\lambda = e^{\text{slope}}$ to find the actual growth rate.
- **Interpreting λ**: Make sure students understand that $\lambda > 1$ indicates growth, $\lambda = 1$ indicates a stable population, and $\lambda < 1$ indicates population decline.

Stochastic population growth

Introduction

This exercise introduces students to the stochastic version of population growth models, focusing on how randomness and variability can influence population dynamics over time. By working with both Excel and R, students will explore the differences between deterministic and stochastic population models, specifically applying them to geometric (discrete) growth models. The exercise allows students to build skills in mathematical modeling, data analysis, and stochastic simulation, all of which are essential for understanding real-world ecological systems and predicting population trajectories under uncertainty.

Key Concepts

- **Deterministic vs. Stochastic Models:**
  Deterministic models assume a fixed growth rate, while stochastic models incorporate randomness, leading to more realistic projections.

- **Geometric Growth Model:**
  The model is expressed as $N_{t+1} = \lambda N_t$, where $\lambda = e^{r_m}$ and $r_m = \ln(\lambda)$. It is used to predict population size in the next generation.

- **Stochasticity:**
  Variability in growth rates, often modeled by drawing random values from a normal distribution for r_m. This randomness reflects environmental fluctuations and individual-level variation.

- **Extinction Risk:**
  As stochasticity increases, populations are more likely to decline or go extinct. Extinction risk depends on factors such as variance in r_m, initial population size, and mean growth rate.

Learning Outcomes

- Understand and apply stochastic models to population dynamics.
- Build competence in using Excel for mathematical modeling and simulations.
- Grasp the relationship between stochasticity, extinction risk, and environmental variability.
- Use R to simulate population growth and estimate extinction risk.

Activity Overview

Suggested Timings:

- **5 minutes:** Introduce the concept of stochastic population growth.
- **5 minutes:** Students read through the background and instructions.
- **20 minutes:** Students work on Excel-based deterministic and stochastic population growth modeling. Students with R experience may also explore stochastic simulations using R.
- **10 minutes:** Wrap up discussion and review key takeaways.

Instructions for Facilitating

1. **Introduction:**
   Briefly explain the difference between deterministic and stochastic models, focusing on why stochasticity is more reflective of real-world populations. Emphasize how the exercise will involve building models in Excel (and optionally R).

2. **Excel Modeling:**
   Guide students through calculating deterministic population growth first, then introduce stochastic variation in growth rates by using the provided formula [English Excel: `=NORMINV(RAND(),$F$10,SQRT($F$11))`/ Danish Excel: `=NORMINV(SLUMP();$F$10;KVROD($F$11))`. If you get errors, check whether Excel is expecting commas or semi-colons].

3. **R Simulation:**
   For the R component, ensure students understand the basic structure of the code and how the simulation works. Encourage them to modify parameters like `mean.r` and `var.r` to observe different outcomes.

4. **Discussion:**
   Facilitate a discussion on extinction risk, the impact of variability, and how different levels of stochasticity affect population trajectories.

Questions & Model Answers

1. What is the main difference between deterministic and stochastic population growth models? - Deterministic models use fixed growth rates, while stochastic models incorporate random variability, making them more realistic for representing natural populations.

2. Describe how incorporating randomness into the stochastic model makes it more realistic for understanding real-world populations. - Real-world populations face unpredictable environmental conditions and other factors that influence growth. Stochastic models account for these fluctuations, better mimicking actual population dynamics.

3. Simulate a scenario where two populations with identical growth rates experience different outcomes due to stochastic factors. Explain the implications of these findings. - Due to randomness, populations with the same initial conditions can diverge significantly over time. This demonstrates how chance events can lead to different outcomes, including extinction for one population and growth for another.

4. What can this stochastic model tell us about extinction risk and population size? - Smaller populations are more vulnerable to extinction in stochastic models because random negative growth events can have a greater impact.

5. What can this stochastic model tell us about extinction risk and environmental variation? - As environmental variability (represented by increased stochasticity) increases, populations face a higher risk of extinction due to more frequent poor years.

Teaching Tips

- **Stochasticity:**
  Ensure students understand that stochasticity represents environmental and biological variability. Highlight how the normal distribution used to model r_m generates different growth rates across generations.
- **Excel Formulae:**
  Some students may struggle with Excel formula syntax, particularly in different language settings. Double-check that students are using the correct formula (e.g., commas vs. semicolons).
- **R Simulations:**
  Not all students may be familiar with R, so you may need to provide extra guidance on running the simulations and interpreting results.
- **Comparing Models:**
  Emphasize the importance of comparing deterministic and stochastic models using visual charts. This comparison helps students see how randomness impacts long-term population trends.

Common Pitfalls

- **Formula Errors in Excel:**
  Ensure students understand how to use the Excel function to generate stochastic r_m values. Remind them that Excel might expect different delimiters (commas or semicolons).

- **Misinterpreting Stochasticity:**
  Students may confuse the effects of stochasticity with systematic trends. Clarify that stochasticity introduces random fluctuations that are just as likely to be negative as positive, not directional trends.

- **R Familiarity:**
  If students are unfamiliar with R, they may find the simulation code challenging. Ensure they don't modify critical parts of the script unnecessarily.

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Basic logistic population growth

Introduction

This exercise allows students to explore the logistic population growth model by manipulating parameters in an Excel spreadsheet and analyzing the resulting population dynamics. Students will apply the model to observe how population growth behaves under different conditions, deepening their understanding of ecological processes such as carrying capacity, population regulation, and deterministic chaos. The exercise will strengthen their ability to use Excel for modeling and analysis, while also helping them to grasp the mathematical principles behind population ecology and biological conservation.

Key Concepts

The exercise involves the following key concepts:

- **Logistic Growth Model**: A population growth model that accounts for environmental limitations, leading to a stabilization at the carrying capacity (K).
- **Carrying Capacity (K)**: The maximum population size that an environment can support long-term, based on resources and other limiting factors.
- **Intrinsic Rate of Increase (r_m)**: The maximum per capita growth rate under ideal conditions, which determines how fast a population grows.
- **Deterministic Chaos**: A concept where slight changes in initial conditions can lead to drastically different outcomes, making long-term predictions challenging.

Mathematically, the logistic growth equation is given by:

$$N_{t+1} = N_t + r_m N_t \left(1 - \frac{N_t}{K}\right)$$

This equation shows that as population size approaches the carrying capacity, the growth rate decreases until the population stabilizes at K.

Learning Outcomes

Students will achieve the following learning outcomes:

- Increased competence in using Excel for mathematical modeling of biological processes.
- Understanding the parameters of the logistic population growth model, particularly how r_m and K affect population dynamics.
- Ability to explain how population dynamics vary with changes in the population growth rate, from stable to chaotic dynamics.
- Understanding the concept of deterministic chaos and its difference from randomness.
- Practical experience using mathematical models in ecology and conservation.

Activity Overview

Suggested timings: - **5 minutes**: Introduce the exercise and demonstrate how to use the Excel spreadsheet. - **5 minutes**: Students familiarize themselves with the Excel sheet and instructions. - **20-30 minutes**: Students complete the exercise by experimenting with different parameter values and analyzing the graphs. - **5 minutes**: Wrap up by discussing the key findings and concepts.

Instructions for Facilitating

1. Begin by introducing the logistic growth model and its relevance in ecology.
2. Walk students through the Excel spreadsheet, highlighting the areas they will interact with (the pink block) and the three graphs.
3. Encourage students to change the initial population size, growth rate (r_m), and carrying capacity (K) and observe the results on the graphs.
4. Ask students to predict outcomes before modifying parameters, fostering engagement with the model's underlying logic.
5. Guide students through the additional questions to reinforce theoretical understanding.

Questions & Model Answers

Students will answer the following questions:

1. **What is the maximum population size?**
    - Focus on comparing the maximum population size with the carrying capacity (K). Students should observe that when r_m is around 1 or lower, the maximum population size matches K. For higher values of r_m the population size can overshoot carrying capacity.

2. **What do you predict will happen if you increase K to 300?**
    - The population will adjust, and the new maximum population size will equal the increased K.
3. **What happens if you reduce r_m to 0.4?**
    - The time to reach the maximum population size will increase, as a lower growth rate slows down the population's approach to K.
4. **What happens if you set r_m to 1.8?**
    - The population will overshoot K and oscillate around it with damped oscillations. The dynamics will show a period of fluctuation before stabilizing.
5. **What do you observe when you set r_m to 2.8 or higher?**
    - The population will display chaotic dynamics, with irregular fluctuations around K. The system becomes harder to predict as r_m increases beyond 2.57.

Teaching Tips

- **Clarify the Concept of Carrying Capacity (K)**: Students may confuse carrying capacity with a fixed limit on growth rather than an equilibrium point.
- **Demonstrate the Importance of r_m**: Encourage students to try different values of r_m to understand the transition from stable growth to chaotic behavior.
- **Excel Skills**: Some students may need assistance with basic Excel functions, particularly using formulas and interpreting graph outputs.
- **Connect to Real-World Applications**: Relate the logistic model to real-world population management scenarios, such as pest control or endangered species conservation.

Common Pitfalls

- **Misunderstanding Population Oscillations**: Students may assume that overshooting K means the model is broken. Explain that oscillations are a natural result of high growth rates and density dependence.
- **Confusion Between Chaos and Randomness**: Students might think chaotic dynamics are purely random. Emphasize that chaotic systems are deterministic but highly sensitive to initial conditions.
- **Excel Formula Errors**: Watch for common Excel mistakes, such as incorrect cell references when entering formulas in the pink block.

Concrete Real-World Examples

1. Pest Control (e.g., Locusts)

- **Scenario**: Locusts have a high growth rate and can quickly overrun an area during favorable conditions.
- **Logistic Model**: Locusts overshoot the carrying capacity, leading to resource depletion and population crashes. The model helps predict outbreaks and plan timely interventions.

2. Endangered Species Conservation (e.g., California Condor)

- **Scenario**: Conservation efforts focus on increasing populations without exceeding K.
- **Logistic Model**: The model helps determine sustainable population levels, ensuring growth without resource depletion.

3. Fisheries Management (e.g., Atlantic Cod)

- **Scenario**: Overfishing can drive populations below the sustainable level.
- **Logistic Model**: Managers use the model to balance fish harvest with population growth, ensuring long-term viability.

4. Invasive Species Management (e.g., Cane Toads in Australia)

- **Scenario**: Cane toads expand rapidly without natural predators, surpassing K and impacting ecosystems.
- **Logistic Model**: Predicts rapid expansion and highlights the need for quick control measures to manage invasive populations.

By using these real-world examples, students can see how the logistic growth model is a practical tool for predicting and managing population dynamics in various environmental and conservation contexts.

Deeper into logistic growth

This exercise helps students dive deeper into understanding the relationship between exponential (or geometric) and logistic growth models and how mathematical models can be explored from different perspectives. By experimenting with the Excel worksheet, students will observe how the logistic growth model can be modified and visualized in various ways. The exercise is designed to strengthen students' competence in using Excel for mathematical modeling and to enhance their understanding of population dynamics.

Key Concepts

This exercise covers the following key concepts:

- **Exponential Growth Model**: A simple population growth model where the population grows continuously without any limiting factors.
- **Logistic Growth Model**: A model that accounts for environmental constraints, introducing a carrying capacity (K) that limits population growth.
- **Carrying Capacity (K)**: The maximum population size that an environment can sustain long-term.
- **Intrinsic Rate of Increase (r_m)**: The maximum per capita population growth rate under ideal conditions.
- **Time Lag in Population Growth**: A delay in how population size at a previous time step influences current growth dynamics, which can lead to cyclic behavior.
- **Per Capita Growth Rate (r)**: The rate of population growth per individual as a function of population size.

Mathematically, the logistic growth equation is:

$$\frac{\delta N}{\delta t} = r_m N \left(1 - \frac{N}{K}\right)$$

If K is set to infinity, the logistic model reduces to the exponential growth model:

$$\frac{\delta N}{\delta t} = r_m N$$

Learning Outcomes

- Increased competence in using Excel formulae for mathematical modeling.
- Understanding the relationship between exponential and logistic growth models.
- Ability to modify mathematical models to explore different phenomena, such as time lags.
- Understanding how and why model outputs can be explored from different perspectives.
- Practical skills in using Excel to strengthen their understanding of biological processes, specifically population dynamics.

Activity Overview

Suggested timings:

- **5 minutes**: Introduce the exercise and explain the relationship between exponential and logistic growth models.
- **10 minutes**: Students explore different views of the logistic growth model in Excel.
- **20-30 minutes**: Students experiment with r_m, K, and the time lag in the Excel worksheet to observe changes in the population dynamics.
- **5 minutes**: Wrap up by discussing how exponential growth differs from logistic growth and how time lags affect population dynamics.

Instructions for Facilitating

1. Start by explaining the connection between exponential and logistic growth models, using the example of K approaching infinity to show how the logistic model reduces to the geometric growth equation.
2. Walk students through the Excel worksheet, particularly focusing on the `BasicLogistic` tab where they can manipulate r_m and K values.
3. Guide students through the analysis of **Figure 1** (population size over time), **Figure 2** (per capita growth rate vs. population size), and **Figure 3** (population growth rate vs. population size).
4. Encourage students to predict population dynamics as they adjust parameters, such as r_m and K.
5. Introduce the concept of time lags and direct students to the `TimeLag` tab to observe how introducing a delay in population feedback influences the system's dynamics.

Questions & Model Answers

Students will answer the following questions:

1. **What dynamics do you observe in Figure 1 as you change r_m?**
   - With small r_m values, the population grows smoothly and stabilizes at K. As r_m increases, the system shows oscillations, damped oscillations, and eventually chaotic or unpredictable behavior.
2. **What do you notice about the intercepts in Figure 2?**
   - The intercept on the x-axis occurs at K, while the intercept on the y-axis depends on r_m. As K and r_m change, the shape of the graph shifts, indicating changes in how population size affects per capita growth rate.
3. **How does adding a time lag affect the population dynamics?**
   - Adding a time lag can introduce cycling into the system, even when the intrinsic growth rate (r_m) is small. This shows that delayed responses in population feedback can lead to fluctuations in population size, despite stable conditions.
4. **How do the figures for exponential growth differ from those for logistic growth?**
   - For exponential growth, population size increases without any upper limit in Figure 1, the per capita growth rate remains constant in Figure 2, and the population growth rate rises continuously with population size in Figure 3. In contrast, logistic growth levels off as the population approaches K.

Teaching Tips

- **Clarify the Relationship Between Exponential and Logistic Growth**: Make sure students understand how the logistic model becomes the exponential model when K is removed (i.e. when it is infinity).
- **Highlight the Role of r_m**: Encourage students to experiment with different r_m values to understand the transition from stable growth to chaotic dynamics.
- **Time Lags and Cyclic Behavior**: Some students may struggle to grasp how time lags cause population cycles. Show them step-by-step how changing the reference population size (e.g., N_{t-1}) affects the dynamics.
- **Connect to Real-World Applications**: Discuss how these models apply to real-world populations, such as predator-prey systems or species with delayed reproductive responses.

Common Pitfalls

- **Overlooking the Impact of Time Lags**: Students might expect that small changes in the model have minimal effects. Emphasize that even slight time delays can drastically alter population dynamics.

- **Misinterpreting Figure 2**: Some students may find it confusing that the per capita growth rate decreases as population size approaches K. Reinforce the concept that as resources become limited, growth slows.
- **Excel Formula Errors**: Students may struggle with modifying Excel formulas, especially when introducing time lags. Ensure they understand how to correctly reference previous population sizes.

Concrete Real-World Examples

1. Insect Population Control (e.g., Mosquitoes)

- **Scenario**: Mosquito populations often experience delayed responses to environmental changes, such as seasonal rainfall.
- **Time Lag**: Adding a time lag to the logistic growth model demonstrates how insect populations might cyclically fluctuate before stabilizing, helping to predict pest outbreaks.

2. Conservation of Slow-Reproducing Species (e.g., Elephants)

- **Scenario**: For species with long gestation periods, the impact of population growth may be delayed.
- **Application of Time Lag**: Introducing time lags helps model how long-term population growth might respond to conservation efforts, showing periods of slow recovery followed by more rapid growth.

3. Fisheries Management

- **Scenario**: Fish stocks often experience delayed population responses to overfishing or recovery efforts.
- **Time Lag in Growth Models**: Managers use time-lagged models to account for the slow recovery of fish populations, ensuring sustainable harvest rates.

These examples help students understand how the logistic growth model, with or without time lags, can be applied to real-world population management and conservation challenges.

Life tables and survivorship types

Coming soon…

Matrix population modelling

Coming soon…

Pre- and Post-reproduction census

Coming soon...

Life Table Response Experiments

Coming soon...

How many eggs should a bird lay?

Coming soon…

Trade-offs and the declining force of selection

Coming soon…

(PART) Population Genetics and Evolution

Hardy-Weinberg equilibrium

Coming soon…

The Gene Pool Model

Coming soon. . .

Neutral or Adaptive Evolution in Humans: What Drives Evolution of Our Traits?

Coming soon…

Heritability from a linear regression

Coming soon…

(PART) Interactions Between Species and Community Structure

Lotka-Volterra competition

Coming soon…

Lotka-Volterra predator-prey dynamics

Coming soon…

(PART) Animal behaviour, altruism and sexual selection

Game theory: Hawks and doves

Coming soon...

(PART) Appendix - extras

Exponential growth in detail

Coming soon. . .

The legend of Ambalapuzha

Coming soon. . .

From population biology to fitness

Coming soon…