

## Radio Tracking and Animal Populations

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**Radio Tracking and Animal Populations.**—Joshua J. Millspaugh and John M. Marzluff, Eds. 2001. Academic Press, San Diego, California. xvii + 474 pp. ISBN 0-12-497781-2. \$69.95.—*Radio Tracking and Animal Populations* is a valuable book that should be of interest to a wide readership. The editors, however, may have done themselves a disservice in their choice of a title—in my view the title suggests a book written primarily for researchers conducting radiotelemetry studies. Admittedly, telemetry is often the most efficient means to acquire large amounts of location data, but the utility of this collection of edited chapters go far beyond the analysis of, and insights provided by, radio tracking data. The majority of chapters will be of interest to any researchers studying resource selection and patterns of space use by mobile organisms. What makes the book so valuable in my opinion is the degree to which it both updates the art of radio tracking and the extent to which it extends and offers guidance to the analysis of point location data. The book should prove valuable to anyone interested in spatial and landscape ecology. Multiple chapters address design principles for studies of space use and the analysis and inference from point process data. There are clear linkages in many chapters to the literature on spatial statistics and its emerging significance in ecology.

Only one chapter of the book is devoted exclusively to a discussion of radio tracking technology. The editors do not downplay the importance of the technology nor do they ignore the significant advances that have occurred in the last decade (e.g. global positioning systems and geographic information system technology). Rather, the editors start the book with a historic perspective by Robert Kenward that prepares the reader for a discussion of recent technological advances. Current telemetry technology is then thoroughly reviewed by Arthur Rogers in chapter 4. Based on chapter 4 and Kenward's excellent books (*Wildlife Radio Tagging: Equipment, Field Techniques, and Data Analysis*, and *A Manual for Wildlife*

*Radio Tagging*), there is no need to devote further discussion to this topic in this book. Readers should note that *A Manual for Wildlife Radio Tagging* was favorably reviewed recently (Millspaugh 2001).

After the introductory chapter by Kenward, the book is divided into six sections: experimental design (two chapters), equipment and technology (one chapter), animal movements (three chapters), resource selection (five chapters), population demographics (two chapters), and a concluding chapter on trends and future needs.

Chapter 2 addressed fundamental design components for radiotelemetry studies. This chapter serves as a useful checklist for researchers considering the use of radiotelemetry by posing a series of questions that should be addressed before the first transmitter is ever attached to an animal. Particularly relevant is the discussion of the primary sample unit—it is most often the individual animal, not the individual location—and the allocation of sampling effort. The trade-off between the number of animals sampled versus the number of locations collected per animal is first addressed in this chapter but is a recurring theme in a number of subsequent chapters. The use of telemetry data in hypothesis-testing (e.g. testing for differences in survival rates between males and females—chapter 14) is discussed in the context of a *priori* specification of a biologically significant effect. Before beginning our field work, few of us explicitly consider what magnitude of difference or what precision of estimation is biologically relevant. The topic of location errors and their effects on biological inference concludes this chapter and serves as a logical introduction to a more detailed discussion in the following chapter.

The effects of transmitters on the behavior and fates of birds and mammals is the first section in chapter 3. That is followed by a discussion of sources of location error and recommendations for testing and reporting error estimates. These topics seemed a bit distinct to me and perhaps would have been better addressed in separate chapters. The discussion of sources of location errors, however, is good and the authors correctly point out that many researchers do not give it the attention it deserves. This chapter would have been improved by the addition of some figures such as those that appear in White and Garrott (1990, *Analysis of Wildlife Radio-Tracking Data*) to illustrate error polygons and the effects of bearing errors.

As discussed previously, chapter 4 thoroughly reviews recent advances in telemetry technology. I found the discussion of observational bias arising from GPS-based telemetry systems to be particularly important. It is easy to fall into the trap of thinking that problems with location errors have largely been addressed by GPS technology. However, as pointed out in this chapter GPS locations may be biased by habitat type—for example, it may be less likely to re-

ceive a location in closed-canopy forest than in open habitats. The potential for serious bias in use versus available and resource-selection studies is obvious.

The next three chapters (5–7) address the topic of assessing patterns of animal movement using the temporal sequence of telemetry-derived location data. Chapter 5 discusses home range estimation clarifying the temporal dependency of patterns of space use. Of all the estimators discussed, particular emphasis is given to the use of kernel-based estimators because of their ability to address the differential intensity of space-use within the boundaries of the home range. This chapter also contains a very useful table that summarizes and compares 12 different home range estimators in terms of their sample size requirements, sensitivity to spatial autocorrelation of the locations, as well as several other comparative statistics. One of the very few typographical errors that I noticed in the entire book occurs in that chapter in equation 5.4. The concluding sections of the chapter address the important topic of animal interactions, how such interactions affect observed patterns of space use, and how to estimate those effects.

Chapter 6 is the most theoretical of all the chapters, addressing the use of fractal geometry to analyze movement patterns based on a time series of location data. Unless the reader is very familiar with the applications of fractal geometry to movement data, full comprehension of the material discussed in this chapter will require considerable additional reading. Estimation and visualization of movement paths is the topic of chapter 7. This chapter illustrates the strong linkage between spatially referenced telemetry locations and GIS technology. Several examples of moving window estimation procedures, used to smooth discrete, temporal point data into continuous paths, are illustrated. The authors show how estimated movement paths can be linked to habitat and landscape features via a GIS interface such as the ARCVIEW extension ANIMAL MOVEMENT (Hooge and Eichenlaub 1997). Such analyses are particularly relevant to metapopulation models that must explicitly address how different matrix habitats affect movement and connectivity among patches (i.e. local populations or individual home ranges).

The dominant part of the book, resource selection, covers five chapters and 116 pages. Perhaps because that topic most closely parallels my own research interests, I found this set of chapters to be the most informative and forward-looking. Chapter 8 discusses statistical issues in resource selection studies, building on compositional analysis (Aebischer 1993) and resource selection functions estimated by logistic regression models (Manly et al. 1993). There is a wonderful table in this chapter comparing the seven most common methods of estimating resource selection in terms of numerous characteristics relevant to the design of resource selection studies (e.g. assumptions

of independence among animals and locations, allowance for continuous or categorical covariates, allowable levels of inference, etc.). Lesser-known methods of analysis, including polytomous logistic regression and Mahalanobis distance methods, are also discussed. The differences among methods, and how the data are analyzed, are made particularly clear by a thorough analysis of two example data sets.

The relationships between various behaviors of the focal organism (e.g. foraging, resting, predator avoidance) and its patterns of resource selection conditioned on a particular behavior (e.g. different habitat types) are explored in chapter 9. That is done in the context of discrete choice models borrowed from econometrics theory. If you are like me, you may not have had previous exposure to those models. They appear to be particularly powerful for exploring the spatial heterogeneity among resources available to individual organisms (their choice sets) as well as allowing for temporal dynamics in resource availability. Perhaps the greatest potential of those models is that they may be less likely to yield inappropriate definitions of available resources. If you are statistically challenged, you will find this chapter a difficult read.

One of the most direct and intuitively understandable methods to evaluate resource selection is through the use of distance metrics. Chapter 10 proposes a metric based on the differences in Euclidean distance between various habitat types and a set of random points compared to a set of used points from a sample of animals. The premise is simple: if habitat (resource) use occurs at random, the distances between animal locations and each habitat type should equal the distances between random points and each habitat. Tests of the null hypothesis of equal distance distributions are easily conducted via multivariate analysis of variance procedures and existing statistical software.

The topic of chapter 11 is the effect of sample size on resource-selection analyses. The discussion is restricted to a comparison of traditional chi-square methods (e.g. Neu et al. 1974) with more sophisticated compositional analyses (Aebischer et al. 1993). This chapter deals explicitly with the sampling trade-off question—is it better to sample fewer animals more frequently, or the converse? The authors conclude that sampling more individuals is generally to be preferred. The rule of thumb is that a minimum sample is 20 animals with  $\geq 50$  observations per animal. Those conclusions are in accord with other chapters in the book.

Chapter 12 offers some general philosophical perspective on the analysis of space use patterns. The authors argue strongly for the value of utilization distribution (i.e. the kernel density function) because it estimates space use a continuous random variable allowing one to make explicit probability statements about use at particular locations within in an ani-

mal's range. I agree with the author's emphasis—it is in accord with recent applications of spatial statistics to ecological questions, particular those that address the inherent spatial autocorrelation in the distribution of animals and their resources. The authors conclude this chapter with an appeal to better understand why animals use resources in a nonrandom fashion. One way to do that is to relate different patterns of space use to variation in demographic processes.

The two chapters on demographics illustrate the use of telemetry data to estimate fundamental population parameters, population size ( $n$ ) and survival rate ( $s$ ), respectively. Chapter 12 addresses three methods of estimation: direct mark–resighting estimation of  $n$  based on modifications of closed population Lincoln-Peterson estimators; sightability models to estimate probability of sighting a radio-tagged individual known to be in the population at the time of the survey; and the use of the movement behavior of tagged individuals to estimate the proportion of time individuals were located within the study during the period of study. Information on sightability can be used in other populations under similar conditions to adjust raw counts of unmarked individuals to provide an unbiased estimate of  $n$ . Information of the proportion of time individuals spend in the study area is used to provide an unbiased estimate of density. In addition to the defensibility and statistical rigor of those methods, relatively user-friendly software has been developed to aid in parameter estimation and model selection (White 1996, White and Burnham 1999).

The penultimate chapter (13) examines the analysis of survival data from radiotelemetry studies. Emphasis is given to the Mayfield methodology and the Kaplan-Meier product limit estimator. The key advantage of those models is that they allow for variable times of radio tagging (staggered entry), and for censoring—that is, the loss of information of the true fate of a radio-tagged individual arising from radio failure, signal interference, or emigration from the study area. In this chapter, the authors strongly emphasize the need to critically evaluate the degree to which the assumptions that underlie the analyses have been fulfilled. The chapter concludes with a thorough discussion of hypothesis testing, comparison of survival curves, and the incorporation of environmental covariates into the estimation process.

In the concluding chapter, the editors provide their perspectives on the scope and requirements for future wildlife radio-tracking studies. They focus their discussion on three critical issues: the assumption that radio-tagged individuals are representative of the behavior and fates on untagged individuals; the assumption of independence among sequential locations; and the problem with defining what is truly available to the animal seeking resources. They state,

and I agree, that the first and third issues are in most need of further investigation. The reality of spatial and temporal dependence in nature is not something to be avoided, but rather a phenomena to be explicitly estimated. Increased application of geostatistical methods to ecological questions is enabling us to explore the nonindependence of locational data.

The book concludes with a useful appendix that catalogues software available for the analysis of radiotelemetry data.

In summary, I highly recommend this book for individuals conducting radiotelemetry studies. It does not stand alone, but should be used in combination with Kenward's recent text as well as the 1990 text by White and Garrott. The book will also prove useful to individuals studying patterns of space use and resource selection but not necessarily using telemetry techniques. I also would recommend the use of this book in a two-credit graduate course for students interested in the analysis of location data, resource selection, and statistical modeling. I envision the book to be widely read by my graduate students.—BARRY R. NOON, *Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, Colorado 80523, USA. E-mail: brnoon@cnr.colostate.edu.*

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