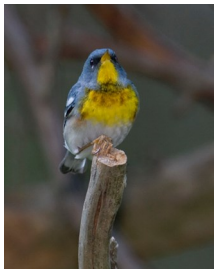
Spatial Capture-Recapture Models to Estimate Abundance and Density of Animal Populations

The Study of Animal Populations

Estimating abundance and density are fundamental objectives in conservation and wildlife management of animal populations. To achieve these objectives, a huge body of methodologies known as capture-recapture have been developed. Capture-recapture methods make use of individual encounter history data, a record of when each individual was captured during the course of study.

Limitations of Classical Capture-Recapture Models

A number of technical and conceptual limitations of classical capture-recapture models have been noted and discussed in the literature for many decades. First, it is difficult to define precisely a study area because animals move freely through space, and so the area containing animals exposed to sampling efforts is greater than the area immediately surrounding the sampling devices (e.g., traps); thus, estimates of population size have no explicit spatial context and cannot be converted to density. Secondly, animals experience variable exposure to encounter due to the location of their home ranges relative to sampling devices. The essence of these limitations is the basic problem that classical capture-recapture models are distinctly *non-spatial*, they do not account either for the locations of traps, the locations of encounters, or the spatial pattern of individual encounters.



Basic Elements of Spatial-Capture Recapture: Making Use of Spatial Data

Recent methodological efforts have yielded extensions of capture-recapture models to accommodate the spatial organization of sampling devices and the spatial information inherent in essentially all capture-recapture studies of animal populations. These spatial capture-recapture (SCR) models (also spatially-explicit capture-recapture, SECR) show great promise in the study of animal populations and in facilitating the study of spatial processes in animal populations from ordinary encounter data which arise in the routine study of animal populations.

Obtaining Spatial Encounter History Data

Simultaneous to the developments of new SCR models has been the development of new technologies for producing spatial encounter information on individuals. In the past, capture-recapture studies could only occur by physically capturing and marking individuals (e.g., live traps, mist nets). However, new technologies allow for passive marking and encountering, including acoustic sampling, camera trapping, and DNA methods which obtain individuality from animal scat, hair, feathers, urine, and other body tissues. SCR models provide a natural modeling framework for data that arise from these emerging technologies which are being rapidly adopted in the study of animal populations.

Box 1: SCR Model Framework

SCR models are naturally described as a hierarchical or state-space model with distinct model components representing an ecological state process and an observation process.

In SCR models, the process model is a point process model, describing the distribution of animal activity centers/home ranges across the study area (Fig. 1).

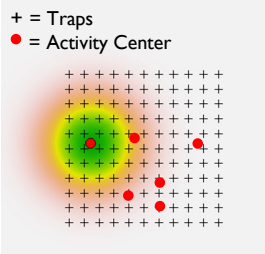


Fig. 1. Location of activity centers relative to traps. The colored bands radiating from the activity center for one of the individuals represents detection decreasing as you move away from the center of the home range.

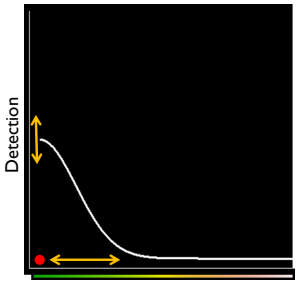


Fig. 2. Frequency of detection decreases with distance between trap and activity center. The color bar at the bottom of the figure depicts this relationship for one of the individuals in Fig. 1.

The observation model is an implicit model of individual movement governing the process associated with encountering individuals at sampling devices (e.g., traps), which is conditional on the unobserved activity centers (random effects). As such, we can specify a model that relates the probability of detecting an individual to the distance from the trap to the center of the individuals home range (Fig. 2).

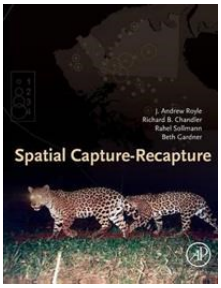
SCR models are easily analyzed using Bayesian methods and Markov chain Monte Carlo (Royle and Young 2008) or classical likelihood methods (Borchers and Efford 2008).

Integrating Ecological Theory with Observation

SCR models are not simply an extension of a technique to resolve certain technical problems. Instead, they provide a flexible framework for making ecological processes explicit in models of individual encounter history data, and for studying spatial processes such as individual movement, resource selection, space usage, population dynamics, and density. Historically, researchers studied these questions independently, using ostensibly unrelated study designs and statistical procedures. SCR models can bring all of these problems together into a single unified framework for modeling and inference, and they promise the ability to integrate explicit ecological theories into the models so that ecologists can test explicit hypotheses about space usage, resource selection, landscape connectivity, movement, and spatial distribution.

Conclusion

Together, the two technological innovations of SCR models and methodologies for producing spatial encounter history data stand to revolutionize the study of animal populations. New technology provides an efficient means of obtaining individual encounter information which doesn't require physical capture of individuals, thereby affording the possibility to study species which historically could not be effectively studied by capture-recapture methods due to the difficulty of capturing and physically marking them. At the same time, the on-going development of SCR modeling technology provides a technical framework for integrating ecological theory into models of individual encounter and providing statistically rigorous inferences about population size, density and spatial dynamics. A monograph-level treatment of SCR models (Royle et al. 2013) was recently published by Academic Press which synthesizes the explosive development of SCR models over the last several years.



Box 2: Application of SCR to New York Fisher Study

Historically, fishers were distributed across New York, but the species was nearly extirpated by the 1930s as a result of unregulated trapping. Populations have since recovered in many areas, however, data are lacking on the abundance and density of fishers in areas of New York where harvest opportunities for this species do not exist. In this example analysis, we estimate the abundance of fishers using SCR, which could be used to help inform management, including possibly the consideration of opening new areas of central New York to fisher harvest.

Fig. 3. Fisher eating bait at a hair snare site.

Data: Fishers were sampled at 300 sites during a 12-week season (January—March). Hair snare sites were checked weekly for 4 weeks each and then moved to new sites. Hair snares were constructed of 3 chloroplast plastic strips with 3 gun brushes per strip surrounded by a piece of bait (Fig. 3). DNA was extracted from the root follicles of collected hair samples and genetic analyses provided unique genotypes of individuals.

Analysis: We identified 99 unique individual fishers that were captured 157 times (Fig. 4). We recorded 13 spatial recaptures (individuals caught in more than one trap). We fitted a model to 63 individuals whose sex could be determined. The SCR model allowed sex-specificity of encounter model parameters and included a trap-level behavioral response. The parameter estimates are summarized in Table 1. The population size (posterior mean) of about 199 individuals included 51% females. A strong behavioral response indicating "trap happiness" is noted. We are continuing to use these data in SCR models that allow us to incorporate resource selection, space usage, and spatial dynamics of the population.

Table 1. Posterior summary statistics from the SCR model. N is the population size for the prescribed study area, λ_0 is the baseline encounter rate, ψ_{Sex} is the probability of being a male, and $\beta_{Behavior}$ is a trap-specific behavioral response.

Parameter	Mean	SD	2.5%	50%	97.5%
N	198.864	55.391	121.000	188.000	339.000
λ_0	0.003	0.003	0.001	0.002	0.012
ψ_{Sex}	0.489	0.100	0.263	0.497	0.665
$\beta_{Behavior}$	4.409	0.649	3.251	4.374	5.528

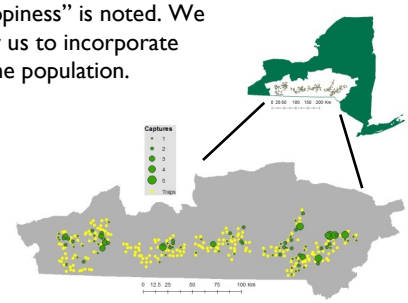


Fig. 4. Distribution of hair snare sites (n = 300) across the central NY study area and the number of fisher captures at each site.

References

Borchers, D.L. and M.G. Efford. (2008). Spatially explicit maximum likelihood methods for capture-recapture studies. Biometrics, 64:377-385.

Chandler, R.B. and J.A. Royle (2013). Spatially explicit models for inference about density in unmarked or partially marked populations. The Annals of Applied Statistics 7:936-954.

Dawson, D.K. and M.G. Efford. (2009). Bird population density estimated from acoustic signals. Journal of Applied Ecology, 46:1201-1209.

Efford, M. G. (2004). Density estimation in live-trapping studies. Oikos, 106:598-610.

Efford, M. G., D.K. Dawson and D.L. Borchers. (2009). Population density estimated from locations of individuals on a passive detector array. Ecology, 90:2676-2682.

Efford, M. G. (2011). Estimation of population density by spatially explicit capture-recapture analysis of data from area searches. Ecology, 92:2202-2207.

Gardner, B., J. Reppucci, M. Lucherini and J.A. Royle. (2010). Spatially explicit inference for open populations: estimating demographic parameters from camera-trap studies. Ecology, 91:3376-3383.

Howe, E. J., M.E. Obbard and C.J. Kyle. (2013). Combining data from 43 standardized surveys to estimate densities of female American black bears by spatially explicit capture-recapture. Population Ecology, 1-13.

Royle, J.A. and K.V. Young. (2008). A hierarchical model for spatial capture-recapture data. Ecology, 89:2281-2289.

Royle, J. A., K.U. Karanth, A.M. Gopalaswamy and N.S. Kumar. (2009). Bayesian inference in camera trapping studies for a class of spatial capture-recapture models. Ecology, 90:3233-3244.

Royle, J.A., R.B. Chandler, R. Sollmann and B. Gardner. (2013). Spatial Capture-Recapture. Academic Press/Elsevier. 612 pages.

Royle, J.A., R.B.Chandler, K.D. Gazenski and T.A. Graves. (2013). Spatial capture-recapture models for jointly estimating population density and landscape connectivity. Ecology, 94:287-294.

Royle, J.A., R.B. Chandler, C.C. Sun and A.K. Fuller. (2013). Integrating resource selection information with spatial capture-recapture. Methods in Ecology and Evolution, 3:545-554.

Sollmann, R., B. Gardner, A.W. Parsons, J.J. Stocking, B.T. McClintock, T.R. Simons, A.F. O'Connell. (2013). A spatial mark-resight model augmented with telemetry data. Ecology, 94:553-559.

Sollmann, R., B. Gardner, R.B. Chandler, D.B. Shindle, D.P. Onorato, J.A. Royle, and A.F. O'Connell. (2013). Using multiple data sources provides density estimates for endangered Florida panther. Journal of Applied Ecology, 50:961-968.

Thompson, C.M., J.A. Royle and J.D. Garner. (2012). A framework for inference about carnivore density from unstructured spatial sampling of scat using detector dogs. The Journal of Wildlife Management, 76:863-871.

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