Cornell Institute
for
Biology Teachers

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Title: **Tales from the Crypt**

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Appropriate Level: General Biology, Regents, AP. AP students may do the optional sections on life expectancy.

Abstract: Life tables and survivorship curves summarize the likelihood of death at various points in an organism's life history. After reading background information on survivorship and the construction of life tables, the student is asked to propose hypotheses comparing survivorship between historical and modern populations and between males and females.

For this exercise, students visit a graveyard to gather mortality data for a human population that lived at an earlier time, preferably before 1900. The students also gather information for a comparable modern population from the obituary pages of a local newspaper or from health department data. They construct life tables for males and for females in each of these populations and graph survivorship curves for each.

The student is asked to discuss hypotheses she formulated with respect to the actual survivorship data, and to reflect on factors that may have caused observed differences.

The calculation of "expectation of further life" is presented as an option. It is not conceptually more difficult than the other elements of the life table, but is more involved, requiring a couple of intermediate calculations. The results are interesting, however, and students should be encouraged to attempt them if time and aptitudes permit. The mortality data may be supplemented by data on age-specific birth or fecundity, and population growth rates such as **r**, the intrinsic rate of natural increase, can be estimated. Addition of such information allows comparisons of biotic potential of populations. Other information relevant to a species' ecology and evolution can also be derived from life tables.

Time Required: If the students gather the data outside of class time, the exercise should take two full periods, one to introduce the subject and organize the data gathering, and another to do the calculations and discuss the results. Including a field trip to gather graveyard or newspaper data would, of course require more class time.

Additional Teacher Information

Materials

Students will need the data sheets included with this lab, graph paper, and calculators.

Preparation Instructions:

The exercise assumes that the students will gather the necessary data outside of class time in visits to graveyards and libraries. Since many rural cemeteries are very small, the teacher might note in advance where they are and assign students to them to assure coverage of enough pre-1900 graves without duplication. If the students gather the data outside of class, they must take care not to duplicate each other's efforts by visiting the same graves or extracting dates from the same obituaries. The class as a whole should record data from 300-500 graves.

Summary data from obituaries may be available from your local newspaper and could be used instead of the newspapers or microfilms of newspapers themselves. Age at death data may also be available from the county health department. Cemetery data can also be found at http://www.totentanz.de/usa.htm#newyork

Advise students to make some common sense assumptions where necessary. If the sex of the person in a grave is not clear from the tombstone, omit that person. On the other hand, since infants may be particularly likely to be buried without the sex being noted on the tombstone, omitting many of them would obscure infant mortality in the data set. Suggest that students may arbitrarily put half of the infants of unknown gender in the male column and half in the female column.

It is very important that the data gathering, and especially the life table calculations, be organized to reduce tedium and chance for error. Assigning different individuals or groups of students to different tasks and later pooling results is highly recommended. Each student, however, should work through the calculation of at least one life table and plot the survivorship curves. As with any exercise involving calculations, students must be warned to check their results frequently. They should be taught to ask themselves repeatedly, "Does this calculation pass built-in, internal checks?" "Does that number look reasonable?"

Traditionally, survivorship curves are plotted on a semi-log scale. When thus plotted, the slope of the curve is the mortality rate. Introducing students to semi-log plots may be valuable, but it adds another level of quantitative abstraction, and arithmetic plots show the results adequately.

The work by Stümpke, cited in the bibliography is a humorous farce describing a fictitious order of mammals. It does not deal with life tables, but may be entertaining for both teacher and student.

Background Information for the Teacher

Andrewartha (1961) defined ecology as, "the scientific study of the distribution and abundance of animals,"[read "organisms"]. Abundance, how many organisms there are in a population, is determined by the balance between births and deaths; so mortality becomes a critical factor in a species' ecology. For some purposes it is sufficient to work with "crude" birth and death rates, simply the number of organisms that are born or die per unit time (day, month year). Deeper insight can be gained, however, by examining "age-specific" vital rates, i.e. the likelihood of dying or giving birth at a specific age. The mortality data for both natural populations of animals and plants, as well as for human populations, are summarized in life tables. The fundamental data in such a table is a schedule of survivorship, a summary of the probability of surviving to reach a given age. These data may also be presented in graphical form as a survivorship curve.

The "Background" in the student section of this write-up introduces the concept of life tables and defines the symbols that are used for the various life-history parameters they deal with. Life tables are covered in most of the college textbooks in general ecology, some of which are listed in the bibliography below.

Expected Results / Sources of Error

It is important that this be presented as an exercise in the scientific method, not as a demonstration of expected results. Students are asked to formulate hypotheses and to collect data to test their hypotheses. The teacher, however, might facilitate the process by leading the student in the direction of interesting research questions: Is there evidence for high infant mortality before 1900? Can you find evidence for "childbed" deaths among reproductive-age women in the historic population? Who lives longer, males or females? Why?

Infant mortality should be noticeably greater (survivorship less) for the pre-1900 population, but once one reached adulthood, the chances of living to be old should be only slightly less than today. There should, therefore, be large differences between historic and modern populations in expectation of further life (e_x) at birth, but relatively little for someone who reached age 40. When we say, as we often do, that people are living longer these days, our longevity is due nearly entirely to years added to the *beginning* of our life by vaccines against childhood diseases, better sanitation and better nutrition, not to years added to the *end* of our life. When infant mortality is high, as it is likely to have been for the population before 1900, one's life expectancy actually increases as one gets older, up to a point.

Students may find that there is a steep section in the survivorship curve (high mortality rates) for 18th Century women of child-bearing age, though the effect might be slight for some populations. The greater longevity of women, compared to men, in our modern population, however, is likely to be striking.

Bibliography

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Smith, R. 1990. Ecology and Field Biology. 3rd ed. Harper and Row, NY. Ch 14, pp. 337-352.

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CIBT
Student Laboratory Exercise

Tales from the Crypt:

A Study of Patterns of Mortality in an Historical and a Modern Human Population

Introduction

Organisms are born, live for some period of time and then die. If we add to this the observations that organisms give birth to offspring and that many organisms move from place to place during their lives, we have summarized the most fundamental facts of ecology. Changes in the rates at which births and deaths occur in a population of organisms lead to changes in abundance of the population, and changes in patterns of movement lead to changes in the distribution of organisms. Indeed, one useful definition of ecology is the study of the distribution and abundance of organisms. Environmental and genetic factors affect births, deaths, and movements, and thereby affect distribution and abundance.

A **life table** summarizes **age-specific survivorship**, the probability that an individual in a population will live to reach a certain age. This information can also be expressed as a **survivorship curve**. From this information we can determine other important things about the population: the age-specific **mortality rate** is the proportion of individuals of a certain, specified age who die each year (or month, week or day, depending on the type of organism); and **expectation of further life** is the number of years (or months, week or days) remaining to an individual who has reached a given age. Together with age-specific birth rates, these data are called **age-specific vital statistics**.

Why might an ecologist want to construct a life table for a population? The answer is that life tables and survivorship curves can tell us a great deal about life histories, and can help us find environmental factors that limit population size or otherwise control distribution and abundance. For example, we may be cued into the existence of age-specific diseases or predators by finding steep dips in a survivorship curve or high q_x values for a particular age. When we combine data on age-specific birth rates with data on age-specific survivorship, we can calculate growth rates for populations, an essential piece of information if we want to predict if a population will grow, remain stable, or become extinct.

Although population ecologists working with many different species of plants and animals use life tables, the methods were originally developed by **demographers** working with insurance companies, especially life insurance companies. Can you guess why an insurance company might want to know about age-specific rates?

How could we get life-table figures for a real population? The most straightforward way is to select all of the individuals born at a given time and follow them until every one is dead, noting the age at which each one died. In natural populations it's often impossible to follow individuals through their entire lives. Ecologists are sometimes able to get around this problem by studying a group of organisms that have already died. In the following example, the ecologist began by collecting skulls of hares that had died and then determined the age at death from the skull characteristics. Table 1 below shows a life table for this group (cohort) of snowshoe hares.

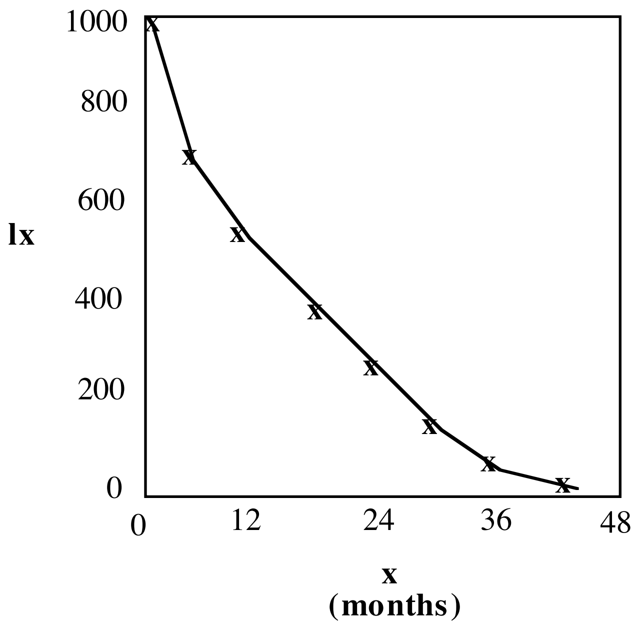
Table 1. Life Table for Snowshoe Hares. (After Krebs, 1989)

x		d_x	l_x	q_x
Age Interval (mos.)	**No. of hares dying during the interval (no. of skulls)**	**no. dying during age interval of a cohort of 1000**	**no. surviving to beginning of age interval from an initial 1000**	**mortality rate per 1000 alive at start of age interval**
0-6	21	334	1000	334
6-12	6	95	666	143
12-18	12	190	571	333
18-24	9	143	381	375
24-30	8	127	238	534
30-36	5	79	111	712
36-42	2	32	32	1000
Total Skulls Recovered	63			

- The first column, titled **x**, is the age interval, in this case, a period of 6 months.
- The second column shows the number of skulls the ecologist found in each age category.
- $\mathbf{d_x}$ represents the number of animals who died during a given age interval, but standardized to a beginning cohort of 1000 animals. It is found by dividing the number of skulls in one class by 63, the total number of skulls found, and multiplying by 1000.
- The $\mathbf{l_x}$ column represents the number of animals surviving to age **x** (i.e. the beginning of an age interval) from an initial **cohort** of 1000. This is found by subtracting the first $\mathbf{d_x}$ from 1000, the second $\mathbf{d_x}$ from the remainder, and so on.
- $\mathbf{q_x}$ is the **mortality rate**, i.e., the number we would expect to die during that age interval out of 1000 animals who attained that age, not of 1000 who were born. In this case it's based on 6-month intervals. We may express it as a monthly rate (i.e., per month) by dividing by 6.

We can plot the **lx** column vs. age (the **x** column) to visualize what happens as individuals in the population age. Such a graph is usually called a **survivorship curve**. The survivorship data for snowshoe hares is shown in Figure 1 below.

Figure 1. Survivorship curve for snowshoe hares.



Questions:

1. From an initial cohort of 1000 snowshoe hares, how many live to be 18 months old?

2. What is the chance that a hare will live to be 3 years old?

3. What age would you say is the safest age for hares?

4. How safe is the first 6 months of life for snowshoe hares?

Objectives

In this lab you will use information taken from old tombstones in a local cemetery and from the obituary pages of a current local newspaper or from your county health department to investigate the differences in the patterns of mortality in the human population that lived in your area in the last century and the population that lives there now. You will construct life tables for these two human populations.

Begin your study by formulating hypotheses concerning different patterns of mortality for these two populations. You will construct life tables and survivorship curves for males and females separately in these two populations, so your hypotheses might relate to expected sex differences in patterns of mortality as well as differences between the historical and the modern populations.

An hypothesis can be thought of as an educated or informed guess, and you know enough about the human populations you will be studying to make good guesses. The best hypotheses are written as statements, not questions. They may be true or false, but since they are based on educated guesses, you should have a logical argument for why your hypothesis might be true.

- Write out at least 2 hypotheses concerning mortality differences between men and women that might pertain in either the historic or modern population.
- Write out at least 2 hypotheses concerning differences in mortality between the historic and the modern populations.

1. ____

   ____

2. ____

   ____

3. ____

   ____

4. ____

   ____

Procedure

Collect the Data:

Historical Population

1. Visit an old cemetery, preferably one in which there are many graves dating from before 1900. It is important that each gravestone be sampled only once; so make sure that your classmates don't visit the same cemetery you do or that the territory is divided in such a way that the data aren't duplicated. Take this handout, including Tables 2 and 3 with you. A pocket calculator will be useful too.

2. Work through the cemetery in an orderly way, observe the information on the stones or grave markers, select only those graves dug before 1900 and note the sex of the person buried in each grave. Subtracting birth date from death date, determine the age at death for each grave and make a tally mark in the appropriate place in Table 2.

3. Make some common sense assumptions where necessary. If the sex of the person in a grave is not clear from the tombstone, assign it to one sex, and the next unknown to the other sex. Try to sample all the tombstones in your area, not just the biggest or easiest. Otherwise you may bias the data: earlier deaths, poor people, women, and infants may have less clearly marked graves.

4. Get age-at-death information from as many graves as you can. You will pool your data with your classmates, and the class as a whole should aim for information from 300-500 graves.

5. Add the tally marks in each row of your data sheet and record the sum in the column marked headed

"your totals".

Modern Population

1. These data come from the obituary or death notice sections of the local newspaper for the current year, or from census data from the county or state health departments. If you use newspaper data it's important not to introduce seasonal biases, so the class should sample an entire year's volume of the newspaper. Different portions of the class might be assigned different dates to sample.

   Age at death is usually given as part of the death notice or obituary. Note the sex of the person who died and put a tally mark in the appropriate row on Table 3. Some papers include both death notices and obituaries, so there may be some duplication of entries. Be watchful for such duplication, and count each person only once in your sample. Try as a class to get 300-500 entries.

2. If groups of students sample newspapers for data, add your tally marks in each row and place the sum in the column marked "your totals". Pool your data with the other groups to get class totals for each age group.

3. Alternatively, you may ask the county health department to supply you with the age and sex of all the persons who died in your county last year.

Construct the Life Tables

Even though the populations you have sampled are not cohorts in the sense of being a group of organisms all of whom were all born at the same time, you will treat them as such and will construct a cohort or dynamic life table. You might think a bit about what assumptions you have to make in order to treat your samples a cohort. Basically, you are assuming that all the individuals were subject to the same mortality rates, regardless of when they were born.

Complete Tables 2 & 3 by pooling your data with those of your classmates. Enter these sums in the column marked "class total" on each of the tables. You should now have 4 data sets, males and females from the modern and from the historical populations.

In a group, do the following calculations. Record the results in the columns in Data Tables 4 and 5. Record your numbers **in pencil**.

Calculate d_X (mortality)

1. Add each of the "class total" columns to find a sum for each. Check your addition with other groups.

2. For each age interval, divide the number in the "class total" column for that interval by the total number of individuals, to find what proportion of the cohort died at that age. Your number should be a value less than 1.0, a proportion of the whole sample.

3. Multiply each of the proportions above by 1000 to get a cohort of 1000. Round off to the nearest whole individual.

4. Record these numbers in the $\mathbf{d_x}$ column. Check that your d_X column total is 1000. Rounding errors may make it off by 1 or 2, but that's OK.

Calculating l_X (survivorship)

1. In the first row of the l_X column (age interval 0-.9) write "1000". This is $\mathbf{l_0}$, the starting cohort of 1000 births on which you will base your table.

2. To find out how many survived to enter the next age interval, $\mathbf{l_1}$, subtract the number who died in the $\mathbf{l_0}$ age interval from 1000. Record this number in the next row of the table.

3. To get those who survived to enter $\mathbf{l_2}$**,** subtract the number of deaths that occurred during the fist time interval, $\mathbf{d_1}$**,** from $\mathbf{l_1}$**.**

4. Repeat this calculation all the way down the column. At the end, no one should be left to enter the next interval.

Calculate q_X (age-specific mortality rate)

1. For each row (i.e., for each x or age interval), divide d_X by l_X and multiply by 1000 (for the cohort total). Having entered a particular age class, one's chance of dying before getting old enough to enter the next age class is equal to the number dying during that age interval divided by the number who enter that age interval.

2. Most of our age intervals are 10 years, but some are shorter. In order to get comparable mortality rates for all ages, annualize your rates by dividing each by the

   number of years in that age interval. This is an individual's chance of dying in a given year.

3. Enter these numbers in the appropriate cells of the q_X column.

Plot Survivorship Curves

1. Make a single graph with age at the start of the interval (x) as the horizontal axis and l_X as the vertical axis. Age is the independent variable in this case and survivorship is the dependent variable. Scale your axes so that the age axis goes from 0 to just a little above 100 years and the l_X axis goes from 0 at the bottom to 1000 at the top.

2. Plot the l_X data from all 4 of your life tables on the same graph. Use different symbols for the data points or different colors for the curves to differentiate the 4 different populations.

Table 2. Data Sheet for Collection of Age at Death Data for the Historic Population from Graveyards. Use only graves from before 1900. Keep tallies for females and males separately.

Name and Location of Cemetery ______________________________________

Collectors names____________________________________ **Date**____________

	Females			**Males**		
Age at Death (yrs)	Number of Graves	Your Total	Class Total	Number of Graves	Your Total	Class Total
0-0.9						
1-9.9						
10-19.9						
20-29.9						
30-39.9						
40-49.9						
50-59.9						
60-69.9						
70-79.9						
80-89.9						
90-99.9						
100+						
Totals						

Table 3. Data Sheet for Collection of Age at Death Data for a Modern Population. Make sure a whole year is included. You and your classmates may have to coordinate a sampling scheme for the records available to you. Keep tallies for females and males separately.

Source of Data: ____

Year and Months Examined: ________________________________

	Females			**Males**		
Age at Death (yrs)	Number of Persons	Your Total	Class Total	Number of Persons	Your Total	Class Total
0-0.9						
1-9.9						
10-19.9						
20-29.9						
30-39.9						
40-49.9						
50-59.9						
60-69.9						
70-79.9						
80-89.9						
90-99.9						
100+						
Totals						

Table 4. Life Table for Females and Males of an Historic Population Living Before 1900.
(Remember to divide by the number of years in the age interval to get q_x.)

	FEMALES					MALES			
x	**Class totals**	**l_x**	**d_x**	**q_x**		**Class totals**	**l_x**	**d_x**	**q_x**
0									
1									
10									
20									
30									
40									
50									
60									
70									
80									
90									
100									

Table 5. Life Table for Females and Males of a Modern Population. Persons who died in a recent year.

FEMALES						MALES			
x	**Class totals**	**l_x**	**d_x**	**q_x**		**Class totals**	**l_x**	**d_x**	**q_x**
0									
1									
10									
20									
30									
40									
50									
60									
70									
80									
90									
100									

Discussion

Discuss your results in light of your hypotheses. Do the data support your hypotheses? Do they contradict them? Can your hypotheses be confirmed or denied with this data?

Questions

1. What are the differences between survivorship of males and survivorship of females?

2. What are the differences between people who lived before 1900 and those in modern times?

3. Can you tell whether the causes you proposed to affect survivorship were in fact causing the effect you hypothesized?

4. How did the age-specific mortality rates change from interval to interval?

5. What are the riskiest age intervals in these populations? The safest intervals?

Calculation of e_x (expectation of further life)

This calculation is somewhat more complicated than the others, but, at least for human populations, the results are interesting. The easiest way to perform this calculation is to complete the columns labeled L_x and Y_x in Tables 4 and 5.

1. Fill in the column marked L_x by employing the following formula: $L_x = [l_{(x+1)} + l_x]/2$. For a given row in the L_x column, add together the l_x value for that row and the l_x value from the row immediately below, then divide by 2. These L_x values are the average number of individuals living a particular age interval, assuming deaths occur uniformly through the interval.

2. To fill in the Y_x column, you must start at the bottom of the L_x column. Furthermore, since we want the life expectancy for our human life tables to come out in years, we must account for the length of our age intervals at this step. Multiply the last L_x value by 10 (the length of the age interval), and enter the result in the cell for the last Y_x value. Add to this value the next higher L_x value, also multiplied by 10, and place the sum in the next higher Y_x cell. To find each successive Y_x value, add the L_x times the length of the age interval to the Y_x value ($Y_{(x+1)}$) from the row below. In our human life tables, the first age interval is 1 year long and the second age interval is 9 years long. Don't forget to take this into account as you do the calculations of Y_x.

   For each age class, Y_x is the total number of person-years left to be lived by the cohort. (Remember, for the hare data, the interval is 6 mos., so, to arrive at hare life expectancy in months, we'd need to multiply the L_x values by 6.)

3. Calculate e_x as $e_x = Y_x/l_x$. For each row, divide Y_x by the l_x value in the same row. This e_x value is given in 6 mo. intervals for the hare data. To find the further life expectancy in months, multiply this by 6.

These calculations can be illustrated with the snowshoe hare example in Table 1.

Table 2. Calculation of expectation of further life (e_x) for snowshoe hares.

x		l_x	L_x	Y_x	e_x (6 mos.)	e_x
Age Class	**Age Interval (mos.)**	**no. surviving to beginning of age interval from an initial 1000**	**Ave. no. living thru age interval**	**No. of hare-intervals yet to be lived by entire cohort**	**Ave. no. of 6-mo. periods remaining to those entering interval**	**Ave. lifetime remaining to those entering age interval**
0	0-6	1000	833	2499	2.4	14.4
1	6-12	666	618	1666	2.5	15.0
2	12-18	571	476	1048	1.8	10.8
3	18-24	381	310	572	1.5	9.0
4	24-30	238	174	262	1.1	6.6
5	30-36	111	72	88	0.8	4.8
6	36-42	32	16	16	0.5	3.0
7	42-48	0	0	0	0	0

Questions:

1. What is the average life expectancy for a hare that has survived for 18 months?

2. Why is the life expectancy higher in the second interval than in the first interval?

3. About how many hares of this cohort would you expect to see still alive at 39 months?

Table 4. Life Table for Females and Males of an Historic Population Living Before 1900.
(Remember to divide by the number of years in the age interval to get q_x.)

	FEMALES						MALES					
x	l_x	d_x	q_x	L_x	Y_x	e_x	l_x	d_x	q_x	L_x	Y_x	e_x
0												
1												
10												
20												
30												
40												
50												
60												
70												
80												
90												
100												

Table 5. Life Table for Females and Males of a Modern Population. Persons who died in a recent year.

	FEMALES						MALES					
x	**l_x**	**d_x**	**q_x**	**L_x**	**Y_x**	**e_x**	**l_x**	**d_x**	**q_x**	**L_x**	**Y_x**	**e_x**
0												
1												
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40												
50												
60												
70												
80												
90												
100												

Questions

1. If you calculated e_x, how does life expectancy at birth compare for the historic and modern populations?

2. How does it compare for males and females?

3. Before 1900, how many years, on the average, remained to a male or to a female of age 40?

4. How does this compare with today's population?