

Overview of Unmarked: An R Package for the Analysis of Data from Unmarked Animals

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Abstract

Unmarked aims to be a complete environment for the statistical analysis of data from surveys of unmarked animals. Currently, the focus is on hierarchical models that separately model a latent state (or states) and an observation process. Unmarked uses S4 classes to help the user explore and analyze their data in a transparent manner.

1 Overview of unmarked

Unmarked provides methods to estimate site occupancy, abundance, and density of animals (or possibly other organisms/objects) that cannot be detected with certainty. Numerous models are available that correspond to specialized survey methods such as temporally replicated surveys, distance sampling, removal sampling, and double observer sampling. These data are often associated with metadata related to the design of the study. For example, in distance sampling, the study design (line- or point-transect), distance class break points, transect lengths, and units of measurement need to be accounted for in the analysis. Unmarked uses S4 classes to store data and metadata in a way that allows for easy data manipulation, summarization, and model specification. Table 1 lists the currently implemented models and their associated fitting functions and data classes.

Model	Fitting Function	Data	Citation
Occupancy	occu	unmarkedFrameOccu	[2]
Royle-Nichols	occuRN	unmarkedFrameOccu	[5]
Point Count	pcount	unmarkedFramePCount	[4]
Distance-sampling	distsamp	unmarkedFrameDS	[6]
Arbitrary multinomial-Poisson	multinomPois	unmarkedFrameMPois	[3]
Colonization-extinction	colect	unmarkedMultFrame	[1]
Generalized multinomial-mixture	gmultmix	unmarkedFrameGMM	[3]

Table 1: Models handled by unmarked.

Each data class can be created with a call to the constructor function of the same name as described in the examples below.

2 Typical unmarked session

The first step is to import the data into R. This can be accomplished with either a call to the appropriate type of `unmarkedFrame`:

```
> library(unmarked)
> wt <- read.csv(system.file("csv", "widewt.csv", package = "unmarked"))
> head(wt)
  site y.1 y.2 y.3      elev    forest  length  date.1
1    1  0  0  0 -1.1729446 -1.156228147 1.824549 -1.761481
2    2  0  0  0 -1.1265010 -0.501483710 1.629241 -2.904339
3    3  0  0  0 -0.1976283 -0.101362109 1.458615 -1.690053
4    4  0  0  0 -0.1047411  0.007761963 1.686399 -2.190053
```

```

5   5   0   0   0 -1.0336137 -1.192602838 1.280934 -1.832910
6   6   0   0   0 -0.8478392  0.917129237 1.808289 -2.618624
      date.2   date.3     ivel.1     ivel.2     ivel.3
1  0.3099471 1.3813757 -0.5060353 -0.5060353 -0.5060353
2 -1.0471958 0.5956614 -0.9336151 -0.9907486 -1.1621491
3 -0.4757672 1.4528042 -1.1355754 -1.3388644 -1.6099164
4 -0.6900529 1.2385185 -0.8193481 -0.9272669 -1.1970640
5  0.1670899 1.3813757  0.6375563  0.8803737  1.0422520
6  0.1670899 1.3813757 -1.3288666 -1.0422624 -0.8989603
> y <- wt[, 2:4]
> siteCovs <- wt[, c("elev", "forest", "length")]
> obsCovs <- list(date = wt[, c("date.1", "date.2", "date.3")],
      ivel = wt[, c("ivel.1", "ivel.2", "ivel.3")])
> wt <- unmarkedFrameOccu(y = y, siteCovs = siteCovs, obsCovs = obsCovs)
> summary(wt)

```

unmarkedFrame Object

237 sites
Maximum number of observations per site: 3
Mean number of observations per site: 2.81
Sites with at least one detection: 79

Tabulation of y observations:

```

0    1 <NA>
483 182  46

```

Site-level covariates:

elev	forest	length
Min. : -1.436125	Min. : -1.265e+00	Min. : 0.1823
1st Qu.: -0.940726	1st Qu.: -9.744e-01	1st Qu.: 1.4351
Median : -0.166666	Median : -6.499e-02	Median : 1.6094
Mean : 0.007612	Mean : 8.798e-05	Mean : 1.5924
3rd Qu.: 0.994425	3rd Qu.: 8.080e-01	3rd Qu.: 1.7750
Max. : 2.434177	Max. : 2.299e+00	Max. : 2.2407

Observation-level covariates:

date	ivel
Min. : -2.9043386	Min. : -1.753e+00
1st Qu.: -1.1186243	1st Qu.: -6.660e-01
Median : -0.1186243	Median : -1.395e-01
Mean : -0.0002173	Mean : -3.008e-11
3rd Qu.: 1.3099471	3rd Qu.: 5.493e-01
Max. : 3.8099471	Max. : 5.980e+00
NA's : 42.0000000	NA's : 4.600e+01

or by using the convenience function csvToUMF:

```

> wt <- csvToUMF(system.file("csv", "widewt.csv", package = "unmarked"),
      long = FALSE, type = "unmarkedFrameOccu")

```

If not all sites have the same numbers of observations, then manual importation of data in long format can be tricky. csvToUMF seamlessly handles this situation.

```

> pcru <- csvToUMF(system.file("csv", "frog2001pcru.csv",
      package = "unmarked"), long = TRUE, type = "unmarkedFrameOccu")
> summary(pcru)
unmarkedFrame Object

```

130 sites
Maximum number of observations per site: 3
Mean number of observations per site: 2.59
Sites with at least one detection: 96

Tabulation of y observations:

```

  0   1   2   3 <NA>
197  25  28  87  53

```

Observation-level covariates:

```

MinAfterSunset      Wind      Sky      Temperature
Min.      :-21.00    Min.      : 0.0000    Min.      : 0.0000    Min.      : 4.00
1st Qu.: 66.00    1st Qu.: 0.0000    1st Qu.: 0.0000    1st Qu.:13.00
Median : 97.00    Median : 1.0000    Median : 0.0000    Median :17.50
Mean      : 97.57    Mean      : 0.8813    Mean      : 0.4837    Mean      :16.61
3rd Qu.:126.00    3rd Qu.: 2.0000    3rd Qu.: 1.0000    3rd Qu.:20.60
Max.      :228.00    Max.      : 3.0000    Max.      : 5.0000    Max.      :28.00
NA's      : 53.00    NA's      :53.0000    NA's      :53.0000    NA's      :53.00

JulianDate
Min.      : 72.0
1st Qu.: 95.0
Median :123.0
Mean      :127.4
3rd Qu.:159.0
Max.      :179.0
NA's      : 53.0

```

To help stabilize the numerical optimization algorithm, we recommend standardizing the covariates.

```
> obsCovs(pcru) <- scale(obsCovs(pcru))
```

Occupancy models can then be fit with the `occu()` function:

```

> fm1 <- occu(~1 ~ 1, pcru)
> fm2 <- occu(~MinAfterSunset + Temperature ~ 1, pcru)
> summary(fm1)

```

Call:

```
occu(formula = ~1 ~ 1, data = pcru)
```

Occupancy (logit-scale):

```

Estimate   SE      z P(>|z|)
    2.95 1.44 2.05    0.04

```

Detection (logit-scale):

```

Estimate   SE      z P(>|z|)
   -0.249 0.170 -1.47    0.142

```

AIC: 461.0042

Number of sites: 130

optim convergence code: 0

optim iterations: 22

Bootstrap iterations: 0

```
> summary(fm2)
```

Call:

```
occu(formula = ~MinAfterSunset + Temperature ~ 1, data = pcru)
```

Occupancy (logit-scale):

```

Estimate   SE      z P(>|z|)
    1.54 0.292 5.26 1.42e-07

```

Detection (logit-scale):

```

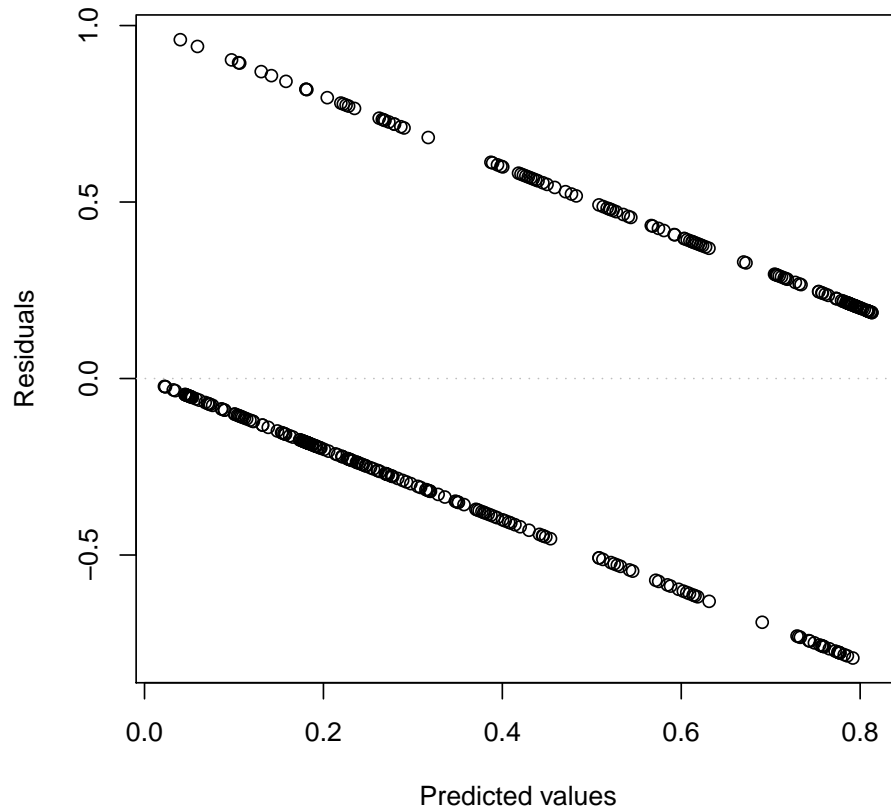
              Estimate   SE      z P(>|z|)
(Intercept)    0.2098 0.206  1.017 3.09e-01
MinAfterSunset -0.0855 0.160 -0.536 5.92e-01
Temperature    -1.8936 0.291 -6.508 7.60e-11

```

```

AIC: 356.7591
Number of sites: 130
optim convergence code: 0
optim iterations: 21
Bootstrap iterations: 0
> plot(fm2)

```



Here, we have specified that the detection process is modeled with the MinAfterSunset and Temperature covariates. No covariates are specified for occupancy here. See ?occu for more details.

Unmarked fitting functions return unmarkedFit objects which can be queried to investigate the model fit. Variables can be back-transformed to the unconstrained scale using backTransform. Standard errors are computed using the delta method.

```

> backTransform(fm2, "state")
Backtransformed linear combination(s) of Occupancy estimate(s)

Estimate      SE LinComb (Intercept)
0.823 0.0425    1.54                1

Transformation: logistic

```

Because the detection component was modeled with covariates, covariate coefficients must be specified to back-transform. Here, we request the probability of detection given a site is occupied and all covariates are set to 0.

```

> backTransform(linearComb(fm2, coefficients = c(1, 0,
0)), type = "det"))

```

Backtransformed linear combination(s) of Detection estimate(s)

Estimate	SE	LinComb (Intercept)	MinAfterSunset	Temperature
0.552	0.051	0.210	1	0

Transformation: logistic

A predict method also exists.

```
> newData <- data.frame(MinAfterSunset = 0, Temperature = -2:2)
> predict(fm2, type = "det", newdata = newData, appendData = TRUE)
```

	Predicted	SE	lower	upper	MinAfterSunset
1	0.98196076	0.01266193	0.9306044	0.99549474	0
2	0.89123189	0.04248804	0.7763166	0.95084836	0
3	0.55225129	0.05102660	0.4514814	0.64890493	0
4	0.15658708	0.03298276	0.1021713	0.23248007	0
5	0.02718682	0.01326263	0.0103505	0.06948653	0

	Temperature
1	-2
2	-1
3	0
4	1
5	2

Confidence intervals are requested with confint, using either the asymptotic normal approximation or profiling.

```
> confint(fm2, type = "det")
```

		0.025	0.975
p(Int)		-0.1946872	0.6142292
p(MinAfterSunset)		-0.3985642	0.2274722
p(Temperature)		-2.4638797	-1.3233511

```
> confint(fm2, type = "det", method = "profile")
```

Profiling parameter 1 of 3 ... done.
Profiling parameter 2 of 3 ... done.
Profiling parameter 3 of 3 ... done.

		0.025	0.975
p(Int)		-0.1929210	0.6208837
p(MinAfterSunset)		-0.4044794	0.2244221
p(Temperature)		-2.5189984	-1.3789261

Model selection and multi-model inference can be implemented after organizing models using the fitList function.

```
> fms <- fitList(Null = fm1, TimeTemp = fm2)
> modSel(fms, nullmod = "Null")
```

	n	nPars	AIC	delta	AICwt	cumltvWt	Rsqr
TimeTemp	130	4	356.76	0.00	1.0e+00	1.00	0.58
Null	130	2	461.00	104.25	2.3e-23	1.00	0.00

```
> predict(fms, type = "det", newdata = newData, appendData = TRUE)
```

	Predicted	SE	MinAfterSunset	Temperature
1	0.98196076	0.01266193	0	-2
2	0.89123189	0.04248804	0	-1
3	0.55225129	0.05102660	0	0
4	0.15658708	0.03298276	0	1
5	0.02718682	0.01326263	0	2

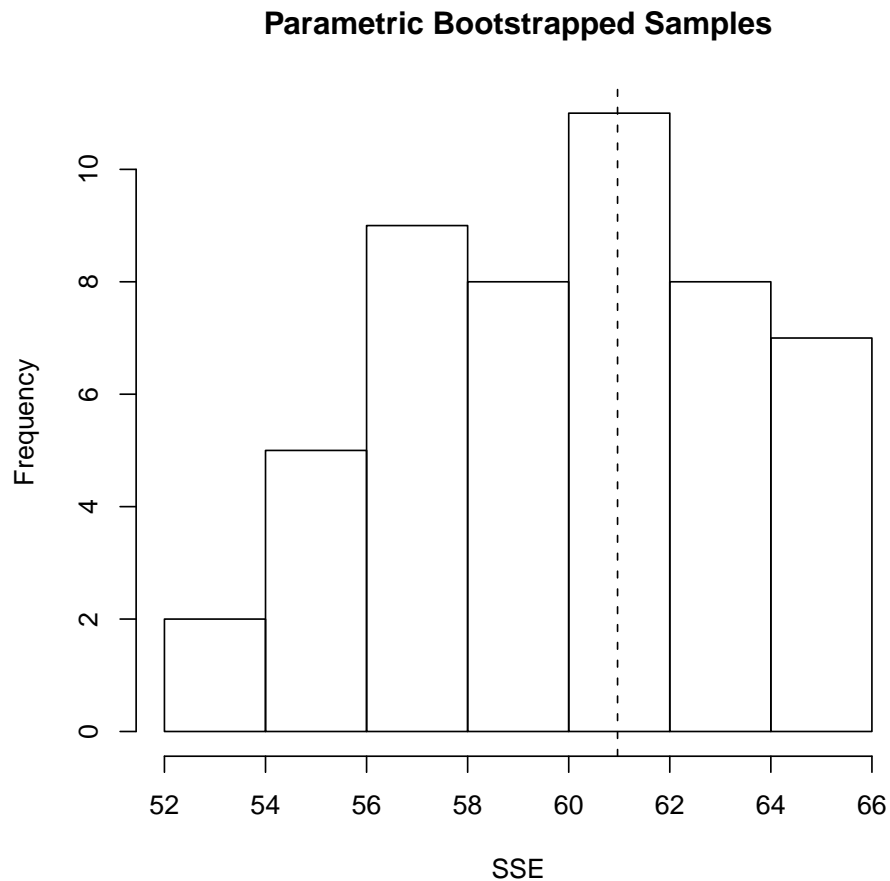
Parametric bootstrapping can be used to check the adequacy of model fit.

```
> pcru.pb <- parboot(fm2, statistic = SSE, nsim = 50, report = 5)
t0 = 60.9664
61.9, 56.6, 58.9, 52.8, 65.6
60.2, 63.5, 62.5, 55, 58.9
```

```

59.5, 57.3, 61.5, 64.6, 59.9
58.6, 60.4, 60.5, 59.3, 58.3
53.9, 58.8, 66.2, 63.4, 61.7
56.5, 59.6, 59.9, 59.4, 64.3
61.7, 61.3, 61.2, 61.5, 61.3
61.8, 60.9, 58.8, 55.5, 61.9
61.4, 57.6, 60.3, 60.7, 59
61, 54.2, 60.1, 59.2, 55.6
> plot(pcru.pb)

```



This example suggests an adequate fit.

References

- [1] Darryl I. MacKenzie, James D. Nichols, James E. Hines, Melinda G. Knutson, and Alan B. Franklin. Estimating site occupancy, colonization, and local extinction when a species is detected imperfectly. *Ecology*, 84(8):2200–2207, 2003.
- [2] Darryl I. MacKenzie, James D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, 83(8):2248–2255, 2002.
- [3] J. A. Royle. Generalized estimators of avian abundance from count survey data. *Animal Biodiversity and Conservation*, 27(1):375–386, 2004.
- [4] J. A. Royle. N-mixture models for estimating population size from spatially replicated counts. *Biometrics*, 60(1):108–115, 2004.

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- [6] JA Royle, DK Dawson, and S. Bates. Modeling abundance effects in distance sampling. *Ecology*, 85(6):1591–1597, 2004.