Package ‘extr’

March 17, 2026

Title Extinction Risk Estimation

Version 1.1.0

Description Estimates extinction risk from population time series under a drifted Wiener process using MLE and observation-error-and-autocovariance-robust estimators, with confidence intervals based on the w-z method.

License BSD_2_clause + file LICENSE

Encoding UTF-8

Language en-US

RoxygenNote 7.3.3

NeedsCompilation no

Author Hiroshi Hakoyama [aut, cre, cph] (ORCID: <https://orcid.org/0000-0001-7464-0754>)

Maintainer Hiroshi Hakoyama <hiroshi.hakoyama@gmail.com>

Repository CRAN

Date/Publication 2026-03-17 08:10:13 UTC

Contents

`ext_di` *Extinction Risk Estimation for a Density-Independent Model*

Description

Estimates demographic parameters and extinction probability under a density-independent (drifted Wiener) model. From a time series of population sizes, it estimates growth rate and variance using either a naive MLE variance estimator or an observation-error-and-autocovariance-robust (OEAR) estimator, then evaluates extinction risk over a horizon t^* with confidence intervals from the w–z method. In the observation-error-free setting, the naive w–z interval achieves near-nominal coverage, while OEAR can be more robust under additive observation error and unknown short-run autocovariance.

Usage

```
ext_di(
  dat,
  ne = 1,
  th = 100,
  alpha = 0.05,
  unit = "years",
  qq_plot = FALSE,
  formatted = TRUE,
  digits = getOption("extr.digits", 5L),
  method = c("naive", "oear")
)
```

Arguments

`dat`	Data frame with two numeric columns: time (strictly increasing) and population size. Column names are not restricted.
`ne`	Numeric. Extinction threshold $n_e \geq 1$. Default is 1.
`th`	Numeric. Time horizon $t^* > 0$. Default is 100.
`alpha`	Numeric. Significance level $\alpha \in (0, 1)$. Default is 0.05.
`unit`	Character. Unit of time (e.g., "years", "days", "generations"). Default is "years".
`qq_plot`	Logical. If `TRUE`, draws a QQ-plot of standardized increments to check model assumptions (naive method only). Default is `FALSE`.
`formatted`	Logical. If `TRUE`, returns an `"ext_di"` object; otherwise returns a raw list. Default is `TRUE`.
`digits`	Integer. Preferred significant digits for printing. Affects display only. Default is `getOption("extr.digits", 5)`.
`method`	Character. Variance estimation method. `"naive"` uses the MLE variance. `"oear"` uses the OEAR HAC long-run-variance estimator (AR(1) pre-whitening + Bartlett kernel). Default is `"naive"`.

Details

Population dynamics follow

$$dX = \mu\, dt + \sigma\, dW,$$

where $X(t) = \log N(t)$ and W is a Wiener process. Extinction risk is

$$G = \Pr[T \leq t^* \mid N(0) = n_0, n_e, \mu, \sigma],$$

the probability that population size falls below n_e within t^*. Irregular observation intervals are allowed.

The function first estimates μ, then estimates a variance quantity according to `method`:

1. `naive`: uses the drifted-Wiener MLE variance (Dennis et al., 1991).
2. `oear`: uses an observation-error-and-autocovariance-robust (OEAR) HAC long-run-variance estimator with AR(1) pre-whitening and a Bartlett kernel (Hakoyama, in press).

For `method = "oear"`, robustness to additive observation error relies on long-run-variance cancellation of differenced observation error (McNamara and Harding, 2004), while robustness to unknown short-run autocovariance comes from HAC estimation of long-run variance.

Extinction probability is then computed as $G(w, z)$ (Lande and Orzack, 1988), and confidence intervals are constructed using the w–z method (Hakoyama, in press).

Value

A list (class `"ext_di"` when `formatted=TRUE`) containing extinction-risk estimates and diagnostics. Core elements include `Growth.rate`, `Variance`, `Unbiased.variance`, `lower_cl_s`, `upper_cl_s`, `linear_g`, `log_g`, `log_q`, `ci_linear_g`, `ci_log_g`, `ci_log_q`, and data/input summaries (`nq`, `xd`, `sample.size`, `unit`, `ne`, `th`, `alpha`).

`Variance` is method-dependent (naive MLE for `method="naive"`, OEAR HAC estimate for `method="oear"`). `aic` is reported only for `method="naive"` and is `NA` for `method="oear"`. `method_diag` is `NULL` for naive and contains `rho_tilde_pw` and `j` for oear. `lower_cl_s` and `upper_cl_s` are chi-square based: exact under `method="naive"` model assumptions, and pragmatic plug-in approximations for `method="oear"`.

References

Andrews, D. W. K. (1991). Heteroskedasticity and autocorrelation consistent covariance matrix estimation. *Econometrica*, 59(3), 817-858.

Dennis, B., Munholland, P.L., and Scott, J.M. (1991) Estimation of growth and extinction parameters for endangered species. *Ecological Monographs*, 61, 115-143.

Hakoyama, H. Confidence intervals for extinction risk: validating population viability analysis with limited data. *Methods in Ecology and Evolution*. In press. Preprint, doi:10.48550/arXiv.2509.09965

Lande, R. and Orzack, S.H. (1988) Extinction dynamics of age-structured populations in a fluctuating environment. *Proceedings of the National Academy of Sciences*, 85(19), 7418–7421.

McNamara, J. M. and Harding, K. C. (2004). Measurement error and estimates of population extinction risk. *Ecology Letters*, 7(1), 16-20.

Newey, W. K. and West, K. D. (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3), 703-708.

See Also

`statistics_di`, `oear_sigma2_hac`, `extinction_probability_di`, `confidence_interval_wz_di`, `print.ext_di`

Examples

```
# Example from Dennis et al. (1991), Yellowstone grizzly bears.
# Population is a running 3-year sum (3-year moving total) digitized from
# Fig. 5.
dat <- data.frame(Time = 1959:1987,
Population = c(44, 47, 46, 44, 46, 45, 46, 40, 39, 39, 42, 44, 41, 40,
33, 36, 34, 39, 35, 34, 38, 36, 37, 41, 39, 51, 47, 57, 47))

# Probability of decline to 1 individual within 100 years
ext_di(dat, th = 100)

# Probability of decline to 10 individuals within 100 years
ext_di(dat, th = 100, ne = 10)

# With QQ-plot
ext_di(dat, th = 100, ne = 10, qq_plot = TRUE)

# OEAR method
ext_di(dat, th = 100, method = "oear")
```

Index