

Capture-recapture models in `unmarked`

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Abstract

The “`un`” in `unmarked` is somewhat misleading because the package can be used to analyze data from marked animals. The three most common sampling methods that produce suitable data are removal sampling, double observer sampling, and capture-recapture methods¹. This document focuses on the analysis of capture-recapture data using a class of models known as multinomial N -mixture models [2, 1], which assume that capture-recapture data have been collected at a collection of sample locations (“sites”). Capture-recapture models can be fitted with constant parameters (M_0), time-specific parameters (M_t), and behavioral responses (M_b). In addition, spatial variation in abundance or capture probability can also be modeled using site-specific covariates. `unmarked` has two functions for fitting capture-recapture models: `multinomPois` and `gmultmix`. Both allow for user-defined functions to describe the capture process, and the latter allows for modeling of temporary emigration.

1 Introduction

Capture-recapture models have a long history in ecology and are used to estimate population size while controlling for variation in capture probability [3]. Traditional capture-recapture models, however, do not allow one to model spatial variation in abundance—a central objective of much ecological research. (author?) [2] proposed a simple hierarchical model to overcome this limitation. The model requires that R “sites” are surveyed using capture-recapture methods, and that site-specific abundance ($N_i; i = 1, 2, \dots, R$) can be modeled as a discrete random variable. For example, if abundance is Poisson distributed, we can describe the model as

$$\begin{aligned} N_i &\sim \text{Poisson}(\lambda) \\ \mathbf{y}_i | N_i &\sim \text{Multinomial}(N_i, \pi(p)) \end{aligned} \tag{1}$$

In the above, λ is the expected number of individuals at each site. \mathbf{y}_i is a vector containing the number of individuals with encounter history $k; k = 1, 2, \dots, K$ at site i . The number of observable encounter histories K depends on the sampling protocol. For a capture-recapture study with 2 time periods, K equals 3 because the possibilities are (11, 10, 01). In Equation 1, $\pi(p)$ is a function that converts capture probability (p) to multinomial cell probabilities, *i.e.*, the proportion of individuals expected to have capture history k . The definition of $\pi(p)$ is also specific to the sampling protocol. For example, the cell probabilities corresponding to the capture histories listed above are

$$\pi(p) = \{p^2, p(1-p), (1-p)p, (1-p)^2\}.$$

Note that the last multinomial cell probability corresponds to the probability of not being captured.

Traditional capture-recapture methods were developed for sampling situations in which a single site was surveyed using trap arrays, and the objective was to estimate the number of individuals exposed to sampling N . Since there was not variation in abundance to model, emphasis was placed on modeling variation in capture probability (p). [Mention standard models] Often, however, ecologists collect data at a collection of sites, and interest lies in describing variation in abundance among those sites. For instance, capture-recapture arrays might be established in replicates sites in 2 different habitat types to make inferences about differences in abundance among the two habitats. as with all the abundance models in `unmarked`, spatial variation in abundance can be modeled using covariates with a log-link function

$$\exp(\lambda_i) = \beta_0 + \beta_1 x_i$$

¹Sometimes animals are not actually marked when using these methods, but they are treated as though they are

where x_i is some site-specific covariate such as habitat type or elevation. A more general form is written as

$$\exp(\lambda_i) = X_i' \beta$$

where X is a design matrix and β is a vector of coefficients, possibly including an intercept. Capture probability can be modeled in the same way using the logit instead of the log link. For instance, we could have

$$\text{logit}(p_{ij}) = \alpha_0 + \alpha_1 v_{ij}$$

where v_{ij} is some covariate specific to the site and capture occasion.

2 Data

Earlier we mentioned that the data \mathbf{y} must be a $R \times K$ matrix in which each row is the vector of tabulated encounter histories for animals captured at some site. Capture-recapture data, however, is typically recorded in the format shown in Table

AnimalID	Site	Capture history
GB	A	101
RO	A	111
GY	B	100

The raw data that one collects in a capture-recapture study is typically of the form shown in Table 1. Each row of the matrix corresponds to a capture of some individual. Associated with this capture we need to know the capture occasion, the site at which it was captured, and perhaps some covariates. Note that if we have multiple traps at a site, as is often the case, traditional capture-recapture, and the models considered here, models ignore this information. Recently developed spatial capture-recapture models, however, make use of the trap location data to model density and distance-related heterogeneity in capture probability. SCR models thus offer important advantages over traditional methods and should be used when possible if the assumptions are deemed reasonable. See xyz for more information.

Simple capture-recapture data is shown in Table.

In the absence of individual covariates, these data can be collapsed and formatted as shown in Table YYY.

SHOW TYPICAL MULTINOMIAL DATA

3 Capture-recapture Models

3.1 Model M_0

3.2 Model M_t

3.3 Model M_b

3.4 Model M_h

Cite Royle and Dorazio pg 173 “In the absence of individual effects on p , the individual encounter histories can be pooled into groups of unique encounter histories, indexed by h , a unique combination of zeros and ones.”.

`unmarked` does not, however, allow for the modeling of individual heterogeneity in capture probability although data cou

4 Analysis in unmarked

5 Closed population capture-recapture models

```
> alfl.capRecap <- read.csv(system.file("csv", "alfl.capRecap.csv",
  package = "unmarked"), row.names = 1)
> names(alfl.capRecap)
```

```

[1] "visit1_001" "visit1_010" "visit1_011" "visit1_100" "visit1_101"
[6] "visit1_110" "visit1_111" "visit2_001" "visit2_010" "visit2_011"
[11] "visit2_100" "visit2_101" "visit2_110" "visit2_111" "visit3_001"
[16] "visit3_010" "visit3_011" "visit3_100" "visit3_101" "visit3_110"
[21] "visit3_111" "struct"      "woody"      "time.1"     "time.2"
[26] "time.3"      "date.1"     "date.2"     "date.3"

```

```

> crPiFun <- function(p) {
  cbind((1 - p[, 1]) * (1 - p[, 2]) * p[, 3], (1 -
    p[, 1]) * p[, 2] * (1 - p[, 3]), (1 - p[, 1]) *
    p[, 2] * p[, 3], p[, 1] * (1 - p[, 2]) * (1 -
    p[, 3]), p[, 1] * (1 - p[, 2]) * p[, 3], p[,
    1] * p[, 2] * (1 - p[, 3]), p[, 1] * p[, 2] *
    p[, 3])
}
> p <- matrix(0.4, 2, 3)
> crPiFun(p)
      [,1] [,2] [,3] [,4] [,5] [,6] [,7]
[1,] 0.144 0.144 0.096 0.144 0.096 0.096 0.064
[2,] 0.144 0.144 0.096 0.144 0.096 0.096 0.064
> rowSums(crPiFun(p))
[1] 0.784 0.784

```

obsToY needs to be a matrix with the number of rows equal to the number of columns for some obsCov, and the number columns equal to the number of columns in y. If obsToY[i,j] is 1, then a missing value in obsCov translates to a missing value in y.

```

> o2y <- matrix(1, 3, 7)

> visitMat <- matrix(c("V1", "V2", "V3"), 50, 3, byrow = TRUE)
> visitMat[1, 2] <- NA
> visitMat[2, ] <- NA
> head(visitMat)
      [,1] [,2] [,3]
[1,] "V1" NA  "V3"
[2,] NA  NA  NA
[3,] "V1" "V2" "V3"
[4,] "V1" "V2" "V3"
[5,] "V1" "V2" "V3"
[6,] "V1" "V2" "V3"
> library(unmarked)
> umf.cr1 <- unmarkedFrameMPois(y = alfl.capRecap[, 1:7],
  siteCovs = alfl.capRecap[, c("woody", "struct")],
  obsCovs = list(visit = visitMat), obsToY = o2y, piFun = "crPiFun")
> (M0 <- multinomPois(~1 ~ 1, umf.cr1))

```

Call:

```
multinomPois(formula = ~1 ~ 1, data = umf.cr1)
```

Abundance:

Estimate	SE	z	P(> z)
0.00714	0.141	0.0504	0.96

Detection:

Estimate	SE	z	P(> z)
1.43	0.216	6.63	3.41e-11

AIC: 258.2382

```
> (Mt <- multinomPois(~visit ~ 1, umf.cr1))
```

```
Call:
multinomPois(formula = ~visit ~ 1, data = umf.cr1)
```

```
Abundance:
Estimate      SE          z P(>|z|)
-0.0137 0.146 -0.0938  0.925
```

```
Detection:
Estimate      SE          z P(>|z|)
(Intercept)  1.402 0.371  3.779 0.000157
visitV2      0.292 0.543  0.538 0.590599
visitV3     -0.248 0.499 -0.496 0.619611
```

```
AIC: 250.449
```

6 Capture-recapture models allowing for temporary emigration

References

- [1] Ian Fiske and Richard Chandler. **unmarked**: An **R** package for fitting hierarchical models of wildlife occurrence and abundance. *Journal of Statistical Software*, 43(10):1–23, 2011.
- [2] J. A. Royle. Generalized estimators of avian abundance from count survey data. *Animal Biodiversity and Conservation*, 27(1):375–386, 2004.
- [3] B K Williams, J D Nichols, and M J Conroy. *Analysis and management of animal populations: modeling, estimation, and decision making*. Academic Pr, 2002.