Answers to Exercise 12

Life Tables, Survivorship Curves, and Population Growth

1. We plot survivorship curves on semi-log graphs because l_x is a *proportion*: the proportion of the original cohort surviving to age *x*. The distance between points on a logarithmic axis reflects their proportional relationship, and so a logarithmic scale is appropriate.

   This kind of graph also makes clear important differences between the three types of survivorship curve. Note that on the linear graph, type II and type III curves have qualitatively similar shapes, whereas on the semi-log graph they look quite different.

2. The keys to interpreting the shapes of survivorship curves are to look at their slopes compared with the graphs of age-specific survival (g_x). The type I curve begins with a shallow slope, indicating low mortality among the young—that is, a high proportion of individuals of each age survive to the next age throughout the early part of life. The curve steepens at older ages, indicating increased mortality in old age. A type I curve tells us that most individuals in this population survive a long time and die at old ages. The graph of g_x supports this interpretation: survival is high in the young, and drops off with age. Inspect columns E and H to see these patterns numerically.

   The type III curve reflects the opposite pattern of survival and mortality. The curve begins with a steep slope, indicating low survival (and high mortality) among the young. The shallow slope in middle and old ages indicates that most of the individuals that survive their youth survive to old age. The graph of g_x shows the same thing—survival among the young is very low, and increases with age (until the oldest age). Inspect columns F and I to see these patterns numerically.

   The type II curve indicates a constant rate of survival across all ages (until the last). Note that a straight line on a semi-log plot indicates change by a constant proportion. The graph of g_x (a horizontal line) also shows that survival is the same for all ages (except the oldest). Inspect columns G and J to see these patterns numerically.

3. The type I curve of life expectancy is probably not surprising, as it shows that the expected number of years of life remaining decreases with increasing age.

   The type II curve may strike you as somewhat surprising. It indicates that an individual can expect to live about 2 more years, regardless of age, up to about 6 years of age. After this, life expectancy decreases, to 1 year at 10 years of age. How can this be? A type II survivorship curve occurs when the same proportion of survivors die at each age (in other words, when the risk of death is constant for all ages). In this circumstance, life expectancy is the reciprocal of risk of death. If you look at the spreadsheet, you will see that half of the survivors die at each age. The reciprocal of _ is 2—the life expectancy.

The type III curve is probably the most unexpected. It shows life expectancy increasing with age up to 3 years of age, after which it declines. How can an older individual expect to live longer than a younger one? Because of high juvenile mortality. A newborn individual is unlikely survive its first year. However, individuals that *do* survive can expect to live a bit more than 3 additional years. Those that survive to 2 years of age can expect to live almost another 6 years.

This last pattern of survival and mortality brings up a common misinterpretation of demographic data. You may have heard that people in some region or society have high infant and juvenile mortality and short life expectancy. Sometimes people conclude from this that everyone in the society dies young and there are no old people. However, the type III pattern of survival and life expectancy should show you that this is not exactly the case. Once a person in reaches young adulthood, he or she may live many years more, and the oldest members of the society may be nearly as old as the oldest individuals in any other. It is true, however, that there will be proportionately fewer old people.

4. You should see that Dall Moutain Sheep have a type I survivorship curve, Song Thrushes a type II, and barnacles a type III. None of these will be as neat as the hypothetical examples given in the procedures, but they come close. Other populations may display a mixture of types. Human populations, especially in developing countries, often have high infant and juvenile mortality followed by low mortality until old age. Such curves have features of type III and type I survivorship.

5. Notice that the S_x values given in Figure 8 on p. 172 result in a type I survivorship curve. With the b_x values given, the net reproductive rate (R_0) is 1. The estimated and corrected values of r are 0. This indicates that the population is stable, and the members are exactly replacing themselves.

   If you shift reproduction earlier in the life cycle, by changing b_1 to 4.0 and all other b_x values to 0.0, you will see that R_0 and r increase. This occurs for two reasons. First, because reproduction occurs sooner, offspring appear sooner and begin reproducing sooner. Second, because survival is always a decreasing function of age, there are more individuals alive at the earlier age, and the same per capita fertility means more total offspring.

   If you shift reproduction later in the life cycle, by changing b_3 to 4.0 and all other b_x values to 0, you will see R_0 and r decrease. This is the mirror image of shifting reproduction to younger ages. That is, reproduction occurs later, so offspring appear later and begin reproducing later. Furthermore, there are fewer survivors to reproduce at the later age.

If you spread reproduction out over a longer time span by changing b_1, b_2, b_3, and b_4 to 1.0 and leaving b_0 at 0.0, you will see that the resulting values of R_0 and r are slightly larger than the original scenario (with $b_2 = 4.0$). However, the increase is much smaller than the increase that occurred when you shifted reproduction entirely to age 1. The reason is that some reproduction occurs earlier, which increases R_0 and r. However, much of the reproduction occurs later, decreasing R_0 and r. The net result is a slight increase.

The values given here are only examples; you can experiment with other numbers.

Another interesting thing to try is to figure out how many offspring an individual must produce to keep the population stable under various fertility schedules. This number of offspring is called **replacement fertility**—another statistic you may have heard. It is often said that the replacement fertility for human females is about 2.1. You may ask yourself, how does that depend on the ages at which women bear children and the number they bear at each age?

6. Try changing the S_x values given to those given in the table below, observing the effects on R_0 and r.

Table 1. Hypothetical survivorship schedules for investigating the effect of survivorship on population growth

Age (x)	S_x	Age (x)	S_x
0	1000	0	1000
1	500	1	250
2	250	2	125
3	125	3	100
4	0	4	0

Notice that the first set of S_x values in the table gives a type II survivorship curve, and the second set gives a type III curve.

If you now try the various fertility schedules described in the answer to Question 1, you will see somewhat different effects, depending on the survivorship schedule. Shifting reproduction earlier produces the greatest increase in R_0 and r in the type III survivorship schedule. This occurs because type III survivorship has the highest mortality in young ages, and so reproducing earlier means there are many more survivors to reproduce.

Shifting reproduction later decreases R_0 and r to in all three types of survivorship schedules, but most noticeably in type II. In the type I schedule, there is little mortality in middle ages, so delaying reproduction has little effect unless it is delayed to the very end of the life-span. In the type III schedule, most of the mortality has already occurred by the time reproduction starts, so delaying reproduction slightly has little effect. In the type II schedule however, the proportional mortality is constant across ages, so delaying reproduction has a greater effect.

Spreading reproduction out over a longer time span decreases R_0 and r in both type II and type III survivorship schedules, and the effect is greater in type III. This results from the lower number of survivors in the later reproductive ages. In type II and type III, this effect of delayed reproduction outweighs the effect or earlier reproduction, and results in a net decrease in R_0 and r.

As you did in analyzing the effects of changing fertility schedules, you may also ask yourself the effects of different survival schedules on replacement fertility.