

# Package ‘ecocbo’

May 8, 2026

**Title** Calculating Optimum Sampling Effort in Community Ecology

**Version** 1.0.0

**Description** A system for calculating the optimal sampling effort, based on the ideas of “Ecological cost-benefit optimization” as developed by A. Underwood (1997, ISBN 0 521 55696 1). Data is obtained from simulated ecological communities with `prep_data()` which formats and arranges the initial data, and then the optimization follows the following procedure of four functions: (1) `prep_data()` takes the original dataset and creates simulated sets that can be used as a basis for estimating statistical power and type II error. (2) `sim_beta()` is used to estimate the statistical power for the different sampling efforts specified by the user. (3) `sim_cbo()` calculates then the optimal sampling effort, based on the statistical power and the sampling costs. Additionally, (4) `scompvar()` calculates the variation components necessary for (5) `Underwood_cbo()` to calculate the optimal combination of number of sites and samples depending on either an economic budget or on a desired statistical accuracy. Lastly, (6) `plot_power()` helps the user visualize the results of `sim_beta()`.

**License** GPL (>= 3)

**URL** <https://github.com/arturoSP/ecocbo>

**BugReports** <https://github.com/arturoSP/ecocbo/issues>

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**Imports** ggplot2, ggpubr, stats, rlang, tibble, dplyr, tidyr, tidyselect, parabar, parallelly, vegan, SSP (>= 1.1.0), plotly

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ecocbo-package	<i>ecocbo: Calculating Optimum Sampling Effort in Community Ecology</i>
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## Description

A system for calculating the optimal sampling effort, based on the ideas of "Ecological cost-benefit optimization" as developed by A. Underwood (1997, ISBN 0 521 55696 1). Data is obtained from simulated ecological communities, and the optimization follows the following procedure of two functions (1) scompvar() calculates the variation components necessary for (2) sim\_cbo() to calculate the optimal combination of number of sites and samples depending on either an economical budget or on a desired statistical accuracy. Additionally, (3) sim\_beta() estimates statistical power and type 2 error by using Permutational Multivariate Analysis of Variance, and (4) plot\_power() represents the results of the previous function.

## Details

The functions in **ecocbo** package can be used to identify the optimal number of sites and samples that must be considered in a community ecology study by using simulated data. Together with **SSP** package, **ecocbo** proposes a novel approach to the determination of the appropriate sampling effort in community ecology studies.

**ecocbo** is composed by five functions: `prep_data` gives the appropriate format to the data so that it can be used by the other functions in the package. `scompvar` calculates the components of variation for the analyzed dataset, and finally, `sim_cbo` determines an estimate of the number of sites and samples to consider to optimize the cost-benefit for an ecological sampling study. For getting more information on the data, `sim_beta` calculates statistical power for different sampling efforts and `plot_power` plots those results to help the user define the a combination of sampling effort and power to move on.

**ecocbo** is being developed at Github(<https://github.com/arturoSP/ecocbo>), where up-to-date versions can be found.

## Author(s)

The **ecocbo** development team is Edlin Guerra-Castro and Arturo Sanchez-Porras.

## References

Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.

Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. *Journal of Experimental Marine Biology and Ecology*, 296(1), 49-70.

Anderson, M. J. (2014). Permutational multivariate analysis of variance (PERMANOVA). *Wiley statsref: statistics reference online*, 1-15.

Guerra-Castro, E. J., Cajas, J. C., Simões, N., Cruz-Motta, J.J., & Mascaró, M. (2021). SSP: an R package to estimate sampling effort in studies of ecological communities. *Ecography*, 44(4), 561-573.

## Examples

```
# Load and adjust data.
data(epiDat)

simResults <- prep_data(data = epiDat, type = "counts", Sest.method = "average",
                        cases = 5, N = 100, M = 10,
                        n = 5, m = 6, k = 20,
                        transformation = "none", method = "bray",
                        dummy = TRUE, useParallel = FALSE,
                        model = "single.factor")

simResults

# Computing components of variation
compVar <- scompvar(data = simResults)
```

```

compVar

# Determination of statistical power
epiBetaR <- sim_beta(simResults, alpha = 0.05)
epiBetaR

# Cost-benefit optimization
cboResult <- sim_cbo(epiBetaR, cn = 75)
cboResult

# Visualization of statistical power
plot_power(data = epiBetaR, method = "power")

```

---

betaNested	<i>Data set containing the results of applying <code>ecocbo::sim_beta()</code> to a nested factors experiment.</i>
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---

### Description

The dataset contains the results of applying `ecocbo::sim_beta()` to the dataset from PAPIIT experiment. The result is a list with 4 components.

### Usage

```
betaNested
```

### Format

An object of class "ecocbo\_beta", also a list containing four components. The format is:

**\$Power m** number of sites considered for the result.

**n** number of replicates within each site for the result.

**Power** estimated statistical power.

**Beta** estimated type II error.

**fCrit** estimated pseudoF value that corresponds to the 1-alpha quartile of the distribution of pseudoF.

**\$Results dat.sim** simulation from which the results are obtained.

**k** number of resample for the result.

**m** number of sites considered for the result.

**n** number of replicates within each site for the result.

**pseudoFH0** observed F value for the experimental design, when all observations belong to one site.

**pseduoFHa** observed F value for the experimental design, when observations belong to different sites.

**MSB(A)** calculated mean squares among sites in the experiment.

**MSR** calculated mean squares for the residuals in the experiment.

**\$alpha** usually 0.05

**\$model** "nested.symmetric"

**attribute** "ecocbo.beta"

### Details

This dataset can be used to study the variability of the pseudoF-statistic, beta and the power when an experiment is applied to a varying number of samples, sampling units, or sampling sites.

### Source

Data available from the GitHub Digital Repository: [https://github.com/edlinguerra/IA206320\\_publico/tree/main/datos](https://github.com/edlinguerra/IA206320_publico/tree/main/datos) (Guerra-Castro et al. 2022).

---

dataFish

*Data set containing results from the PRCRMP.*

---

### Description

The dataset contains biomass data from monitoring fish individuals in coral reefs in Puerto Rico, through the Puerto Rico Coral Reef Monitoring Program.

### Usage

dataFish

### Format

A dataframe. The data is formed by:

**\$REGION** A list of regions in which the observations were made.

**\$LOCATION** A list of locations in which the observations were made.

**\$Acanthurus tractus (bahianus)** A series of observations.

...

**Trachinotus falcatus** A series of observations.

### Details

This dataset can be used to test the functions in the nested.symmetric model, and using the cover/biomass version of the algorithms.

### Source

Data available from the PRCRMP.

---

epiBetaR	<i>Data set containing the results of applying <code>ecocbo::sim_beta()</code> to a single factor experiment.</i>
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---

### Description

The dataset contains the results of applying `ecocbo::sim_beta()` to an excerpt from the dataset `epibionts` from the package `SSP`. The result is a list with 4 components.

### Usage

```
epiBetaR
```

### Format

An object of class "ecocbo\_beta", also a list containing four components. The format is:

**\$Power** **m** number of sites considered for the result.  
**n** number of replicates within each site for the result.  
**Power** estimated statistical power.  
**Beta** estimated type II error.  
**fCrit** estimated pseudoF value that corresponds to the 1-alpha quartile of the distribution of pseudoF.

**\$Results** **dat.sim** simulation from which the results are obtained.  
**k** number of resample for the result.  
**m** number of sites considered for the result.  
**n** number of replicates within each site for the result.  
**pseudoFH0** observed F value for the experimental design, when all observations belong to one site.  
**pseduoFHa** observed F value for the experimental design, when observations belong to different sites.  
**MSB(A)** calculated mean squares among sites in the experiment.  
**MSR** calculated mean squares for the residuals in the experiment.

**\$alpha** usually 0.05  
**\$model** nested.symmetric  
**attribute** ecocbo.beta

### Details

This dataset can be used to study the variability of the pseudoF-statistic, beta and the power when an experiment is applied to a varying number of samples, sampling units, or sampling sites.

### Source

Data available from the GitHub Digital Repository: <https://github.com/edlinguerra/SSP/tree/master/data> (Guerra-Castro et al. 2022).

---

epiDat

*Dataset on species count of marine communities.*

---

**Description**

This is a dataset containing a subset from the epibionts dataset from SSP which was made by using the three local communities that differ the most.

**Usage**

epiDat

**Format**

A data frame with count of individuals for 24 observations on 151 species.

**Source**

Data available from the Dryad Digital Repository: [doi:10.5061/dryad.3bk3j9kj5](https://doi.org/10.5061/dryad.3bk3j9kj5) (Guerra-Castro et al. 2020).

---

macrofDat

*Dataset on species count of coastal macrofauna.*

---

**Description**

This is a dataset containing a subset from the macrofauna recorded in the PAPIIT experiment.

**Usage**

macrofDat

**Format**

A dataframe with counts of individuals for 43 observations on 34 species.

**Source**

Data available from the GitHub Digital Repository: [https://github.com/edlinguerra/IA206320\\_publico/tree/main/datos](https://github.com/edlinguerra/IA206320_publico/tree/main/datos) (Guerra-Castro et al. 2022).

---

plot\_power

*Plot Statistical Power and Pseudo-F Distributions*


---

### Description

Visualizes the statistical power of a study as a function of the sampling effort. The power curve plot illustrates how power increases with sample size, while the density plot highlights overlapping areas where  $\alpha$  and  $\beta$  are significant.

### Usage

```
plot_power(
  data,
  cbo = NULL,
  n = NULL,
  m = NULL,
  method = "power",
  completePlot = TRUE
)
```

### Arguments

data	Object of class "ecocbo_beta" obtained from <a href="#">sim_beta()</a> .
cbo	Optional. Object of class "cbo_result" obtained from <a href="#">sim_cbo()</a> . If this is included, plot_power() uses the optimal values that have been already calculated.
n	Optional. Integer. Number of samples n within the selected m. Defaults to NULL, and the function selects the number of samples yielding a power close to $1 - \alpha$ .
m	Optional. Integer. Number of replicates m to use for power computation. Defaults to NULL, in which case the function selects the number of sites that result in a sampling effort that is close to $1 - \alpha$ .
method	Character. Type of plot to generate: <ul style="list-style-type: none"> <li>• "power": Plots the power curve.</li> <li>• "density": Plots the density distribution of pseudo-F values.</li> <li>• "both": Displays both plots side by side.</li> <li>• "surface": Displays a 3d surface plot of the power curves for nested factors experiments.</li> </ul>
completePlot	Logical. Is the plot to be drawn complete? If TRUE the plot will be trimmed to present a better distribution of the density plot.

### Value

A plot displaying:

- If method = "power", power curves for different values of m, with the selected n highlighted in red.

- If method = "density": a density plot of observed pseudo-F values with a vertical line indicating significance from `sim_beta()`.
- If method = "both": a composite figure with both the power curve and the density plot.
- If method = "surface": a surface plot for the statistical power in different sampling designs.

The selected values of m, n, and the corresponding component of variation are displayed in all cases.

### Author(s)

Edlin Guerra-Castro (<edlinguerra@gmail.com>), Arturo Sanchez-Porras

### References

- Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.
- Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. *Journal of Experimental Marine Biology and Ecology*, 296(1), 49-70.

### See Also

[sim\\_beta\(\)](#) [scompvar\(\)](#) [sim\\_cbo\(\)](#) [prep\\_data\(\)](#)

### Examples

```
# Power curve visualization
plot_power(data = epiBetaR, method = "power")

# Density plot of pseudo-F values
plot_power(data = betaNested, method = "density")

# Composite plot with both power curve and density plot
plot_power(data = betaNested, method = "both")
```

---

prep\_data

*Prepare Data for Evaluation*

---

### Description

Formats and arranges the initial data so that it can be readily used by the other functions in the package. The function first gets the species names and the number of samples for each species from the input data frame. Then, it permutes the sampling efforts and calculates the pseudo-F statistic and the mean squares for each permutation. Finally, it returns a data frame with the permutations, pseudo-F statistic, and mean squares.

**Usage**

```

prep_data(
  data,
  type = "counts",
  Sest.method = "average",
  cases = 5,
  N = 100,
  M = NULL,
  n,
  m = NULL,
  k = 50,
  transformation = "none",
  method = "bray",
  dummy = FALSE,
  useParallel = TRUE,
  model = "single.factor",
  jitter.base = 0.5
)

```

**Arguments**

data	Data frame where columns represent species names and rows correspond to samples. <ul style="list-style-type: none"> <li>For "single.factor" analysis: The first column should indicate the replicate to which the sample belongs.</li> <li>For "nested.symmetric" analysis: The first column should indicate the treatment, and the second column should indicate the replicate.</li> </ul>
type	Character. Nature of the data to be processed. It may be presence / absence ("P/A"), counts of individuals ("counts"), or coverage ("cover").
Sest.method	Character Method for estimating species richness using <code>vegan::specpool()</code> . Available methods are the incidence-based Chao ("chao"), first order jackknife ("jack1"), second order jackknife ("jack2") and Bootstrap ("boot"). By default, the average ("average") of the four estimates is used.
cases	Integer. Number of simulated datasets.
N	Integer. Total number of samples simulated per site.
M	Integer. Total number of replicates simulated per dataset. Not needed for single factor experiments.
n	Integer. Maximum number of samples to consider (must be $\leq N$ ).
m	Integer. Number of replicates to consider. (must be $\leq M$ ). Not needed for single factor experiments.
k	Integer. Number of resampling iterations. Defaults to 50.
transformation	Character. Transformation applied to reduce the weight of dominant species: "square root", "fourth root", "Log (X+1)", "P/A", "none".
method	Character. Dissimilarity metric used <code>vegan::vegdist()</code> . Common options include: "Gower", "Bray-Curtis", "Jaccard", etc.

<code>dummy</code>	Logical. If TRUE, adds a small constant to empty observations.
<code>useParallel</code>	Logical. If TRUE, enables parallel computation. Defaults to TRUE.
<code>model</code>	Character. Select the model to use. Options are "single.factor" and "nested.symmetric".
<code>jitter.base</code>	Numeric. Standard deviation multiplier used to add Gaussian jitter to fs and fw. Defaults to 0.5.

## Details

The input dataset should have:

- One or two leading columns for treatment/replicate labels.
- Subsequent columns representing species presence/absence, counts, or coverage.
- "single.factor" requires a single column for replicates.
- "nested.symmetric" requires two columns: treatment and replicate in that order.

## Value

`prep_data()` returns an object of class "ecocbo\_data".

An object of class "ecocbo\_data" is a list containing:

- `$Results`, a data frame that lists the estimates of pseudoF for `simH0` and `simHa`, useful for statistical power analysis. It also includes mean squares for variance component estimation.
- `$model`, a label for keeping track of the model that is being used in the analysis.
- `$a`, an integer for the number of treatments recorded from the original data.

## Author(s)

Edlin Guerra-Castro (<edlinguerra@gmail.com>), Arturo Sanchez-Porras

## References

- Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.
- Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. *Journal of Experimental Marine Biology and Ecology*, 296(1), 49-70.

## See Also

[sim\\_beta\(\)](#) [plot\\_power\(\)](#) [sim\\_cbo\(\)](#) [scompvar\(\)](#)

## Examples

```
simResults <- prep_data(data = epiDat, type = "counts", Sest.method = "average",
                        cases = 5, N = 100, M = 10,
                        n = 5, m = 5, k = 30,
                        transformation = "none", method = "bray",
                        dummy = FALSE, useParallel = FALSE,
                        model = "single.factor",
                        jitter.base = 0)

simResults
```

---

scompvar

*Simulated Components of Variation*

---

## Description

Computes the average components of variation among sampling units and within samples in relation to sampling effort.

## Usage

```
scompvar(data, n = NULL, m = NULL)
```

## Arguments

data	Object of class "ecocbo_data" obtained from <a href="#">prep_data()</a> .
n	Optional. Integer. Number of samples to consider.
m	Optional. Integer. Number of replicates to consider.

## Details

If *m* or *n* are set to NULL, the function automatically uses the largest available values from the experimental design set in [sim\\_beta\(\)](#).

## Value

A data frame containing the values for the variation component among sites `compVarA` and in the residuals `compVarR`.

## Author(s)

Edlin Guerra-Castro (<edlinguerra@gmail.com>), Arturo Sanchez-Porras

## References

- Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.
- Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. Journal of Experimental Marine Biology and Ecology, 296(1), 49-70.

## See Also

[sim\\_beta\(\)](#) [plot\\_power\(\)](#) [sim\\_cbo\(\)](#) [prep\\_data\(\)](#)

## Examples

```
scompvar(data = simResults)
scompvar(data = simResults, n = 5, m = 2)
```

---

simResults	<i>Data set containing the results of applying <code>ecocbo::prep_data()</code>.</i>
------------	--

---

## Description

The dataset contains the results of applying `ecocbo::prep_data()` to `epiDat`. The result is a list with one level: `$Results` is a data frame with the results of applying PERMANOVA to `epiDat` a number of times, it contains the values of `pseudoF` and the mean squares for different repeated sampling efforts.

## Usage

```
simResults
```

## Format

An object of class "ecocbo\_data", also a list containing one data frame. The format is:

**\$Results** **dat.sim** simulation from which the results are obtained.

**k** number of resample for the result.

**n** number of replicates within each site for the result.

**pseudoFH0** observed F value for the experimental design, when all observations belong to one site.

**pseudoFH<sub>a</sub>** observed F value for the experimental design, when observations belong to different sites.

**MSR** calculated mean squares for the residuals in the experiment.

**\$model** "single.factor"

**attribute** class: ecocbo\_data

**Details**

This dataset can be used to study the variability of the pseudoF-statistic, beta and the power when an experiment is applied to a varying number of samples, sampling units, or sampling sites.

**Source**

Data available from the Dryad Digital Repository: [doi:10.5061/dryad.3bk3j9kj5](https://doi.org/10.5061/dryad.3bk3j9kj5) (Guerra-Castro et al. 2020).

---

simResultsNested	<i>Data set containing the results of applying <code>ecocbo::prep_data()</code> to a nested factors experiment.</i>
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---

**Description**

The dataset contains the results of applying `ecocbo::prep_data()` to `epiDat`. The result is a list with one level: `$Results` is a data frame with the results of applying PERMANOVA to `epiDat` a number of times, it contains the values of pseudoF and the mean squares for different repeated sampling efforts.

**Usage**

```
simResultsNested
```

**Format**

An object of class "ecocbo\_data", also a list containing one data frame. The format is:

**\$Results** **dat.sim** simulation from which the results are obtained.

**k** number of resample for the result.

**m** number of sites considered for the result.

**n** number of replicates within each site for the result.

**pseudoFH0** observed F value for the experimental design, when all observations belong to one site.

**pseudoFH<sub>a</sub>** observed F value for the experimental design, when observations belong to different sites.

**MSB(A)** calculated mean squares among sites in the experiment.

**MSR** calculated mean squares for the residuals in the experiment.

**\$model** "single.factor"

**attribute** class: ecocbo\_data

**Details**

This dataset can be used to study the variability of the pseudoF-statistic, beta and the power when an experiment is applied to a varying number of samples, sampling units, or sampling sites.

**Source**

Source data is available from [https://github.com/edlinguerra/IA206320\\_publico/tree/main/datos](https://github.com/edlinguerra/IA206320_publico/tree/main/datos) (Guerra-Castro et al. 2020).

---

`sim_beta`*Calculate Beta Error and Statistical Power from Simulated Samples*

---

**Description**

Estimates the statistical power of a study by comparing variation under null and alternative hypotheses. For instance, if the beta error is 0.25, there is a 25% chance of failing to detect a real difference, and the power of the study is  $1 - \beta$ , meaning 0.75 in this case.

**Usage**

```
sim_beta(data, alpha = 0.05)
```

**Arguments**

<code>data</code>	An object of class "ecocbo_data" that results from applying <code>prep_data()</code> to a community dataset.
<code>alpha</code>	Numeric. Significance level for Type I error. Defaults to 0.05.

**Details**

The function displays a summary matrix with estimated power values for various sampling efforts.

**Value**

A list of class "ecocbo\_beta", containing:

- `$Power`: a data frame with power and beta estimates across different sampling efforts (m sites and n samples).
- `$Results`: a data frame with pseudo-F estimates for `simH0` and `simHa`.
- `$alpha`: significance level for Type I error.

**Author(s)**

Edlin Guerra-Castro (<edlinguerra@gmail.com>), Arturo Sanchez-Porras

## References

- Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.
- Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. Journal of Experimental Marine Biology and Ecology, 296(1), 49-70.
- Anderson, M. J. (2014). Permutational multivariate analysis of variance (PERMANOVA). Wiley statsref: statistics reference online, 1-15.
- Guerra-Castro, E. J., Cajas, J. C., Simões, N., Cruz-Motta, J. J., & Mascaró, M. (2021). SSP: an R package to estimate sampling effort in studies of ecological communities. Ecography, 44(4), 561-573.

## See Also

[plot\\_power\(\)](#) [scompvar\(\)](#) [sim\\_cbo\(\)](#) [prep\\_data\(\)](#) [SSP::asempar\(\)](#) [SSP::simdata\(\)](#)

## Examples

```
sim_beta(data = simResults, alpha = 0.05)
```

---

sim\_cbo

*Cost-Benefit Optimization for Sampling Effort*

---

## Description

Given a table of statistical power estimates produced by [sim\\_beta](#), `sim_cbo` finds the sampling design (number of replicates/site and sites) that minimizes total cost while achieving a user-specified power threshold.

## Usage

```
sim_cbo(data, cn, cm = NULL, perm = 100)
```

## Arguments

<code>data</code>	Object of class "ecocbo_beta", as returned by <a href="#">sim_beta</a> .
<code>cn</code>	Numeric. Cost per sampling unit.
<code>cm</code>	Numeric. Fixed cost per replicate.
<code>perm</code>	Integer. Minimum number of permutations needed to reject the null hypothesis. Defaults to 100, as it would allow for rejecting with $\alpha = 0.05$ , the user can change this value to make the testing more strict (e.g. 200 for testing $\alpha = 0.01$ or 5000 for testing $\alpha = 0.001$ ).

**Value**

A data frame with one row per candidate design. In the single factor case, the results include the available  $n$  values, their statistical power and cost. For the nested symmetric experiments, the results include all the available values for  $m$ , the optimal  $n$ , according to the power, and the associated cost. The results also mark a suggested sampling effort, based on the cost and power range as selected by the user.

**Author(s)**

Edlin Guerra-Castro (<edlinguerra@gmail.com>), Arturo Sanchez-Porrás

**References**

- Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.
- Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. Journal of Experimental Marine Biology and Ecology, 296(1), 49-70.

**See Also**

[sim\\_beta\(\)](#) [plot\\_power\(\)](#) [scompvar\(\)](#) [Underwood\\_cbo\(\)](#)

**Examples**

```
# Optimization of single factor experiment
sim_cbo(data = epiBetaR, cn = 80)

# Optimization of a nested factor experiment
sim_cbo(data = betaNested, cn = 80, cm = 180)
```

---

Underwood\_cbo

*Cost-Benefit Optimization after Underwood's equations*

---

**Description**

Applies a cost-benefit optimization model based on either a desired level of precision or a predefined budget, following the approach of Underwood (1997).

**Usage**

```
Underwood_cbo(
  comp.var,
  multSE = NULL,
  budget = NULL,
  a = NULL,
```

```

    ca = NULL,
    cm = NULL,
    cn
  )

```

### Arguments

comp.var	Data frame as obtained from <code>scompvar()</code> , containing variance component estimates
multSE	Optional. Numeric. Required multivariate standard error for the sampling experiment.
budget	Optional. Numeric. Total budget available for the sampling experiment.
a	Numeric. Number of treatments to consider.
ca	Numeric. Cost per treatment.
cm	Numeric. Cost per replicate.
cn	Numeric. Cost per sampling unit.

### Value

A data frame containing the optimized values for m number of sites to sample and n number of samples per site.

### Author(s)

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### References

- Underwood, A. J. (1997). Experiments in ecology: their logical design and interpretation using analysis of variance. Cambridge university press.
- Underwood, A. J., & Chapman, M. G. (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. *Journal of Experimental Marine Biology and Ecology*, 296(1), 49-70.

### See Also

`sim_beta()` `plot_power()` `scompvar()` `sim_cbo()`

### Examples

```

compVar <- scompvar(data = simResults)

# Optimization based on budget constraint
Underwood_cbo(comp.var = compVar, multSE = NULL, budget = 20000, a = 3, ca = 2500, cn = 100)

# Optimization based on precision constraint
Underwood_cbo(comp.var = compVar, multSE = 0.15, cn = 150)

```

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