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Research Article

# A Microsoft Excel program for bootstrap estimates of reproductive-life table parameters

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**Abstract:** Demographic parameters such as intrinsic rate of increase estimates are of main interest in a wide range of ecological researches. Two widely used uncertainty estimate techniques are bootstrap and jackknife methods. Bootstrap estimates are time-consuming processes that are impossible to use without a computer program. Unfortunately few programs, if any, have been developed for this task. In this study a guideline was offered to prepare a program in Microsoft Excel environment to carry out time-consuming calculations of reproductive life table data in a minute or two by repeatedly pressing a shortcut key.

**Keywords**: software, life-history parameters, uncertainty, resampling techniques

## Introduction

Reproductive-life table users well know that variance and uncertainty estimates of stable population growth parameters like intrinsic rate of population increase is not possible via traditional variance formulae. This is because each parameter is the result of plenty of calculations bearing all individuals of a cohort over a generation (Meyer *et al*. 1986; Carey, 1993; Ebert, 1999). So there is no replication per parameter to enter in variance formula. Some solutions were offered by scientists that (Ebert, 1999) divided them into two classes of Monte Carlo estimates and resampling or recombination methods. The latter group itself is divided into two separate procedures; one Jackknife, and the other Bootstrap technique. Meyer *et al*. (1986) prefer Jackknife to Bootstrap except in circumstances that data deviate from normality. In contrast some researchers (Huang and Chi, 2013; Ebrahimi *et al*., 2013; Yu *et al*., 2013) recommend using Bootstrap and leaving Jackknife procedure. But this technique is more difficult to use without a program. In Jackknife method number of replications is limited and is equal to original number of individuals of cohort. Hence it is possible for a user to exclude individuals from the original set of data and recalculate the parameters based on the original program in a short interval. But this is not true for bootstrap technique, because bootstrap includes at least 500 replications (Meyer *et al*., 1986). So we need an easier and more straightforward way to do random resampling from the original cohort for at least 500 times. In this article I focused on a guideline for writing a program in Microsoft Excel environment to resolve this problem.

## Materials and Methods

### Reference population

Because the main task of our article is training for writing a program for doing Bootstrap calculations, we start with a small hypothetical reproductive life table with 10 replications and

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20 ages (Table 1). In table 1 only reproduction of females was included and 0 has been inserted for no reproductive output of a female in a day and an empty cell appears after death. Let this hypothetical cohort be referred as "original or reference cohort or population".

**Table 1** Reproductive table of a hypothetical cohort.

| x | Replication | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 2 | 0 | 1 |
| 8 | 2 | 0 | 5 | 2 | 0 | 0 | 0 | 0 | 3 | 0 |
| 9 | 4 | 0 | 2 | 0 | 3 | 0 | 4 | 1 | 4 | 0 |
| 10 | 3 | 0 | 0 | 4 | 1 | 0 | 0 | | 0 | 3 |
| 11 | 0 | 0 | | 1 | 3 | 2 | 0 | | 1 | 7 |
| 12 | 2 | 0 | | 2 | 2 | 4 | 0 | | 2 | 2 |
| 13 | 1 | | | 0 | 3 | 8 | 2 | | 2 | 0 |
| 14 | 0 | | | 5 | 1 | 5 | 1 | | 1 | 4 |
| 15 | 0 | | | 2 | 0 | 2 | 0 | | 0 | 1 |
| 16 | 0 | | | 0 | | 1 | 0 | | | 2 |
| 17 | | | | 1 | | 0 | 0 | | | 0 |
| 18 | | | | 0 | | 0 | | | | 0 |
| 19 | | | | 2 | | | | | | 1 |
| 20 | | | | 1 | | | | | | |

**Computer program for analysis of life history parameters in Excel**

I assume that readers are familiar with Excel environment. So First let's insert the data in Excel worksheet. Open a new Excel file. For inserting data we need 11 columns (C) for replications plus age column "x". Moreover we need 22 rows (R) for age classes and number of females. So we will have an 11C × 22R table of reproduction entries in Excel. We need another table with the same dimensions for survival data *i. e*. life table. An easy way is copying the reproductive data and pasting it in a free space just beneath the previous table and replace all data by 1 that means female has been alive at that day. Subsequent empty cells correspond to zero that may imply as mortality. A further modification also was done in order to facilitate some actions in the future. The data were transposed (rotate and columns displayed as rows). For doing the final modification choose data series, copy them, select an empty area of cells then right click on the mouse button, click on "paste special" phrase and check the box behind the "Transpose" and confirm the request by clicking on "OK". We did these actions by pasting data in another worksheet (sheet 2). Now your worksheet must seem like Fig. 1.

When a female is chosen by a random manner in bootstrap resampling, all relevant data must be picked up together. This point increases the problem. I pursued the following solution to overcome this problem. In order to choose a random sample from females 1 to 10, use RANDBETWEEN function. A dialog box like Fig. 2 will appear that asks bottom and top number among which user wishes to search and choose a random number. Let's "Bottom" and "Top" tapes to be addressed to a determined cell rather than a numerical value to give the option of manual control of the data range to user.

You need to conduct this function for an arbitrary number of replications for example for n = 10 times. So in a free space just under the original data insert numbers 1 for bottom and 10 for top and in right hand cells, then run the "RANDBETWEEN" function. Your worksheet now resembles Fig. 3 but random numbers in cells B18 to B27 may be different. Structure of the function is displayed in formula bar, by double clicking on cell B18. Absolute cell addresses were used in both tapes of dialog box of Fig. 2 by pressing button F4 after entering the reference cells A14 and A16, so they appear as $A$14 and $A$16 in formula (Fig. 3).

Now we are going to pick up data related to the chosen females. Each female determined by a specific number of replications. In Excel there is a function as VLOOKUP (Fig. 4) that may refer to a series of reference data, choose a determined row referring to the specific

value, looking up among the data of the first left hand column and read and enter one of the data related to the mentioned row in one of the right hand cells chosen by user. For example in Fig. 4, the first blank rectangle in front of "Lookup_value" looks up for specific data in left hand column and finds it. You can insert directly a value such as 4 that tells Excel to find specific value 4 or the 4$^{th}$ female in reference population. But here we will address a cell with a random selection from 1 to 10, for example cell B18 in which RANDBETWEEN function has already been run. In order to have 10 random selections we run this function 10 times each time with a different address cell (B18 to B27). The second phrase "Table_array" refers to data array of reference population including also specific values or numbers of replications. In our example you may address data as cells A2 to V11. Because reference population is the same in all subsequent choices, so please use absolute address as $A$2:$V$11 in front of this phrase. The 3$^{rd}$ phrase "Col_index_num" refers to column within which the mentioned datum has been inserted. For example if you insert 1, 2, 3, … in front of this phrase, it will imply that go 1, 2, 3, … cells right hand and select datum in final cell. Thus Excel will select a data that its coordinates obtains by putting row addressed in the first tape together column addresses in the third one by seeking data array addressed in 2$^{nd}$ tape of dialog box of Fig. 4. Leave the 4$^{th}$ box blank. Press OK for confirming actions. Now the following address will appear in the cell C18 as well as formula bar:

= VLOOKUP($B$18;$A$2:$V$11;C1)

Finally we have to run this function in 10 successive rows, each time with a different address in front of the first tape. Choose all 10 rows together and drag and drop them to the right while absolute addresses were used in front of the first two tapes but the 3$^{rd}$ one allowed to increase one unit each time. The data of the first row (age x) were addressed at the 3$^{rd}$ tape.

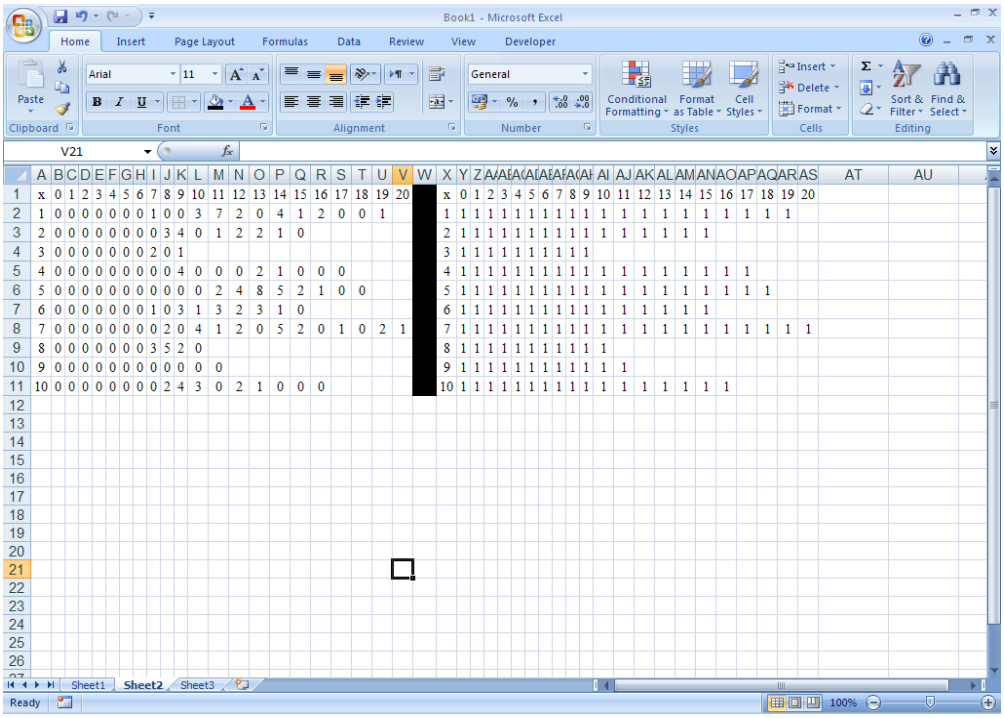


**Figure 1** Reproduction and life table data entered in an Excel worksheet and transposed for starting bootstrap calculations.

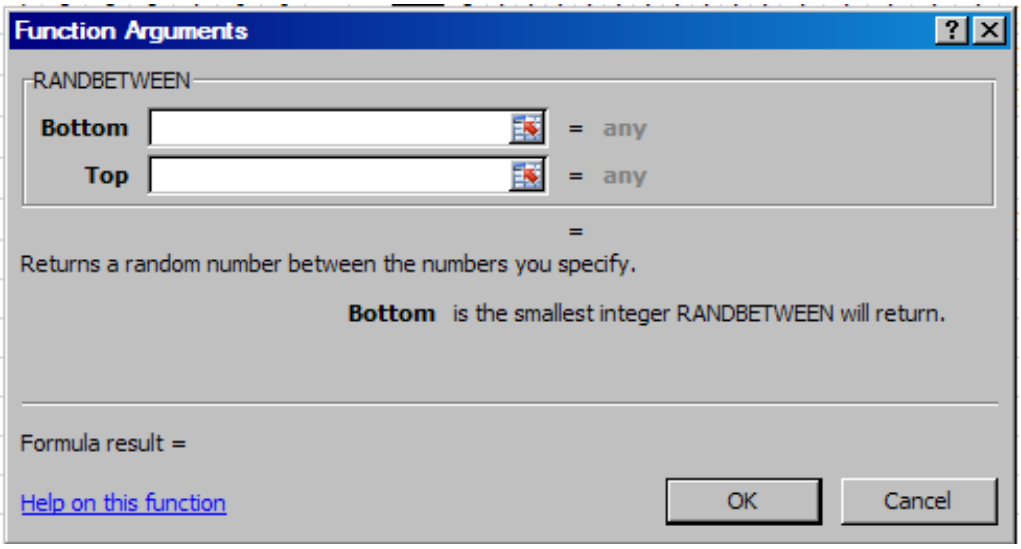


**Figure 2** Dialog box of the function "RANDBETWEEN" in Excel.

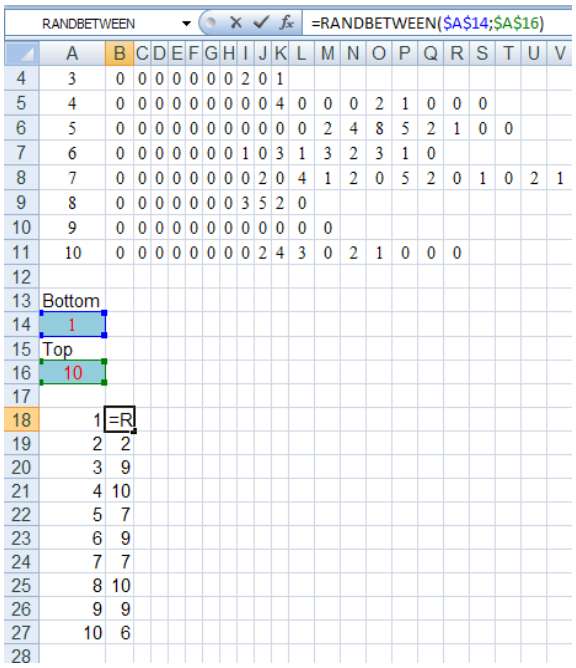


**Figure 3** Conducting the function of RANDBETWEEN in cells B18 to B27 and presenting the first cell in formula bar by clicking on cell B18.

The only change in processing survival data is referring to different cells ($X$2 to $AS$11 instead of $A$2 to $V$11). As soon as random data is selected you may choose different combination of individuals by successive pressing of button F9. Each time you will see different random numbers in column B (cells B18 to B27), but each time you will find whole data belonging to the selected females in front of these numbers. Let's call this table "recombined table".

We have to write our program for larger possible numbers of replications. Suppose 100 replications are foreseen in our program, but we are concerned with a cohort as large as 45 individuals. Therefore we further need to exclude extra replications *e. g.* replications 46 to 100. We will do it by conducting IF function (Fig. 5). The first phrase in IF function lets us do a logical test, the second one lets us do an action to check if the logical test is true; otherwise, you can do another action in the 3rd tape. We ask Excel to insert 0 if a datum is an extra one, otherwise insert the datum itself. These actions will be done in a third table "exclusion table". A specific number between 1 and 10 is assigned to each row in recombined table. If for example we are working with a cohort of size 7, data in rows 8, 9 and 10 must be excluded. If number of rows is larger than sample size displayed in cell A16, then the data must be considered as null (0) whether for survival or reproduction. Otherwise the data will be directly inserted in the third table. Use absolute address for $A$16.

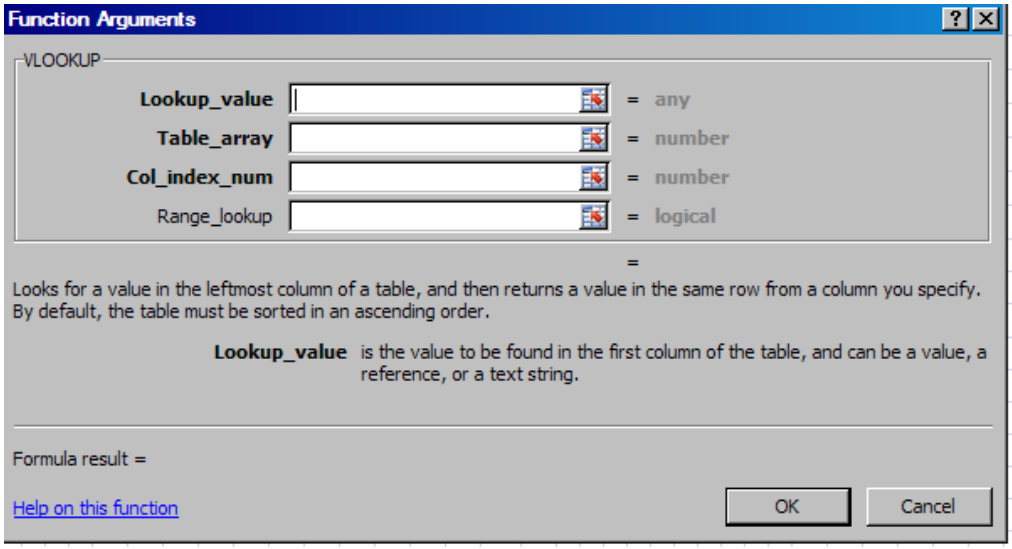


**Figure 4** Dialog box of VLOOKUP function in Excel.

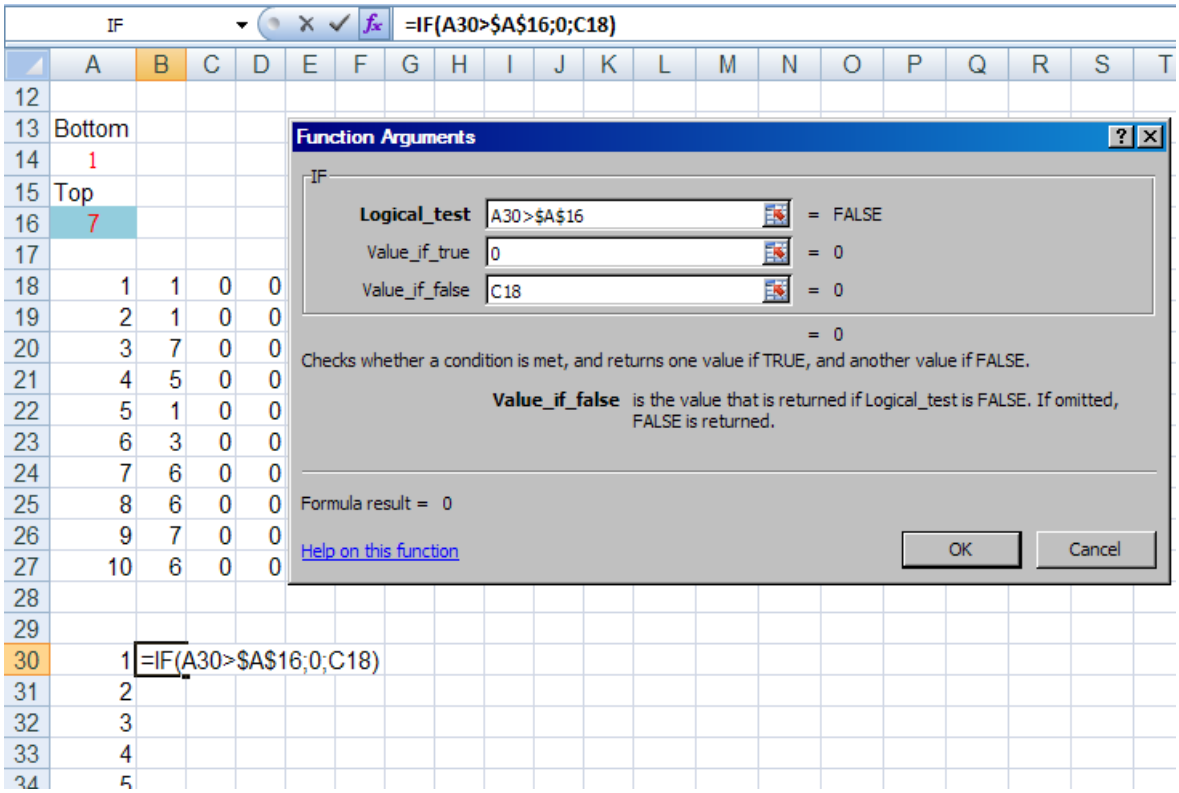


**Figure 5** Dialog box of function IF in Excel.

**Calculations of life history parameters**

Hereafter we will be concerned with parameter estimations of reproductive-life tables. Our calculations will proceed through the third table. The row 41 was assigned for pivotal age (x + 0.5) by adding value 0.5 to cell values in row 1 and choosing caption of x + 0.5 at cell A41 (Fig. 6). The second

function is $B_x$ that represents total reproduction of cohort at age x summed over an age class for all 10 replications. Whenever a datum is excluded or an individual dies, 0 will be contributed in the summation. The third row is assigned to $N_x$ or number of females alive at age x. These values are obtained by summing up survival data over each age for all replications. These sets of data (pivotal age, $B_x$ and $N_x$) constitute the raw data for subsequent calculations. The first function is age-specific survival rate ($l_x$). Mind that $l_x$ may be obtained by dividing each $N_x$ to $N_0$. Value of $N_0$ in our program appears in cell B43 (Fig. 6). So formula = B43/$B$43 should be inserted in cell B44 and dragged to right and dropped in cell V44. According to Carey (1993) $L_x$ rather than $l_x$ is used in calculations because it is assumed that all events occur at pivotal age rather than at its onset. So we need to calculate $L_x$ values as average of the two successive $l_x$ values in a distinct row. Therefore you may insert = (B44 + C44)/2 in cell B45 and drag it to right as long as previous row and then drop. As mentioned earlier, $B_x$ represents overall number of eggs laid by all females at age x and because this number of eggs are deposited by $N_x$ females, it seems adequate to divide $B_x$ values by $N_x$'s, but two further problems need to resolve. First problem arises when individuals with shorter life spans are selected by chance. This will lead to values of 0 in denominator of higher age classes because $N_x$ is zero. A conditional IF function is needed again for overcoming the problem. In this function it is asked if the data in $N_x$ row (row 43) is 0; if true then 0 is inserted, otherwise the value of the fraction $B_x/N_x$ will be inserted For the first cell the function will be as = IF(B43 = 0; 0; B42/B43) and for subsequent ones only drag and drop is used. The second correction is averaging two successive values for the same reason already mentioned for $L_x$. The divisions and further averaging has been done in rows 46 and 47 respectively. In order to calculate $m_x$ values we need be aware of age-specific sex ratios $S_x$. Often sexing the progeny at birth is impossible. So a common sex ratio of 0.5 is a logical value for many bisexual organisms that may apply for all ages. If significant deviations from 0.5, however, is present we may use the observed sex ratios instead of 0.5. Let cell B14 be assigned for common sex ratio. Hence in row 48 run = B47*$B$14 for $m_0$ and drag and drop it for completing the row.

Prior to solving Euler-Lotka equation we need two calculation rows, one for $L_xm_x$ and the other for (x + 0.5) $L_xm_x$. These values are obtained easily by multiplication, so further explanation is avoided. Sum of the recent columns as well as values of $lnR_0$, $T_c$ and $r_c$ are displayed in cells B52 to B56 (Fig. 6). Because $r_c$ is near to $r_m$, it is a good starting point for solving Euler-Lotka equation.

There are several methods like interpolation (Birch, 1948), Newton-Raphson algorithm (Carey, 1993; Ebert, 1999), projection (Ebert, 1999) and trial and error (Ebert, 1999) for estimating $r_m$. I followed Newton-Raphson algorithm owing to its high accuracy. This algorithm consists of a series of iterative calculations of Euler-Lotka equation by trying an initial value of $r_i$, solving the equation and calculating the first derivative of the equation, a value of $r_{i+2}$ nearer than $r_i$ to $r_m$ is reached using eq. 1 below:

$r_{i+1} = r_i - f(r)/f'(r)$ (eq. 1)

This action is repeated again by trying the new value. The f (r) = 0 is the same Euler-Lotka equation rearranged by subtracting from both sides by unity to obtain a function leading to 0 per $r_m$ value (eq. 2):

$$f(r) = \sum e^{-r_m x} l_x m_x - 1 = 0 \quad \text{(eq. 2)}$$

and f'(r) is its first derivative (Carey, 1993; Ebert, 1999). The nearer $r_i$ to $r_m$, the fewer iteration. This is why we start by $r_c$. Often four or five iterations are adequate, but we continue for 10 iterations to insure rare events. We use a couple of rows for calculations of each round of iterations; the first one for Euler-Lotka

equation and the second one for its derivative (Fig. 7). As a result 20 rows (58-77) are assigned for these calculations. Because all pairs of these rows are similar in structure and differ only in reference cell for initial number of $r_i$, so let's be concerned only with calculations of the first iteration. In column B (cells B58 to B77) we just insert row captions (Fig. 7), and calculations begin from column C. Our task is to make an input of an initial $r_i$ value ($r_c$ in this case) in eq. 2 and get an output as $r_{i+1}$. Exponential phrase in eq. 2 will repeat in all cells of row 58 from C58 to W58 by absolute addressing to cell B56 ($r_c$ value) and changing the other components by age. Remember that x + 0.5 and $L_x$ will be used instead x and $l_x$ respectively. Exponential function in Excel is EXP, hence formula in cell C58 will appear as = EXP(-$B$56*B41)*B49 that commands to Excel to pick up minus value in cell B56 multiply it by value in cell B41, give exponent of the result, then multiply the exponent value by value in cell B49. Drag and drop this cell content to the right up to cell W58. In cell X58 sum up all these values. Herewith you run ∑ in eq. 2. You can subtract unity in a separate cell but it preferably should be combined with the next step that will be defined soon. Let derivative calculations be done in row 59. Only multiply contents of previous row by negative value of x + 0.5 or contents of corresponding cells in row 41. Sum of the recent row is also required, that we obtained it in column Y, to avoid confusion. Now we are going to calculate new $r_{i+1}$ in cell A59 using eq. 1. The obtained value is displayed by $r_1$ which is calculated in cell A59. In this cell formula = B56-((X58-1)/(Y59)) has been used where B56 is the value of $r_c$, X58 is the value of Euler-Lotka equation solved for $r_c$ and Y59 is the value of first derivative. Now $r_1$ in cell A59 is a better estimate than $r_c$ for $r_m$ and in turn it is the starting point of the second iteration. In the second set of calculations, reference cell for $r_i$ value will be A59 and the remaining steps are the same. Please look at green right column in Fig. 7. Right hand of Euler-Lotka equation became unity at fourth iteration. Difference between $r_3$ and $r_{10}$ is actually zero. The difference of the two final $r_i$'s has been shown in blue in the left bottom cell A80. As a result $r_m$-value is 0.184 $d^{-1}$ in a random sample taken from the original population. Calculation of birth rate (row 82) is similar to Euler-Lotka equation so we avoid further explanation.

B56 =B54/B55

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |
| 40 | | | | | | | | | | | | | | | | | | | | | | | | |
| 41 | x+.5 | 0.5 | 1.5 | 2.5 | 3.5 | 4.5 | 5.5 | 6.5 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.5 | 15.5 | 16.5 | 17.5 | 18.5 | 19.5 | 20.5 | | |
| 42 | Bx | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 14 | 9 | 16 | 12 | 18 | 18 | 5 | 3 | 1 | 0 | 3 | 1 | | |
| 43 | Nx | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 5 | 5 | 3 | 2 | 1 | | |
| 44 | lx | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.71 | 0.71 | 0.43 | 0.29 | 0.14 | | |
| 45 | Lx | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.86 | 0.71 | 0.57 | 0.36 | 0.21 | 0.07 | | |
| 46 | Mx | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.3 | 2 | 1.29 | 2.29 | 1.71 | 2.57 | 2.57 | 0.71 | 0.6 | 0.2 | 0 | 1.5 | 1 | | |
| 47 | | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 1.1 | 1.6 | 1.79 | 2 | 2.14 | 2.57 | 1.64 | 0.66 | 0.4 | 0.1 | 0.75 | 1.25 | 0.5 | | |
| 48 | mx | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.6 | 0.8 | 0.89 | 1 | 1.07 | 1.29 | 0.82 | 0.33 | 0.2 | 0.05 | 0.38 | 0.63 | 0.25 | | |
| 49 | Lxmx | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.2 | 0.6 | 0.8 | 0.89 | 1 | 1.07 | 1.29 | 0.82 | 0.28 | 0.14 | 0.03 | 0.13 | 0.13 | 0.02 | | |
| 50 | xLxmx | 0 | 0 | 0 | 0 | 0 | 0 | 0.7 | 1.3 | 4.9 | 7.8 | 9.38 | 11.5 | 13.4 | 17.4 | 11.9 | 4.37 | 2.36 | 0.5 | 2.48 | 2.61 | 0.37 | | |
| 51 | | | | | | | | | | | | | | | | | | | | | | | | |
| 52 | ΣLxmx | 7.48878 | | | | | | | | | | | | | | | | | | | | | | |
| 53 | ΣxLxmx | 90.9099 | | | | | | | | | | | | | | | | | | | | | | |
| 54 | ln R0 | 2.01341 | | | | | | | | | | | | | | | | | | | | | | |
| 55 | Tc | 12.1395 | | | | | | | | | | | | | | | | | | | | | | |
| 56 | rc | 0.16586 | | | | | | | | | | | | | | | | | | | | | | |
| 57 | | | | | | | | | | | | | | | | | | | | | | | | |

**Figure 6** Fecundity life table of a random sample of seven individuals taken from a reference population presented in table 1 excluding last three replications.

A59 =B56-((X58-1)/(Y59))

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | rc | 0.174198 | | | | | | | | | | | | | | | | | | | | | | |
| 57 | | | | | | | | | | | | | | | | | | | | | | | | |
| 58 | r1 | Lotka1 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.07 | 0.09 | 0.15 | 0.21 | 0.17 | 0.11 | 0.13 | 0.09 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 0.001 | 1.1172 |
| 59 | 0.183469579 | derivative1 | 0 | 0 | 0 | 0 | 0 | 0 | -0.22 | -0.5 | -0.8 | -1.4 | -2.2 | -1.9 | -1.4 | -1.7 | -1.4 | -0.5 | -0.2 | -0.05 | -0.18 | -0.17 | -0.02 | |
| 60 | r2 | Lotka2 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1.00621 |
| 61 | 0.184017972 | derivative2 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.15 | -0.02 | |
| 62 | r3 | Lotka3 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1.00002 |
| 63 | 0.184019755 | derivative3 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 64 | r4 | Lotka4 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 65 | 0.184019755 | derivative4 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 66 | r5 | Lotka5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 67 | 0.184019755 | derivative5 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 68 | r6 | Lotka6 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 69 | 0.184019755 | derivative6 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 70 | r7 | Lotka7 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 71 | 0.184019755 | derivative7 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 72 | r8 | Lotka8 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 73 | 0.184019755 | derivative8 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 74 | r9 | Lotka9 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 75 | 0.184019755 | derivative9 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 76 | r10 | Lotka10 | 0 | 0 | 0 | 0 | 0 | 0 | 0.03 | 0.06 | 0.08 | 0.14 | 0.19 | 0.15 | 0.1 | 0.11 | 0.08 | 0.03 | 0.01 | 0.003 | 0.01 | 0.01 | 8E-04 | 1 |
| 77 | 0.184019755 | derivative1 | 0 | 0 | 0 | 0 | 0 | 0 | -0.21 | -0.5 | -0.7 | -1.3 | -2 | -1.7 | -1.2 | -1.5 | -1.2 | -0.4 | -0.2 | -0.05 | -0.15 | -0.14 | -0.02 | |
| 78 | | | | | | | | | | | | | | | | | | | | | | | | |
| 79 | r10-r9 | | | | | | | | | | | | | | | | | | | | | | | |
| 80 | 0 | | | | | | | | | | | | | | | | | | | | | | | |
| 81 | | | | | | | | | | | | | | | | | | | | | | | | |

**Figure 7** Newton-Raphson method of iterative calculations of Euler-Lotka equation and its derivative for stepwise reaching to $r_m$-value.

We need to do 1000 trials for 1000 bootstrap replications. Let's assign rows 84 and 85 for parameter captions and parameter values of our random sample respectively. We wish to run a sampling by pressing F9 button, copy and paste parameter values to a blank row and then take another sample, move downward and copy and paste again the new series of parameter estimations and go on till the 1000$^{th}$ sample. This is a time consuming task but we can define a Macro with a shortcut key to do all sampling and copy paste actions by pressing the shortcut key. Assign cells A86 to A1085 as captions of each trial. Name them as Trial 1, Trial2 … Trial 1000. You can use drag and drop ability for this task. Also assign cells B84 to I84 to parameters captions respectively as GRR, $R_0$, $r_m$, λ, b, d, T, and DT. Row 85 just behind the captions is where random samples exhibit and just behind it copy and paste results are displayed. Now you need to record a Macro or short program to do copy and paste tasks in front of captions Trial 1 to Trial 1000. You need first to assure that Macro recording tool is installed. If however it is not installed you need to follow these steps. First click on Office button. It appears like this in Excel 2007, but may be in other shapes in other versions (2010, 2013 or 2016). Click on "Excel options" behind Office box, then select Popular in left hand rectangle and finally put a checkmark behind phrase: "Show Developer tab in the Ribbon" in right hand box under "Top options for working with Excel" bar. Confirm the action by clicking on "OK". Now a new menu as "Developer" appears among the other menus. Now you can record a Macro. Before saving your Macro you need a further change. You need to change calculations to manual position. Once again click on Office button. Select "Formulas" and change workbook calculations from Automatic to Manual under "Calculation options" bar. Press "OK" and go back to "Developer" menu and start recording Macro by clicking on it. A dialog box like Fig. 8 will open and from this moment on all actions you do are recording.

Change the default name of Macro1 to "Bootstrap" and define a shortcut key as Ctrl + b. You can also optionally add a description for your Macro. Press Ok and go on. Select a new sample by pressing F9. Then copy data in cells B85 to I85. We wish to paste only values not the formulae themselves. Also we wish to paste "next row" each time. So we must first move cursor one cell downward then run paste. For the first task, go to Home menu, choose "Find

and Select" option under submenu "Editing" and click on the first option "Find". Dialog box like Fig. 9 will appear. Leave "Find what" box blank. Select the second option "Replace". Click on button "Options >>". Now the dialog box must appear as Fig. 10.

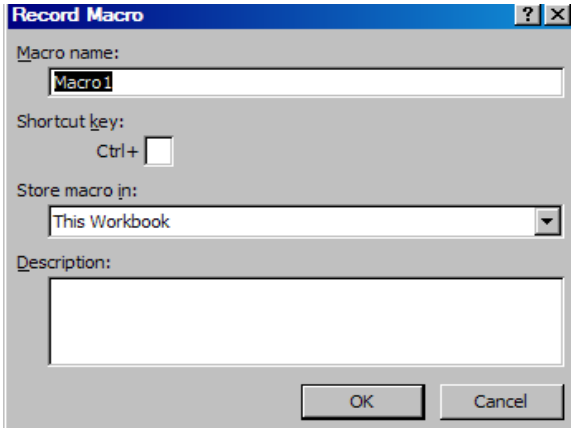


**Figure 8** Dialog box of "Record Macro".

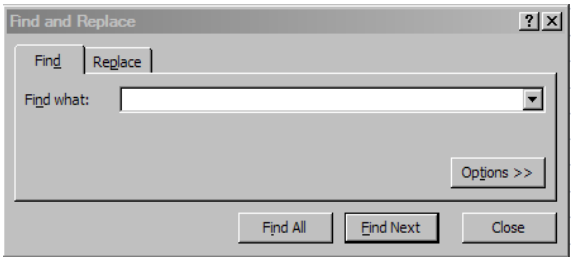


**Figure 9** Dialog box of Find and Replace.

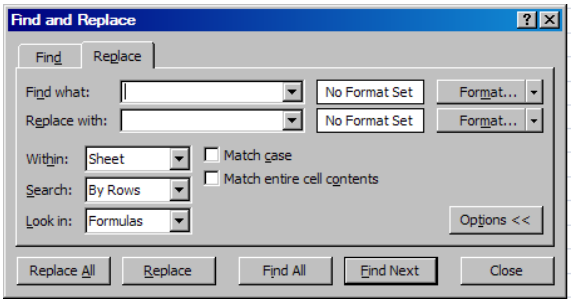


**Figure 10** Second sheet of dialog box "Find".

Change the phrase "By Rows" to "By Columns" in front of "Search" option. Click on "Find Next" button and exit. You can now observe that cursor has been moved one cell downward. Now right click and choose paste special option put checkmark behind value and confirm action by "OK". All data in row 85 now is copied in lower row. Stop recording Macro in menu "Developer". Before using shortcut key for successive trials don't forget to change calculation options once again to automatic position by following similar orders as mentioned earlier. Now keep and hold button Ctrl in key board and press sequentially button "b" to take new random samples and copying and pasting them in successive rows. In a span of time as short as 3 min you can run 1000 trials.

As a final step you need to calculate mean and standard error of 1000 trials for all eight parameters. I also presented minimum and maximum amounts of each parameter by conducting MIN and MAX functions. Remember that variance of the 1000 trials is variance of the mean and then standard deviation of mean or those of the trials is the same SE (Fig. 11).

B1088 =MIN(B86:B1085)

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1073 | Trial988 | 9.043 | 6.12 | 0.1699 | 1.185 | 0.228 | 0.058 | 10.656 | 4.0785 | | |
| 1074 | Trial989 | 8.464 | 7.86 | 0.1867 | 1.205 | 0.237 | 0.05 | 11.042 | 3.7118 | | |
| 1075 | Trial990 | 11.19 | 10.2 | 0.1876 | 1.206 | 0.236 | 0.048 | 12.384 | 3.694 | | |
| 1076 | Trial991 | 8.536 | 7.59 | 0.1677 | 1.183 | 0.21 | 0.042 | 12.085 | 4.1327 | | |
| 1077 | Trial992 | 9.179 | 5.65 | 0.1538 | 1.166 | 0.215 | 0.062 | 11.264 | 4.5081 | | |
| 1078 | Trial993 | 8.012 | 6.57 | 0.1745 | 1.191 | 0.228 | 0.053 | 10.788 | 3.9723 | | |
| 1079 | Trial994 | 7.5 | 6.19 | 0.1657 | 1.18 | 0.216 | 0.05 | 11.001 | 4.1838 | | |
| 1080 | Trial995 | 10.44 | 7.3 | 0.1718 | 1.187 | 0.227 | 0.056 | 11.576 | 4.0351 | | |
| 1081 | Trial996 | 9.349 | 7.56 | 0.1785 | 1.195 | 0.23 | 0.051 | 11.334 | 3.8838 | | |
| 1082 | Trial997 | 8.75 | 7.82 | 0.1753 | 1.192 | 0.22 | 0.045 | 11.734 | 3.9551 | | |
| 1083 | Trial998 | 6.85 | 5.28 | 0.1553 | 1.168 | 0.212 | 0.056 | 10.716 | 4.4624 | | |
| 1084 | Trial999 | 8.375 | 5.1 | 0.148 | 1.16 | 0.207 | 0.059 | 11.009 | 4.6819 | | |
| 1085 | Trial1000 | 8.602 | 6.7 | 0.1642 | 1.178 | 0.213 | 0.048 | 11.582 | 4.2219 | | |
| 1086 | | | | | | | | | | | |
| 1087 | | **GRR** | **R0** | **rm** | **λ** | **b** | **d** | **T** | **DT** | | |
| 1088 | **Min** | **3.357** | **2.82** | **0.1021** | **1.108** | **0.151** | **0.04** | **9.9011** | **3.5523** | | |
| 1089 | **Max** | **11.89** | **10.4** | **0.1951** | **1.215** | **0.246** | **0.068** | **12.639** | **6.7856** | | |
| 1090 | **Mean** | **8.981** | **7.18** | **0.1712** | **1.187** | **0.222** | **0.051** | **11.401** | **4.0728** | | |
| 1091 | **$S^2x$** | **1.572** | **1.66** | **0.0002** | **2E-04** | **1E-04** | **2E-05** | **0.2133** | **0.1086** | | |
| 1092 | **SE** | **1.254** | **1.29** | **0.0127** | **0.015** | **0.012** | **0.004** | **0.4618** | **0.3296** | | |
| 1093 | | | | | | | | | | | |

**Figure 11** Summary statistics of the 1000 bootstrap estimates of eight life history parameters of table1.

### *3. Analysis of real data*

In order to examine our program, we analyzed two series of data. 1) Hypothetical population mentioned earlier. 2) Data available by Moshtaghi *et al*. (2016) collected in laboratory on an artificial diet of grapevine moth *Lobesia botrana* (Lep., Tortricidae).

An extended version of the program including 200 age classes and 100 replications is available that was used for these estimations.

## Results and Discussion

The above program was used to estimate two series of life history data:

1) Hypothetical data mentioned earlier in this article: Table 2 shows the results of Jackknife and bootstrap estimates as well as estimates of original population without recombination. No distinct trend is seen in SE estimated in the two methods. It seems that estimates of both methods are broadly logical and similar to each other and the original population.

2) Moshtaghi *et al*. (2016) used both Jackknife and bootstrap method using our program for estimating the same parameters of three cohorts of grapevine moth *Lobesia botrana* in three sets of temperatures. The results are presented in Table 3. The results are even closer in the two methods by these series of data compared with the hypothetical data presented in table 2.

**Table 2** Jackknife, bootstrap and original estimates of hypothetical data available in Table 1.

| Entries | | GRR | $R_0$ | $r_m$ | λ | b | d | T | DT |
|---|---|---|---|---|---|---|---|---|---|
| No recombined | | 8.73 | 6.0921 | 0.166 | 1.181 | 0.1834874 | 0.017 | 10.857 | 4.16 |
| Jackknife | Min | 2.69 | 0.025 | 0.074 | 1.072 | 0.1143161 | -9E-04 | 7.4916 | 2.92 |
| | Max | 17.3 | 11.213 | 0.215 | 1.238 | 0.2300839 | 0.047 | 14.404 | 6.34 |
| | Mean | 9.18 | 6.0864 | 0.168 | 1.182 | 0.1840587 | 0.0166 | 10.901 | 4.11 |
| | SE | 1.42 | 1.1919 | 0.015 | 0.017 | 0.0110379 | 0.0052 | 0.6157 | 0.36 |
| Bootstrap | Min | 3.82 | 2.548 | 0.094 | 1.098 | 0.1574092 | 0.0426 | 8.6218 | 3.52 |
| | Max | 12.6 | 9.6629 | 0.197 | 1.217 | 0.2587049 | 0.0705 | 12.442 | 7.4 |
| | Mean | 8.41 | 6.0678 | 0.165 | 1.179 | 0.2192626 | 0.0545 | 10.820 | 4.25 |
| | SE | 1.31 | 1.1574 | 0.016 | 0.019 | 0.0164046 | 0.0047 | 0.5557 | 0.47 |

**Table 3** Comparison of jackknife and bootstrap estimates of life table parameters of the grapevine moth *Lobesia botrana* reared on an artificial diet. Data contributed by Moshtaghi *et al*. (2016).

| Population parameters | Variance Estimation Technique (Mean ± SE)[a, b] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Original | | | Jackknife | | | Bootstrap | | |
| | 20 ± 1 ºC | 25 ± 1 ºC | 30 ± 1 ºC | 20 ± 1 ºC | 25 ± 1 ºC | 30 ± 1 ºC | 20 ± 1 ºC | 25 ± 1 ºC | 30 ± 1 ºC |
| Gross reproductive rate (GRR) (offspring) | 24.47 | 55.47 | 12.40 | 24.44 ± 0.64b | 55.47 ± 2.26a | 12.40 ± 0.73c | 24.50 ± 0.63b | 55.54 ± 2.19a | 12.38 ± 0.69c |
| Net reproductive rate ($R_0$) (offspring) | 7.87 | 22.99 | 4.09 | 7.87 ± 1.51b | 22.98 ± 3.37a | 4.09 ± 0.77b | 7.83 ± 1.47b | 23.00 ± 3.35a | 4.06 ± 0.77c |
| Intrinsic rate of increase ($r_m$) ($day^{-1}$) | 0.0183 | 0.0719 | 0.0386 | 0.0184 ± 0.0017c | 0.0723 ± 0.0036a | 0.0391 ± 0.0052b | 0.0180 ± 0.0017c | 0.0717 ± 0.0034a | 0.0379 ± 0.0054b |
| Finite rate of increase (λ) ($day^{-1}$) | 1.0184 | 1.0746 | 1.0394 | 1.0186 ± 0.0017c | 1.0749 ± 0.0036a | 1.0399 ± 0.0054b | 1.0182 ± 0.0018c | 1.0744 ± 0.0037a | 1.0386 ± 0.0056b |
| Mean generation time (T) (day) | 113.02 | 43.55 | 36.50 | 113.02 ± 0.20a | 43.55 ± 0.12b | 36.49 ± 0.27c | 113.03 ± 0.19a | 43.55 ± 0.11b | 36.51 ± 0.25c |
| Doubling time (DT) (day) | 37.96 | 9.63 | 17.94 | 37.29 ± 3.61a | 9.57 ± 0.45b | 17.39 ± 2.46b | 38.81 ± 4.13a | 9.68 ± 0.48c | 18.74 ± 3.23b |
| Instantaneous birth (b) | 0.0385 | 0.1159 | 0.0894 | 0.0384 ± 0.0023c | 0.1164 ± 0.0055a | 0.0886 ± 0.0055b | 0.0386 ± 0.0024c | 0.1162 ± 0.0055a | 0.0896 ± 0.0059b |
| Intrinsic death rate (d) | 0.0202 | 0.044 | 0.0508 | 0.0200 ± 0.0035b | 0.0442 ± 0.0076a | 0.0495 ± 0.0083a | 0.0206 ± 0.0036c | 0.0444 ± 0.0077b | 0.0517 ± 0.0089a |

a) Sample size of grapevine moth is n = 120 for original and jackknife estimation and n = 1000 for bootstrap estimation.

b) Means followed by different letters within a row, separately for jackknife and bootstrap method, were significantly different at $P < 0.05$ (Tukey HSD test).

In this article we focused on sampling from a reference cohort many times to provide a bootstrap estimate of 1000 replications. This is a

difficult task because it needs extraordinarily great calculations. Donovan and Welden (2002) offered a guideline for random bootstrap samplings from a reference population to examine central limit theorem in statistical context. Their program largely was used in preparing the present program, but we tackled with one more complicated problem. They did sampling among a determined number of identities that each represented an attribute of a live organism. For example a sample consisted of a population of stem length of a plant species. So each time they took a random sample from a population with determined values of stem length. In our program however there was no determined measure of a variable for an individual to choose as random. Rather there are individuals with a series of conjunct data all of which must be chosen simultaneously to constitute age specific survival and reproduction data of an individual. The same series of data must be taken from many individuals of the cohort to construct a random cohort. Therefore we had to apply a common random number of individuals for all series of data belonging to different age classes of an individual. An expanded version of program including 100 replications and 200 age classes was used for the more realistic situations of Moshtaghi *et al.* (2016) data. We believe that such dimensions meet requirements of majority of entomological studies. This program also can be extended to cover age-stage two sex life table data (Chi and Liu, 1985), but is deliberately prepared for traditional female-cohort life table analyses, to provide needs of users whose data are in female-cohort framework and hence have to ignore twosex-MSChart (Chi, 2013).

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# برنامه‌ی رایانه‌ای برای تخمین پارامترهای جدول زندگی تولیدمثلی در محیط مایکروسافت اکسل

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**چکیده:** پارامترهای دموگرافیک نظیر نرخ ذاتی افزایش جمعیت در بسیاری از پژوهش‌های اکولژیک از توجه زیادی برخوردارند. دو روش پر استفاده در تخمین عدم قطعیت این پارامترها روش‌های بوتسترپ و جکنایف هستند. برآوردهای بوتسترپ وقت‌گیر می‌باشند که بدون یک برنامه رایانه‌ای قابل محاسبه نیستند. متأسفانه برنامه‌های رایانه‌ای چندان برای این منظور توسعه نیافته‌اند. در این بررسی، راهنمایی برای تهیه‌ی یک برنامه‌ی رایانه‌ای در محیط مایکروسافت اکسل ارایه شده که محاسبات وقت‌گیر جدول‌های زندگی تولیدمثلی را با فشار دادن مکرر یک دگمه‌ی میانبر ظرف یکی دو دقیقه عملی می‌سازد.

**واژگان کلیدی:** نرم‌افزار، پارامترهای جدول زندگی، عدم قطعیت، روش‌های نمونه‌گیری مجدد