J Raptor Res. 21(4):132–134

ANALYSIS OF SURVIVAL DATA FROM TELEMETRY PROJECTS

CHRISTINE M. BUNCK

Telemetry is an increasingly popular method for studying animal movements and habitat use. Additionally, telemetry provides a means for studying survival and causes of mortality. In this paper I will be describing some statistical techniques which can provide valid estimates of survival rates based on data from telemetry studies.

Two basic study schemes are used to observe survival time. In the first, observations on all animals begin at the same time. In some instances time origin will correspond to some biologically meaningful date such as average fledging date, but often time origin is simply the beginning of the study. In practice it is often impossible to mark all animals in one day, but the period of capturing and marking should be as short as possible. In the second study scheme animals enter the study periodically. For wildlife studies this scheme will probably be more common than the first.

The techniques I will describe can be applied to lifetime data as recorded under the first scheme. Some, but not all, of these techniques generalize to the second scheme. The following five assumptions apply:

Assumption 1) The sample is representative of the population to be studied; requires that trapping techniques result in random captures from the population without age bias, sex bias, etc.
Assumption 2) Survival is not influenced by radio-marking; if not, study will give a biased estimate of population survival rate.
Assumption 3) The fate of each animal studied is independent of the fate of any other animal studied; would not be the case for nestlings. If a predator finds the nest, all or most of the nestlings will probably die. Similarly, the fate of a young animal is closely linked to its mother's fate in many instances.
Assumption 4) Censoring [censoring occurs when an animal's fate becomes unknown (e.g., when its transmitter fails)] is independent of fate; a censored animal is just as likely to be alive as dead.
Assumption 5) Exact time of death is known. Simulation studies have shown that this assumption can be relaxed (Heisey and Fuller 1985).

Assumptions 1–3 are also required for band recovery models. Assumptions 4 and 5 are unique to techniques for the analysis of survival data.

I have classified techniques as discrete or continuous models. All equations have been eliminated from this summary, but can be found in the literature cited. Discrete models are those in which survival is described as an outcome observed after some unit of time, such as a day or a week. One widely used discrete model uses an approach originally proposed by Mayfield (1961) for the study of nest success. Mayfield's model is distinguished from other discrete models by two assumptions:

Assumption 1) The probability of surviving a period is the same throughout the study (e.g., chance of surviving in any day/week is the same as in any other day/week).
Assumption 2) Each time unit (trial) is independent of the next trial.

Estimation of survival rate over a period of days and testing procedures have been described in papers by Johnson (1979), Hensler and Nichols (1981) and Bart and Robson (1982) concerning study of nesting success but results can be applied to data from telemetry studies with application to both single-origin and staggered-entry study schemes.

I'd like to mention three other papers that employ discrete models for data analysis from telemetry studies. Trent and Rongstad (1974) were among the first to use a Mayfield-type approach to obtain survival estimates from telemetry data. White (1983) proposed a multinomial model to estimate survival rates from telemetry data and obtained estimates and tested survival rates. Heisey and Fuller (1985) refined the Mayfield approach to permit calculation of survival rates which are not constant over long periods (for many species, survival rates vary between seasons, etc.). Intervals were set in which survival rates were nearly constant, Mayfield estimates were computed for each interval and the product of these estimates used for the entire period. Programs by White and by Heisey and Fuller are available from them.

Continuous models treat survival time as a con-

Table 2. Nonparametric tests[a] for comparison of survival times.

TEST AND CONDITIONS
No censoring
(fate of all animals is known)
Mann-Whitney U
Wilcoxon Rank Sum
Kruskal-Wallis
Savage
Logrank
Censoring
(some fates unknown)
Gehan
Peto-Peto
Peto-Pentice
Mantel-Haenszel
Logrank

[a] For further information on individual tests, see Lee, E. T., Statistical methods for survival data analysis. Lifetime Learning Publ., Belmont, CA, 1980.

tinuous measure using two major approaches. A parametric approach requires that distribution of survival time values be completely specified. A nonparametric approach does not make assumptions about form of survival time distribution.

For parametric approaches one of three functions must be precisely defined.

Table 3. Contacts for computer software programs.

PROGRAM	CONTACT
BMDP[a]	BMDP Statistical Software 1964 Westwood Blvd. Suite 202 Los Angeles, CA 90025
GLIM[b]	Numerical Algorithms Group 7 Banbury Road Oxford OX2 6NN, Britain
SAS	SAS Institute, Inc. Box 8000 Cary, NC 27511
SURVREG[c]	Dr. Douglas B. Clarkson IMSL Inc. 2500 Citywest Blvd. Houston, TX 77042-3020 (713)782-6060

[a] Biomedical Computer Package.
[b] General Linear Interactive Modelling.
[c] Survival Analysis with Regression.

Function 1) The probability density function which describes the expected occurrence of survival time values.
Function 2) Survival function which is the probability of surviving longer than given periods of time.
Function 3) Hazard function defines chance of dying in the next small interval, given that the bird is alive at the beginning of the interval.

Given one of these functions, the others can be derived.

Exponential distribution is commonly used in survival analysis and assumes that the chance of dying does not change with age or time—essentially the Mayfield approach with a continuous model. The approach is straightforward for studies with no censored animals and a defined time of origin. When censoring occurs, iterative (usually computer-calculated) procedures are required to obtain estimates, and staggered entries introduce further complexities into the estimation and computation process. Nonparametric approaches are applied when one is unwilling to specify a model for survival time, but it is still desirable to treat survival time as a continuous variable.

Kaplan-Meier (Lee 1980), or product-limit, estimate provides a method for estimating survival function—probability a bird survives longer than some given time. Censored animals and staggered entry schemes are permissible with this approach. The Kaplan-Meier estimate can be used descriptively to evaluate the assumption of independence between censoring and fate of the bird by displaying worst-case/best-case scenarios. Estimates can also be used to describe cause-specific mortality. Table 2 lists additional nonparametric tests based on linear rank statistics. In the literature there are several variations for each. All can be applied to single-origin schemes, but only the logrank test generalizes to the staggered entry scheme.

Programs for parametric and nonparametric approaches can be found in statistical packages BMDP (Biomedical Computer Programs) (Dixon 1983) and SAS (supplemental library; SAS Institute 1985) and in SURVREG (Survival Analysis with Regression) (Clarkson and Preston 1983). See Table 3 for contacts.

Finally, the Cox proportional hazards model (Cox and Oates 1984) provides a semi-nonparametric continuous approach which assesses the relationship between survival time and related variables such as age, sex, weight at capture and condition at capture. Cox models can be fit using BMDP, a procedure in the supplemental library of SAS, and GLIM (General Linear Interactive Modelling) (Baker and Nelder 1978). See Table 3 for contacts.

For the study of survival with telemetry techniques, enough locations should be obtained to avoid censoring and obtained often enough to avoid misclassifying a death when causes of death are being studied. For some discrete models, locations should be obtained at equal intervals.

REFERENCES

Discrete Models:

BART, J. AND D. S. ROBSON. 1982. Estimating survivorship when the subjects are visited periodically. *Ecology* 63:1078–1089.

HEISEY, D. M. AND T. K. FULLER. 1985. Evaluation of survival and cause-specific mortality rates using telemetry data. *J. Wildl. Manage.* 49:668–674.

HENSLER, G. L. 1985. Estimation and comparison of functions of daily nest survival probabilities using the Mayfield method. Pages 289–301. *In* B. T. T. Morgan and P. M. North, EDS. Statistics in ornithology. Springer-Verlag, New York, NY.

——— AND J. D. NICHOLS. 1981. The Mayfield method of estimating nesting success: a model, estimators and simulation results. *Wilson Bull.* 93:42–53.

JOHNSON, D. H. 1979. Estimating nest success: the Mayfield method and an alternative. *Auk* 96:651–661.

MAYFIELD, H. 1961. Nesting success calculated from exposure. *Wilson Bull.* 73:255–261.

WHITE, G. C. 1983. Numerical estimation of survival rates from band recovery and biotelemetry data. *J. Wildl. Manage.* 47:716–728.

Continuous Models and Proportional Hazards Model:

BAKER, R. J. AND J. A. NELDER. 1978. The GLIM system. Numerical Algorithm Group, Oxford, England.

CLARKSON, D. B. AND D. PRESTON. 1983. SURVREG a program for the interactive analysis of survival regression models. *Amer. Stat.* 37:174.

COX, D. R. AND D. OATES. 1984. Analysis of survival data. Chapman and Hall, New York, NY.

DIXON, W. J. 1983. BMDP statistical software. University of California Press, Berkeley, CA.

HOLFORD, T. R. 1980. The analysis of rates and survivorship using log-linear models. *Biometrics* 36:299–305.

KALBFLEISCH, J. D. AND R. L. PRENTICE. 1980. The statistical analysis of failure time data. Wiley, New York, NY.

LEE, E. T. 1980. Statistical methods for survival data analysis. Lifetime Learning Publ., Belmont, CA.

SAS INSTITUTE. 1985. SAS users guide. SAS Institute, Raleigh, NC.

Sample Size Considerations:

PETO, R., M. C. PIKE, P. ARMITAGE, N. E. BRESLOW, D. R. COX, S. V. HOWARD, N. MANTEL, K. MCPHERSON, J. PETO AND P. G. SMITH. 1976. Design and analysis of randomized clinical trials requiring prolonged observation of each patient. I. Introduction and design. *British J. Cancer* 34:585–612.

Field Studies:

NELSON, M. E. AND L. D. MECH. 1986. Mortality of White-tailed Deer in northeastern Minnesota. *J. Wildl Manage.* 50:691–698.

TRENT, T. T. AND O. J. RONGSTAD. 1974. Home range and survival of Cottontail Rabbits in southwestern Wisconsin. *J. Wildl. Manage.* 38:459–472.

Patuxent Wildlife Research Center, U.S. Fish and Wildlife Service, Laurel, MD 20708.