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

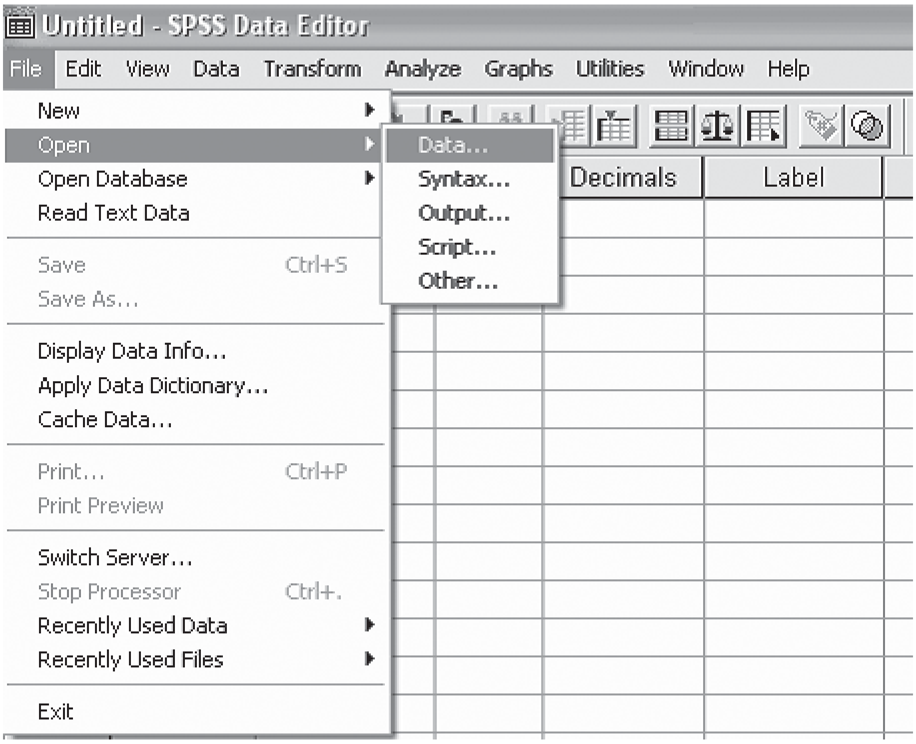
Constant survival is a strong assumption to make. Unless there are very good reasons to make this assumption, a more general and mathematically correct method for the detailed analysis of survivorship data from radio-telemetry studies is the Kaplan-Meier (KM) procedure, which produces a nonparametric 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.

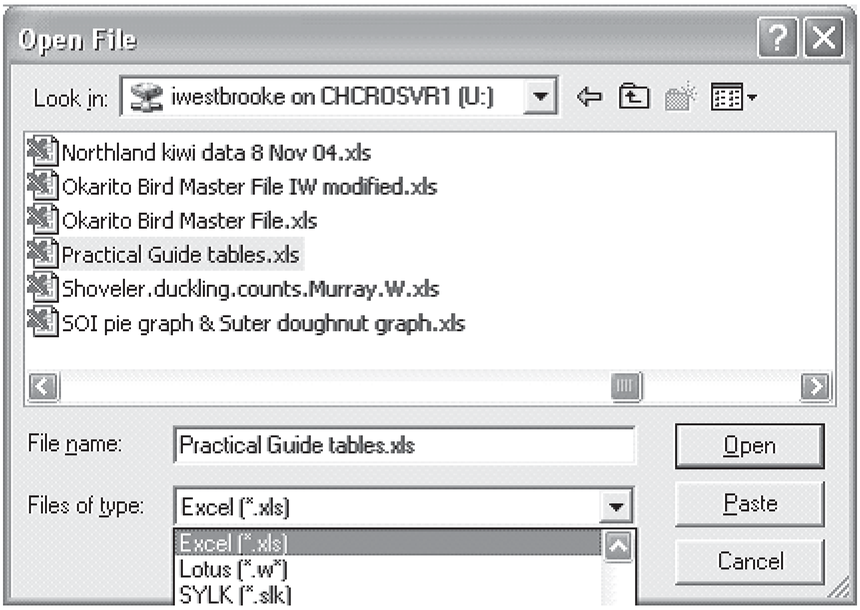
5.3.1 Kaplan-Meier procedure using SPSS

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.



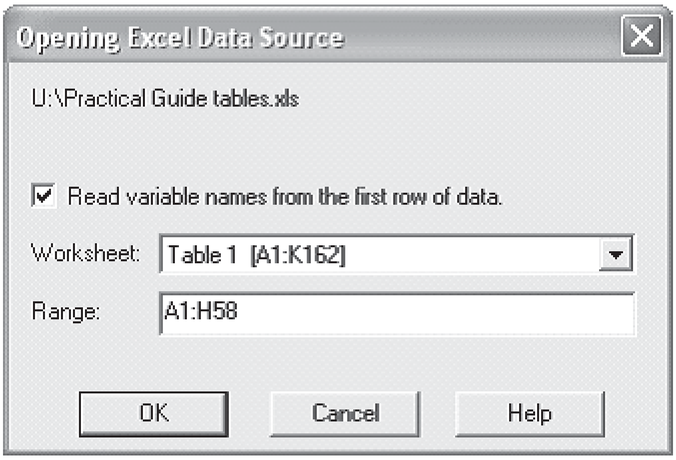
Look in: iwestbrooke on CHCROSVR1 (U:)

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)

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]

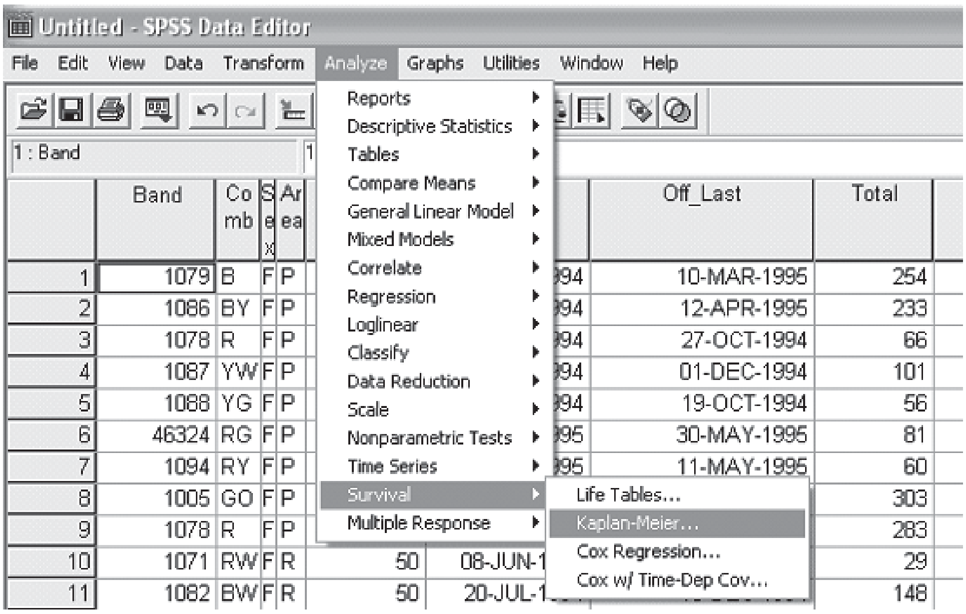
Range: A1:H58

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**.

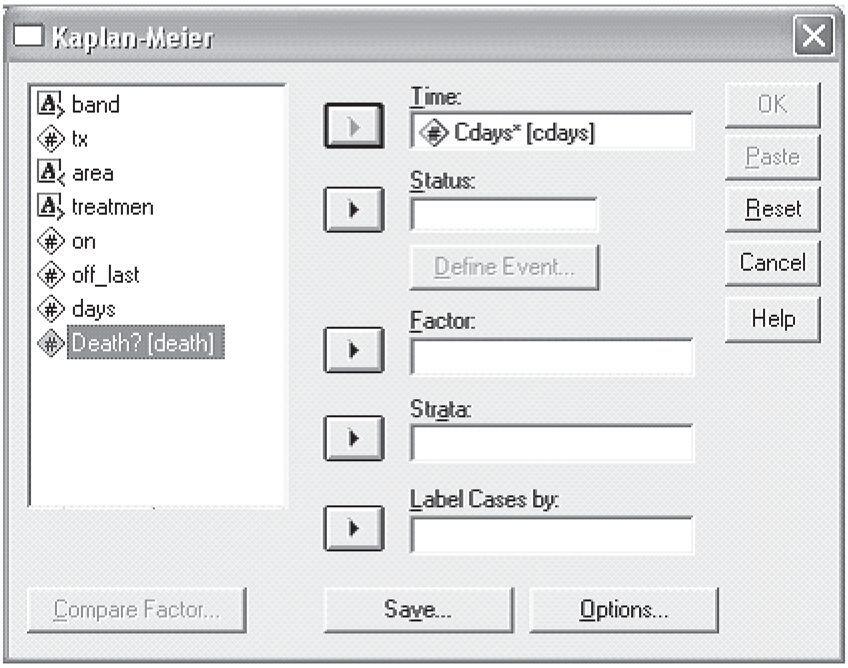
SPSS may give '********' in columns for dates (i.e. *On* and *Off_last*), which can usually be fixed by widening the column to fit the date in.

(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.