A practical guide to the management and analysis of survivorship data from radio-tracking studies

Hugh A. Robertson and Ian M. Westbrooke

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A practical guide to the management and analysis of survivorship data from radio-tracking studies

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ABSTRACT

Radio-telemetry studies allow the accurate measurement of the survivorship of many vertebrates, without many of the mathematical problems associated with capture-recapture analysis using markers such as bands, tags or toe-clips. The assumptions involved in the analysis of radio-telemetry data are described and rules are given for the consistent handling and analysis of data. Some examples of different survivorship estimates are given from ongoing studies of the threats to brown kiwi (*Apteryx mantelli*) in Northland, New Zealand, and from a published study of the survival of kereru (*Hemiphaga novaeseelandiae*). From the kiwi study, we give a sample Excel spreadsheet for the storage of raw data and for processing and transferring them to the SPSS statistical package to carry out survival analysis. We provide worked examples in Excel for the calculation of survivorship rate using simple methods. We also give a worked example in both Excel and SPSS for the Kaplan-Meier procedure and for testing differences in survival between two or more groups of individuals using a log-rank (Mantel-Haenszel) test. Under certain circumstances, these methods can be used to estimate survivorship, and compare survival in two or more groups of animals (or plants) marked in other ways.

Keywords: Excel, Kaplan-Meier, log-rank (Mantel-Haenszel) test, Mayfield method, product-moment, survival analysis

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1. Introduction

Conservation managers often aim to maintain or enhance populations of threatened species and / or reduce populations of pest species. In any animal population, fluctuations in the number of individuals result from changes in four different components of life history: birth rate, death rate, immigration and emigration. It is useful for conservation managers to be able to measure or estimate these four variables for threatened species and pest species alike. For example, in New Zealand managers aim to increase birth rate and / or decrease death rate of kiwi by increasing the death rate (through trapping or poisoning) of pest species such as possums, stoats and ferrets.

This paper was written in response to requests for advice from conservation managers in the Northland and West Coast Conservancies of the Department of Conservation (DOC) who are collecting survivorship data on kiwi through radio-tracking studies. We assume a basic knowledge of mathematics, and do not go into the mathematical theory behind the tests used, but we provide some key references that give that background for those who are interested. We also assume an ability to use Excel spreadsheets, but a copy of an Excel workbook at hand with real or dummy data will enhance the understanding of this paper. The aim has been to provide a practical guide to help field workers and researchers to record and analyse data used to calculate the death rate and hence longevity of animals from radio-telemetry data. Some of the mathematics used here can be more generally applied to data from studies of animals (or plants) marked in different ways, where individuals are checked very regularly.

2. Background

2.1 SURVIVAL RATES

The term ‘survival rate’ is usually used as a more positive expression than death rate or mortality rate. Survival rate, s, is the complement of the death or mortality rate, m, i.e. $s = 1 - m$. For example, if 70% of kiwi survive from one year to the next ($s = 0.7$), then 30% have died ($m = 0.3$). The probability that an animal survives may vary with individual characteristics such as age, sex, size and colour, or as a function of external variables such as management regime, habitat type, exposure to predation, population density, weather or season. It is often useful for conservation managers to compare survival rates between two or more different groups of individuals. For example, comparisons can be made between survival in treatment and non-treatment areas, or between males and females (a population may be in grave danger even though the overall survival rate appears reasonable, if there is a very low number of individuals of one gender).

2.2 METHODS AVAILABLE FOR CALCULATING SURVIVAL

There is a large body of scientific literature describing methods for estimating the survivorship of animals (and plants), much of it derived from medical and engineering studies. The simplest method (survivorship = number of survivors/ number at start) is used when the entire initial population is marked (or otherwise known); immigration and emigration are impossible (e.g. some birds on islands, plants in a quadrat); all surviving animals or plants can be relocated with confidence at fixed intervals thereafter; and all individuals have an equal chance of surviving from one time interval to the next. Because real life is not usually that simple, and all four conditions are seldom met simultaneously, a number of complex mathematical methods have been developed for the analysis of capture-recapture / resighting data when only part of the population is marked, immigration and emigration are possible, when sampling intervals are irregular and when chances of resighting or survival vary between individuals (for reviews and an introduction to the literature, see Clobert & Lebreton 1991; Lebreton et al. 1992). All methods include one or more assumptions, such as that the animals are equally likely to be captured and then recaptured / resighted; marked animals are not affected by being marked; or, for some methods, the population is closed (no immigration or emigration). The relatively recent development of radio-telemetry to mark animals removes the need for some of these assumptions or allows assumptions to be better examined. As a method for the field, we believe that radio-telemetry provides the best available tool to achieve the ideal situation of being able to follow individual wild animals from birth through to death, enabling researchers to record the outcome of each of the animal's breeding attempts, and to record movements and social behaviour during its lifespan. The intensive study of a relatively small sample of individuals can provide answers to a number of conservation management questions more readily than alternative approaches, such as a broader mark-recapture study.

2.3 RADIO-TELEMETRY

Radio-telemetry is an unrivalled technique for determining the movements, home-range and habitat use of animals in the wild. It is also proving to be an exceptionally useful technique for studying the survival of wild animals. A miniature radio-transmitter is attached to a study animal by a harness, glue or sutures. By using an aerial and receiver tuned to the correct frequencies, researchers can track the animal manually, by automated tracking stations or by satellite, and its location and / or behaviour can be noted. Mortality transmitters emit a different signal (e.g. increased pulse rate) if the transmitter becomes stationary for more than a specified length of time, thus indicating that the animal has died or the transmitter has fallen off; these can be programmed to change the signal characteristics in an ordered way after changing to mortality mode, so that the time of day and date of death or transmitter loss can be recorded.

There are four main drawbacks to using radio-transmitters in studies of wild animals. Firstly, the animal has to be recaptured periodically to replace the transmitter because battery life is limited and transmitters have to be sufficiently small (usually nominally taken as < 5% of body weight) not to unduly interfere with the mobility of the animal. Secondly, despite improvements in transmitter components and batteries in the last decade, some transmitters fail well before their due date. Thirdly, only a relatively small number of individuals (< 100) can usually be tracked in an area at one time by an observer, often because there are only a limited number of frequencies available. In the past, confusion has arisen when more than one research team has been using transmitters on different study animals that overlap in distribution. Finally, the costs of radio-telemetry can be high: standard transmitters retail at $220–$400 each, satellite transmitters at about $5000 each, and receivers, aerials and replacement batteries are significant additional costs.

2.4 ASSUMPTIONS IN SURVIVORSHIP ANALYSIS OF RADIO-TELEMETRY DATA

The most important assumption in radio-tracking studies is that the transmitters do not interfere with the behaviour or survival of marked animals or, for purposes of comparing two or more subsets of the study animals, if they do cause some effect, then it is evenly or randomly spread through the entire radio-tagged population. Another important assumption is that when a record is entered as censored (i.e. the tracking record is completed but recorded only as surviving to this time) the censorship should not be linked to a higher chance of death. This assumption is clearly violated when loss of transmitter contact occurs in conjunction with death, for example, when an animal drowns in a river and is washed away, or during human predation, as reported for radio-tagged kereru (*Hemiphaga novaeseelandiae*) at Wenderholm (Clout et al. 1995). Equally important is the assumption that a random sample has been obtained, so that the radio-tagged sample is representative of the whole population (e.g. kiwi chick samples should be stratified according to time of year and geographical location because of the marked seasonal changes in the abundance of stoats, their main predator, and because of edge effects). Another assumption is that each animal’s fate is independent of the fate of others (although this may not be the case if animals are killed during catastrophic events, e.g. bad weather, fire or predator irruption, or if animals are associated with each other, e.g. by coming from the same nest or pair). In some cases, we make the additional assumption that the probability of survival remains constant through time, at least within each subpopulation being studied.

3. Rules for the handling of survivorship data

As soon as a radio-tagged animal is released, data can start to accumulate. However, for species that suffer post-handling shock, deaths shortly after release are often excluded (e.g. Clout et al. (1995) excluded kereru that died within 1 week of capture). In this case, data collection from survivors should also start only after this window has passed.

Survivorship data must be handled carefully and consistently to ensure that estimates made for the population are valid. For example, estimates can be systematically in error if censoring (the cessation of a tracking record with no evidence that the individual has died) is not correctly and accurately recorded.

When a field search is made for the animal there are five possible outcomes: confirmation that the animal is alive; the animal is dead and the transmitter is recovered; the animal is not found because either it has emigrated or the transmitter has failed; a shed transmitter is found working but there is no sign of the animal; or the animal is not actually seen (e.g. because it is in a deep burrow) but the site of the transmitter is identified. These are outlined below.

Confirmed alive

The date on which an animal is recorded alive, with a functioning transmitter, becomes the ‘last date’ that the animal was known to be alive. If the transmitter is removed from the animal at this point, the data from that animal are referred to as being ‘right censored’, i.e. the tracking record is complete even though the animal survived beyond this date. No further information can be added to the survivorship record after transmitter removal even if the animal is resighted alive some time later, because only live animals are available to be resighted.

Confirmed dead

One major advantage of radio-telemetry over other methods of marking is that it often enables researchers to find an animal’s carcass, and so determine the cause of death either from examination of the body (necropsy) or from signs at the site where the animal has died (e.g. a branch had fallen on the animal). For survivorship analysis, we recommend that, wherever possible, the date of death is estimated from the time a mortality transmitter changed its signal, the state of decay of the carcass, or the amount of growth between last capture and the time of death (e.g. the bills of kiwi chicks grow at a nearly linear rate in the first 6 months (R. Colbourne and H. Robertson, unpubl. data), so the time of death can be estimated from bill length).

Where the date of death is not known, use the midpoint between when the animal was last known to be alive and the date on which the animal was found dead if visits are 15 or fewer days apart; where the interval exceeds 15 days, use the date after 40% of the interval between visits has elapsed (Miller & Johnson 1978). It is important to state clearly the method used for these calculations in reports or scientific papers.

The animal is not found because it has either emigrated or the transmitter has failed

Similar rules apply to those used when the animal has died (see above): censor records at an intermediate date between when the animal was last known to be alive and the first time the animal was searched for and not found, using the methods proposed by Miller & Johnson (1978). It is important to record dates on which an animal was searched for and not found, because that information will be used in subsequent calculations of censoring date if the animal is not later found with a functioning transmitter. If the animal reappears bearing a non-functioning transmitter, then the above dates must be used rather than the time it reappeared to avoid increasing the apparent survival rate, since only live animals can reappear. If the animal reappears bearing a functioning transmitter, then the record reverts to being a continuous record from first capture to the date of reappearance. But, in the unlikely event that the animal is later found dead with a non-functioning transmitter, assume that it was alive at the time it disappeared from the tracking record unless it is obvious that death and transmitter failure were simultaneous (e.g. when an animal has been killed by a poacher who has destroyed the transmitter).

The shed transmitter is found working but there is no sign of the animal

Similar rules apply to those used when the animal has disappeared, with the tracking record being censored at an intermediate time between when the animal was certainly alive and when the transmitter was found. If the animal is later found alive, the original endpoint must stand because of the danger of introducing a bias toward increased survivorship.

The animal is not actually seen (e.g. is in a deep burrow) but the site of the transmitter is clearly identified

If the study animal is of a species or age class that is regularly cryptic (e.g. adult kiwi, which often use very deep burrows), then assume that the animal is alive. However, if subsequent searches always lead to the same site, censor the record at an intermediate point before the first record for that site. Whether the animal has died or shed its transmitter in an inaccessible site can be difficult to determine and other cues, such as a resighting (or no resighting), a rotting smell or blowflies associated with the site, or its partner being found with a new mate, must be used.

If the study animal is found in a highly unusual site (e.g. a kiwi chick in a non-natal burrow), then assume that the individual died at an intermediate stage before the first encounter at this site (although note that a dead kiwi chick was once dragged from one stoat den to another between checks; Pat Miller, pers. comm.).

4. Management of data

One of the authors (H.A.R.) developed an Excel spreadsheet for handling survivorship data from a large-scale (c. 100 birds marked at any point in time) radio-telemetry study of the threats to wild brown kiwi (*Apteryx mantelli*) in central Northland, New Zealand (see Robertson et al. (1999) for more information on the study). The spreadsheet used for storing survivorship information about adult brown kiwi from 2 January 1994 to 30 September 1998 is given in Appendix 1 (N.B. data on other age classes of brown kiwi were kept separate because different assumptions apply to them). The following columns are used:

'Band' and 'Combination' identify particular individuals. It is not necessary to include both variables, but they do provide useful checks if there is an identification error in the field or a transcription error from field notebooks to the computer.

'Sex' identifies the sex of the bird.

'Area' identifies the study area in which the bird was located.

'Tx' refers to the most recent transmitter frequency used for the animal. This is also a useful check on the identity of the bird, as band numbers are often obscured by reflective tape.

'On' stores the date on which the continuous record of radio-tracking of each bird started. Dates are best shown with one or two digits for days, three characters for the month, and a two-digit year to avoid ambiguities, e.g. 4-Mar-97 rather than the ambiguous 4/3/97 which could be 4 March or 3 April 1997, depending on the calendar system used. This can be set up in Excel by highlighting the column, using **Format** > **Cells** > **Custom**, and then choosing d-mmm-yy from the options.

'Off_last' is the date the transmitter was removed from a kiwi; the estimated or calculated time of death; the date the record was censored (when a transmitter fell off, failed or the bird disappeared); or the most recent date the functional transmitter was known to be on the bird.

'Total' is the total tracking period. This is found by subtracting the 'On' date from the 'Off_last' date. Excel will want to format this as a date (e.g. 23-Nov-1900). To format cells in this column as numbers, use **Format** > **Cells** > **Number**, and choose Number from the category list. To be tidy, set the number of decimal places to 0. For example, in the first row, the female kiwi with band number 1079 with blue reflector and Tx 37 was caught and radio-tagged at Purua on 29 June 1994 and the transmitter was removed on 10 March 1995 after 254 days.

'Death' is an indicator of whether the record ended with a death (recorded as 1) or not (recorded as 0), the latter corresponding to a censored observation. This should remain at 0 even if an animal is subsequently found dead without a functioning transmitter, as only deaths during the tracking period can be used in estimates of survivorship.

One useful convention is that all ongoing records are shown in bold, all records ending with the animal definitely dying are in italics, and all records that ended with the transmitter being removed, falling off or failing (the last is assumed after only a reasonable time, in case the animal reappears with a functional transmitter) are in normal font. Using different typescripts does not affect the numerical calculations and it makes it easier to locate particular individuals or groups in the spreadsheet, especially when updating the files. Alternatively, a separate column can be added to note the status of each tracking record (alive, dead, missing…).

5. Calculation of annual survivorship and life expectancy

5.1 TIME SCALES

For long-lived animals, such as brown kiwi, it is usual to calculate and report annual survival estimates. However, for short-lived animals, such as kiwi chicks, or for short-term radio-tracking studies, it is better to calculate daily, weekly or monthly survival rates. These can be calculated by raising the survival rate (not the mortality rate!) to the appropriate power, e.g. a monthly survival of 0.90 equates to an annual survival of $0.90^{12} = 0.28$, assuming constant survival throughout the year. Be aware of the effect of raising a rounded number by a large power, as the final result may be quite different from the true result. In the example above, if the true monthly survival rate had been 0.9048, then the annual survival would have been 0.3010. The effect is greatly magnified when converting daily survival rates to annual rates.

5.2 THE MAYFIELD METHOD

The Mayfield method for analysing nesting success of birds (Mayfield 1961, 1975) is often extended to the analysis of radio-telemetry data (e.g. Trent & Rongstad 1974; Heisey & Fuller 1985). It provides a simple approximation of mortality by dividing the number of deaths, d, by the total time, T, that animals have carried active radio-transmitters. This approach is based on two assumptions: that the mortality rate is constant and the sample is random. For example, Clout et al. (1995) recorded ten deaths (d) of radio-tagged kereru at Pelorus Bridge in 19 321 bird-days ($T = 52.9$ years), which gave a crude mortality rate, m, of $10/52.9 = 0.189$ per bird per year; an annual survival, s ($= 1 - m$), of 0.811 or 81.1% per year; and a life expectancy, L ($= 1/m$), of 5.29 years.

From the data in Appendix 1, there were 13 adult brown kiwi deaths in 258.87 bird-years of radio-tracking in central Northland to September 1998, so mortality is 13/258.87 = 0.0502, annual survival is 0.9498 and life expectancy is therefore 19.91 years. It is possible to calculate confidence intervals for these estimates. A confidence interval for mortality rate is:

$$\left\{ \frac{m}{2d}\chi^2_{2d,\frac{\alpha}{2}}\ ,\ \frac{m}{2d}\chi^2_{2d,\left(1-\frac{\alpha}{2}\right)} \right\}$$

where 1 – α is the confidence level (for example $\alpha = 0.05$ for a 95% confidence interval) and the appropriate values for the χ^2 distribution with $2d$ degrees of freedom are derived from a statistical table or computer function (Lawless 1982). A confidence interval for life expectancy is given by the reciprocals of the limits calculated for mortality. For the adult brown kiwi example above, the required χ^2 values (with 26 degrees of freedom) are 13.8 and 41.9, calculated from the Excel formulae *=CHIINV(0.025,26)* and *=CHIINV(0.975,26)*. Thus the 95% confidence interval of the mortality rate is 0.0502/26 × 13.8 = 0.027 to 0.0502/26 × 41.9 = 0.081, and the associated 95% confidence interval for life expectancy becomes 12.4 to 37.4 years.

This method assumes that survivorship is constant. Where this assumption is not violated it provides reasonable estimates of survivorship, especially where sample sizes are large, i.e. the product of the number of tracking years and the number of deaths recorded is > 500 (e.g. ten deaths in 50 years of accumulated radio-tracking data), and can be computed and updated very simply at the foot of the spreadsheet used for storing the survivorship data (see Appendix 1).

5.3 KAPLAN-MEIER PROCEDURE

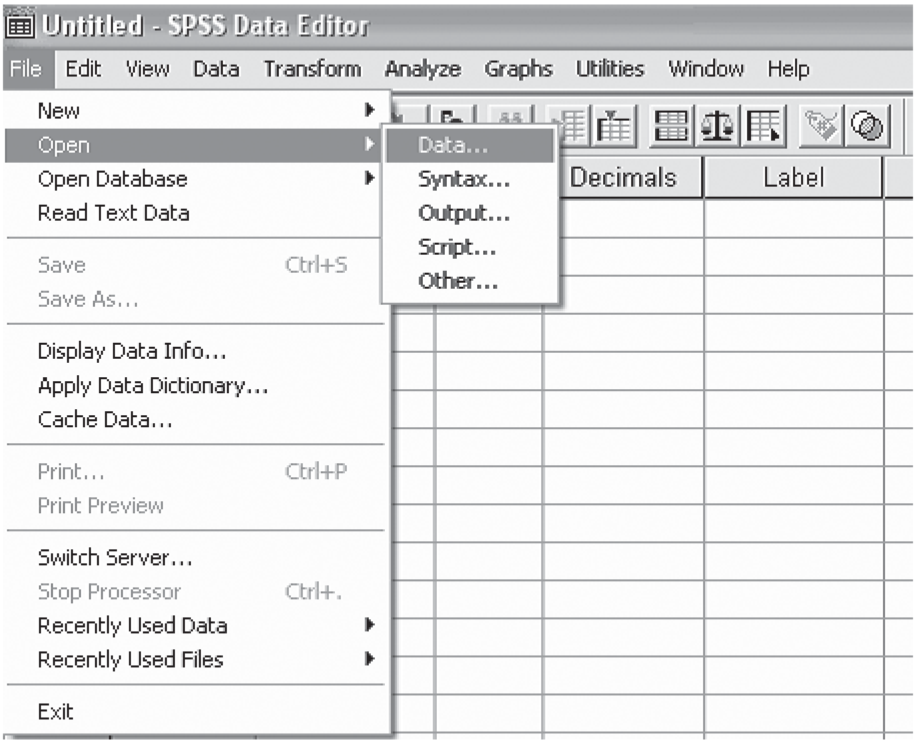
Constant survival is a strong assumption to make. Unless there are very good reasons to make this assumption, a more general and mathematically correct method for the detailed analysis of survivorship data from radio-telemetry studies is the Kaplan-Meier (KM) procedure, which produces a nonparametric estimator also known as the ‘product limit estimator’ (for more detailed discussion of the method see Pollock et al. 1989a,b; Bunck et al. 1995; Klein & Moeschberger 1997). The KM approach is available in many statistical packages, and is straightforward to run in SPSS, where it is available as an add-in: ‘Advanced Models’. For those people who do not have access to commercial statistical packages, we show how, with some manipulations, simple KM curves can be created in Excel. The KM method has the significant advantage that it does not include the assumption that survival rates are constant.

Next we provide a worked example of the KM approach in action in SPSS. The data in Appendix 2 give survivorship information about brown kiwi chicks living in forest patches in Northland under different management regimes: in some bush patches the anticoagulant poison brodifacoum was used for possum control (and probably caused incidental control of rodents and mammalian predators), and in others no management was carried out (Robertson et al. 1999). The data reported here differ slightly from those reported by Robertson et al. (1999) because we have censored observations at an intermediate point according to the rules given above, rather than the more conservative approach they used of censoring data at the last date the animal was known to be alive. The data columns are similar to those in Appendix 1, but 'Treatmen' has been added to enable comparison of the survival of chicks under different management regimes. Data columns start at the top left hand corner of the worksheet, and have simple **unique names of up to eight characters** in the top row. It is easiest if there are no blank rows, and no extraneous data or derived sums or rates in the worksheet.

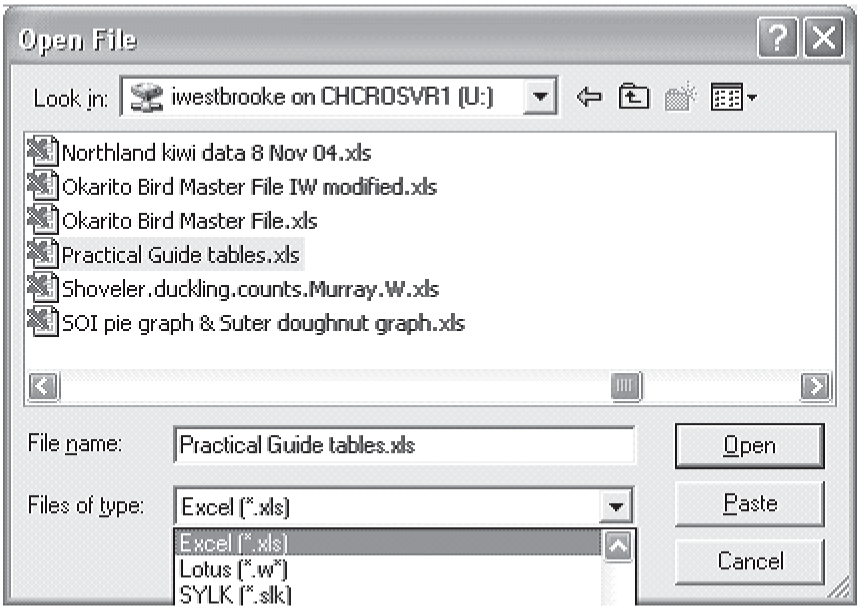
5.3.1 Kaplan-Meier procedure using SPSS

The first step is to create a copy of the data in SPSS. This is most easily done by importing the Excel worksheet into SPSS. Note that the essential variables for any KM analysis are one for the survival time and another for whether the record ended with a particular event (a death in this example). Additional variables can be used to indicate groups being compared.

Open SPSS then **Open** > **Data** >



Select Files of type Excel (*.xls), then find and click on the file to be opened following normal Windows procedures.



Look in: iwestbrooke on CHCROSVR1 (U:)

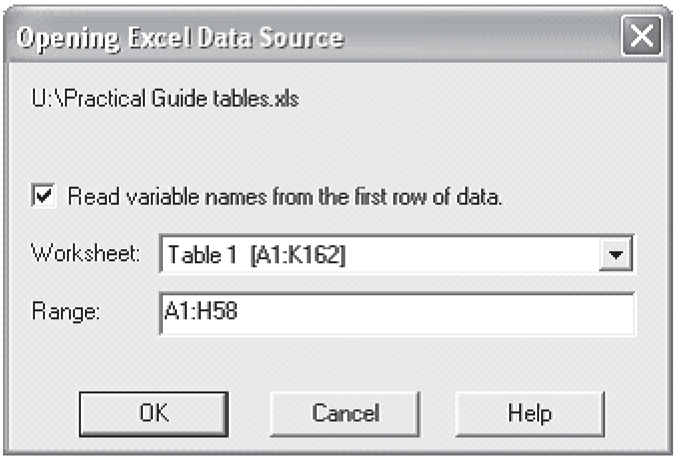
Northland kiwi data 8 Nov 04.xls
Okarito Bird Master File IW modified.xls
Okarito Bird Master File.xls
Practical Guide tables.xls
Shoveler.duckling.counts.Murray.W.xls
SOI pie graph & Suter doughnut graph.xls

File name: Practical Guide tables.xls

Files of type: Excel (*.xls)

Excel (*.xls)
Lotus (*.w*)
SYLK (*.slk)

Clicking on the **Open** button should lead to the next box:



U:\Practical Guide tables.xls

☑ Read variable names from the first row of data.

Worksheet: Table 1 [A1:K162]

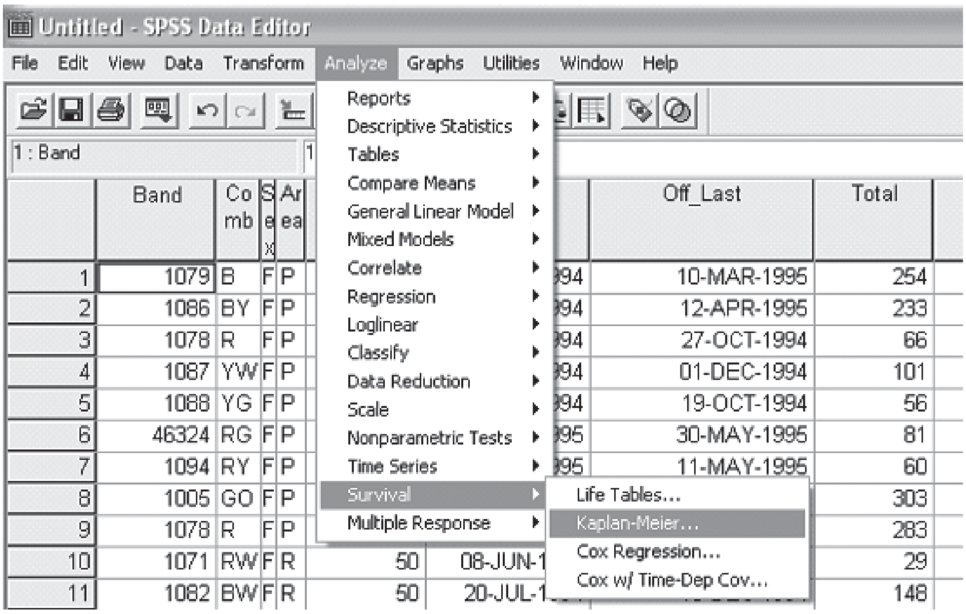
Range: A1:H58

Select the appropriate worksheet. SPSS takes a guess at the range (shown as [A1:K162] in the upper box). This may need to be adjusted by typing the actual range desired in the lower box. When the range is correct, click on **OK**.

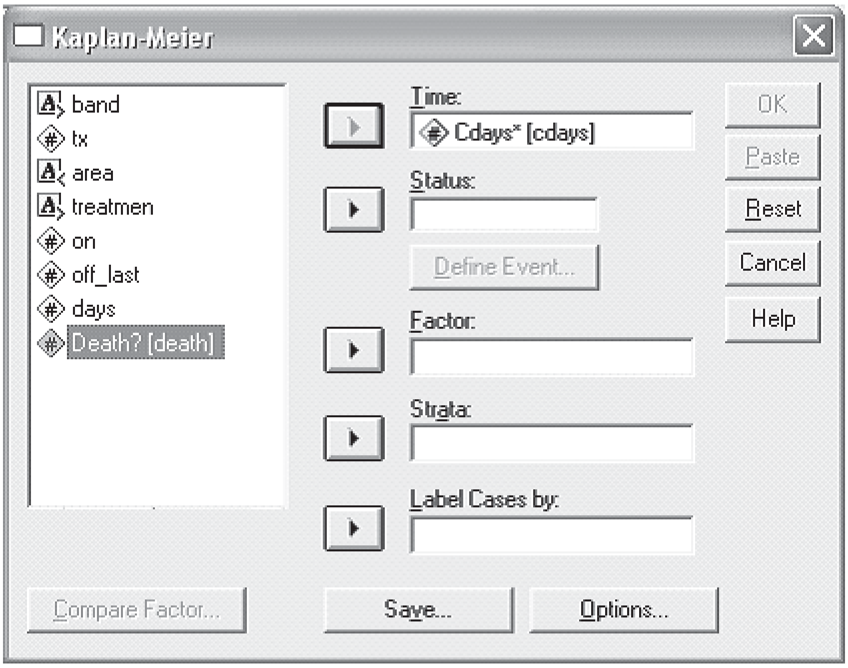
SPSS may give '********' in columns for dates (i.e. *On* and *Off_last*), which can usually be fixed by widening the column to fit the date in.

(Note that although SPSS looks a bit like a spreadsheet, it is very different from Excel. The two tabs are for two different views of the data: the Data View, showing all the values, and the Variable View, showing the characteristics associated with each column of data, which SPSS sees as a statistical variable. The data may need to be tidied up in Excel or in SPSS to make it into tidy columns of variables.)

To create Kaplan-Meier survival curves, select **Analyze > Survival > Kaplan-Meier**.

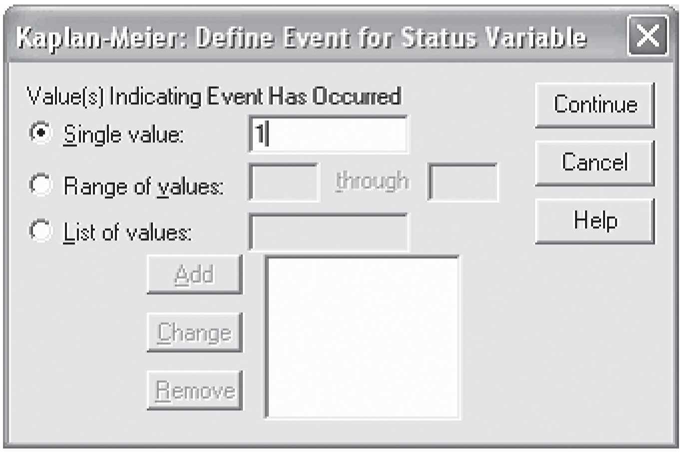


Then select the time variable (in our example *Cdays*) and use the arrow button to put this in the **Time** box and the event indicator (in our example *death*) into the **Status** box.


Time: Cdays* [cdays]

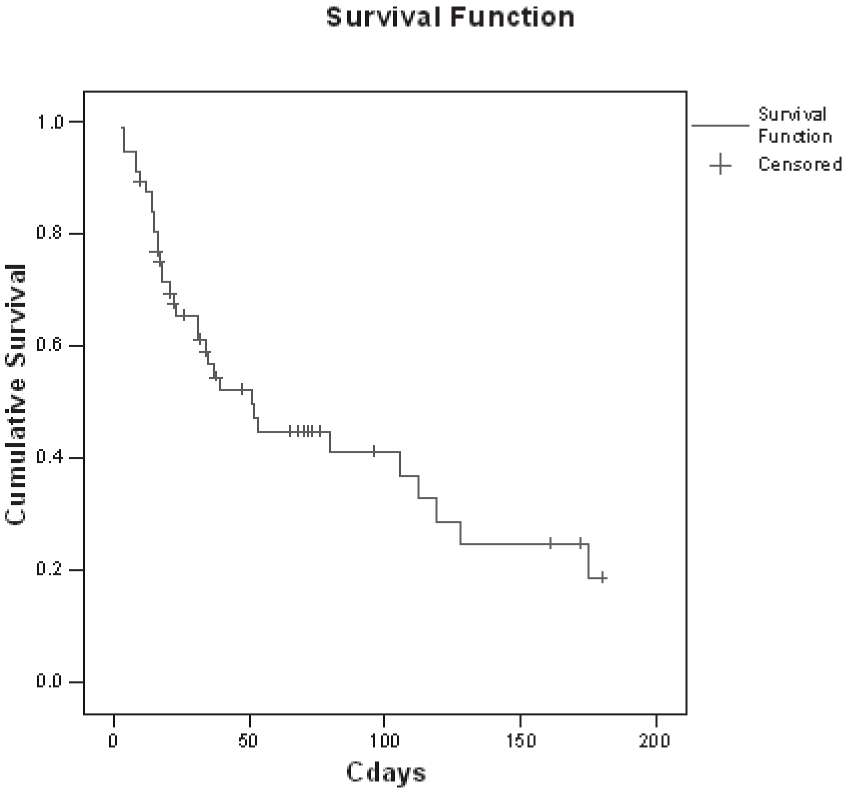
With the death box selected, SPSS must be told what the values of death mean. In the example, 1 signifies a death and anything else is censored.

Click on the **Define event** button, enter 1, and click on **Continue,** which returns the programme to the Kaplan-Meier box.



● Single value: 1

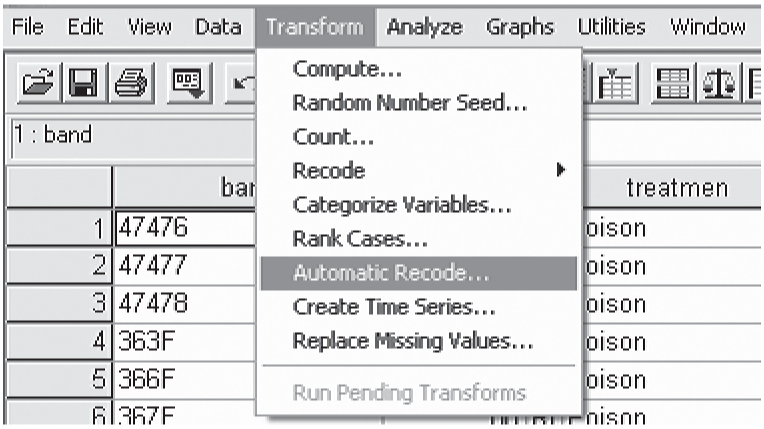
Click on the **Options** button on the Kaplan-Meier box, and select **Plots** > **Survival** (and possibly **Plots** > **Log Survival**) to get a graph. Now click on **OK** and SPSS will spend a while processing, and produce some numerical output in a separate Output window, ending with a survival curve. Note that the y-axis title should be edited to read ‘Cumulative survival’, instead of ‘Cum survival’.



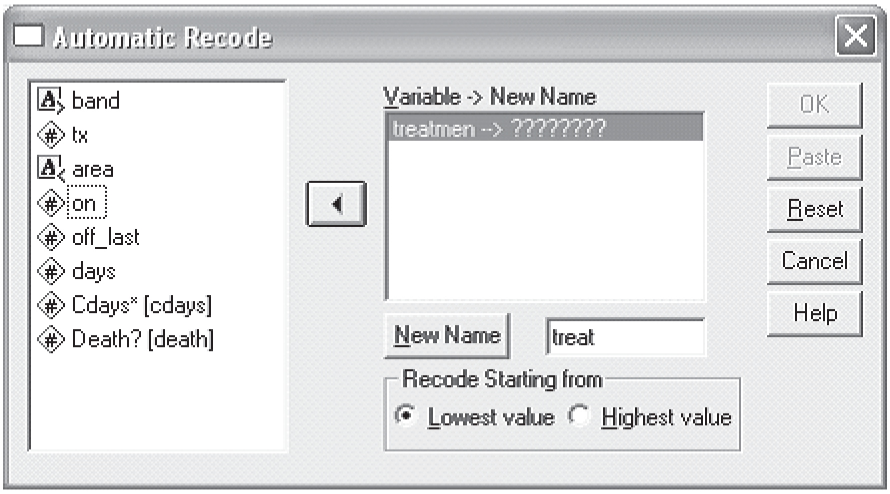
Note for this example that the curve shows an initial, very sharp drop in survival, and then the slope appears to lessen with time.

However, this survival analysis is not very interesting, as it mixes together the ‘Poison’ and ‘Non-treatment’ groups. SPSS will separate these out, using the variable *Treatmen* as a factor, but it needs to be recoded as a number first. (This is just an old-fashioned feature of SPSS.) To recode, return to the SPSS Data Editor (the output is a separate SPSS Output Window).

In the Data Editor, go to **Transform > Automatic Recode**:



Then select the variable *Treatmen,* and type a new variable name into the box toward the bottom right.

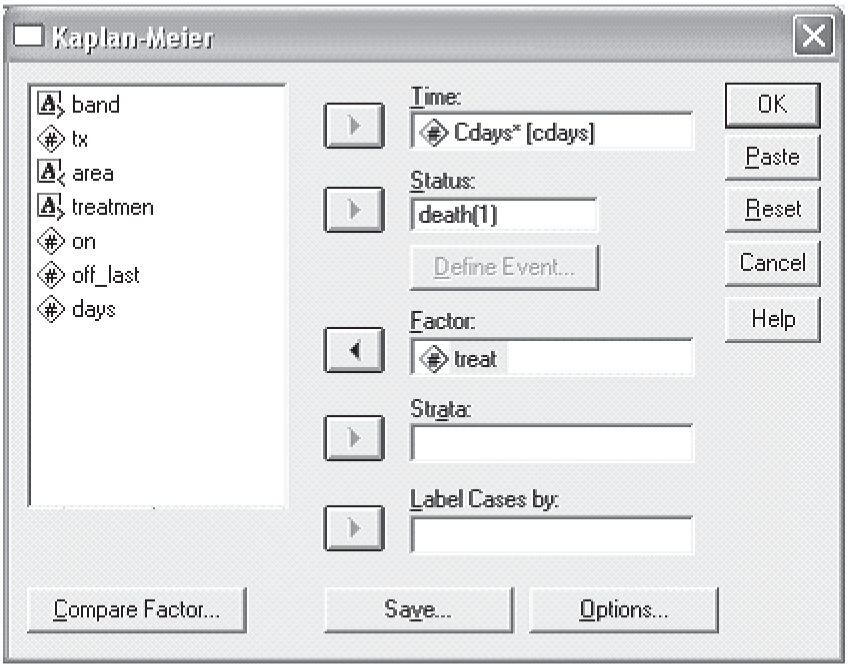


Variable -> New Name: treatmen --> ????????

New Name: treat

Recode Starting from: ● Lowest value ○ Highest value

Click on **New Name** and then **OK**. This adds a new variable *treat* to the data with numbers instead of words for the two treatments. Now add the **new variable** as a **Factor**.



Time: Cdays* [cdays]

Status: death(1)

Factor: treat

Strata:

Label Cases by:

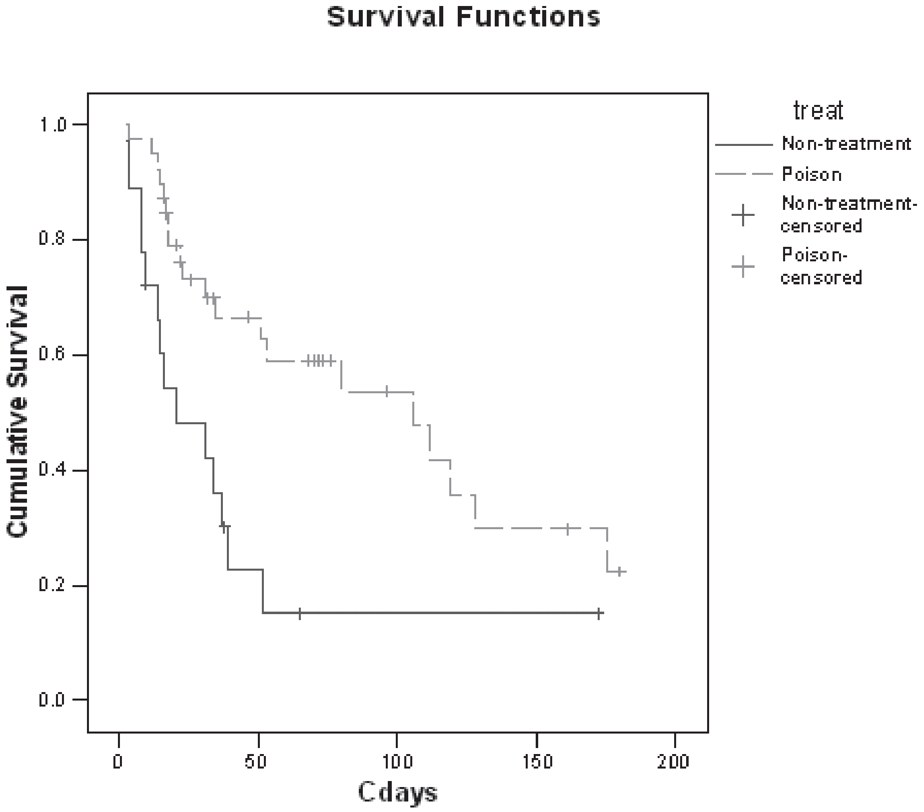
Clicking on **OK** should lead to another lot of output:

```
Survival Analysis for CDAYS

 Factor TREAT = Non-treatment

  Time      Status          Cumulative    Standard     Cumulative     Number
                             Survival      Error         Events      Remaining

       3              1       .9444         .0540             1           17
       4              1       .8889         .0741             2           16
       8              1                                       3           15
       8              1       .7778         .0980             4           14
      10              1       .7222         .1056             5           13
      10              0                                       5           12
      14              1       .6620         .1126             6           11
      15              1       .6019         .1174             7           10
      16              1       .5417         .1201             8            9
      21              1       .4815         .1209             9            8
      31              1       .4213         .1198            10            7
      34              1       .3611         .1168            11            6
      37              1       .3009         .1118            12            5
      38              0                                      12            4
      39              1       .2257         .1062            13            3
      52              1       .1505         .0937            14            2
      65              0                                      14            1
     172              0                                      14            0

 Number of Cases:  18        Censored:   4      ( 22.22%)   Events: 14


          Survival Time    Standard Error   95% Confidence Interval

 Mean:           45                  14     (       17,        72 )
 (Limited to      172 )
 Median:         21                  11     (        0,        42 )
_


 Survival Analysis for CDAYS

 Factor TREAT = Poison

  Time      Status          Cumulative    Standard     Cumulative     Number
                             Survival      Error         Events      Remaining

       4              1       .9744         .0253             1           38
      12              1       .9487         .0353             2           37
      14              1       .9231         .0427             3           36
      15              1       .8974         .0486             4           35
      16              1       .8718         .0535             5           34
      16              0                                       5           33
      17              1       .8454         .0581             6           32
      17              0                                       6           31
      18              1                                       7           30
      18              1       .7908         .0659             8           29
      21              0                                       8           28
      21              0                                       8           27
      22              1       .7615         .0697             9           26
      22              0                                       9           25
      23              1       .7311         .0732            10           24
      26              0                                      10           23
      31              1       .6993         .0766            11           22
      32              0                                      11           21
      34              0                                      11           20
      35              1       .6643         .0804            12           19
      47              0                                      12           18
      51              1       .6274         .0840            13           17
      53              1       .5905         .0868            14           16
      68              0                                      14           15
      70              0                                      14           14
      72              0                                      14           13
      73              0                                      14           12
      76              0                                      14           11
      80              1       .5368         .0940            15           10
      96              0                                      15            9
     106              1       .4772         .1007            16            8
     112              1       .4175         .1043            17            7
```

Continued on next page

```
     119            1       .3579         .1051            18           6
     128            1       .2982         .1031            19           5
     161            0                                      19           4
     175            1       .2237         .1008            20           3
     180            0                                      20           2
     180            0                                      20           1
     180            0                                      20           0

 Number of Cases:  39        Censored:   19     ( 48.72%)   Events: 20
_

          Survival Time    Standard Error   95% Confidence Interval

 Mean:           96                  12     (       72,       120 )
 (Limited to      180 )
 Median:        106                  34     (       39,       173 )

 Survival Analysis for CDAYS

                                    Total     Number      Number      Percent
                                              Events     Censored    Censored

  TREAT       Non-treatment            18         14           4        22.22
  TREAT       Poison                   39         20          19        48.72

Overall                                57         34          23        40.35
```

This output has separate tables for the two treatment levels, and produces a graph with separate lines for them.



The curves look different. Note that each curve changes only when deaths occur, and that censored observations are individually marked. Again, the graph needs the y-axis label edited, and one of the lines needs to be changed to dashes, so that the lines are readily distinguished without colour (enabling black-and-white printing). This is achieved by double-clicking on the graph to open an editing window, carefully selecting just one of the lines, and changing the **Style** in the **Lines** tab of the **Properties** dialogue box.

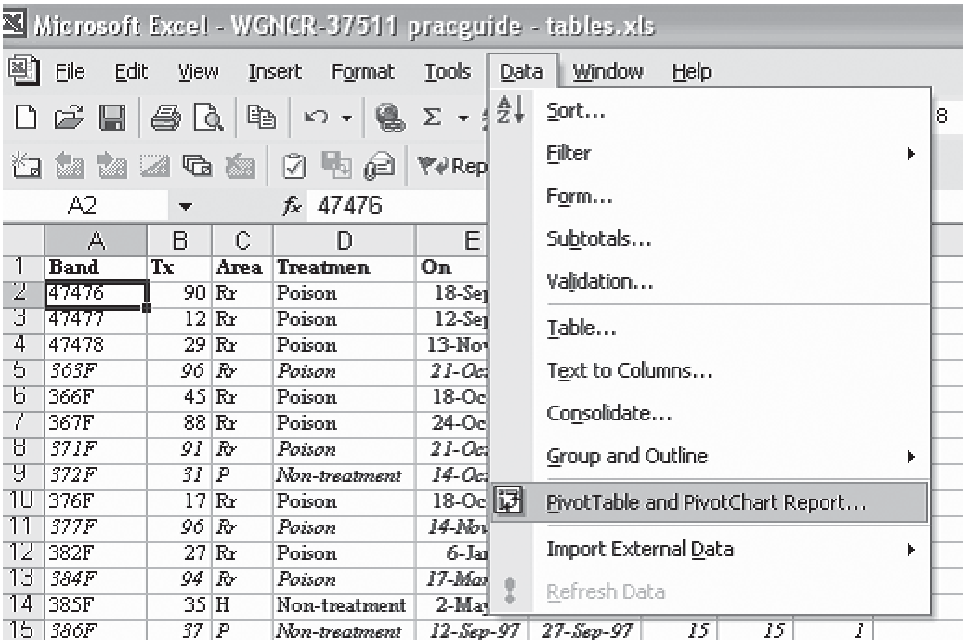
5.3.2 Kaplan-Meier procedure using Excel

We now present Excel 2002 spreadsheets (Appendices 3 and 4) to handle the analysis of radio-telemetry data, designed for those who do not have access to standard statistical packages. While we have attempted to get things right, we cannot guarantee that these sheets will necessarily handle all datasets, nor that they will work in later versions of Excel. The actual spreadsheets used here are available by request from the senior author. Please acknowledge this paper if these Excel spreadsheets are used.

In this section, we will derive the Kaplan-Meier survival rates using the same example used for SPSS.

The key information for each individual is the same as for SPSS: the date of each event and whether there was a death or censorship. There may also be a covariate—in our example, Poison versus Non-treatment. In Excel, the process works best if there are no empty rows or columns in the main data area, and if any other information, such as derived totals, is separated from the actual data to be analysed for each individual by an empty row or column.

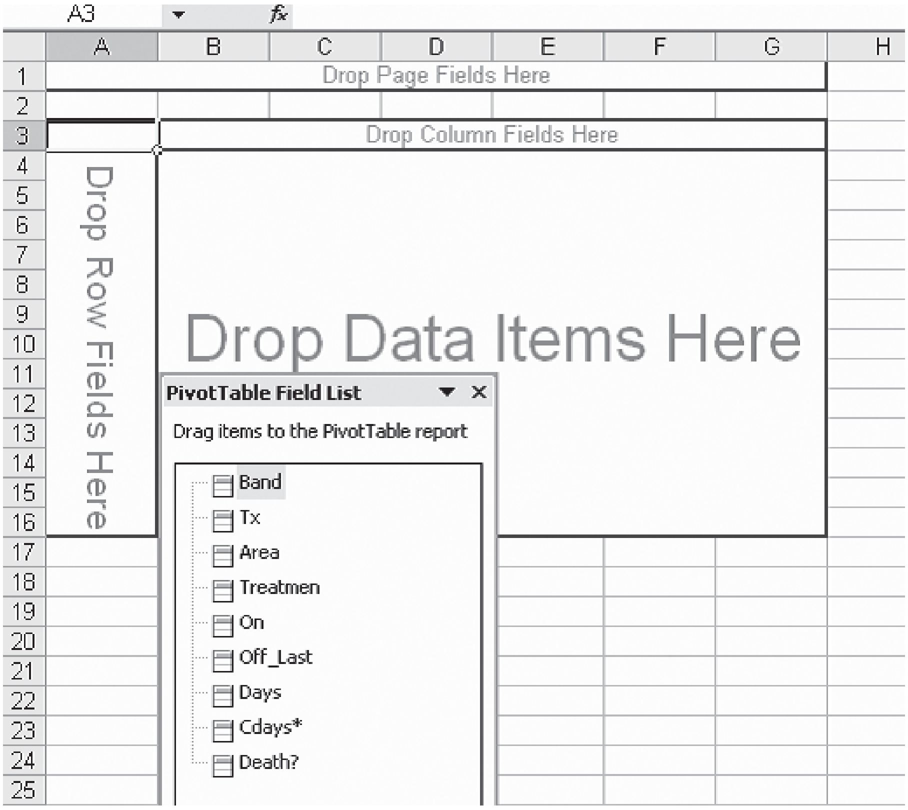
The first step is to select a cell in the main data area and create a pivot table: click on **Data > PivotTable and PivotChart Report**. (Note that the following instructions are for Excel 2002. Details may differ in different versions of Excel, but it will generally be possible to create the same table, providing the Pivot Table tool is available.)



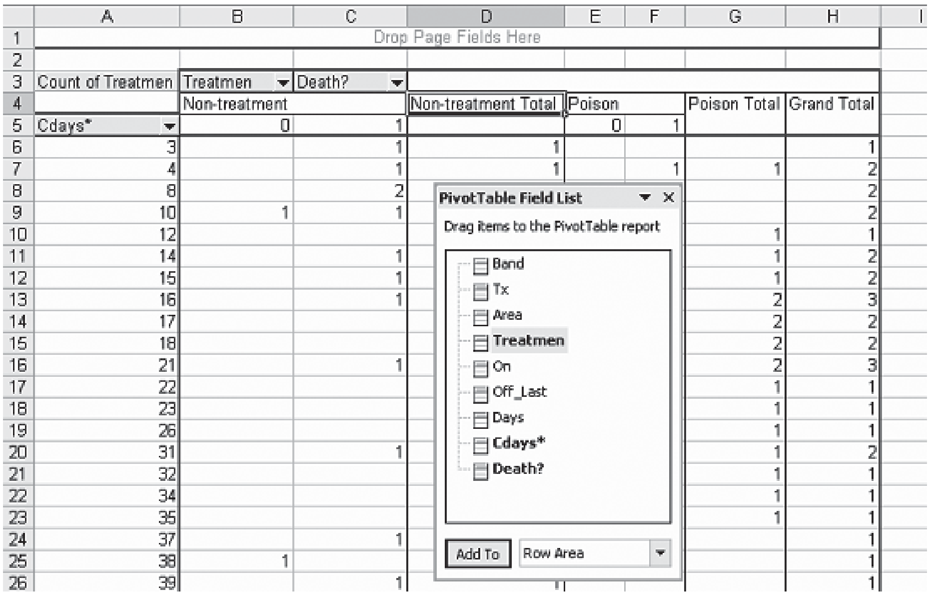
A2 *fx* 47476

	A	B	C	D	E				
1	**Band**	**Tx**	**Area**	**Treatmen**	**On**				
2	47476	90	Rr	Poison	18-Se				
3	47477	12	Rr	Poison	12-Se				
4	47478	29	Rr	Poison	13-No				
5	*363F*	*96*	*Rr*	*Poison*	*21-Oc*				
6	366F	45	Rr	Poison	18-Oc				
7	367F	88	Rr	Poison	24-Oc				
8	*371F*	*91*	*Rr*	*Poison*	*21-Oc*				
9	*372F*	*31*	*P*	*Non-treatment*	*14-Oc*				
10	376F	17	Rr	Poison	18-Oc				
11	*377F*	*96*	*Rr*	*Poison*	*14-Nov*				
12	382F	27	Rr	Poison	6-Ja				
13	*384F*	*94*	*Rr*	*Poison*	*17-Ma*				
14	385F	35	H	Non-treatment	2-Ma				
15	*386F*	*37*	*P*	*Non-treatment*	*12-Sep-97*	*27-Sep-97*	*15*	*15*	*1*

Go through the three steps of the wizard, checking at step 2 that **exactly** the rows and all the columns needed have been selected; extra columns do not matter. All the columns need meaningful headings. At step 3, the default is to put the pivot table on a new worksheet. It is generally a good idea to leave the data uncluttered on its own sheet. The skeleton of the pivot table will now be on the new sheet.



Now drag the time variable (*Cdays* in our example) to the left of the table where it says 'drop row fields here'. Drag the covariate factor if there is one (*Treatmen* in our example), then the event indicator (censorship or death; '*Death?*' here) to the top of the table to be the column fields, and ignore the page fields area. Also drop any variable with a complete set of values (i.e. having no empty cells) in the middle of the table. Preferably use one with character values, as this will default to giving the **count** of items that are required. Excel will automatically choose to **sum** a numeric variable, which will then have to be changed to a count. (In our case we used *Treatmen*.) It is important that the covariate (*Treatmen*) is to the left of the event indicator (*Death?*), which can be achieved by dragging the labels to put them in the correct order. This should produce the following table:



	A	B	C	D	E	F	G	H
1	Drop Page Fields Here							
2								
3	Count of Treatmen	Treatmen	Death?					
4		Non-treatment		Non-treatment Total	Poison		Poison Total	Grand Total
5	Cdays*	0	1		0	1		
6	3		1	1				1
7	4		1	1		1	1	2
8	8		2	[illegible]	[illegible]	[illegible]		2
9	10	1	1	[illegible]	[illegible]	[illegible]		2
10	12			[illegible]	[illegible]	[illegible]	1	1
11	14		1	[illegible]	[illegible]	[illegible]	1	2
12	15		1	[illegible]	[illegible]	[illegible]	1	2
13	16		1	[illegible]	[illegible]	[illegible]	2	3
14	17			[illegible]	[illegible]	[illegible]	2	2
15	18			[illegible]	[illegible]	[illegible]	2	2
16	21		1	[illegible]	[illegible]	[illegible]	2	3
17	22			[illegible]	[illegible]	[illegible]	1	1
18	23			[illegible]	[illegible]	[illegible]	1	1
19	26			[illegible]	[illegible]	[illegible]	1	1
20	31		1	[illegible]	[illegible]	[illegible]	1	2
21	32			[illegible]	[illegible]	[illegible]	1	1
22	34			[illegible]	[illegible]	[illegible]	1	1
23	35			[illegible]	[illegible]	[illegible]	1	1
24	37		1	[illegible]	[illegible]	[illegible]		1
25	38	1		[illegible]	[illegible]	[illegible]		1
26	39		1	[illegible]	[illegible]	[illegible]		1

The Field List can now be closed, and the pivot table values can be used to derive the Kaplan-Meier survival rates.

We now describe in detail the formulae for creating the KM rates. With access to our spreadsheet, they can be copied over to apply to other data. However, it will be necessary to carefully check that the formulae refer to the correct cells. Our workings are shown in Appendix 3, Table A3.1. **Note that in the formulae that follow, a cell reference (e.g. A7) generally must be typed in for cells in the pivot table, rather than selecting the cell to go into a formula, as Excel can create complicated references when a cell in a pivot table is selected.**

The first group: 'Non-treatment'

Column I: **Day** In the first column next to the table, create a copy of the time variable. In our example, we put *=A6* in the cell **I6**, and copied it down the side of the table as far as, but not including, the Grand Total row. Next type 0 in the cell just above the first event day: in our example, **I5**. (This column will make things easier when we want to create a graph, as it is hard to select exactly the cells required from the pivot table itself.) Add a label, e.g. *Day*, immediately above this column, in cell **I4**. Type labels at the head of each column as shown in the table.

Column J: **At risk**. Put the total number at risk (i.e. the sample size of the Non-treatment group) in the cell next to the first day of a record, in our case enter *=D47* in **J6**. In the next cell down we take the value of the cell above, minus the value of total events, both censorships and deaths (i.e. 0s and 1s), from the preceding line. In our example, we put *=J6-D6* in **J7** and then copied this down. This gives the number at risk **before** any events on each day.

Columns K and L: **Empirical death and survival rates**. The empirical death rate is simply the number of deaths divided by the number at risk. Thus, we divide the appropriate cell in column C by the cell in the same row in column J. For example, we typed *=C6/J6* in **K6**, and then copied this down into all the appropriate cells. The empirical survival rate, which is essential, is 1 minus the death rate, so put *=1-K6* in **L6**, and copy that down.

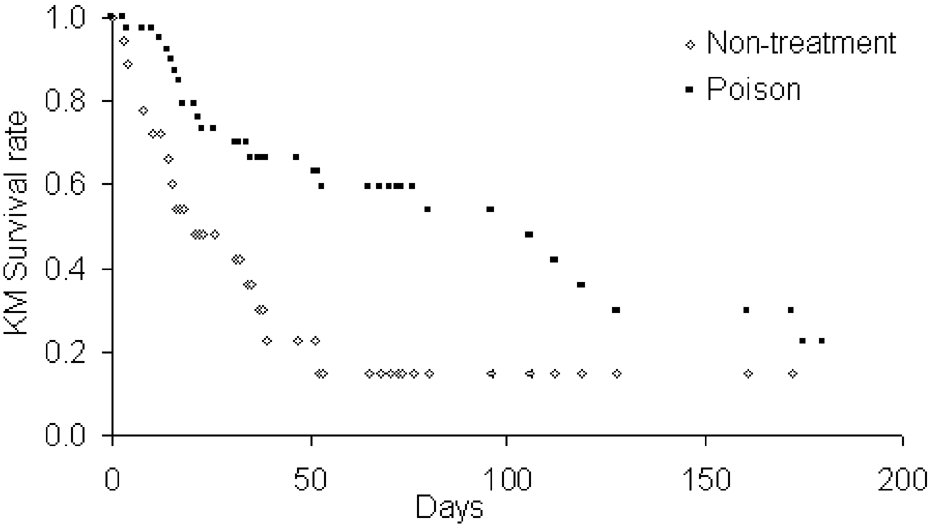
Column M: **Kaplan-Meier (KM) product moment survival rate**. This is the information that we really want. Create it by taking the cumulative product of the survival rates to date. Type '1' in the row corresponding to time 0 (in **M5** in the example), to represent 100% survival rate initially. In **M6**, put *=M5*L6,* and copy it down.

The next group: 'Poison'

Now we have the key item we want for the first group. After putting useful headings on each column, as in our example, copy columns J to M into the next columns (N to Q) so the formulae can be slightly adjusted to give the KM survival rates for the second group (the references need to be corrected). The first cell in the new **At risk** column (**N6**) now must refer to the total in the second group (*=G47* in our example). Adjust the next cell (**N7**) to refer to the cell immediately above, less the total number of losses (censorships and deaths) in this group (*=N6-G6* here) and copy this down. The next column, empirical death rate, must be adjusted to ensure that it refers to the number of deaths in this group, divided by the number at risk. (Thus **O6** has *=F6/N6* in our example.)

There may be some entries '*#DIV/0!*' at the bottom of the table, if there are no longer any at risk in this group. In the example, this happens for the last couple of dates for the first group. It will pay to clear these problem cells (only) before graphing, as Excel will tend to interpret these as zero values. However, note that these formulae were required for the second group, and were used for copying.

Further useful calculations for standard errors and confidence intervals can follow, but first it is worth graphing these results. To graph the KM survival rates against time, put a short heading at the top of each group of KM rates. Select the time (column I), including the heading, and similarly the columns of KM survival rates. Now click on **Insert > Chart**, and select **XY (Scatter)**. This will give a graph of the survival curve like the one below:



This graph has been tidied up by adding labels; adjusting the vertical scale, the position of the legend and the size of each point; changing the symbols; and deleting the background and gridlines. It represents the survival rates adequately, but includes points at days where there are censorship events as well as points at each death. The SPSS graph shows the difference between the two types of events. Excel can also graphically show the differences between the types of events, if extra columns and the IF function are used, but we have not added this refinement.

The median duration of survival can be readily calculated by finding the time at which survival first drops below 0.5. Reading the values for the KM survival rate in the example, this is reached at 106 days for the Poison group, but at 21 days for the Non-treatment group.

The next step is to use Greenwood's formula (Klein & Moeschberger 1997: 84) to calculate the standard error and confidence intervals for the KM survival rate for each group. To do this for group 1, insert five columns after the KM rate for the first group. This and the following steps are shown in Appendix 3, Table A3.2 (Table A3.1 shows only the workings to this point).

Columns N and O: **Two steps to Greenwood's formula**. The first step (to generate the values for column N) involves the following calculation for each group: divide the number of deaths by the product of the number at risk and the number at risk less the number of deaths. In the example, we put _=C6/(J6*(J6-C6))_ in **N6**, and copied it down through both groups. The second step involves calculating the cumulative sum, by putting _=SUM(N$6:N6)_ in **O6**, and copying it down. Note that the $ sign fixes a cell reference so that it does not change during copying.

Column P: **Standard error**. This is simply the product of the KM survival rate and the square root of column O. Put _=M6*SQRT(O6)_ in **P6**, and copy it down through both groups. This gives a measure of the error in the KM rate. However, confidence intervals are often more useful.

Columns Q and R: **95% confidence intervals**. Because survival rates should be between 0 and 1, it is best to use a different approach to the usual ± 1.96 × standard error (Klein & Moeschberger 1997: 97). Instead the formula for Q6 is _=M6^EXP(-1.96*SQRT(O6)/LN(M6))_ and for R6 is _=M6^EXP(1.96*SQRT(O6)/LN(M6))_. Note that the only difference is the change of signs (– then +) after _EXP(_ .

These columns can then be copied after the next group, and almost all the formulae will translate as needed. The only adjustment that should be required is a change in the first step of Greenwood's formula to ensure that it refers twice to the number of deaths in the correct group. In our example, the formula in **W6** should be _=F6/(S6*(S6-F6))_, and this should be copied down.

That is all for the Kaplan-Meier procedure. Note that although SPSS does better charts, SPSS 12 does not give confidence intervals!

5.4 CHOICE OF METHOD

Every time a study animal, dead or alive, is found, the survivorship estimate will change. For day-to-day use, the Mayfield method is very easy to use and understand, the estimate can be easily recalculated (as in Appendix 1), and the method usually gives a reasonable picture of the survivorship rate. However, it is preferable that the more complicated calculations of the Kaplan-Meier procedure are used for reports or scientific papers that include survivorship data. Neither method is particularly accurate where there is a short total tracking time and / or a small number of deaths recorded. For example, there is a big difference between a survivorship rate of 3/20 = 0.15 and one of 4/20 = 0.20 caused by one more death of a study animal, especially if those data are then used to calculate life expectancy as 6.7 years versus 5.0 years, respectively. The number of deaths recorded is the most critical part of the calculations and, as a rough rule, aim to have either total tracking-years of the study being at least ten times the average life expectancy of the study animal, or the product of the number of deaths recorded and the number of tracking years exceeding 500 (e.g. 50 deaths in 10 tracking years' data, ten deaths in 50 years' tracking data or two deaths in 250 tracking years' data). However, remember that the fewer deaths recorded, the greater the change made by a chance event, or non-event; examining confidence intervals for the estimates gives a basis for evaluating the variability in the estimates due to chance.

5.5 HOW TO ESTIMATE SURVIVAL RATE TO A PARTICULAR AGE

There is often interest in calculating the survival of animals to a particular age (for example survival of kiwi chicks to 180 days old, at which time they seem to become reasonably safe from predation by stoats). The Kaplan-Meier procedure gives a survival rate as long as there are members of the group at risk. However, it can be subject to very large error when the sample size is small. For example, the estimate for Non-treatment survival in our kiwi chick sample is 0.1505 from 52 to 172 days, when the single chick left in the study was censored. The 95% confidence interval is (0.027, 0.370). For the Poison treatment, the survival rate estimate at 180 days is 0.2237, with the interval (0.067, 0.436). However, the Non-treatment estimate in particular is based on very few data.

If constant survival rate is assumed, the Mayfield method can be used to estimate a survival rate at any point. This assumption can be checked by looking at a Kaplan-Meier graph with the survival axis on a log scale. The SPSS option to get the log survival curve is described above. In Excel, double click or right click on the vertical (y) axis to bring up the **Format Axis** dialogue box, choose the **Scale** tab, and select **logarithmic scale**. To assess whether the points are reasonably consistent with a straight line, look mainly at the points that correspond to actual event, rather than censorship.

The constant survival estimate of survival rate to time t is:

$$\exp(\frac{-t}{L})$$

where L is the simple estimator of life expectancy described earlier (i.e. total time exposed T, divided by number of deaths observed d). A confidence interval can be calculated for this also, and the results of doing this for the kiwi chick data are shown in Appendix 4 with estimates at 180 days. The data in Appendix 4 are derived from Appendix 2 using a simple pivot table. Note that the estimates are similar to, but not the same as, the Kaplan-Meier estimates, as a different model is being used. In particular, it appears to give a more realistic estimate of survival to 180 days for Non-treatment. It is important to note that the validity of this confidence interval is heavily dependent on the assumption of constant survival.

The sheet used to create Appendix 4 can be modified for other data by entering the appropriate values where there are numbers in bold: the total time exposed, the number of deaths, and the point at which the estimate is desired. The formula used here for the confidence interval is:

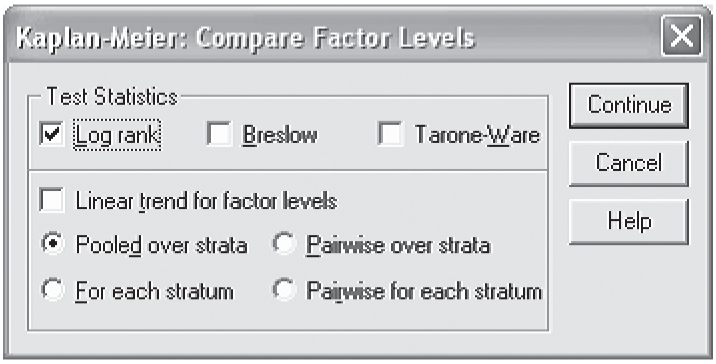
$$\left\{\exp\left[\frac{-t}{2T}\chi^2_{2d,\frac{\alpha}{2}}\right], \exp\left[\frac{-t}{2T}\chi^2_{2d,\left(1-\frac{\alpha}{2}\right)}\right]\right\}$$

following the same notation as given above, in section 5.2 (Lawless 1982). In Excel, the point estimate is given by the formula *=EXP(-t/L),* and the 95% confidence intervals are given by *=EXP(-t/(2*T)*CHIINV(0.025,2*d))* and *=EXP(-t/(2*T)*CHIINV(0.975,2*d))*. When typing these formulae into Excel, the appropriate cell references must be placed where the references L, d, t and T are given above.

6. Comparison between two or more groups

As an extension of the Kaplan-Meier procedure, it is possible to compare the survivorship of animals in two or more different groups, e.g. males versus females, or animals living under a number of different management regimes. The most appropriate statistic to use is the nonparametric Mantel-Haenszel statistic, which is a log-rank test whose distribution approximates a χ^2 distribution with 1 degree of freedom for two groups, or (G – 1) degrees of freedom if there are G groups. The statistic is computed by combining the two (or more) samples to be compared. It is then determined whether the times when deaths were recorded in the two groups are sufficiently different from one another (given the number of animals at risk in each group at each age that an animal died).

To carry out this test in SPSS, continue the previous SPSS analysis by simply clicking on the **Compare Factor** button on the Kaplan-Meier dialogue box, and select **Log rank > Continue** to exit that box, and **OK** to run the survival analysis again.



Test Statistics
☑ Log rank ☐ Breslow ☐ Tarone-Ware

☐ Linear trend for factor levels

● Pooled over strata ○ Pairwise over strata

○ For each stratum ○ Pairwise for each stratum

SPSS has a habit of hiding some of the text output at the bottom of the output. If this happens, try selecting and resizing the box with the output text in it, or run the analysis again with the other output options turned off, so that only the results of the log-rank test are provided. In our previous example, this will give the following SPSS output:

```
Test Statistics for Equality of Survival Distributions for TREAT

               Statistic       df      Significance

 Log Rank          8.60        1           .0034
```

Given that a probability, *P*, of 0.0034 is well below the accepted statistical threshold of 0.05, we conclude that kiwi chicks in the areas treated with brodifacoum poison survived significantly better than in unpoisoned blocks nearby. This was probably because stoats (*Mustela erminea*) and cats (*Felis catus*), the main predators of young kiwi, were killed by secondary poisoning after eating dead or dying rats or possums, and this clearly outweighed any risk from accidental poisoning of the kiwi chicks themselves.

The steps in using Excel to compare two or more groups are described below and refer to the spreadsheet in Appendix 5. The data presented is the same chick survival data used earlier (Appendix 2).

We start by using the same pivot table as for the Kaplan-Meier procedure. Either follow the instructions above to create an identical pivot table or copy the pivot table shown in Table A3.1 to a new sheet and remove all the workings. (It would be possible to add this material to the KM table, but it could become difficult to follow.)

Column I: **n1j**. The number at risk in the first group (Non-treatment) at that time (it includes the animal that died and any animals censored at exactly that time). This is calculated from the total in the group, less earlier deaths and censorship. The Excel formula in the first cell in the example is *=D$47-SUM(D$5:D5),* and should be copied down. The formulae for the first cell for columns J–Q is given below in italics, and should be copied down the sheet.

Column J: **n2j**. The number of animals at risk in the second group (*=G$47-SUM(G$5)*).

Column K: **nj**. The combined total number of chicks at risk (*=I6+J6*).

Column L: **dj**. The total number of deaths at that particular tracking time (the sum of **d1j**, the number of deaths in group 1 from the pivot table column C, and **d2j**, the number of deaths in group 2 from the pivot table column F (*=C6+F6*).

Column M: **e1j**. The expected number of deaths in groups 1 at that particular time if survival was the same in the two groups (*=L6*I6/K6*).

Column N: **e2j**. The expected number of deaths in group 2 (*=L6*J6/K6).*

Column O: **d1j – e1j.** The difference between observed deaths and expected deaths in group 1 (*=C6-M6*).

Column P: **d2j – e2j**. The difference between observed deaths and expected deaths in group 2 *(=F6-N6).*

Column Q: The **estimated variance** of the differences (*=I6*(K6-I6)*(K6-L6)*L6/(K6*K6*(K6-1)))*.

(Note that columns N and P are unnecessary for this two-sample test because they are the complement of columns M and O. They are shown here because they would be needed if the number of groups was greater than 2.)

Next, sum the differences and square this sum to get the test statistic: add up values in column O or column P (= ± 6.83 in the kiwi example), square the answer (= 46.64) and divide it by the sum of variances (add up values in column O (= 5.421)); this gives a test statistic of 8.60. This figure can then be compared with the percentile values in statistical tables of the χ^2 distribution with 1 degree of freedom. Excel calculates these for us, using the function *CHIDIST()*, with the test statistic as the first argument and the degrees of freedom as the second argument. From this kiwi example, we concluded that chick survival was significantly better in the poisoned areas than in nearby unpoisoned areas ($P = 0.0034$), as previously reported by Robertson et al. (1999).

7. Further topics in survival data analysis

This guide provides some simple robust tools for analysing survival data. The Kaplan-Meier survival rate and log-rank test described herein do not include specific assumptions about the distribution of survival times. In addition to these tools, there are other very well-developed tools available for survival data analysis, which can extract further information from various sorts of data. One approach involves making specific assumptions about the way survival times are distributed—leading to parametric models, such as the exponential model used above, and the more flexible Weibull model. Another very important direction involves using the Cox proportional hazard model, which allows the inclusion of various covariates in a semi-parametric model. As more survival studies are designed, implemented and their results analysed, some of these more advanced approaches may be needed, but the tools covered in this guide should provide a good starting point.

8. Availability of Excel files

Copies of the Excel files used in Appendices 1–5 are available by request from the senior author. The files can be saved and new data substituted for the old in the files—**taking great care not to write over formulae—**and after some adjustments to data references the calculations will be done automatically. Alternatively, the data could be copied into Excel from an electronic (pdf) version of this manuscript. Use the text import wizard (**Data > Text to columns**... using Space as the delimiter) to recreate the data tables in Excel and follow the instructions given. Similarly, the more complex formulae could be clipped from the pdf into Excel.

9. Discussion

Radio-tracking has become a very powerful tool for determining the survivorship of wild animals. It is free from many of the assumptions inherent in other methods of calculating survival using capture-recapture techniques. Researchers must, however, be ever vigilant, because catching wild animals, attaching transmitters to them and regularly radio-tracking them (with its various levels of disturbance) may affect the survival chances of the study animal. It is important to keep up with improvements in transmitter technology, packaging and attachment methods, and to use mortality transmitters wherever possible. If the chances of mortality are increased through an animal wearing a transmitter, survival estimates will be conservative, whereas with other methods biases can lead to either conservative or inflated survival estimates.

The main problem with radio-tracking studies is obtaining a sufficiently large sample of animals and—most importantly for long-lived species—getting a sufficient number of recorded deaths to make the estimates reliable. The methods described above require considerable time in the field to obtain good survivorship estimates; however, the aim of most radio-telemetry studies is for more than just collection of survivorship information, to ‘kill two (or more) birds with one stone’!

The tests described here can also be used in some other situations where animals are marked in other ways and then recaptured / resighted later. However, be aware that with some methods the assumptions can be seriously violated, e.g. birds often avoid recapture in mist-nets, and this can create serious problems with capture-recapture analysis. It will often be best to use specialist software, which is now available for this sort of data. The statistical methods presented here also seem to be appropriate for studies of plant survival, permitting, for instance, comparison of the survival of tagged or counted plants in one plot or quadrat with another (e.g. grazed versus ungrazed) at various (regular or irregular) intervals.

10. Acknowledgements

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Appendix 1

SURVIVORSHIP DATA FOR ADULT FEMALE BROWN KIWI

Survivorship data and calculations of simple survivorship measures from radio-tagged adult female brown kiwi in central Northland, New Zealand (see Robertson et al. (1999) for details of the study).

The dataset includes each individual's band number (Band), band colour combination (Comb) and sex (M: male; F: female); the study area in which the individual was located (Area: P = Purua; Rp = Riponui; H = Hodge's; Rr = Rarewarewa); the most recent transmitter frequency used for the animal (Tx); the date on which the continuous record of radio-tracking started (On) and finished (Off_last), and the total tracking period (Total); and the fate of the bird (Death: 0 = alive; 1 = dead) and cause of death (Cause), if applicable.

Ongoing records are presented in bold and records ending with death of the individual are in italics; all other records ended due to transmitter removal or failure, and are presented in normal font. For further information about this data, see section 4.

Band	Comb	Sex	Area	Tx	On	Off_last	Total	Death	Cause
1079	B	F	P	37	29-Jun-94	10-Mar-95	254	0	
1086	BY	F	P	9	22-Aug-94	12-Apr-95	233	0	
1078	R	F	P	52	22-Aug-94	27-Oct-94	66	0	
1087	YW	F	P	5	22-Aug-94	1-Dec-94	101	0	
1088	YG	F	P	36	24-Aug-94	19-Oct-94	56	0	
46324	RG	F	P	39	10-Mar-95	30-May-95	81	0	
1094	RY	F	P	55	12-Mar-95	11-May-95	60	0	
1005	GO	F	P	5	21-Nov-95	19-Sep-96	303	0	
1078	**R**	**F**	**P**	**48**	**12-Dec-97**	**21-Sep-98**	**283**	**0**	
1071	RW	F	Rp	50	8-Jun-94	7-Jul-94	29	0	
1082	BW	F	Rp	50	20-Jul-94	15-Dec-94	148	0	
1083	W	F	Rp	67	26-Jul-94	13-Sep-94	49	0	
1071	RW	F	Rp	36	20-Oct-95	15-Jan-96	87	0	
1069	B	F	Rp	82	17-Sep-96	27-Nov-96	71	0	
951	**YB**	**F**	**Rp**	**71**	**22-Jul-97**	**25-Sep-98**	**430**	**0**	
953	YBY	F	Rp	10	24-Dec-97	25-Sep-98	275	0	
1083	W	F	Rp	65	18-Oct-97	22-Oct-97	4	0	
1001	WO	F	H	25	26-May-95	31-May-95	5	0	
1004	BO	F	H	50	20-Sep-95	20-Dec-95	91	0	
1012	O	F	H	16	17-May-96	18-Jun-96	32	0	
44912	B	F	H	82	25-Jun-96	27-Feb-97	247	0	
1015	BR	F	H	17	22-Aug-96	23-Dec-96	123	0	
44917	G	F	H	72	18-Apr-97	13-Mar-98	329	0	
1012	O	F	H	28	26-Apr-97	6-Oct-97	163	0	
1004	*BO*	*F*	*H*	*69*	*16-Jul-97*	*6-Oct-97*	*82*	1	*Unknown*
1092	RW	F	H	25	24-Sep-97	12-Mar-98	169	0	

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Appendix 1—continued

Band	Comb	Sex	Area	Tx	On	Off_last	Total	Death	Cause
1092	RW	F	H	30	28-Apr-97	11-Jun-97	44	0	
1012	O	F	H	14	17-Nov-97	17-Jun-98	212	0	
35022	Y	F	Rr	20	2-Jan-94	19-May-94	137	0	
35023	G	F	Rr	26	3-Jan-94	3-Jun-94	151	0	
35025	O	F	Rr	18	3-Jan-94	24-May-94	141	0	
35022	Y	F	Rr	37	19-May-94	27-Jun-94	39	0	
44966	WG	F	Rr	77	20-May-94	25-Jun-94	36	0	
1064	BR	F	Rr	34	24-May-94	23-Jun-94	30	0	
35025	O	F	Rr	52	15-Jun-94	3-Aug-94	49	0	
1072	G	F	Rr	21	21-Jun-94	22-Jun-94	1	0	
1073	OB	F	Rr	58	21-Jun-94	8-Oct-94	109	0	
47365	**G**	**F**	**Rr**	**31**	**22-Jun-94**	**24-Sep-98**	**1555**	**0**	
1075	WR	F	Rr	17	23-Jun-94	26-Jun-94	3	0	
1076	WY	F	Rr	61	25-Jun-94	24-Aug-94	60	0	
1077	BW	F	Rr	77	26-Jun-94	25-Jul-94	29	0	
1084	GR	F	Rr	77	27-Jul-94	21-Dec-94	147	0	
1076	WY	F	Rr	34	28-Sep-94	19-Apr-95	203	0	
47368	RY	F	Rr	52	31-Oct-94	25-Nov-94	25	0	
1072	**GO**	**F**	**Rr**	**62**	**11-Mar-95**	**3-Jul-98**	**1210**	**0**	
1065	*R*	*F*	*Rr*	*16*	*6-Mar-95*	*24-Aug-98*	*1267*	1	*Dog*
1062	**RW**	**F**	**Rr**	**49**	**3-Mar-95**	**14-Sep-98**	**1291**	**0**	
1073	RG	F	Rr	12	1-Mar-95	28-Jul-95	149	0	
1064	**BR**	**F**	**Rr**	**16**	**11-Mar-95**	**10-Sep-98**	**1279**	**0**	
949	**YR**	**F**	**Rr**	**63**	**1-Mar-95**	**11-Sep-98**	**1290**	**0**	
1075	**WR**	**F**	**Rr**	**66**	**11-Mar-95**	**24-Sep-98**	**1293**	**0**	
35025	O	F	Rr	80	16-Mar-95	12-Dec-96	637	0	
46329	**YW**	**F**	**Rr**	**34**	**27-Apr-95**	**31-Aug-98**	**1222**	**0**	
1061	**BY**	**F**	**Rr**	**71**	**28-Apr-95**	**7-Sep-98**	**1228**	**0**	
1095	**RB**	**F**	**Rr**	**13**	**29-Apr-95**	**14-Sep-98**	**1234**	**0**	
44901	GY	F	Rr	28	23-Nov-95	8-May-96	167	0	
1099	OBO	F	Rr	77	13-May-96	7-Jun-96	25	0	
1084	**GR**	**F**	**Rr**	**72**	**5-Aug-96**	**24-Sep-98**	**780**	**0**	
931	YGY	F	Rr	41	16-Aug-96	1-May-98	623	0	
35025	**O**	**F**	**Rr**	**52**	**20-May-97**	**24-Sep-98**	**492**	**0**	
44970	O	M	P	69	25-May-94	8-Sep-95	471	0	
44971	**Y**	**M**	**P**	**55**	**25-May-94**	**21-Sep-98**	**1580**	**0**	
44972	**G**	**M**	**P**	**31**	**25-May-94**	**21-Sep-98**	**1580**	**0**	
35027	**R**	**M**	**P**	**32**	**28-Jun-94**	**21-Sep-98**	**1546**	**0**	
44905	RW	M	P	34	22-Aug-94	21-Jun-96	669	0	
47377	**OG**	**M**	**P**	**32**	**24-Sep-94**	**7-Apr-95**	**195**	**0**	
44911	**WG**	**M**	**P**	**58**	**24-Sep-94**	**23-Sep-98**	**1460**	**0**	
35029	**YG**	**M**	**P**	**54**	**19-Oct-94**	**21-Sep-98**	**1433**	**0**	
1091	*YW*	*M*	*P*	*66*	*1-Dec-94*	*7-May-96*	*523*	1	*Ferret*
46322	**B**	**M**	**P**	**47**	**10-Mar-95**	**21-Sep-98**	**1291**	**0**	
46323	W	M	P	36	10-Mar-95	17-Oct-95	221	0	
46325	**BW**	**M**	**P**	**46**	**10-Mar-95**	**23-Sep-98**	**1293**	**0**	
44927	**BO**	**M**	**P**	**62**	**12-Mar-95**	**18-Sep-98**	**1286**	**0**	
46327	**BY**	**M**	**P**	**30**	**12-Apr-95**	**21-Sep-98**	**1258**	**0**	
44941	RY	M	P	55	11-May-95	19-Apr-96	344	0	
44947	GR	M	P	9	23-Jan-96	23-Sep-98	974	0	
47468	**GO**	**M**	**P**	**19**	**19-Sep-96**	**21-Sep-98**	**732**	**0**	

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Appendix 1—continued

Band	Comb	Sex	Area	Tx	On	Off_last	Total	Death	Cause
47481	**S/S**	**M**	**P**	**81**	**18-May-98**	**23-Sep-98**	**128**	**0**	
45925	S/S	M	P	34	18-May-98	17-Sep-98	122	0	
1067	**YO**	**M**	**Rp**	**26**	**26-May-94**	**25-Sep-98**	**1583**	**0**	
44974	**G**	**M**	**Rp**	**67**	**26-May-94**	**25-Sep-98**	**1583**	**0**	
44975	R	M	Rp	54	26-May-94	21-Oct-94	148	0	
44976	**O**	**M**	**Rp**	**80**	**27-May-94**	**1-Apr-98**	**1405**	**0**	
44977	*B*	*M*	*Rp*	*32*	*27-May-94*	*10-May-95*	*348*	1	*Unknown*
44978	**RW**	**M**	**Rp**	**77**	**27-May-94**	**25-Sep-98**	**1582**	**0**	
44907	**BW**	**M**	**Rp**	**40**	**23-Aug-94**	**25-Sep-98**	**1494**	**0**	
44904	**WO**	**M**	**Rp**	**74**	**19-Aug-94**	**28-Sep-98**	**1501**	**0**	
44908	**W**	**M**	**Rp**	**86**	**13-Sep-94**	**28-Sep-98**	**1476**	**0**	
44903	**YB**	**M**	**Rp**	**36**	**18-Aug-94**	**25-Sep-98**	**1499**	**0**	
44910	*BY*	*M*	*Rp*	*54*	*21-Oct-94*	*9-Dec-94*	*49*	1	*Unknown*
34167	**RB**	**M**	**Rp**	**60**	**16-Oct-97**	**28-Sep-98**	**347**	**0**	
44914	**Y**	**M**	**H**	**3**	**25-Sep-94**	**29-Sep-98**	**1465**	**0**	
44921	**BW**	**M**	**H**	**17**	**26-Sep-94**	**1-Sep-98**	**1436**	**0**	
44920	*RW*	*M*	*H*	*32*	*23-Jan-95*	*27-Sep-96*	*613*	1	*Ferret*
47451	**YB**	**M**	**H**	**65**	**25-May-95**	**29-Sep-98**	**1223**	**0**	
47452	RG	M	H	12	26-May-95	8-Aug-95	74	0	
44953	*YO*	*M*	*H*	*31*	*27-May-95*	*15-Oct-96*	*507*	1	*Ferret*
44916	*G*	*M*	*H*	*47*	*27-May-95*	*8-Aug-96*	*439*	1	*Ferret*
47454	RY	M	H	49	27-May-95	13-Aug-95	78	0	
47457	YG	M	H	27	29-May-95	7-Aug-95	70	0	
47458	**GR**	**M**	**H**	**64**	**30-May-95**	**29-Sep-98**	**1218**	**0**	
47459	BO	M	H	18	31-May-95	7-Sep-95	99	0	
44918	*R*	*M*	*H*	*44*	*31-May-95*	*1-Sep-98*	*1189*	1	*Possum*
47459	BO	M	H	62	20-Dec-95	8-Jan-98	750	0	
47463	**O**	**M**	**H**	**70**	**18-Jun-96**	**29-Sep-98**	**833**	**0**	
47457	**YG**	**M**	**H**	**37**	**22-Aug-96**	**29-Sep-98**	**768**	**0**	
43485	**ROYG**	**M**	**H**	**47**	**4-Dec-96**	**29-Sep-98**	**664**	**0**	
47459	**BO**	**M**	**H**	**79**	**20-May-98**	**29-Sep-98**	**132**	**0**	
47454	**RY**	**M**	**H**	**14**	**17-Jun-98**	**29-Sep-98**	**104**	**0**	
35024	O	M	Rr	1	3-Jan-94	3-Jan-94	0	0	
44962	**W**	**M**	**Rr**	**33**	**19-May-94**	**24-Sep-98**	**1589**	**0**	
44963	**B**	**M**	**Rr**	**30**	**19-May-94**	**24-Sep-98**	**1589**	**0**	
44964	**RW**	**M**	**Rr**	**57**	**20-May-94**	**24-Sep-98**	**1588**	**0**	
44965	BY	M	Rr	46	20-May-94	27-Jun-94	38	0	
44967	**O**	**M**	**Rr**	**50**	**24-May-94**	**24-Sep-98**	**1584**	**0**	
44968	**R**	**M**	**Rr**	**29**	**24-May-94**	**7-Sep-98**	**1567**	**0**	
44979	WO	M	Rr	67	21-Jun-94	29-Jun-94	8	0	
44980	GO	M	Rr	79	22-Jun-94	18-Feb-96	606	0	
44981	**BR**	**M**	**Rr**	**85**	**22-Jun-94**	**24-Sep-98**	**1555**	**0**	
47366	*G*	*M*	*Rr*	*7*	*22-Jun-94*	*6-Dec-96*	*898*	1	*Drowned*
47367	*YR*	*M*	*Rr*	*85*	*23-Jun-94*	*21-Feb-96*	*608*	1	*Unknown*
44983	*GW*	*M*	*Rr*	*74*	*24-Jun-94*	*19-Aug-96*	*787*	1	*Dog / Ferret*
47369	**RY**	**M**	**Rr**	**77**	**24-Jun-94**	**28-Sep-98**	**1557**	**0**	
44984	**RO**	**M**	**Rr**	**78**	**25-Jun-94**	**24-Sep-98**	**1552**	**0**	
44987	**YO**	**M**	**Rr**	**39**	**25-Jun-94**	**11-Sep-98**	**1539**	**0**	
47370	WY	M	Rr	34	26-Jun-94	16-Aug-94	51	0	
44988	WR	M	Rr	15	**26-Jun-94**	11-Feb-98	1326	0	
44989	**GB**	**M**	**Rr**	**27**	**26-Jun-94**	**24-Sep-98**	**1551**	**0**	

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Appendix 1—continued

Band	Comb	Sex	Area	Tx	On	Off_last	Total	Death	Cause
44990	**BW**	**M**	**Rr**	**59**	**6-Jul-94**	**24-Sep-98**	**1541**	**0**	
44909	OB	M	Rr	58	8-Oct-94	29-Aug-95	325	0	
47370	**G**	**M**	**Rr**	**53**	**19-Apr-95**	**24-Sep-98**	**1254**	**0**	
46328	*YW*	*M*	*Rr*	*70*	*27-Apr-95*	*22-Jan-96*	*270*	1	*Unknown*
47373	**YG**	**M**	**Rr**	**21**	**29-Apr-95**	**7-Sep-98**	**1227**	**0**	
44928	**RB**	**M**	**Rr**	**11**	***29-Apr-95***	**14-Sep-98**	**1234**	**0**	
44929	OR	M	Rr	23	4-May-95	30-Aug-95	118	0	
46330	**OG**	**M**	**Rr**	**18**	**5-May-95**	**24-Sep-98**	**1238**	**0**	
47460	**RG**	**M**	**Rr**	**5**	**11-Jul-95**	**24-Sep-98**	**1171**	**0**	
47462	**GY**	**M**	**Rr**	**15**	**8-May-96**	**24-Sep-98**	**869**	**0**	
47465	**GWB**	**M**	**Rr**	**73**	**16-May-96**	**11-Sep-98**	**848**	**0**	
44980	**YB**	**M**	**Rr**	**75**	**25-Jun-96**	**24-Sep-98**	**821**	**0**	
47474	**YW**	**M**	**Rr**	**24**	**21-Mar-97**	**24-Sep-98**	**552**	**0**	
34169	S/S	M	Rr	65	23-Oct-97	3-Mar-98	131	0	
44988	**WR**	**M**	**Rr**	**35**	**11-May-98**	**24-Sep-98**	**136**	**0**	
47487	**YGY**	**M**	**Rr**	**83**	**16-Jun-98**	**28-Sep-98**	**104**	**0**	
47488	**S/S**	**M**	**Rr**	**25**	**3-Sep-98**	**10-Sep-98**	**7**	0	

Total:	94551	days
	258.87	years
	13	deaths
Estimates based on the assumption of constant survival:		
survival rate	0.9498	(= 1 – (deaths/years))
mortality rate	0.0502	
life expectancy	19.9128	years/deaths

Appendix 2

SURVIVORSHIP DATA FOR BROWN KIWI CHICKS

Survivorship data for brown kiwi chicks exposed to brodifacoum poison (Poison) and in nearby untreated forest patches (Non-treatment) in 1996–98 (see Robertson et al. (1999) for more details). The data have been sorted by tracking interval.

The dataset includes each individual's band number (Band) and transmitter frequency (Tx); the study area in which it was located (Area) and the management regime for that area (Treatmen: Poison = treated with brodifacoum poison; Non-treatment = untreated); the date on which the continuous record of radio-tracking started (On) and finished (Off_last), and the total tracking period (Cdays); and the fate of the bird (Death?: 0 = alive; 1 = dead). Records ending with death of the individual are presented in italics. For further information about this data, see section 5.3.

Band	Tx	Area	Treatmen	On	Off_last	Cdays	Death?
FRI5304	*97*	*P*	*Non-treatment*	*22-Feb-97*	*25-Feb-97*	*3*	*1*
393F	*25*	*P*	*Non-treatment*	*10-Oct-97*	*14-Oct-97*	*4*	*1*
FRI1989	*76*	*Rp*	*Poison*	*15-Oct-97*	*19-Oct-97*	*4*	*1*
C13	*23*	*P*	*Non-treatment*	*9-Feb-97*	*17-Feb-97*	*8*	*1*
C9	*12*	*P*	*Non-treatment*	*19-Sep-96*	*27-Sep-96*	*8*	*1*
C10	*12*	*P*	*Non-treatment*	*9-Oct-96*	*19-Oct-96*	*10*	*1*
C11	25	P	Non-treatment	11-Oct-96	21-Oct-96	10	0
399F	*91*	*Rr*	*Poison*	*17-Oct-97*	*29-Oct-97*	*12*	*1*
387F	*27*	*P*	*Non-treatment*	*26-Sep-97*	*10-Oct-97*	*14*	*1*
C11	*27*	*Rr*	*Poison*	*18-Oct-96*	*1-Nov-96*	*14*	*1*
386F	*37*	*P*	*Non-treatment*	*12-Sep-97*	*27-Sep-97*	*15*	*1*
B0884	*74*	*Rr*	*Poison*	*13-Jan-98*	*28-Jan-98*	*15*	*1*
363F	*96*	*Rr*	*Poison*	*21-Oct-96*	*6-Nov-96*	*16*	*1*
C12	*29*	*P*	*Non-treatment*	*11-Oct-96*	*27-Oct-96*	*16*	*1*
C8	40	Rp	Poison	24-Dec-97	9-Jan-98	16	0
366F	45	Rr	Poison	18-Oct-96	4-Nov-96	*17*	0
387F	*91*	*Rr*	*Poison*	*22-Sep-97*	*9-Oct-97*	*17*	*1*
C14	*37*	*Rr*	*Poison*	*22-Oct-96*	*9-Nov-96*	*18*	*1*
FRI1988	*74*	*Rp*	*Poison*	*14-Oct-97*	*1-Nov-97*	*18*	*1*
C7	33	Rp	Poison	19-Dec-97	9-Jan-98	21	0
FRI5303	*94*	*P*	*Non-treatment*	*14-Feb-97*	*7-Mar-97*	*21*	*1*
Huia	95	Rr	Poison	7-Jan-97	28-Jan-97	21	0
396F	*35*	*Rr*	*Poison*	*17-Sep-97*	*9-Oct-97*	*22*	*1*
c15	96	Rr	Poison	5-Sep-97	27-Sep-97	22	0
B-0894	*29*	*Rp*	*Poison*	*31-Mar-98*	*23-Apr-98*	*23*	*1*
C18	91	Rr	Poison	16-Feb-98	14-Mar-98	26	0
395f	*29*	*P*	*Non-treatment*	*26-Sep-97*	*27-Oct-97*	*31*	*1*
FRI1990	*79*	*Rp*	*Poison*	*3-Oct-97*	*3-Nov-97*	*31*	*1*

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Appendix 2—continued

Band	Tx	Area	Treatmen	On	Off_last	Cdays	Death?
C17	90	Rr	Poison	15-Oct-97	16-Nov-97	32	0
372F	*31*	*P*	*Non-treatment*	*14-Oct-96*	*17-Nov-96*	*34*	*1*
400F	95	Rr	Poison	17-Oct-97	20-Nov-97	34	0
B0879	*94*	*Rr*	*Poison*	*23-Dec-97*	*27-Jan-98*	*35*	*1*
B0876	*91*	*P*	*Non-treatment*	*18-Nov-97*	*25-Dec-97*	*37*	*1*
B0885	36	P	Non-treatment	28-Jan-98	7-Mar-98	38	0
C8	*36*	*P*	*Non-treatment*	*19-Sep-96*	*28-Oct-96*	*39*	*1*
C13	27	Rr	Poison	21-Oct-96	7-Dec-96	47	0
398F	*94*	*Rr*	*Poison*	*24-Sep-97*	*14-Nov-97*	*51*	*1*
394F	*40*	*P*	*Non-treatment*	*26-Sep-97*	*17-Nov-97*	*52*	*1*
C9	*40*	*Rp*	*Poison*	*3-Feb-98*	*28-Mar-98*	*53*	*1*
397F	45	P	Non-treatment	26-Sep-97	30-Nov-97	65	0
B0880	25	Rr	Poison	23-Dec-97	1-Mar-98	68	0
FRI5307	31	Rr	Poison	24-Sep-97	3-Dec-97	70	0
367F	88	Rr	Poison	24-Oct-96	4-Jan-97	72	0
382F	27	Rr	Poison	6-Jan-97	20-Mar-97	73	0
376F	17	Rr	Poison	18-Oct-96	2-Jan-97	76	0
392F	*97*	*Rr*	*Poison*	*17-Oct-97*	*5-Jan-98*	*80*	*1*
47476 *	90	Rr	Poison	18-Sep-96	23-Dec-96	96	0
B0877	*90*	*Rr*	*Poison*	*5-Dec-97*	*21-Mar-98*	*106*	*1*
377F	*96*	*Rr*	*Poison*	*14-Nov-96*	*6-Mar-97*	*112*	*1*
384F	*94*	*Rr*	*Poison*	*17-Mar-97*	*14-Jul-97*	*119*	*1*
FRI5306	*17*	*Rr*	*Poison*	*17-Sep-97*	*23-Jan-98*	*128*	*1*
388F	35	Rr	Poison	17-Sep-97	25-Feb-98	161	0
385F	35	H	Non-treatment	2-May-97	21-Oct-97	172	0
371F	*91*	*Rr*	*Poison*	*21-Oct-96*	*14-Apr-97*	*175*	*1*
FRI5308	88	Rr	Poison	17-Oct-97	17-May-98	180	0
47478	29	Rr	Poison	13-Nov-96	1-Oct-97	180	0
47477	12	Rr	Poison	12-Sep-96	3-Sep-97	180	0

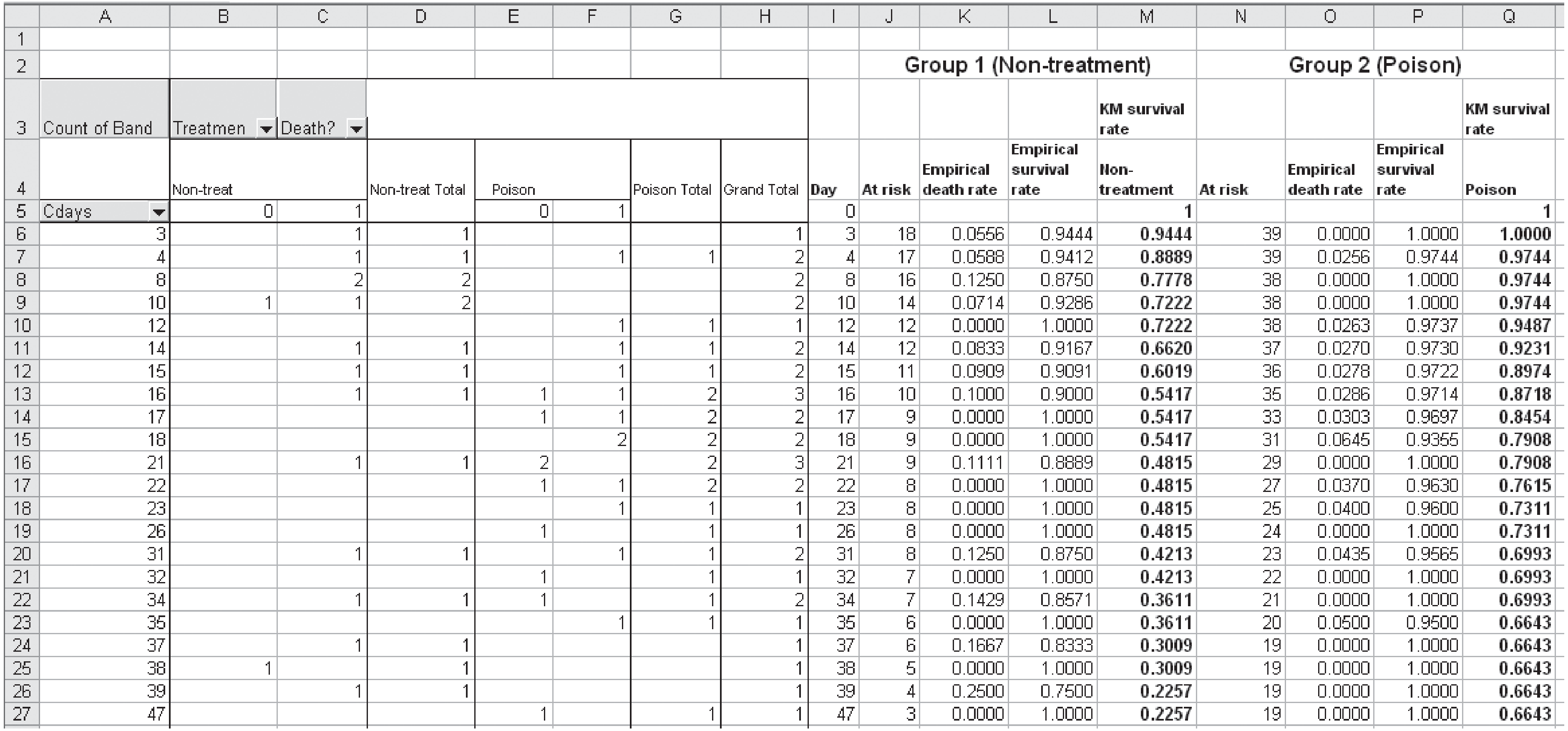
* A second record of chick 47476 was not included as it was already over 180 days old when recaptured.

Appendix 3

CALCULATION OF KAPLAN-MEIER ESTIMATES AND 95% CONFIDENCE INTERVALS

Excel spreadsheets used for deriving Kaplan-Meier estimates (Table A3.1) and 95% confidence intervals (Table A3.2) for the survival of brown kiwi chicks in treated (poison) and non-treated (Non-treat) areas. The raw data are given in Appendix 2. Calculations are outlined in section 5.3.2.

TABLE A3.1. EXCEL SPREADSHEET USED FOR DERIVING KAPLAN-MEIER ESTIMATES OF SURVIVAL OF BROWN KIWI CHICKS, WITH CHART.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2										Group 1 (Non-treatment)				Group 2 (Poison)			
3	Count of Band	Treatmen ▼	Death? ▼										**KM survival rate**				**KM survival rate**
4		Non-treat		Non-treat Total	Poison		Poison Total	Grand Total	**Day**	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Non-treatment**	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Poison**
5	Cdays ▼	0	1		0	1			0				1				1
6	3		1	1				1	3	18	0.0556	0.9444	**0.9444**	39	0.0000	1.0000	**1.0000**
7	4		1	1		1	1	2	4	17	0.0588	0.9412	**0.8889**	39	0.0256	0.9744	**0.9744**
8	8		2	2				2	8	16	0.1250	0.8750	**0.7778**	38	0.0000	1.0000	**0.9744**
9	10	1	1	2				2	10	14	0.0714	0.9286	**0.7222**	38	0.0000	1.0000	**0.9744**
10	12					1	1	1	12	12	0.0000	1.0000	**0.7222**	38	0.0263	0.9737	**0.9487**
11	14		1	1		1	1	2	14	12	0.0833	0.9167	**0.6620**	37	0.0270	0.9730	**0.9231**
12	15		1	1		1	1	2	15	11	0.0909	0.9091	**0.6019**	36	0.0278	0.9722	**0.8974**
13	16		1	1	1	1	2	3	16	10	0.1000	0.9000	**0.5417**	35	0.0286	0.9714	**0.8718**
14	17				1	1	2	2	17	9	0.0000	1.0000	**0.5417**	33	0.0303	0.9697	**0.8454**
15	18					2	2	2	18	9	0.0000	1.0000	**0.5417**	31	0.0645	0.9355	**0.7908**
16	21		1	1	2		2	3	21	9	0.1111	0.8889	**0.4815**	29	0.0000	1.0000	**0.7908**
17	22				1	1	2	2	22	8	0.0000	1.0000	**0.4815**	27	0.0370	0.9630	**0.7615**
18	23					1	1	1	23	8	0.0000	1.0000	**0.4815**	25	0.0400	0.9600	**0.7311**
19	26				1		1	1	26	8	0.0000	1.0000	**0.4815**	24	0.0000	1.0000	**0.7311**
20	31		1	1		1	1	2	31	8	0.1250	0.8750	**0.4213**	23	0.0435	0.9565	**0.6993**
21	32				1		1	1	32	7	0.0000	1.0000	**0.4213**	22	0.0000	1.0000	**0.6993**
22	34		1	1	1		1	2	34	7	0.1429	0.8571	**0.3611**	21	0.0000	1.0000	**0.6993**
23	35					1	1	1	35	6	0.0000	1.0000	**0.3611**	20	0.0500	0.9500	**0.6643**
24	37		1	1				1	37	6	0.1667	0.8333	**0.3009**	19	0.0000	1.0000	**0.6643**
25	38	1		1				1	38	5	0.0000	1.0000	**0.3009**	19	0.0000	1.0000	**0.6643**
26	39		1	1				1	39	4	0.2500	0.7500	**0.2257**	19	0.0000	1.0000	**0.6643**
27	47				1		1	1	47	3	0.0000	1.0000	**0.2257**	19	0.0000	1.0000	**0.6643**

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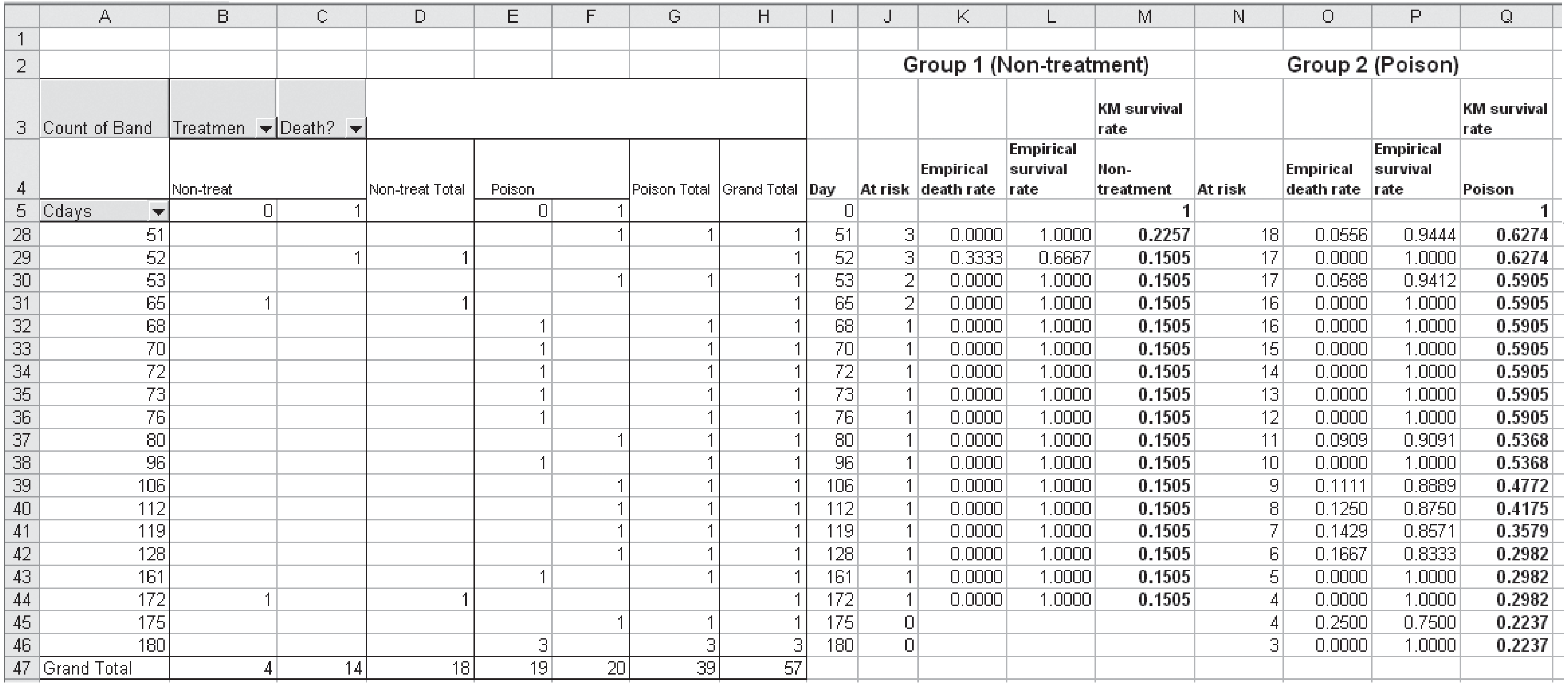
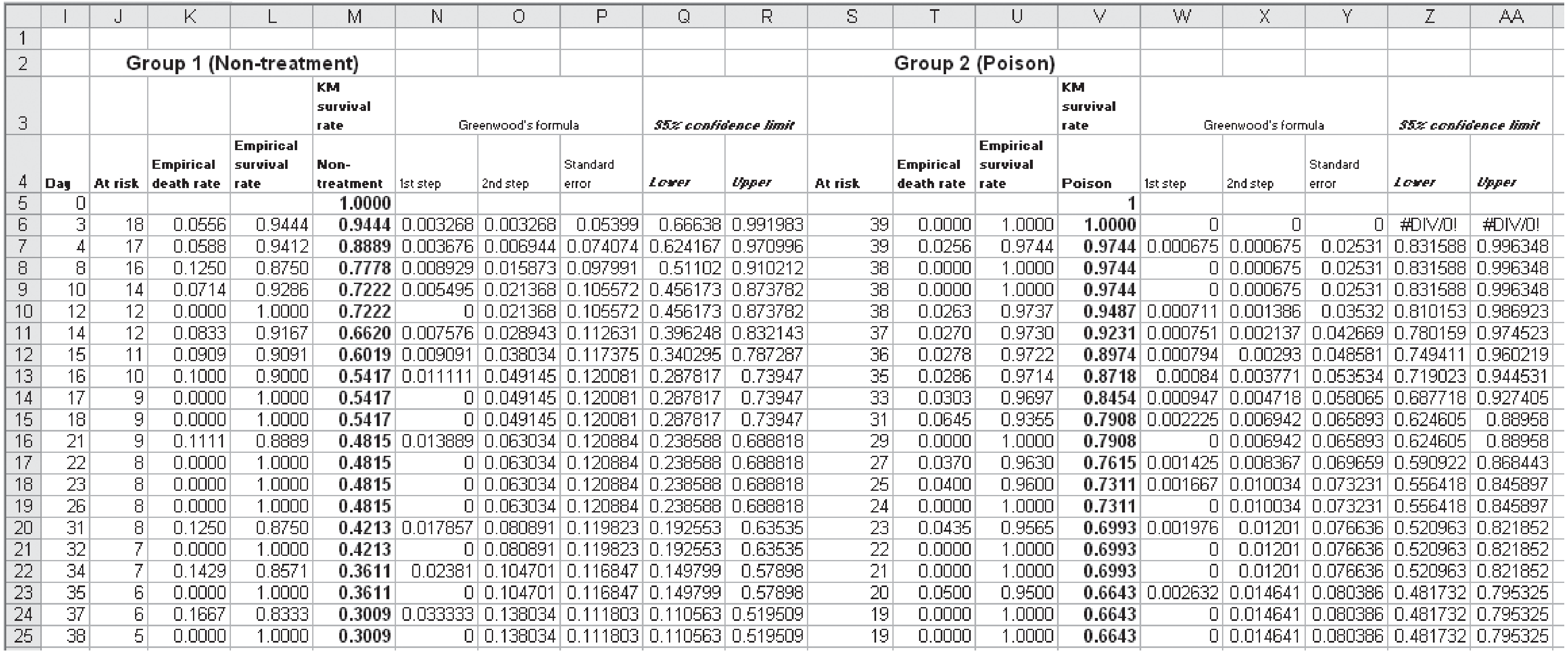
Table A3.1—continued



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2										**Group 1 (Non-treatment)**				**Group 2 (Poison)**			
3	Count of Band	Treatmen ▼	Death? ▼										**KM survival rate**				**KM survival rate**
4		Non-treat		Non-treat Total	Poison		Poison Total	Grand Total	**Day**	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Non-treatment**	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Poison**
5	Cdays ▼	0	1		0	1			0				**1**				**1**
28	51					1	1	1	51	3	0.0000	1.0000	**0.2257**	18	0.0556	0.9444	**0.6274**
29	52		1	1				1	52	3	0.3333	0.6667	**0.1505**	17	0.0000	1.0000	**0.6274**
30	53					1	1	1	53	2	0.0000	1.0000	**0.1505**	17	0.0588	0.9412	**0.5905**
31	65	1		1				1	65	2	0.0000	1.0000	**0.1505**	16	0.0000	1.0000	**0.5905**
32	68				1		1	1	68	1	0.0000	1.0000	**0.1505**	16	0.0000	1.0000	**0.5905**
33	70				1		1	1	70	1	0.0000	1.0000	**0.1505**	15	0.0000	1.0000	**0.5905**
34	72				1		1	1	72	1	0.0000	1.0000	**0.1505**	14	0.0000	1.0000	**0.5905**
35	73				1		1	1	73	1	0.0000	1.0000	**0.1505**	13	0.0000	1.0000	**0.5905**
36	76				1		1	1	76	1	0.0000	1.0000	**0.1505**	12	0.0000	1.0000	**0.5905**
37	80					1	1	1	80	1	0.0000	1.0000	**0.1505**	11	0.0909	0.9091	**0.5368**
38	96				1		1	1	96	1	0.0000	1.0000	**0.1505**	10	0.0000	1.0000	**0.5368**
39	106					1	1	1	106	1	0.0000	1.0000	**0.1505**	9	0.1111	0.8889	**0.4772**
40	112					1	1	1	112	1	0.0000	1.0000	**0.1505**	8	0.1250	0.8750	**0.4175**
41	119					1	1	1	119	1	0.0000	1.0000	**0.1505**	7	0.1429	0.8571	**0.3579**
42	128					1	1	1	128	1	0.0000	1.0000	**0.1505**	6	0.1667	0.8333	**0.2982**
43	161				1		1	1	161	1	0.0000	1.0000	**0.1505**	5	0.0000	1.0000	**0.2982**
44	172	1		1				1	172	1	0.0000	1.0000	**0.1505**	4	0.0000	1.0000	**0.2982**
45	175					1	1	1	175	0				4	0.2500	0.7500	**0.2237**
46	180				3		3	3	180	0				3	0.0000	1.0000	**0.2237**
47	Grand Total	4	14	18	19	20	39	57									

TABLE A3.2. ADDITIONAL COLUMNS USED TO CALCULATE 95% CONFIDENCE INTERVALS USING GREENWOOD'S FORMULA.

Note: 95% confidence limit is the log-confidence interval (see Klein & Moeschberger 1997: 97).



	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1																			
2		**Group 1 (Non-treatment)**									**Group 2 (Poison)**								
3					**KM survival rate**	Greenwood's formula			***95% confidence limit***					**KM survival rate**	Greenwood's formula			***95% confidence limit***	
4	**Day**	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Non-treatment**	1st step	2nd step	Standard error	***Lower***	***Upper***	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Poison**	1st step	2nd step	Standard error	***Lower***	***Upper***
5	0				**1.0000**									1					
6	3	18	0.0556	0.9444	**0.9444**	0.003268	0.003268	0.05399	0.66638	0.991983	39	0.0000	1.0000	**1.0000**	0	0	0	#DIV/0!	#DIV/0!
7	4	17	0.0588	0.9412	**0.8889**	0.003676	0.006944	0.074074	0.624167	0.970996	39	0.0256	0.9744	**0.9744**	0.000675	0.000675	0.02531	0.831588	0.996348
8	8	16	0.1250	0.8750	**0.7778**	0.008929	0.015873	0.097991	0.51102	0.910212	38	0.0000	1.0000	**0.9744**	0	0.000675	0.02531	0.831588	0.996348
9	10	14	0.0714	0.9286	**0.7222**	0.005495	0.021368	0.105572	0.456173	0.873782	38	0.0000	1.0000	**0.9744**	0	0.000675	0.02531	0.831588	0.996348
10	12	12	0.0000	1.0000	**0.7222**	0	0.021368	0.105572	0.456173	0.873782	38	0.0263	0.9737	**0.9487**	0.000711	0.001386	0.03532	0.810153	0.986923
11	14	12	0.0833	0.9167	**0.6620**	0.007576	0.028943	0.112631	0.396248	0.832143	37	0.0270	0.9730	**0.9231**	0.000751	0.002137	0.042669	0.780159	0.974523
12	15	11	0.0909	0.9091	**0.6019**	0.009091	0.038034	0.117375	0.340295	0.787287	36	0.0278	0.9722	**0.8974**	0.000794	0.00293	0.048581	0.749411	0.960219
13	16	10	0.1000	0.9000	**0.5417**	0.011111	0.049145	0.120081	0.287817	0.73947	35	0.0286	0.9714	**0.8718**	0.00084	0.003771	0.053534	0.719023	0.944531
14	17	9	0.0000	1.0000	**0.5417**	0	0.049145	0.120081	0.287817	0.73947	33	0.0303	0.9697	**0.8454**	0.000947	0.004718	0.058065	0.687718	0.927405
15	18	9	0.0000	1.0000	**0.5417**	0	0.049145	0.120081	0.287817	0.73947	31	0.0645	0.9355	**0.7908**	0.002225	0.006942	0.065893	0.624605	0.88958
16	21	9	0.1111	0.8889	**0.4815**	0.013889	0.063034	0.120884	0.238588	0.688818	29	0.0000	1.0000	**0.7908**	0	0.006942	0.065893	0.624605	0.88958
17	22	8	0.0000	1.0000	**0.4815**	0	0.063034	0.120884	0.238588	0.688818	27	0.0370	0.9630	**0.7615**	0.001425	0.008367	0.069659	0.590922	0.868443
18	23	8	0.0000	1.0000	**0.4815**	0	0.063034	0.120884	0.238588	0.688818	25	0.0400	0.9600	**0.7311**	0.001667	0.010034	0.073231	0.556418	0.845897
19	26	8	0.0000	1.0000	**0.4815**	0	0.063034	0.120884	0.238588	0.688818	24	0.0000	1.0000	**0.7311**	0	0.010034	0.073231	0.556418	0.845897
20	31	8	0.1250	0.8750	**0.4213**	0.017857	0.080891	0.119823	0.192553	0.63535	23	0.0435	0.9565	**0.6993**	0.001976	0.01201	0.076636	0.520963	0.821852
21	32	7	0.0000	1.0000	**0.4213**	0	0.080891	0.119823	0.192553	0.63535	22	0.0000	1.0000	**0.6993**	0	0.01201	0.076636	0.520963	0.821852
22	34	7	0.1429	0.8571	**0.3611**	0.02381	0.104701	0.116847	0.149799	0.57898	21	0.0000	1.0000	**0.6993**	0	0.01201	0.076636	0.520963	0.821852
23	35	6	0.0000	1.0000	**0.3611**	0	0.104701	0.116847	0.149799	0.57898	20	0.0500	0.9500	**0.6643**	0.002632	0.014641	0.080386	0.481732	0.795325
24	37	6	0.1667	0.8333	**0.3009**	0.033333	0.138034	0.111803	0.110563	0.519509	19	0.0000	1.0000	**0.6643**	0	0.014641	0.080386	0.481732	0.795325
25	38	5	0.0000	1.0000	**0.3009**	0	0.138034	0.111803	0.110563	0.519509	19	0.0000	1.0000	**0.6643**	0	0.014641	0.080386	0.481732	0.795325

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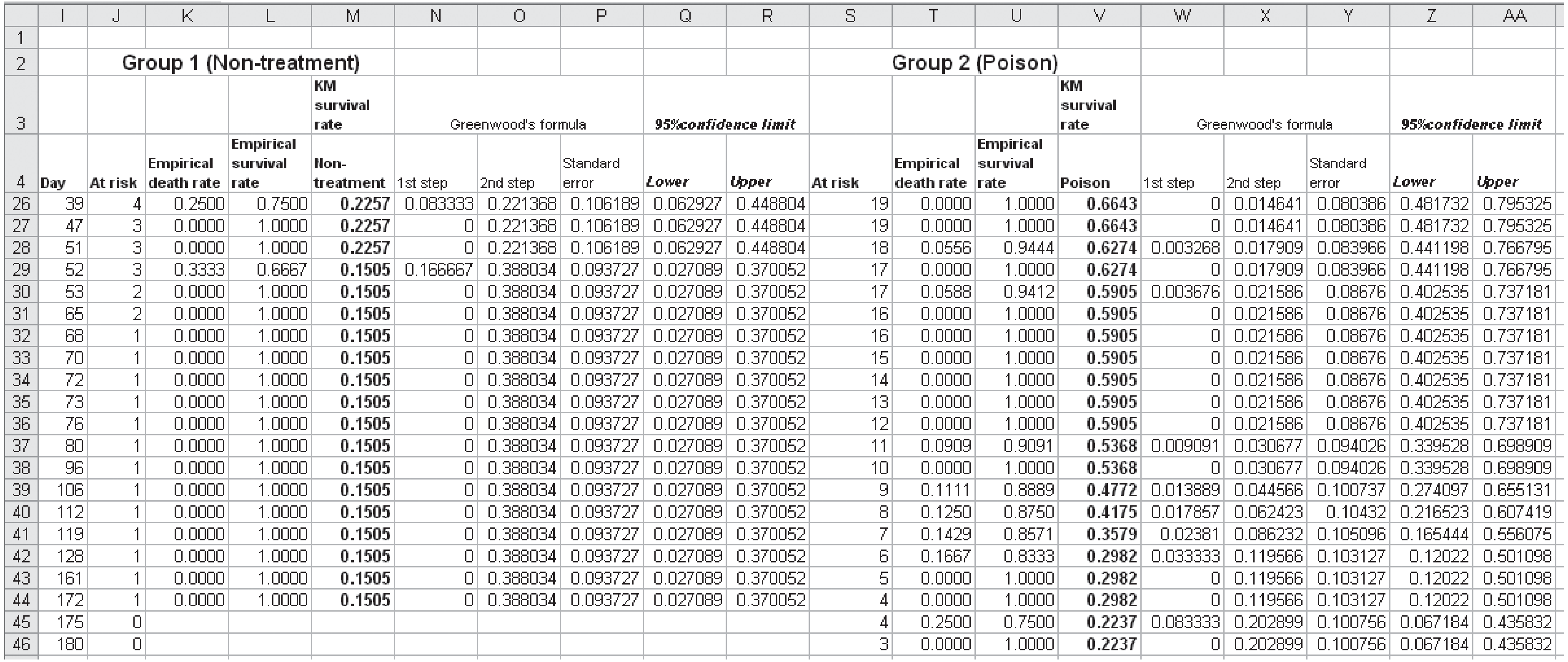
Table A3.2—continued

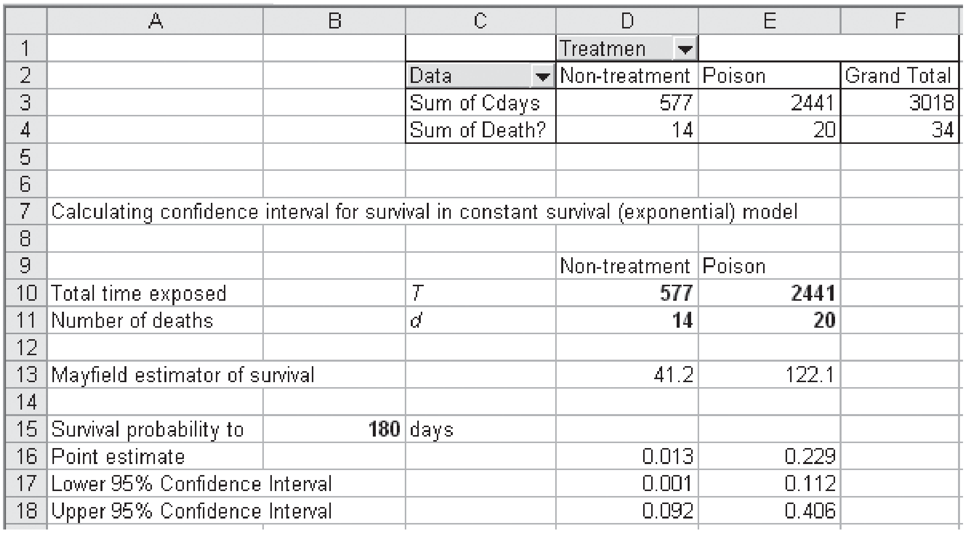


	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1																			
2		Group 1 (Non-treatment)									Group 2 (Poison)								
3					**KM survival rate**	Greenwood's formula			***95%confidence limit***					**KM survival rate**	Greenwood's formula			***95%confidence limit***	
4	**Day**	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Non-treatment**	1st step	2nd step	Standard error	***Lower***	***Upper***	**At risk**	**Empirical death rate**	**Empirical survival rate**	**Poison**	1st step	2nd step	Standard error	***Lower***	***Upper***
26	39	4	0.2500	0.7500	**0.2257**	0.083333	0.221368	0.106189	0.062927	0.448804	19	0.0000	1.0000	**0.6643**	0	0.014641	0.080386	0.481732	0.795325
27	47	3	0.0000	1.0000	**0.2257**	0	0.221368	0.106189	0.062927	0.448804	19	0.0000	1.0000	**0.6643**	0	0.014641	0.080386	0.481732	0.795325
28	51	3	0.0000	1.0000	**0.2257**	0	0.221368	0.106189	0.062927	0.448804	18	0.0556	0.9444	**0.6274**	0.003268	0.017909	0.083966	0.441198	0.766795
29	52	3	0.3333	0.6667	**0.1505**	0.166667	0.388034	0.093727	0.027089	0.370052	17	0.0000	1.0000	**0.6274**	0	0.017909	0.083966	0.441198	0.766795
30	53	2	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	17	0.0588	0.9412	**0.5905**	0.003676	0.021586	0.08676	0.402535	0.737181
31	65	2	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	16	0.0000	1.0000	**0.5905**	0	0.021586	0.08676	0.402535	0.737181
32	68	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	16	0.0000	1.0000	**0.5905**	0	0.021586	0.08676	0.402535	0.737181
33	70	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	15	0.0000	1.0000	**0.5905**	0	0.021586	0.08676	0.402535	0.737181
34	72	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	14	0.0000	1.0000	**0.5905**	0	0.021586	0.08676	0.402535	0.737181
35	73	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	13	0.0000	1.0000	**0.5905**	0	0.021586	0.08676	0.402535	0.737181
36	76	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	12	0.0000	1.0000	**0.5905**	0	0.021586	0.08676	0.402535	0.737181
37	80	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	11	0.0909	0.9091	**0.5368**	0.009091	0.030677	0.094026	0.339528	0.698909
38	96	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	10	0.0000	1.0000	**0.5368**	0	0.030677	0.094026	0.339528	0.698909
39	106	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	9	0.1111	0.8889	**0.4772**	0.013889	0.044566	0.100737	0.274097	0.655131
40	112	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	8	0.1250	0.8750	**0.4175**	0.017857	0.062423	0.10432	0.216523	0.607419
41	119	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	7	0.1429	0.8571	**0.3579**	0.02381	0.086232	0.105096	0.165444	0.556075
42	128	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	6	0.1667	0.8333	**0.2982**	0.033333	0.119566	0.103127	0.12022	0.501098
43	161	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	5	0.0000	1.0000	**0.2982**	0	0.119566	0.103127	0.12022	0.501098
44	172	1	0.0000	1.0000	**0.1505**	0	0.388034	0.093727	0.027089	0.370052	4	0.0000	1.0000	**0.2982**	0	0.119566	0.103127	0.12022	0.501098
45	175	0									4	0.2500	0.7500	**0.2237**	0.083333	0.202899	0.100756	0.067184	0.435832
46	180	0									3	0.0000	1.0000	**0.2237**	0	0.202899	0.100756	0.067184	0.435832

Appendix 4

CALCULATION OF SURVIVAL TO A GIVEN NUMBER OF DAYS

Excel spreadsheet for the calculation of survival of brown kiwi to a given number of days based on the assumption of constant survival rate, using data from Appendix 2. Calculations are outlined in section 5.5.

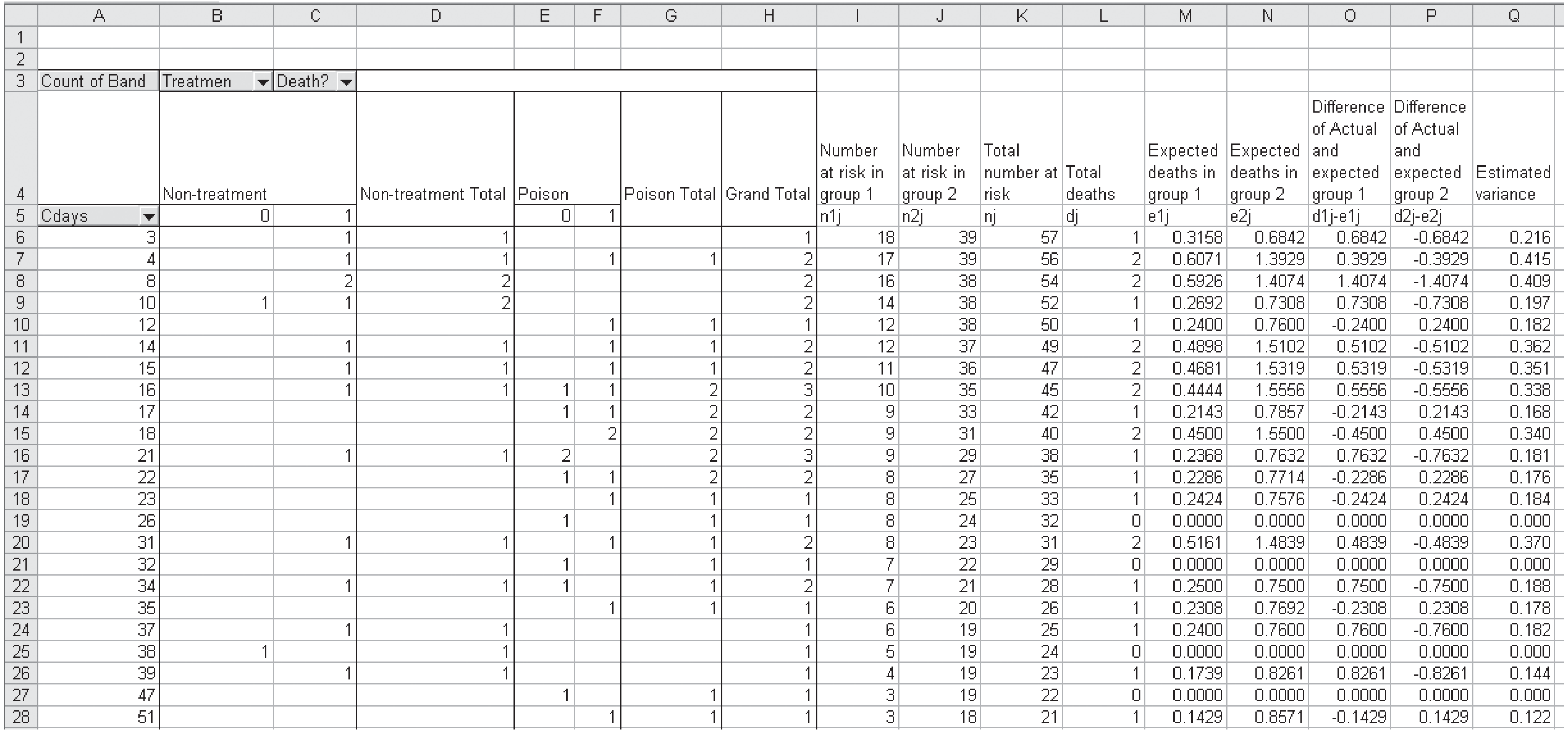


	A	B	C	D	E	F
1				Treatmen		
2			Data	Non-treatment	Poison	Grand Total
3			Sum of Cdays	577	2441	3018
4			Sum of Death?	14	20	34
5						
6						
7	Calculating confidence interval for survival in constant survival (exponential) model					
8						
9				Non-treatment	Poison	
10	Total time exposed		*T*	**577**	**2441**	
11	Number of deaths		*d*	**14**	**20**	
12						
13	Mayfield estimator of survival			41.2	122.1	
14						
15	Survival probability to	**180**	days			
16	Point estimate			0.013	0.229	
17	Lower 95% Confidence Interval			0.001	0.112	
18	Upper 95% Confidence Interval			0.092	0.406	

Appendix 5

CALCULATION OF THE MANTEL-HAENSZEL STATISTIC

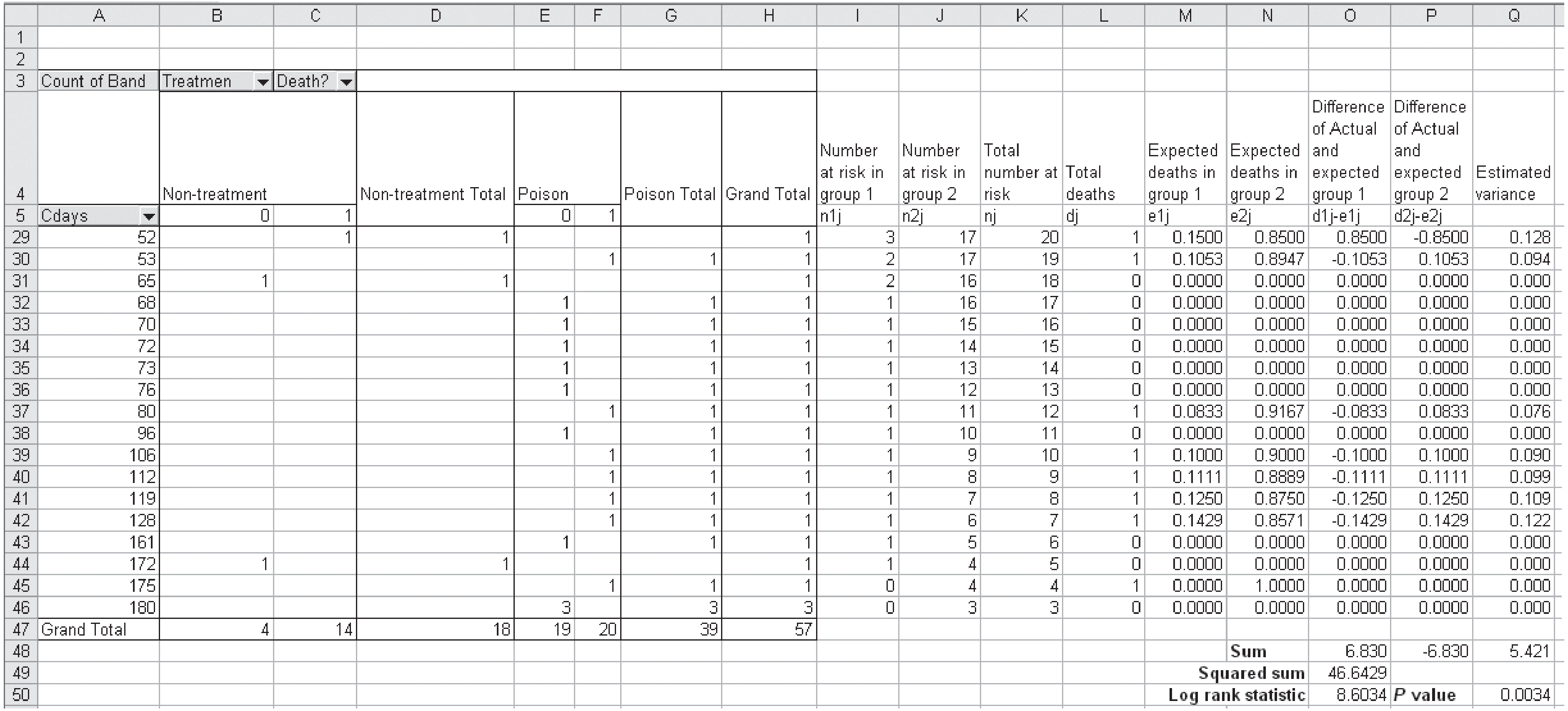
Excel spreadsheet used to calculate the Mantel-Haenszel statistic comparing the survival rate in two populations of brown kiwi chicks, one in an area where possums (and probably other predators) were being poisoned, and a second in a nearby non-treatment area. The raw data are given in Appendix 2. Calculations are outlined in section 6.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2																	
3	Count of Band	Treatmen ▼	Death? ▼														
4		Non-treatment		Non-treatment Total	Poison		Poison Total	Grand Total	Number at risk in group 1	Number at risk in group 2	Total number at risk	Total deaths	Expected deaths in group 1	Expected deaths in group 2	Difference of Actual and expected group 1	Difference of Actual and expected group 2	Estimated variance
5	Cdays ▼	0	1		0	1			n1j	n2j	nj	dj	e1j	e2j	d1j-e1j	d2j-e2j	
6	3		1	1				1	18	39	57	1	0.3158	0.6842	0.6842	-0.6842	0.216
7	4		1	1		1	1	2	17	39	56	2	0.6071	1.3929	0.3929	-0.3929	0.415
8	8		2	2				2	16	38	54	2	0.5926	1.4074	1.4074	-1.4074	0.409
9	10	1	1	2				2	14	38	52	1	0.2692	0.7308	0.7308	-0.7308	0.197
10	12					1	1	1	12	38	50	1	0.2400	0.7600	-0.2400	0.2400	0.182
11	14		1	1		1	1	2	12	37	49	2	0.4898	1.5102	0.5102	-0.5102	0.362
12	15		1	1		1	1	2	11	36	47	2	0.4681	1.5319	0.5319	-0.5319	0.351
13	16		1	1	1	1	2	3	10	35	45	2	0.4444	1.5556	0.5556	-0.5556	0.338
14	17				1	1	2	2	9	33	42	1	0.2143	0.7857	-0.2143	0.2143	0.168
15	18					2	2	2	9	31	40	2	0.4500	1.5500	-0.4500	0.4500	0.340
16	21		1	1	2		2	3	9	29	38	1	0.2368	0.7632	0.7632	-0.7632	0.181
17	22				1	1	2	2	8	27	35	1	0.2286	0.7714	-0.2286	0.2286	0.176
18	23					1	1	1	8	25	33	1	0.2424	0.7576	-0.2424	0.2424	0.184
19	26				1		1	1	8	24	32	0	0.0000	0.0000	0.0000	0.0000	0.000
20	31		1	1		1	1	2	8	23	31	2	0.5161	1.4839	0.4839	-0.4839	0.370
21	32				1		1	1	7	22	29	0	0.0000	0.0000	0.0000	0.0000	0.000
22	34		1	1	1		1	2	7	21	28	1	0.2500	0.7500	0.7500	-0.7500	0.188
23	35					1	1	1	6	20	26	1	0.2308	0.7692	-0.2308	0.2308	0.178
24	37		1	1				1	6	19	25	1	0.2400	0.7600	0.7600	-0.7600	0.182
25	38	1		1				1	5	19	24	0	0.0000	0.0000	0.0000	0.0000	0.000
26	39		1	1				1	4	19	23	1	0.1739	0.8261	0.8261	-0.8261	0.144
27	47				1		1	1	3	19	22	0	0.0000	0.0000	0.0000	0.0000	0.000
28	51					1	1	1	3	18	21	1	0.1429	0.8571	-0.1429	0.1429	0.122

Continued on next page

Appendix 5—continued



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																	
2																	
3	Count of Band	Treatmen ▼	Death? ▼														
4		Non-treatment		Non-treatment Total	Poison		Poison Total	Grand Total	Number at risk in group 1	Number at risk in group 2	Total number at risk	Total deaths	Expected deaths in group 1	Expected deaths in group 2	Difference of Actual and expected group 1	Difference of Actual and expected group 2	Estimated variance
5	Cdays ▼	0	1		0	1			n1j	n2j	nj	dj	e1j	e2j	d1j-e1j	d2j-e2j	
29	52		1	1				1	3	17	20	1	0.1500	0.8500	0.8500	-0.8500	0.128
30	53					1	1	1	2	17	19	1	0.1053	0.8947	-0.1053	0.1053	0.094
31	65	1		1				1	2	16	18	0	0.0000	0.0000	0.0000	0.0000	0.000
32	68				1		1	1	1	16	17	0	0.0000	0.0000	0.0000	0.0000	0.000
33	70				1		1	1	1	15	16	0	0.0000	0.0000	0.0000	0.0000	0.000
34	72				1		1	1	1	14	15	0	0.0000	0.0000	0.0000	0.0000	0.000
35	73				1		1	1	1	13	14	0	0.0000	0.0000	0.0000	0.0000	0.000
36	76				1		1	1	1	12	13	0	0.0000	0.0000	0.0000	0.0000	0.000
37	80					1	1	1	1	11	12	1	0.0833	0.9167	-0.0833	0.0833	0.076
38	96				1		1	1	1	10	11	0	0.0000	0.0000	0.0000	0.0000	0.000
39	106					1	1	1	1	9	10	1	0.1000	0.9000	-0.1000	0.1000	0.090
40	112					1	1	1	1	8	9	1	0.1111	0.8889	-0.1111	0.1111	0.099
41	119					1	1	1	1	7	8	1	0.1250	0.8750	-0.1250	0.1250	0.109
42	128					1	1	1	1	6	7	1	0.1429	0.8571	-0.1429	0.1429	0.122
43	161				1		1	1	1	5	6	0	0.0000	0.0000	0.0000	0.0000	0.000
44	172	1		1				1	1	4	5	0	0.0000	0.0000	0.0000	0.0000	0.000
45	175					1	1	1	0	4	4	1	0.0000	1.0000	0.0000	0.0000	0.000
46	180				3		3	3	0	3	3	0	0.0000	0.0000	0.0000	0.0000	0.000
47	Grand Total	4	14	18	19	20	39	57									
48														**Sum**	6.830	-6.830	5.421
49														**Squared sum**	46.6429		
50														**Log rank statistic**	8.6034	***P* value**	0.0034