Simulating Human Population Dynamics

Peter Ashton and Dianne Lebryk

Purpose

A key element to understanding humans' interactions with their environment is to grasp the various modes within which a population can develop and evolve. Typically this apprehension is gained through the use of several descriptive parameters (fertility, mortality, etc.) applied to a variety of scenarios. However, this subject also lends itself to an agent-based modeling approach. At its core, population dynamics is a study of how the actions of an individual influence the large-scale behavior of the general population. Here we have the opportunity to perform experiments on a simulated population so that students may get a more intuitive feel for the forces and reactions involved in the study of population dynamics.

Overview

The instructor will introduce a NetLogo model of a human population, and students will work through a series of investigations leading them to study how demographic parameters influence population dynamics.

Student Outcomes

- Describe how values of demographic parameters will be reflected in an age structure diagram.
- Determine approximate values of these parameters given the age structure diagram of a real population.
- Use a model to perform an experiment determining the limiting behavior in a system with opposing forces.

Standards Addressed

HS-LS2-1: Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

HS-LS2-2: Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

HS-LS2-6: Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2-8: Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.

Time

1 class period (approx. 1 hour)

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Level
High school (10^{th} – 12^{th} grade) AP Environmental Science

Materials and Tools
- PC, Mac, or UNIX computers with the NetLogo desktop client installed. See https://ccl.northwestern.edu/netlogo/ for download and system requirements. NB: As of this writing (January 2015) NetLogo models cannot be run in an internet browser. The developers have stated that at some point in the future they hope to make this feature available, which would make the desktop client unnecessary for this lesson. See https://github.com/NetLogo/NetLogo/wiki/Applets for more information.
- NetLogo simulation file HumanPopDynamics.nlogo
- Attached handout pop_sim_handout.pdf

Preparation
Install NetLogo on computers and make model file available to students to download and run. Print copies of attached handout.

Prerequisites
None.

Background
This activity will let us look at how a population of humans changes with time, by simulating the things that happen to individual people. You can read a lot more detail about how the model works in the "Info" tab in NetLogo, but here's some more background to the background to get you started. A model like this has two important parts.

The first part is the "agents", or "turtles" in the NetLogo language. These are the people in our model, and they wander around, living their lives and interacting with each other and their environment. These agents have properties; our people know their age, and whether they're male or female. That's the minimum amount of information we need for this simulation. We're not looking at their jobs or their families or anything like that – the model lets us ignore everything but the information that's relevant to us.

The second part is the rules that the agents follow, laid out in the code. Time passes in the model like a ticking clock. Here, each "tick" represents one year. Every year, the agents follow the same set of instructions (also called an "algorithm"). This algorithm has them do all the things we want to be able to model – in this case, births, deaths, and aging.

Again, make sure to read the "Info" tab, as that also provides definitions for important vocabulary we'll use when discussing the model inputs and outputs.

Teaching Notes
Direct the students on how to download and access the NetLogo simulation file, and start NetLogo. Ideally each student will have their own instance of the model running on their own computer, with their own copy of the handout to complete. However, they should be encouraged to discuss what they're doing or thinking about in pairs or small groups.

As the class moves through the sections of the handout, stop them periodically to talk about their answers to the questions as a group. Especially emphasize using the "Info" tab as a reference for explaining how the model works and what they're seeing.

Following are some sample answers to questions:

I. Introduction
   - The model won't necessarily produce the same result every time. This is because it relies on a random number generator to make events like births and deaths happen based on probabilities.
   - One example is given. Others are increases or decreases in disease or violence decreasing or increasing life expectancy, respectively. Availability of contraceptives could decrease the TFR.

II. The Ways a Population Can Change With Time
   1) The population should crash quickly. This is because no new babies are born, while older people continue to die. When looking at the age structure diagram over time, point out that you can see the population structure moving to the right (increasing in age) without replacing itself with young people.
   2) In addition to a cohort moving to the right, when mortality is increased, you can see the effect of people dying, decreasing the height of the bars, causing the age structure diagram to "pinch" into more of a point at the older end. Read off the age of the bar that's farthest to the right in the plot. In testing, this was somewhere around 60 when life expectancy is low. This point moves farther out when life expectancy is higher, and the "point" on the graph gets less sharp.
   3) The effect of infant mortality on the graph may be subtle. An infant mortality rate of 300 means 300 out of every 1000 births die before their first birthday, we would expect the second bar in the graph to be about 30% shorter than the first bar. When infant mortality is low, very few young people are dying, so differences in the 0-year-old and 1-year-old population will be due mainly due to random differences in the number of babies born year-to-year.

III. Simulating Real Countries.

Numerical answers may vary. Common features should be a high TFR and low life expectancy in Kenya, vice versa in Japan, and balanced in the United States. Values from the CIA World Factbook are as follows:

	TFR	Life Expectancy	Infant Mortality
Kenya	3.54	63.5	40.7
Japan	1.4	84.5	2.13
United States	2.0	79.6	6.17

Source: https://www.cia.gov/library/publications/the-world-factbook/

Note: students' answers may disagree due to the fact that the model does not include population changes due to immigration/emigration, which is a significant contribution in the United States. Japan and U.S. may require a TFR raised for ~20 years and then lowered to reflect a postwar baby boom.

IV. Investigating Long-term Behavior

When mortality is low, the replacement fertility rate should be close to 2.0, as two parents would need to produce 2 children to replace themselves, on average. As life expectancy is lowered, however, TFR will need to be increased so that some people will have more children to account for people who die without having any children. Encourage students to choose a variety of life expectancies for their investigations, and discuss as a class how and why this makes a difference. The method for the investigation is important here, and students may disagree on how long you need to watch to determine the population will *never* go to zero, for example. Many answers are acceptable, but students should be encouraged to be as explicit as possible with their procedure.

A possible addition or homework follow-up to this lesson is to have students read and reflect in writing on this blog post on the Gompertz Law of Mortality, which is what this model uses to determine the likelihood of an agent dying in a given year: https://gravityandlevity.wordpress.com/2009/07/08/your-body-wasnt-built-to-last-a-lesson-from-human-mortality-rates/ (PDF copy attached). Mathematically inclined students may appreciate a look at the relevant statistics that underlie the simulation, and ultimately, real life.

Assessment

The teacher should periodically regroup the class and discuss their answers to questions posed on the handout to make sure students are on the right track. The handouts can also be collected following the activity to be examined more closely.

Additional Information

Remind students not to base any conclusions on the first ~10 years of a model run, as it takes time for the simulation to “forget” about its unrealistic initial conditions. In testing, the simulation slowed down significantly once there are about 2,000 – 3,000 turtles. This can be helped by unchecking the “View Updates” box, to a point. Your mileage may vary.