

Package ‘detect’

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Type Package

Title Analyzing Wildlife Data with Detection Error

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Depends R (>= 3.5.0), Formula, stats4, pbapply

Imports Matrix

Suggests dclone, dcmlc

Description Models for analyzing site occupancy and count data models with detection error, including single-visit based models (Lele et al. 2012 <[doi:10.1093/jpe/rtr042](https://doi.org/10.1093/jpe/rtr042)>, Moreno et al. 2010 <[doi:10.1890/09-1073.1](https://doi.org/10.1890/09-1073.1)>, Solymos et al. 2012 <[doi:10.1002/env.1149](https://doi.org/10.1002/env.1149)>, Denes et al. 2016 <[doi:10.1111/1365-2664.12818](https://doi.org/10.1111/1365-2664.12818)>), conditional distance sampling and time-removal models (QPAD) (Solymos et al. 2013 <[doi:10.1111/2041-210X.12106](https://doi.org/10.1111/2041-210X.12106)>, Solymos et al. 2018 <[doi:10.1650/CONDOR-18-32.1](https://doi.org/10.1650/CONDOR-18-32.1)>), and single bin QPAD (SQPAD) models (Lele & Solymos 2025 <[doi:10.1093/ornithapp/duaf078](https://doi.org/10.1093/ornithapp/duaf078)>). Package development was supported by the Alberta Biodiversity Monitoring Institute and the Boreal Avian Modelling Project.

License GPL-2

URL <https://github.com/psolymos/detect>

BugReports <https://github.com/psolymos/detect/issues>

LazyLoad yes

LazyData true

NeedsCompilation no

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detect-package	<i>Analyzing Wildlife Data with Detection Error</i>
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Description

Models for analyzing site occupancy and count data models with detection error, including single-visit based models, conditional distance sampling and time-removal models. Package development was supported by the Alberta Biodiversity Monitoring Institute and the Boreal Avian Modelling Project.

Details

[svocc](#): single visit occupancy model (Lele et al. 2012, Moreno et al. 2010).
[svabu](#): single visit abundance model based on conditional maximum likelihood (Solymos et al. 2012, Solymos and Lele 2016, Denes et al. 2016).
[cmulti](#): conditional multinomial maximum likelihood estimation for removal and (point count) distance sampling, efficient and flexible setup for varying methodologies (Solymos et al. 2013, Solymos et al. 2018).

Author(s)

Peter Solymos, Monica Moreno, Subhash R Lele

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References

- Denes, F., Solymos, P., Lele, S. R., Silveira, L. & Beissinger, S. 2017. Biome scale signatures of land use change on raptor abundance: insights from single-visit detection-based models. *Journal of Applied Ecology*, **54**, 1268–1278. <doi:10.1111/1365-2664.12818>
- Lele, S.R., Moreno, M. and Bayne, E. 2012. Dealing with detection error in site occupancy surveys: What can we do with a single survey? *Journal of Plant Ecology*, **5**(1), 22–31. <doi:10.1093/jpe/rtr042>
- Moreno, M. and Lele, S. R. 2010. Improved estimation of site occupancy using penalized likelihood. *Ecology*, **91**, 341–346. <doi:10.1890/09-1073.1>
- Solymos, P., Lele, S. R. and Bayne, E. 2012. Conditional likelihood approach for analyzing single visit abundance survey data in the presence of zero inflation and detection error. *Environmetrics*, **23**, 197–205. <doi:10.1002/env.1149>
- Solymos, P., Matsuoka, S. M., Bayne, E. M., Lele, S. R., Fontaine, P., Cumming, S. G., Stralberg, D., Schmiegelow, F. K. A. & Song, S. J., 2013. Calibrating indices of avian density from non-standardized survey data: making the most of a messy situation. *Methods in Ecology and Evolution*, **4**, 1047–1058. <doi:10.1111/2041-210X.12106>
- Solymos, P., Lele, S. R. 2016. Revisiting resource selection probability functions and single-visit methods: clarification and extensions. *Methods in Ecology and Evolution*, **7**, 196–205. <doi:10.1111/2041-210X.12432>
- Solymos, P., Matsuoka, S. M., Cumming, S. G., Stralberg, D., Fontaine, P., Schmiegelow, F. K. A., Song, S. J., and Bayne, E. M., 2018. Evaluating time-removal models for estimating availability of boreal birds during point-count surveys: sample size requirements and model complexity. *Condor*, **120**, 765–786. <doi:10.1650/CONDOR-18-32.1>
- Supporting info, including a tutorial for the QPAD method: <https://github.com/psolymos/QPAD/tree/master/inst/doc/v2>

AUC

AUC ROC plot for fitted models

Description

Area under the receiver-operator (ROC) curve (AUC), and ROC plot methods for fitted models.

Usage

```
AUC(object, ...)
rocplot(x, ...)
```

Arguments

object, x	a fitted model object
...	other arguments

Value

AUC returns AUC value for a model, or a data frame with values for more models.

rocplot returns the values used for the plot invisibly, and as a side effect it draws a graph.

Author(s)

Peter Solymos and Monica Moreno

bootstrap	<i>Do bootstrap and extract bootstrap results</i>
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Description

Do bootstrap and extract bootstrap results.

Usage

```
bootstrap(object, ...)  
extractBOOT(object, ...)
```

Arguments

object	a fitted model object
...	other arguments

Value

bootstrap performs bootstrap.

extractBOOT is used to extract bootstrap results.

Author(s)

Peter Solymos

Description

Conditional Multinomial Maximum Likelihood Estimation for different sampling methodologies.

Usage

```
cmulti(formula, data, type = c("rem", "mix", "dis", "fmix"),
        inits = NULL, method = "Nelder-Mead", ...)
cmulti.fit(Y, D, X=NULL, type=c("rem", "mix", "dis", "fmix"),
           inits=NULL, method="Nelder-Mead", ...)

cmulti2.fit(Y, D1, D2, X1=NULL, X2=NULL,
            inits=NULL, method="Nelder-Mead", ...)

## S3 method for class 'cmulti'
fitted(object, ...)
## S3 method for class 'cmulti'
model.frame(formula, ...)
## S3 method for class 'cmulti'
model.matrix(object, ...)
## S3 method for class 'cmulti'
predict(object, newdata = NULL,
        type = c("link", "response"), ...)
```

Arguments

formula	formula, LHS takes 2 matrices in the form of $Y \mid D$, RHS is either 1 or some covariates, see Examples.
data	data.
type	character, one of "rem" (removal sampling, homogeneous singing rates), "mix" and "fmix" (removal sampling, heterogeneous singing rates, "mix" implies that 'phi' is constant but 'c' can vary; "fmix" implies that 'c' is constant but 'phi' can vary), "dis" (distance sampling, half-normal detection function for point counts, circular area). For the predict method it is the type of prediction required; the default is on the scale of the linear predictors; the alternative "response" is on the scale of the response variable.
Y	this contains the cell counts. <code>cmulti.fit</code> requires that Y is a matrix (observations x intervals), dimensions and pattern in NAs must match that of D. <code>cmulti2.fit</code> requires that Y is a 3-dimensional array (observations x time intervals x distance intervals), dimensions and pattern in NAs must match that of D1 and D2.
D, D1, D2	design matrices, that describe the interval endpoints for the sampling methodology, dimensions must match dimensions of Y.

X, X1, X2	design matrices, X is the matrix with covariates for the removal/distance sampling parameters. X1 is the matrix with covariates for the removal, X2 is the matrix with covariates for the distance sampling parameters.
inits	optional initial values.
method	method for <code>optim</code> .
object	fitted model object.
newdata	optionally, a data frame in which to look for variables with which to predict. If omitted, the fitted linear predictors are used.
...	additional options for <code>optim</code> .

Details

Conditional Multinomial Maximum Likelihood Estimation for different sampling methodologies.

Value

An object of class 'cmulti'.

Author(s)

Peter Solymos

References

Solymos, P., Matsuoka, S. M., Bayne, E. M., Lele, S. R., Fontaine, P., Cumming, S. G., Stralberg, D., Schmiegelow, F. K. A. & Song, S. J., 2013. Calibrating indices of avian density from non-standardized survey data: making the most of a messy situation. *Methods in Ecology and Evolution*, **4**, 1047–1058. <doi:10.1111/2041-210X.12106>

Solymos, P., Matsuoka, S. M., Cumming, S. G., Stralberg, D., Fontaine, P., Schmiegelow, F. K. A., Song, S. J., and Bayne, E. M., 2018. Evaluating time-removal models for estimating availability of boreal birds during point-count surveys: sample size requirements and model complexity. *Condor*, **120**, 765–786. <doi:10.1650/CONDOR-18-32.1>

Supporting info, including a tutorial for the QPAD method: <https://github.com/psolymos/QPAD/tree/master/inst/doc/v2>

Examples

```
simfun1 <- function(n = 10, phi = 0.1, c=1, tau=0.8, type="rem") {
  if (type=="dis") {
    Dparts <- matrix(c(0.5, 1, NA,
                      0.5, 1, Inf,
                      1, Inf, NA), 3, 3, byrow=TRUE)
    D <- Dparts[sample.int(3, n, replace=TRUE),]
    CP <- 1-exp(-(D/tau)^2)
  } else {
    Dparts <- matrix(c(5, 10, NA,
                      3, 5, 10,
                      3, 5, NA), 3, 3, byrow=TRUE)
```

```

      D <- Dparts[sample.int(3, n, replace=TRUE),]
      CP <- 1-c*exp(-D*phi)
    }
    k <- ncol(D)
    P <- CP - cbind(0, CP[, -k, drop=FALSE])
    Psum <- rowSums(P, na.rm=TRUE)
    PPsum <- P / Psum
    Pok <- !is.na(PPsum)
    N <- rpois(n, 10)
    Y <- matrix(NA, ncol(PPsum), nrow(PPsum))
    Ypre <- sapply(1:n, function(i) rmultinom(1, N, PPsum[i,Pok[i,]]))
    Y[t(Pok)] <- unlist(Ypre)
    Y <- t(Y)
    list(Y=Y, D=D)
  }

n <- 200
x <- rnorm(n)
X <- cbind(1, x)

## removal, constant
vv <- simfun1(n=n, phi=exp(-1.5))
m1 <- cmulti(vv$Y | vv$D ~ 1, type="rem")
coef(m1)
## mixture, constant (mix and fmix are identical)
vv <- simfun1(n=n, phi=exp(-1.5), c=plogis(0.8))
m2 <- cmulti(vv$Y | vv$D ~ 1, type="mix")
coef(m2)
m2f <- cmulti(vv$Y | vv$D ~ 1, type="fmix")
coef(m2f)
## dist, constant
vv <- simfun1(n=n, tau=exp(-0.2), type="dis")
m3 <- cmulti(vv$Y | vv$D ~ 1, type="dis")
coef(m3)

## removal, not constant
log.phi <- crossprod(t(X), c(-2,-1))
vv <- simfun1(n=n, phi=exp(cbind(log.phi, log.phi, log.phi)))
m1 <- cmulti(vv$Y | vv$D ~ x, type="rem")
coef(m1)
## mixture, fixed phi, varying c
logit.c <- crossprod(t(X), c(-2,1))
vv <- simfun1(n=n, phi=exp(-1.5), c=plogis(cbind(logit.c, logit.c, logit.c)))
m2 <- cmulti(vv$Y | vv$D ~ x, type="mix")
coef(m2)
## mixture, varying phi, fixed c
log.phi <- crossprod(t(X), c(-2,-1))
vv <- simfun1(n=n, phi=exp(cbind(log.phi, log.phi, log.phi)), c=plogis(0.8))
m2f <- cmulti(vv$Y | vv$D ~ x, type="fmix")
coef(m2f)
## dist, not constant
log.tau <- crossprod(t(X), c(-0.5,-0.2))
vv <- simfun1(n=n, tau=exp(cbind(log.tau, log.tau, log.tau)), type="dis")

```

```

m3 <- cmulti(vv$Y | vv$D ~ x, type="dis")
coef(m3)

summary(m3)
coef(m3)
vcov(m3)
AIC(m3)
confint(m3)
logLik(m3)

## fitted values
plot(exp(log.tau), fitted(m3))

## prediction for new locations (type = 'rem')
ndf <- data.frame(x=seq(-1, 1, by=0.1))
summary(predict(m1, newdata=ndf, type="link"))
summary(pr1 <- predict(m1, newdata=ndf, type="response"))
## turing singing rates into probabilities requires total duration
## 5 minutes used here
psing <- 1-exp(-5*pr1)
plot(ndf$x, psing, type="l", ylim=c(0,1))

## prediction for new locations (type = 'dis')
summary(predict(m3, newdata=ndf, type="link"))
summary(pr3 <- predict(m3, newdata=ndf, type="response"))
## turing EDR into probabilities requires finite truncation distances
## r=0.5 used here (50 m)
r <- 0.5
pdet <- pr3^2*(1-exp(-r^2/pr3^2))/r^2
plot(ndf$x, pdet, type="l", ylim=c(0,1))

## joint removal-distance estimation
## is not different from 2 orthogonal estimations

simfun12 <- function(n = 10, phi = 0.1, c=1, tau=0.8, type="rem") {
  Flat <- function(x, DIM, dur=TRUE) {
    x <- array(x, DIM)
    if (!dur) {
      x <- aperm(x,c(1,3,2))
    }
    dim(x) <- c(DIM[1], DIM[2]*DIM[3])
    x
  }
  Dparts1 <- matrix(c(5, 10, NA,
                     3, 5, 10,
                     3, 5, NA), 3, 3, byrow=TRUE)
  D1 <- Dparts1[sample.int(3, n, replace=TRUE),]
  CP1 <- 1-c*exp(-D1*phi)
  Dparts2 <- matrix(c(0.5, 1, NA,
                     0.5, 1, Inf,
                     1, Inf, NA), 3, 3, byrow=TRUE)
  D2 <- Dparts2[sample.int(3, n, replace=TRUE),]
  CP2 <- 1-exp(-(D2/tau)^2)

```

```

k1 <- ncol(D1)
k2 <- ncol(D2)
DIM <- c(n, k1, k2)
P1 <- CP1 - cbind(0, CP1[, -k1, drop=FALSE])
P2 <- CP2 - cbind(0, CP2[, -k2, drop=FALSE])
Psum1 <- rowSums(P1, na.rm=TRUE)
Psum2 <- rowSums(P2, na.rm=TRUE)
Pflat <- Flat(P1, DIM, dur=TRUE) * Flat(P2, DIM, dur=FALSE)
PsumFlat <- Psum1 * Psum2
PPsumFlat <- Pflat / PsumFlat
PokFlat <- !is.na(PPsumFlat)
N <- rpois(n, 10)
Yflat <- matrix(NA, ncol(PPsumFlat), nrow(PPsumFlat))
YpreFlat <- sapply(1:n, function(i) rmultinom(1, N, PPsumFlat[i,PokFlat[i,]]))
Yflat[t(PokFlat)] <- unlist(YpreFlat)
Yflat <- t(Yflat)
Y <- array(Yflat, DIM)
k1 <- dim(Y)[2]
k2 <- dim(Y)[3]
Y1 <- t(sapply(1:n, function(i) {
  count <- rowSums(Y[i,,], na.rm=TRUE)
  nas <- rowSums(is.na(Y[i,,]))
  count[nas == k2] <- NA
  count
}))
Y2 <- t(sapply(1:n, function(i) {
  count <- colSums(Y[,i,,], na.rm=TRUE)
  nas <- colSums(is.na(Y[,i,,]))
  count[nas == k2] <- NA
  count
}))
list(Y=Y, D1=D1, D2=D2, Y1=Y1, Y2=Y2)
}

## removal and distance, constant
vv <- simfun12(n=n, phi=exp(-1.5), tau=exp(-0.2))
res <- cmulti2.fit(vv$Y, vv$D1, vv$D2)
res1 <- cmulti.fit(vv$Y1, vv$D1, NULL, "rem")
res2 <- cmulti.fit(vv$Y2, vv$D2, NULL, "dis")
## points estimates are identical
cbind(res$coef, c(res1$coef, res2$coef))
## standard errors are identical
cbind(sqrt(diag(res$vcov)),
      c(sqrt(diag(res1$vcov)),sqrt(diag(res2$vcov))))

## removal and distance, not constant
vv <- simfun12(n=n,
  phi=exp(cbind(log.phi, log.phi, log.phi)),
  tau=exp(cbind(log.tau, log.tau, log.tau)))
res <- cmulti2.fit(vv$Y, vv$D1, vv$D2, X1=X, X2=X)
res1 <- cmulti.fit(vv$Y1, vv$D1, X, "rem")
res2 <- cmulti.fit(vv$Y2, vv$D2, X, "dis")

```

```
## points estimates are identical
cbind(res$coef, c(res1$coef, res2$coef))
## standard errors are identical
cbind(sqrt(diag(res$vcov)),
      c(sqrt(diag(res1$vcov)), sqrt(diag(res2$vcov))))
```

convertEDT	<i>Conversion between truncated and unlimited effective detection distance (EDR)</i>
------------	--

Description

Conversion between truncated and unlimited effective detection distance (EDR).

Usage

```
convertEDR(edr, r, truncated=FALSE)
```

Arguments

edr	effective detection distance. In same units as r.
r	truncation distance (radius of point count). In same units as edr.
truncated	logical, see Details.

Details

truncated = FALSE means that edr is unlimited EDR, and the function returns the truncated EDR given r.

truncated = TRUE means that edr is truncated EDR given r, and the function returns the unlimited EDR.

Value

A numeric vector with converted EDR values.

Author(s)

Peter Solymos

References

Matsuoka, S. M., Bayne, E. M., Solymos, P., Fontaine, P., Cumming, S. G., Schmiegelow, F. K. A., & Song, S. A., 2012. Using binomial distance-sampling models to estimate the effective detection radius of point-counts surveys across boreal Canada. *Auk*, **129**, 268–282. <doi:10.1525/auk.2012.11190>

Solymos, P., Matsuoka, S. M., Bayne, E. M., Lele, S. R., Fontaine, P., Cumming, S. G., Stralberg, D., Schmiegelow, F. K. A. & Song, S. J., 2013. Calibrating indices of avian density from non-standardized survey data: making the most of a messy situation. *Methods in Ecology and Evolution*, **4**, 1047–1058. <doi:10.1111/2041-210X.12106>

Supporting info, including a tutorial for the above paper: <https://github.com/psolymos/QPAD/tree/master/inst/doc/v2>

Examples

```
convertEDR(1, 0.5, truncated=FALSE)
## should be close to 1
convertEDR(convertEDR(1, 0.5, truncated=FALSE), 0.5, truncated=TRUE)
```

databu

Simulated example for abundance model

Description

Simulated example for abundance model, see code below.

Usage

```
data(databu)
```

Format

A data frame with 1000 observations on the following 11 variables.

N true counts

Y observed counts

x1 random variables used as covariates

x2 random variables used as covariates

x3 random variables used as covariates

x4 random variables used as covariates

x5 random variables used as covariates

x6 random variables used as covariates

p probability of detection

lambda mean of the linear predictor

A occupancy

phi zero inflation probabilities

Details

This simulated example corresponds to the Binomial - ZIP model implemented in the function [svabu](#).

Source

Simulated example.

References

Solymos, P., Lele, S. R. and Bayne, E. 2012. Conditional likelihood approach for analyzing single visit abundance survey data in the presence of zero inflation and detection error. *Environmetrics*, **23**, 197–205. <doi:10.1002/env.1149>

Examples

```
data(databu)
str(databu)
## Not run:
## simulation
n <- 1000
set.seed(1234)
x1 <- runif(n,0,1)
x2 <- rnorm(n,0,1)
x3 <- runif(n,-1,1)
x4 <- runif(n,-1,1)
x5 <- rbinom(n,1,0.6)
x6 <- rbinom(n,1,0.4)
x7 <- rnorm(n,0,1)
X <- model.matrix(~ x1 + x5)
Z <- model.matrix(~ x2 + x5)
Q <- model.matrix(~ x7)
beta <- c(2,-0.8,0.5)
theta <- c(1, 2, -0.5)
phi <- 0.3
p <- drop(binomial("logit")$linkinv(Z %*% theta))
lambda <- drop(exp(X %*% beta))
A <- rbinom(n, 1, 1-phi)
N <- rpois(n, lambda * A)
Y <- rbinom(n, N, p)
databu <- data.frame(N=N, Y=Y, x1, x2, x3, x4, x5, x6, p=p, lambda=lambda, A, phi)

## End(Not run)
```

datocc

Simulated example for occupancy model

Description

Simulated example for occupancy model, see code below.

Usage

```
data(datocc)
```

Format

A data frame with 1000 observations on the following 6 variables.

Y true occupancy
 W observations
 x1 random variables used as covariates
 x2 random variables used as covariates
 x3 random variables used as covariates
 x4 random variables used as covariates
 p.occ probability of occurrence
 p.det probability of detection

Details

This simulated example corresponds to the ZI Binomial model implemented in the function [svocc](#).

Source

Simulated example.

References

Lele, S.R., Moreno, M. and Bayne, E. (2012) Dealing with detection error in site occupancy surveys: What can we do with a single survey? *Journal of Plant Ecology*, **5**(1), 22–31. <doi:10.1093/jpe/rtr042>

Examples

```
data(datocc)
str(datocc)
## Not run:
## simulation
n <- 1000
set.seed(1234)
x1 <- runif(n, -1, 1)
x2 <- as.factor(rbinom(n, 1, 0.5))
x3 <- rnorm(n)
x4 <- rnorm(n)
beta <- c(0.6, 0.5)
theta <- c(0.4, -0.5, 0.3)
X <- model.matrix(~ x1)
Z <- model.matrix(~ x1 + x3)
mu <- drop(X %*% beta)
nu <- drop(Z %*% theta)
p.occ <- binomial("cloglog")$linkinv(mu)
p.det <- binomial("logit")$linkinv(nu)
Y <- rbinom(n, 1, p.occ)
W <- rbinom(n, 1, Y * p.det)
datocc <- data.frame(Y, W, x1, x2, x3, x4, p.occ, p.det)

## End(Not run)
```

hbootindex	<i>Hierarchical bootstrap indices</i>
------------	---------------------------------------

Description

Generates hierarchical bootstrap indices.

Usage

```
hbootindex(groups, strata, B = 199)
```

Arguments

groups	group membership vector.
strata	strata, optional.
B	number of bootstrap iterations.

Details

Resampling with replacement with weights proportional to the number of observations in each of the group level (unique values in groups).

Values of groups within levels (unique values) of strata are resampled independently of other strata levels.

Value

A matrix with bootstrapped indices, number of columns is $B + 1$. The column is a resample without replacement (random subsets can be selected without further reshuffling). Other elements contain indices according to rules described in Details section (these also randomly reshuffled).

Author(s)

Peter Solymos

Examples

```
## equal group sizes
groups <- rep(1:4, each=5)
strata <- rep(1:2, each=10)
hbootindex(groups, strata, 3)

## unequal group sizes
groups <- groups[-c(5,9,10,11)]
strata <- strata[-c(5,9,10,11)]
hbootindex(groups, strata, 3)
```

josm

*Bird point count data from Alberta's Oil Sands region***Description**

Data set used in Mahon et al. 2016 and Mahon et al. 2019.

Usage

```
data("josm")
```

Format

A list with elements surveys, species, and counts.

Source

Mahon et al. 2016 and Mahon et al. 2019.

References

Mahon, C. L., Holloway, G., Solymos, P., Cumming, S. G., Bayne, E. M., Schmiegelow, F. K. A., Song, S. J., 2016. Community structure and niche characteristics of upland and lowland western boreal birds at multiple spatial scales *Forest Ecology and Management* **361**:99-116. <doi:10.1016/j.foreco.2015.11.007>

Mahon, C. L., Holloway, G., Bayne, E. M., Toms, J. D., 2019. Additive and interactive cumulative effects on boreal landbirds: winners and losers in a multi-stressor landscape *Ecological Applications* **29**:e01895. <doi:10.1002/eap.1895>

Examples

```
data(josm)
str(josm)
```

load_BAM_QPAD

*Load BAM QPAD parameter estimates and support functions***Description**

Load BAM QPAD parameter estimates and support functions.

Usage

```
load_BAM_QPAD(version)
```

Arguments

version version of the BAM QPAD estimates. List of selection is provided if missing.

Details

The `load_BAM_QPAD` function in the 'detect' package is deprecated. Use the `load_BAM_QPAD` function 'QPAD' package instead. See <https://github.com/psolymos/QPAD> for more information.

Value

It returns a message.

Author(s)

Peter Solymos

References

Solymos, P., Matsuoka, S. M., Bayne, E. M., Lele, S. R., Fontaine, P., Cumming, S. G., Stralberg, D., Schmiegelow, F. K. A. & Song, S. J., 2013. Calibrating indices of avian density from non-standardized survey data: making the most of a messy situation. *Methods in Ecology and Evolution*, **4**, 1047–1058. <doi:10.1111/2041-210X.12106>

Supporting info, including a tutorial for the above paper: <https://github.com/psolymos/QPAD/tree/master/inst/doc/v2>

 oven

Ovenbird abundances

Description

Ovenbird abundances from BBS

Usage

```
data(oven)
```

Format

A data frame with 891 observations on the following 11 variables.

count observations

route route id

stop stop id within route

pforest proportion of forest

pdecid proportion of deciduous forest

pagri proportion of agricultural areas

long longitude

lat latitude

observ observer, a factor with levels ARS DW RDW SVW

julian Julian day

timeday time of day

Source

BBS, Erin Bayne (Univ. Alberta), unpublished data set used in Solymos et al. 2012.

References

Solymos, P., Lele, S. R. and Bayne, E. 2012. Conditional likelihood approach for analyzing single visit abundance survey data in the presence of zero inflation and detection error. *Environmetrics*, **23**, 197–205. <doi:10.1002/env.1149>

Examples

```
data(oven)
str(oven)
```

paired

Example point count data set with paired human and ARU data

Description

Data set from Van Wilgenburg et al. 2017 <doi:10.5751/ACE-00975-120113>.

Usage

```
data("paired")
```

Format

A data frame with 11340 observations on the following 37 variables.

`sort` A numeric vector, sorting ID.

`UniqueID` Character, unique location ID.

`SurveyDate` Date.

`Time` Time.

`Visit` A numeric vector, visit to same location.

`Observer` Character with the observers' initials.

`SurveyType` Character with values ARU (automated recording unit) HUM (human observer)

`NoiseLevel` Character with values Heavy Light Moderate None Unusable.

`SPECIES` Character with values for species, 4-letter codes following AOU alpha codes.

`Count` A numeric vector, number of individuals counted.

`TimeInterval` Character, original interval the individual was detected in.

`DISTANCE` Character with values >100 m, 0–49 m, 50–100 m, and ARU.

`FID` A numeric vector for FID.

`Strata` Character, strata.

Plot Character, plot.
 Station Character, station.
 Latitude A numeric vector, latitude in decimal degrees.
 Longitude A numeric vector, longitude in decimal degrees.
 Join_Count A numeric vector.
 YearLoss A numeric vector.
 Class_Name Character, the ModisLCC description.
 ModisLCC A numeric vector, Modis land cover class.
 FIRENAME Character, fire name.
 FIREYEAR A numeric vector, year of fire.
 Disturbance Character with levels Cutblock, Fire, and Undisturbed
 PKEY Character, point count ID.
 PKEYm Character, PKEY with abbreviated SurveyType.
 Noise A numeric (ordinal) version of NoiseLevel.
 JULIAN A numeric vector, ordinal day of the year.
 JDAY A numeric vector, normalized version of JULIAN.
 srise A numeric vector, sunrise time in hours.
 start_time A numeric vector, survey start time in hours.
 TSSR A numeric vector, normalized time since sunrise (survey time and sunrise time difference as a fraction of a day).
 Interval Character with levels 0-3 min, 3-5 min, 5-10 min, and UNK.
 SS Character, station ID.
 RandomSel A numeric vector for training (1) and hold-out (0) observations.
 SpeciesName Species common name.

Source

Van Wilgenburg et al. 2016.

References

Van Wilgenburg, S. L., P. Solymos, K. J. Kardynal, and M. D. Frey. 2017. Paired sampling standardizes point count data from humans and acoustic recorders. *Avian Conservation and Ecology* **12(1)**:13. <doi:10.5751/ACE-00975-120113>

Examples

```
data(paired)
str(paired)
```

sqpad

*Single-bin QPAD (SQPAD)***Description**

Single bin QPAD (SQPAD) approach by Lele and Solymos (2025).

Usage

```
sqpad(formula, data, dis, dur,
      type = c("full", "approx"), det = c("joint", "pq"),
      Nmax = NULL, K = NULL, A = NULL,
      montecarlo = FALSE, np = 1000, distcorr = 2/3, ...)

sqpad.fit(Y, dis, dur, X = NULL, Z = NULL,
          type = c("full", "approx", "conv"), det = c("joint", "pq"),
          init = NULL, method = "Nelder-Mead", hessian = TRUE,
          tt1 = NULL, A = NULL, Nmax = NULL, K = NULL,
          montecarlo = FALSE, np = 1000, distcorr = 2/3, dislist = NULL, ...)

## S3 method for class 'sqpad'
print(x, digits, ...)
## S3 method for class 'sqpad'
coef(object, model = c("full", "sta", "det"), ...)
## S3 method for class 'sqpad'
vcov(object, model = c("full", "sta", "det"), ...)
## S3 method for class 'sqpad'
fitted(object, ...)
## S3 method for class 'sqpad'
logLik(object, ...)
## S3 method for class 'sqpad'
summary(object, ...)
## S3 method for class 'summary.sqpad'
print(x, digits, ...)
## S3 method for class 'sqpad'
predict(object, newdata = NULL,
        type = c("link", "response"), ...)

rtriang(n, r = 1)
```

Arguments

formula	formula, LHS takes a vector, RHS is either 1 or some covariates, see Examples.
data	data.
dis, dur	a vector with distance and duration values.

A	a vector with area values. Area is calculated from <code>dis</code> , use A if distance is not directly related to area (e.g. for ARU data).
type	character, one of "full" (full likelihood), "approx" (approximate method), and "conv" (convolution likelihood).
det	character, the detection model: "joint" or independence ("pq").
Y	response vector, non-negative integers.
X, Z	design matrices, X is the matrix with covariates for the density parameters. Z is the matrix with covariates for the cue rate model. NULL means constant density and detection.
K	truncation value, K=1 implements the occupancy version of SQPAD. K>1 implements the truncated count models.
Nmax	maximum abundance value for numerical integration under the full and convolution likelihoods.
montecarlo, np, distcorr	should mean probability (TRUE) using np points or approximation be used with distance correction distcorr in the detection model.
dislist	distance list for the convolution likelihood.
ttl	vector with time to 1st detection values, same units as for <code>dur</code> .
init	optional initial values for <code>optim</code> .
method	method for <code>optim</code> .
hessian	logical, should the Hessian matrix be computed by <code>optim</code> .
object, x	fitted model object.
model	the part of the model for which the coefficients or variance-covariance matrix should be returned: "full" for the full model, "sta" for the state (density) model, and "det" for the detection model.
newdata	optionally, a data frame in which to look for variables with which to predict. If omitted, the fitted linear predictors are used.
digits	digits to use when providing summaries.
...	additional options for <code>optim</code> or the methods.
n	number of random variates to generate from the triangular distribution.
r	maximum value for the triangular distribution.

Details

Single bin QPAD (SQPAD) approach for robust analysis of point count data with detection error by Lele and Solymos (2025).

Value

An object of class 'sqpad'.

Author(s)

Peter Solymos and Subhash Lele

References

Solymos, P., Lele, S. R., 2025. Single bin QPAD (SQPAD) approach for robust analysis of point count data with detection error. *Ornithological Applications*, **128**, 1–14. <doi:10.1093/ornithapp/duaf078>

Supporting info for the SQPAD method: <https://github.com/psolymos/sqpad-paper>, <doi:10.5281/zenodo.16172209>

Examples

```
set.seed(0)
n <- 100
x <- rnorm(n)
D <- exp(-2 + 0.5 * x)
phi <- 0.25
tau <- 1
dur <- sample(1:10, n, replace=TRUE)
dis <- sample(seq(0.5, 2, 0.25), n, replace=TRUE)
A <- dis^2 * pi
dcorr <- 2/3
p <- 1 - exp(-dur * phi * exp(-(dis*dcorr)^2/tau^2))
N <- rpois(n, D*A)
Y <- rbinom(n, N, p)

df <- data.frame(x = x, y = Y)

m <- sqpad(y ~ x | 1, data = df, dis = dis, dur = dur,
  type = "full", det = "joint", K = NULL)

print(m)
summary(m)

coef(m)
coef(m, model = "sta")
coef(m, model = "det")
nobs(m)
vcov(m)
vcov(m, model = "sta")
vcov(m, model = "det")
confint(m)

logLik(m)
AIC(m)
BIC(m)

fitted(m)
predict(m, type = "link")
predict(m, newdata = df[1:10,], type = "response")
predict(m, newdata = df[1:10,], type = "link")

## Not run:
m0 <- sqpad(y ~ 1 | 1, data = df, dis = dis, dur = dur,
  type = "full", det = "joint", K = NULL)
m1 <- sqpad(y ~ 1 | x, data = df, dis = dis, dur = dur,
  type = "full", det = "joint", K = NULL)
```

```

m2 <- sqpad(y ~ x | x, data = df, dis = dis, dur = dur,
  type = "full", det = "joint", K = NULL)

AIC(m, m0, m1, m2) # m2 is best
BIC(m, m0, m1, m2) # this is needed!

# average probability

set.seed(5)
n <- 1000
x <- rnorm(n)
D <- exp(-2 + 0.5 * x)
phi <- 0.25
tau <- 1
dur <- sample(1:10, n, replace=TRUE)
dis <- sample(seq(0.5, 2, 0.25), n, replace=TRUE)
A <- dis^2 * pi

dcorr <- 2/3
p <- 1 - exp(-dur * phi * exp(-(dis*dcorr)^2/tau^2))
N <- rpois(n, D*A)
Y <- rbinom(n, N, p)
df <- data.frame(x = x, y = Y)

np <- 1000
dij <- rtriang(as.integer(np), 1)
dij <- matrix(dij, nrow = n, ncol = np, byrow = TRUE)
p2 <- rowMeans(1 - exp(-dur * phi * exp(-(dis*dij)^2/tau^2)))
Y2 <- rbinom(n, N, p2)
df2 <- data.frame(x = x, y = Y2)

plot(p, p2)
abline(0, 1)

mAP <- sqpad(y ~ x | 1, data = df, dis = dis, dur = dur, type = "full",
  det = "joint", K = NULL, montecarlo = FALSE, hessian = FALSE)
mMC <- sqpad(y ~ x | 1, data = df, dis = dis, dur = dur, type = "full",
  det = "joint", K = NULL, montecarlo = TRUE, hessian = FALSE)
m2AP <- sqpad(y ~ x | 1, data = df2, dis = dis, dur = dur, type = "full",
  det = "joint", K = NULL, montecarlo = FALSE, hessian = FALSE)
m2MC <- sqpad(y ~ x | 1, data = df2, dis = dis, dur = dur, type = "full",
  det = "joint", K = NULL, montecarlo = TRUE, hessian = FALSE)

cbind(mAP=coef(mAP), mMC=coef(mMC), m2AP=coef(m2AP), m2MC=coef(m2MC))

# convolution likelihood

D <- 1
phi <- 0.25
tau <- 1.2
n <- 200

dur <- sample(1:10, n, replace=TRUE)

```

```

dis <- sample(seq(0.25, 2, 0.25), n, replace=TRUE)
A <- dis^2 * pi
N <- rpois(n, D*A)
dislist <- lapply(seq_len(n), function(i) {
  dij <- rtriang(N[i], dis[i])
  # pij is based on time of 1st detection and distance at 1st detection
  pij <- 1 - exp(-dur[i] * phi * exp(-(dij)^2/tau^2))
  Yij <- rbinom(length(pij), 1, pij)
  dij[Yij > 0]
})
Y <- sapply(dis, length)

m4 <- sqpad.fit(Y = Y, dis = dis, dur = dur, dislist = dislist,
  type = "conv", det = "joint", Nmax = 20)
cbind(parameters = c(D = D, phi = phi, tau = tau), estimates = exp(m4$coef))

## End(Not run)

```

svabu

*Single visit N-mixture abundance models***Description**

Binomial-Poisson, Binomial-NegBin, Binomial-ZIP, and Binomial-ZINB models with single visit.

Usage

```

svabu(formula, data, zeroinfl = TRUE, area = 1, N.max = NULL,
  inits, link.det = "logit", link.zif = "logit",
  model = TRUE, x = FALSE, distr = c("P", "NB"), ...)

svabu.fit(Y, X, Z, Q = NULL, zeroinfl = TRUE, area = 1, N.max = NULL,
  inits, link.det = "logit", link.zif = "logit", ...)
svabu_nb.fit(Y, X, Z, Q = NULL, zeroinfl = TRUE, area = 1, N.max = NULL,
  inits, link.det = "logit", link.zif = "logit", ...)

zif(x)
is.present(object, ...)
predictMCMC(object, ...)
svabu.step(object, model, trace = 1, steps = 1000,
  criter = c("AIC", "BIC"), test = FALSE, k = 2, control, ...)

```

Arguments

formula	formula of the form $y \sim x \mid z$, where y is a vector of observations, x is the set of covariates for the occurrence model, z is the set of covariates for the detection model. x can further expanded as $x1 + zif(x2)$ into terms for the nonzero count data part ($x1$) and the zero inflation component ($zif(x2)$) using the <code>zif</code> special.
---------	---

Y, X, Z, Q	vector of observation, design matrix for abundance model, design matrix for detection and design matrix for zero inflation model
data	data
area	area
N.max	maximum of true count values (for calculating the integral)
zeroinfl	logical, if the Binomial-ZIP model should be fitted
inits	initial values used by link{optim}
link.det, link.zif	link function for the detection and zero inflation parts of the model
model	a logical value indicating whether model frame should be included as a component of the returned value, or true state or detection model
x	logical values indicating whether the response vector and model matrix used in the fitting process should be returned as components of the returned value. For the function zif it is any object to be returned.
object	a fitted object.
trace	info returned during the procedure
steps	max number of steps
criter	criterion to be minimized (cAUC=1-AUC)
test	logical, if decrease in deviance should be tested
k	penalty to be used with AIC
control	controls for optimization, if missing taken from object
distr	character, abundance distribution: "P" for Poisson, "NB" for Negative Binomial.
...	other arguments passed to the functions

Details

See Examples.

The right hand side of the formula must contain at least one continuous (i.e. non discrete/categorical) covariate. This is the necessary condition for the single-visit method to be valid and parameters to be identifiable. See References for more detailed description.

The Binomial-Poisson model is the single visit special case of the N -mixture model proposed by Royle (2004) and explained in Solymos et al. (2012) and Solymos and Lele (2016).

Value

An object of class 'svabu'.

Author(s)

Peter Solymos and Subhash Lele

References

- Royle, J. A. 2004. *N*-Mixture Models for Estimating Population Size from Spatially Replicated Counts. *Biometrics*, **60**(1), 108–115. <doi:10.1111/j.0006-341X.2004.00142.x>
- Solymos, P., Lele, S. R. and Bayne, E. 2012. Conditional likelihood approach for analyzing single visit abundance survey data in the presence of zero inflation and detection error. *Environmetrics*, **23**, 197–205. <doi:10.1002/env.1149>
- Solymos, P., Lele, S. R. 2016. Revisiting resource selection probability functions and single-visit methods: clarification and extensions. *Methods in Ecology and Evolution*, **7**, 196–205. <doi:10.1111/2041-210X.12432>
- Denes, F., Solymos, P., Lele, S. R., Silveira, L. & Beissinger, S. 2017. Biome scale signatures of land use change on raptor abundance: insights from single-visit detection-based models. *Journal of Applied Ecology*, **54**, 1268–1278. <doi:10.1111/1365-2664.12818>

Examples

```
data(databu)

## fit BZIP and BP models
m00 <- svabu(Y ~ x1 + x5 | x2 + x5, databu[1:200,])

## print method
m00
## summary: CMLE
summary(m00)
## coef
coef(m00)
coef(m00, model="sta") ## state (abundance)
coef(m00, model="det") ## detection
coef(m00, model="zif") ## zero inflation (this is part of the 'true state'!)

## Not run:
## Diagnostics and model comparison

m01 <- svabu(Y ~ x1 + x5 | x2 + x5, databu[1:200,], zeroinfl=FALSE)
## compare estimates (note, zero inflation is on the logit scale!)
cbind(truth=c(2,-0.8,0.5, 1,2,-0.5, plogis(0.3)),
      "B-ZIP"=coef(m00), "B-P"=c(coef(m01), NA))

## fitted
plot(fitted(m00), fitted(m01))
abline(0,1)

## compare models
AIC(m00, m01)
BIC(m00, m01)
logLik(m00)
logLik(m01)
## diagnostic plot
plot(m00)
plot(m01)
```

```

## Bootstrap

## non parametric bootstrap
## - initial values are the estimates
m02 <- bootstrap(m00, B=25)
attr(m02, "bootstrap")
extractBOOT(m02)
summary(m02)
summary(m02, type="cmle")
summary(m02, type="boot")
## vcov
vcov(m02, type="cmle")
vcov(m02, type="boot")
vcov(m02, model="sta")
vcov(m02, model="det")
## confint
confint(m02, type="cmle") ## Wald-type
confint(m02, type="boot") ## quantile based
## parametric bootstrap
simulate(m00, 5)
m03 <- bootstrap(m00, B=5, type="param")
extractBOOT(m03)
summary(m03)

## Model selection

m04 <- svabu(Y ~ x1 + x5 | x2 + x5 + x3, databu[1:200,], phi.boot=0)
m05 <- drop1(m04, model="det")
m05
m06 <- svabu.step(m04, model="det")
summary(m06)
m07 <- update(m04, . ~ . | . - x3)
m07

## Controls

m00$control
getOption("detect.optim.control")
getOption("detect.optim.method")
options("detect.optim.method"="BFGS")
m08 <- svabu(Y ~ x1 + x5 | x2 + x5, databu[1:100,])
m08$control ## but original optim method is retained during model selection and bootstrap
## fitted models can be used to provide initial values
options("detect.optim.method"="Nelder-Mead")
m09 <- svabu(Y ~ x1 + x5 | x2 + x5, databu[1:100,], inits=coef(m08))

## Ovenbirds dataset

data(oven)
ovenc <- oven
ovenc[, c(4:8,10:11)][] <- lapply(ovenc[, c(4:8,10:11)], scale)
moven <- svabu(count ~ pforest | observ + pforest + julian + timeday, ovenc)

```

```

summary(moven)
drop1(moven, model="det")
moven2 <- update(moven, . ~ . | . - timeday)
summary(moven2)
moven3 <- update(moven2, . ~ . | ., zeroinfl=FALSE)
summary(moven3)
BIC(moven, moven2, moven3)

## End(Not run)

```

svocc

ZI Binomial model with single visit

Description

ZI Binomial model with single visit

Usage

```

svocc(formula, data, link.sta = "cloglog", link.det = "logit",
      penalized = FALSE, method = c("optim", "dc"), inits,
      model = TRUE, x = FALSE, ...)
svocc.fit(Y, X, Z, link.sta = "cloglog", link.det = "logit",
      penalized = FALSE, auc = FALSE, method = c("optim", "dc"),
      inits, ...)

extractMLE(object, ...)
svocc.step(object, model, trace = 1, steps = 1000,
      criter = c("AIC", "BIC", "cAUC"), test = FALSE, k = 2,
      control, ...)

```

Arguments

formula	formula of the form $y \sim x \mid z$, where y is a vector of observations, x is the set of covariates for the occurrence model, z is the set of covariates for the detection model
Y, X, Z	vector of observation, design matrix for occurrence model, and design matrix for detection model
data	data
link.sta, link.det	link function for the occurrence (true state) and detection model
penalized	logical, if penalized likelihood estimate should be computed
method	optimization or data cloning to be used as optimization
inits	initial values
model	a logical value indicating whether model frame should be included as a component of the returned value, or true state or detection model

x	logical values indicating whether the response vector and model matrix used in the fitting process should be returned as components of the returned value
auc	logical, if AUC should be calculated
object	a fitted model object
trace	info returned during the procedure
steps	max number of steps
criter	criterion to be minimized (cAUC=1-AUC)
test	logical, if decrease in deviance should be tested
k	penalty to be used with AIC
control	controls for optimization, if missing taken from object
...	other arguments passed to the functions

Details

See Examples.

The right hand side of the formula must contain at least one continuous (i.e. non discrete/categorical) covariate. This is the necessary condition for the single-visit method to be valid and parameters to be identifiable. See References for more detailed description.

Value

An object of class 'svocc'.

Author(s)

Peter Solymos and Monica Moreno

References

- Lele, S.R., Moreno, M. and Bayne, E. 2012. Dealing with detection error in site occupancy surveys: What can we do with a single survey? *Journal of Plant Ecology*, **5**(1), 22–31. <doi:10.1093/jpe/rtr042>
- Moreno, M. and Lele, S. R. 2010. Improved estimation of site occupancy using penalized likelihood. *Ecology*, **91**, 341–346. <doi:10.1890/09-1073.1>
- Solymos, P., Lele, S. R. 2016. Revisiting resource selection probability functions and single-visit methods: clarification and extensions. *Methods in Ecology and Evolution*, **7**, 196–205. <doi:10.1111/2041-210X.12432>

Examples

```
data(datocc)
## MLE
m00 <- svocc(W ~ x1 | x1 + x3, datocc)
## PMLE
m01 <- svocc(W ~ x1 | x1 + x3, datocc, penalized=TRUE)

## print
```

```

m00
## summary
summary(m00)
## coefficients
coef(m00)
## state (occupancy) model estimates
coef(m00, "sta")
## detection model estimates
coef(m00, "det")
## compare estimates
cbind(truth=c(0.6, 0.5, 0.4, -0.5, 0.3),
mle=coef(m00), pmle=coef(m01))

## AIC, BIC
AIC(m00)
BIC(m00)
## log-likelihood
logLik(m00)
## variance-covariance matrix
vcov(m00)
vcov(m00, model="sta")
vcov(m00, model="det")
## confidence intervals
confint(m00)
confint(m00, model="sta")
confint(m00, model="det")

## fitted values
## (conditional probability of occurrence given detection history:
## if W=1, fitted=1,
## if W=0, fitted=(phi*(1-delta)) / ((1-delta) + phi * (1-delta))
summary(fitted(m00))
## estimated probabilities: (phi*(1-delta)) / ((1-delta) + phi * (1-delta))
summary(m00$estimated.probabilities)
## probability of occurrence (phi)
summary(m00$occurrence.probabilities)
## probability of detection (delta)
summary(m00$detection.probabilities)

## Not run:
## model selection
m02 <- svocc(W ~ x1 | x3 + x4, datocc)
m03 <- drop1(m02, model="det")
## dropping one term at a time, resulting change in AIC
m03
## updating the model
m04 <- update(m02, . ~ . | . - x4)
m04
## automatic model selection
## part of the model (sta/det) must be specified
m05 <- svocc.step(m02, model="det")
summary(m05)

```

```

## nonparametric bootstrap
m06 <- bootstrap(m01, B=25)
attr(m06, "bootstrap")
extractBOOT(m06)
summary(m06, type="mle")
summary(m06, type="pmle") ## no SEs! PMLE!!!
summary(m06, type="boot")
## vcov
#vcov(m06, type="mle") ## this does not work with PMLE
vcov(m06, type="boot") ## this works
## confint
confint(m06, type="boot") ## quantile based

## parametric bootstrap
## sthis is how observations are simulated
head(simulate(m01, 5))
m07 <- bootstrap(m01, B=25, type="param")
extractBOOT(m07)
summary(m07)

data(oven)
ovenc <- oven
ovenc[, c(4:8,10:11)][] <- lapply(ovenc[, c(4:8,10:11)], scale)
ovenc$count01 <- ifelse(ovenc$count > 0, 1, 0)
moven <- svocc(count01 ~ pforest | julian + timeday, ovenc)
summary(moven)
drop1(moven, model="det")
moven2 <- update(moven, . ~ . | . - timeday)
summary(moven)

BIC(moven, moven2)
AUC(moven, moven2)
rocplot(moven)
rocplot(moven2, col=2, add=TRUE)

## End(Not run)

```

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