INQUIRY & INVESTIGATION

Quantifying Ecology: Constructing Life History Tables

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In the biology community there has been a call for integrating lessons on population growth rate and the human population crisis into biology classrooms (Meffe, 1994; Dunning, 1997). Ecologists fear that students do not understand the relationship between the magnitude of the human population growth and Earth's carrying capacity, as well as some basic ecological concepts (Brody, 1994). We suggest that students must first learn how populations are studied and how predictions of population growth rates are made to better grasp the implications of human population dynamics. We have developed a lesson that addresses the National Science Education Standards A (understanding scientific inquiry/analyses) and F (population growth and natural resources) and that reinforces the idea that the discipline of ecology is both descriptive and quantitative (National Resource Council, 1996).

We are not surprised when students mistakenly think that ecology is the study of walking through the woods and listing relationships between organisms. Although ecology does have a rich history of descriptive research upon which much of biology rests, we hope to introduce high school and college students to the quantitative aspects of ecological research. For teachers who aim to integrate mathematics in the science classroom, we propose constructing and analyzing life history tables. However, it is difficult to practice constructing life history tables in the classroom using live animals because they are often too small to measure (especially births) or their generation times are too long to study during the course of an ecology unit. In response to this constraint, we developed an activity that can be completed in one or two class periods. Using school enrollment data, students will practice constructing life history tables. As an extension activity, students apply these approaches to analyze human population data (i.e., county, state, or country).

A life history table is a set of mortality and fecundity data for defined age classes of a population of one species. Depending on the focus of the research, biologists may record different life history parameters, such as mortality and fecundity. In a simplified equation, replacement rate equals the sum of the age-specific percent survivorship times the age-specific fecundites. In other words, organisms in each generation need to survive and reproduce in order for the population to perpetuate. Life history tables are used for a variety of reasons. They are often difficult to construct because several measurements must be made over several generations. It is often difficult to follow large cohorts over an extended time. However, school districts track class sizes, so we decided to modify these data to fit our activity on life history table construction. Our goal was to find a data set in which the students might be particularly interested as we began our lessons on human population growth.

Table 1. Sample enrollment data of high school students.

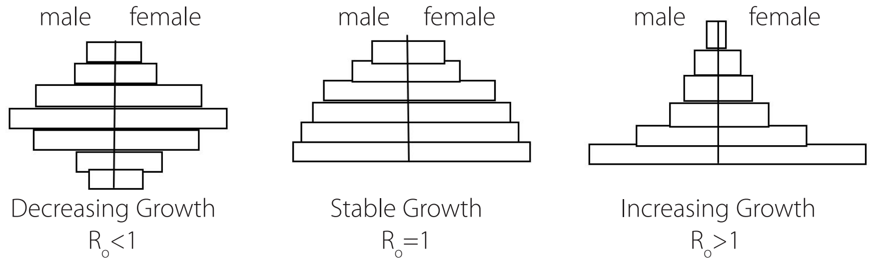
Year	Sophomores	Juniors	Seniors
Sep-94	467	391	396
May-95	435	365	368
Sep-95	491	451	370
May-96	479	407	345
Sep-96	525	474	405
May-97	507	463	392
Sep-97	574	505	451
May-98	553	469	423
Sep-98	527	549	482
May-99	516	511	453
Sep-99	574	528	523
May-00	557	500	475
Sep-00	743	538	507
1-May	530	514	486
Sep-01	583	544	522
May-02	559	524	484
Sep-02	505	548	535
May-03	494	525	490
Sep-03	525	513	533
May-04	510	477	509
Sep-04	569	511	493
Apr-05	558	486	475

○ Studying Populations

Research has demonstrated that when students can draw upon their own experiences or generate their own data, learning can be more meaningful (NRC, 2000). In this lesson during a population ecology unit, students examined population growth at their own high school. Our lesson was developed for an AP Biology class at a school in a section of the city that is experiencing increased population growth rate and development. However, the state, in general, is experiencing a negative population growth rate. Students worked in cooperative groups of two to three and were asked to predict whether they thought their high school population was increasing, decreasing, or remaining stable. Students were encouraged to pick whichever prediction they thought was most plausible and to justify their reasoning in a short paragraph.

We contacted the school district office and requested population data for this high school. We obtained enrollment numbers based on class standing (sophomore, junior, and senior) for each fall (September) and spring (May) for ten years (Table 1). From these data we were able to determine the number of students entering and exiting each grade for each academic year. We were not supplied with information regarding transfers (in or out) or dropouts; however, this information can be inferred. These data would have added another dimension to our study, but, in their absence, our students made inferences for increasing or decreasing population size at the start of each school year. We encourage other teachers to track down enrollment information from their school offices or district offices to construct their own tables. In lieu of a local data set, we have provided the data set used in our activity (Table 1).

Figure 1. Age-structured pyramids help students visualize how the population size is changing.



Most high school (and college) textbooks present age-structured graphs when describing population growth (see Figure 1), which often appear on AP Biology tests. From our experience, many students typically memorize the graphs without making a connection to what the figure actually represents. One of our goals was to help students make a connection between data and the corresponding graphical representation by understanding how "R_o" is calculated.

○ Limitations of This Activity

There are a couple of important clarifications that the teacher should make before beginning this activity. First, student populations are not self-perpetuating since they are not representing all of the age classes of humans. We renamed the sophomores "juveniles," the juniors "recruiters," and the seniors "post-recruiters." In our scenario, juniors were responsible for the next generation of sophomores entering school. Although we modified this activity by identifying only three age classes, we found students to be very engaged as they tried to determine whether their school population was hypothetically growing, shrinking, or remaining stable. In addition, the school district did not break down the data by gender. In other words, we could not construct an age-structured graph for each sex, as the U.S. Census Bureau does (http://www.census.gov).

Another important clarification is that, unlike some populations studied, our system was "open" and not "closed." A closed population restricts movement in and out of the population. For example, if a class was studying the population dynamics of a colony of flour beetles, and if the beetles were enclosed in a glass terrarium that did not allow outside beetles to fly in or to escape, this system would be described as being "closed." Human populations tend to be "open" systems because of immigration and emigration. Our school data reflect the movement of individuals in and out of the population because students transfer or drop out of school. We posit that constructing a life history table prepares students to understand the population dynamics of their city or state. It is important to note to students, though, that world population is a closed system because individuals cannot move on and off planets. There is nowhere for people to go when resources are limited.

○ Instructional Planning

We suggest using this activity during an ecology or environmental science unit during which the teacher would normally discuss world population growth. Before the activity, we had asked students to read assigned chapters from their AP Biology textbook (Campbell & Reece, 2005). Our students had already covered logistic ("S") and exponential ("J") population growth models in class earlier in the unit. We had not assigned a pre-laboratory assessment, although a teacher could certainly do so in order to identify preconceptions about how populations are studied. We recommend two class periods (each about 50 minutes long) to complete the activity and discussion as presented. Extension activities examining human population growth will require additional class periods. This activity does not need to take place in a laboratory room and only requires that students can sit in pairs (with a calculator) to complete their calculations and construct their life tables.

○ Learning Objectives

1. Students will test their predictions about average population growth rate at their own school.
2. Students will use data and a replacement rate equation to construct a life history table.

Table 2. Sample table filled out for the class of 1997. You must fill out the other eight tables. Using the R_o for each graduating class, you can calculate the average growth rate for your school.

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	$m_{x=}$soph/jun	$l_x m_x$
sophomore	467	435	-32	435/467=.93	0	0
junior	451	407	-44	407/451=.9	491/451=1.1	.98
senior	405	392	-13	392/405=.97	0	0

R_o=______

Ave. $l_x m_x$ =[____ + _____+ ____ + _____+ ____ + ____ + ____ + ____ + ____] /9 =_________

The population is ______________________ (increasing, stable, or decreasing).

Student Laboratory Sheet

You are an ecologist studying patterns of the population growth at ABC high school. Populations have specific traits that you must measure and analyze in different age classes. Typically, biologists categorize population data into age classes based on developmental/reproductive stages. This enables biologists to understand how the overall population is affected by the population fluctuations within each age class. In addition, biologists separate data by sex (how is the population growth different for males versus females?). In this population, the age classes are sophomores, juniors, and seniors. In our scenario, juniors play an important role as recruiters of new students to this high school. That is, they are responsible for the number of incoming sophomores. The juniors will replace the role of "reproductives" in our life history table. Our data set does not include information about sex so we will lump the numbers for boys and girls within each age class. When discussing population dynamics, biologists use the terms "birth rate" and "death rate" as measures of population changes over a given time period (Miller & Were, 2008).

I predict the school population is __________________ (increasing, stable, or decreasing) because ____.

Calculating Net Replacement Rate

l_x = survivorship = proportion of students continuing to next grade (# May/# September)

m_x = fecundity = # incoming sophomore recruits/juniors in September

Net gain = immigrants + births = transfer students + incoming sophomores

Net loss = death due to predation/disease/starvation = drop-outs + graduated seniors

$$R_o = \sum l_x(m_x) = \text{net replacement rate}$$

The district office provides you with 10 years worth of data (Table 1). You must now determine l_x, m_x, net change (since we do not have transfer or dropout data). For each graduating class you will calculate R_o and the average R_o over 9 graduating classes. You will determine if:

$$R_o = 1 \text{ (stable pop growth) or } R_o > 1 \text{ (increasing pop) or } R_o < 1 \text{ (decreasing pop)}$$

One set of calculations is completed (Table 2). Now you need to complete the other calculations.

After completing the calculations, answer the accompanying questions with your partner. Write them down and be prepared to share your ideas with the class during our post-lab discussion.

Post Lab Questions

1. What was the average R_o value from your life history analysis? What interpretations can you make about the population at this high school and did your findings match your prediction?
2. Describe what limiting resources may have helped to increase/decrease student enrollment at this high school.
3. Describe what resources in the community might limit or allow population growth.
4. If this was a self-perpetuating population (such as the human population in our city), what factors might limit or allow population growth?
5. Should an ecologist disregard data from a year when incoming sophomore numbers are unusually high? Explain how you would deal with "anomalous data."
6. Draw the general shape of an age-structured graph of a population that is (a) increasing (b) stable, and (c) decreasing, assuming that the male to female sex ratio is 50:50. Indicate which graph best represents your school population growth rate by putting a star next to it.

Glossary of Useful Terms

Birth rate – the number of live births for every 1,000 individuals in a specified area over a given time (usually 1 year)

Death rate – the number of deaths for every 1,000 individuals in a specified area over a given time (usually 1 year)

Population growth rate – the change in the population size over a given time period

Natural growth rate – population growth rate without taking into account immigration or emigration; typically used for closed systems

Replacement rate – the number of new individuals born to replace the parents; often this calculation is determined by how many individuals must be born for the population growth rate to be zero

Carrying capacity – the maximum number of individuals of one species that a geographic area can support without a decrease in population growth rate; known as "K"

3. Students will explain how scientists construct age-structured graphs using life history data.

Extension

4. Students will use their new knowledge about life tables to explain how scientists study world population growth.

○ Discussion

High school populations are obviously not self-perpetuating populations. In fact, the age groups represented in this lesson may very well represent one age class in a study of human populations. This point is important to discuss with students as they read and study about population growth models. Because we modified the age classes to fit a classic life history table, it was important that students understood that the results that they calculated do not actually represent population growth at their high school. More importantly, we asked students to consider the how the relatively stable average R_o (1.03) is related to the limiting resources of a typical high school. Students identified factors that would allow school population growth to increase, including: increased community population, increased taxes, sufficient physical space, sufficient teachers/staff, and sufficient classroom resources. They identified

Table 3. Teacher's key of calculations using the data set provided.

Class of '97

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	467	435	-32	435/467=.93	0	0
junior	451	407	-44	407/451=.9	491/451=1.08	.98
senior	405	392	-13	392/405=.97	0	0

Class of '98

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	491	479	-12	.98	0	0
junior	474	463	-11	.98	525/474=1.11	1.08
senior	451	423	-28	.94	0	0

Class of '99

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	525	507	-18	.97	0	0
junior	505	469	-36	.93	574/505=1.14	1.06
senior	482	453	-29	.94	0	0

Class of '00

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	574	553	-21	.96	0	0
junior	549	511	-38	.93	527/549=.96	.89
senior	523	475	-48	.91	0	0

Class of '01

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	527	516	-11	.98	0	0
junior	528	500	-28	.95	574/528=1.09	1.14
senior	507	486	-21	.96	0	0

Class of '02

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	574	557	-17	.97	0	0
junior	538	514	-24	.96	743/538=1.38	1.33
senior	522	484	-38	.93	0	0

Class of '03

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	743	530	-213	.71	0	0
junior	544	524	-13	.96	583/544=1.07	1.03
senior	535	490	-44	.92	0	0

Class of '04

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	583	559	-24	.96	0	0
junior	548	525	-23	.96	505/548=.92	.88
senior	533	509	-24	.95	0	0

Class of '05

Status	Fall #	Spring #	Net change	Prop. Surviv l_x	m_x=soph/jun	$l_x m_x$
sophomore	505	494	-11	.98	0	0
junior	513	477	-36	.93	525/513=1.02	.95
senior	493	475	-18	.96	0	0

Ave. $l_x m_x$ =[.98+1.08+1.06+.89+1.14+1.33+1.03+.88+.95] /9 = 1.04

The population is ___increasing___ (increasing, stable, or decreasing).

factors that would limit school population growth to decrease or not grow, including: shrinking community population, shrinking taxes, building constraints, lack of teachers/staff, and lack of classroom resources. We discussed possible R_0 values if the school population was actually decreasing or increasing dramatically.

One important objective for us in using this activity was for students to participate in a problem-solving exercise that seemed relevant to their lives. Students were involved in our post-activity class discussion, to our delight. We were initially concerned that the juniors in our class would snicker at the thought that they represented the reproductively-active individuals in a population; however, we found them to be mature about the label. The students enjoyed the integration of math in their science class. Many expressed to us afterwards that they were surprised that there was so much "math" in ecology and that ecologists actually make predictions and test them. Although we did not formally assess our students' opinions about this activity, our informal evaluations of their comments during class discussions were very positive. Our students' enthusiasm subsequently has encouraged us to develop other quantitative exercises for ecology units. We have also used this activity in a non-majors undergraduate course with much success. We hope that other science teachers will integrate mathematical problem-solving activities in addressing human population growth, carrying capacity, and limiting resources in their classrooms. We think that follow-up activities focusing on human world population growth will be more meaningful to students after they have a better understanding of how life history tables are constructed.

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