Package 'ectotemp'

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Title Quantitative Estimates of Small Ectotherm Temperature Regulation Effectiveness

Version 0.2.0

Description Easy and rapid quantitative estimation of small terrestrial ectotherm temperature regulation effectiveness in R. ectotemp is built on classical formulas that evaluate temperature regulation by means of various indices, inaugurated by Hertz et al. (1993) <doi: 10.1086/285573>. Options for bootstrapping and permutation testing are included to test hypotheses about divergence between organisms, species or populations.

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BugReports https://github.com/wouterbeukema/ectotemp/issues

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`ectotemp-package` *ectotemp: Quantitative Estimates of Small Ectotherm Temperature Regulation Effectiveness*

Description

Easy and rapid quantitative estimation of small terrestrial ectotherm temperature regulation effectiveness in R. ectotemp is built on classical formulas that evaluate temperature regulation by means of various indices, inaugurated by Hertz et al. (1993) <doi: 10.1086/285573>. Options for bootstrapping and permutation testing are included to test hypotheses about divergence between organisms, species or populations.

Details

ectotemp builds on work by Hertz et al. (1993, and references therein), Christian and Weavers (1996), and Blouin-Demers and Weatherhead (2001). Users of this package do not need to be particularly experienced in R, but are expected to be familiar with the background, appropriate choice, and caveats of the available functions (Hertz et al. 1993, Christian and Weavers 1996, Wills and Beaupre 2000, Blouin-Demers and Nadeau 2005).

The aim of the ectotemp package is to facilitate easy and rapid estimation of small, terrestrial ectotherm temperature regulation effectiveness after data describing field-active body temperatures (Tb), environmental (operative) temperatures (Te) and preferred temperatures (the set- point range, Tset) have been collected. The package provides functions for the following types of analyses:

- The **accuracy of temperature regulation (*d*b)** and associated descriptive statistics, which estimate the degree to which ectotherms experience body temperature outside of their set-point range;
- The **thermal quality of the habitat (*d*e)** and associated descriptive statistics, which estimate the degree to which environmental temperature matches the set-point range;
- Choice between several approaches to **calculate effectiveness of temperature regulation (*E*)**, including bootstrap resampling of the original distributions of Tb and Te to determine confidence interval for the mean, and permutation tests for between-population or species comparisons;
- **Exploitation of the thermal environment (Ex)**, i.e., the amount of time when field body temperatures (Tb) are within the set-point range, relative to the total amount of time during which this could have been possible as indicated by operative temperatures (Te).

Author(s)

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References

Blouin-Demers, G., & Weatherhead, P. J. (2001). Thermal ecology of black rat snakes (*Elaphe obsoleta*) in a thermally challenging environment. Ecology, 82(11), 3025-3043.
Blouin-Demers, G., & Nadeau, P. (2005). The cost-benefit model of thermoregulation does not predict lizard thermoregulatory behavior. Ecology, 86(3), 560-566.
Christian, K. A., & Weavers, B. W. (1996). Thermoregulation of monitor lizards in Australia: an evaluation of methods in thermal biology. Ecological monographs, 66(2), 139-157.
Hertz, P. E., Huey, R. B., & Stevenson, R. D. (1993). Evaluating temperature regulation by field-active ectotherms: the fallacy of the inappropriate question. The American Naturalist, 142(5), 796-818.
Wills, C. A., & Beaupre, S. J. (2000). An application of randomization for detecting evidence of thermoregulation in timber rattlesnakes (*Crotalus horridus*) from northwest Arkansas. Physiological and Biochemical Zoology, 73(3), 325-334.

See Also

Useful links:

- `https://github.com/wouterbeukema/ectotemp`

`bootstrap_E` *Bootstrap thermoregulation effectiveness*

Description

Bootstrapping of the effectiveness of temperature regulation (E) from the original distributions of Te and Tb as described by Hertz et al. (1993). One can choose the number of resamples and has the option to calculate E as defined by Hertz et al. (1993) or Blouin-Demers & Weatherhead (2001). See `calculate_E_hertz` and `calculate_E_blouin` for more information about these two indices. The thermal quality of the habitat (de) and accuracy of temperature regulation (db) are calculated as part of this formula, so it is not necessary to run `calculate_de` and `calculate_db` before running this function.

Usage

```
bootstrap_E(te, tb, tset_low, tset_up, index, n)
```

Arguments

`te`	A vector containing operative temperatures.
`tb`	A vector containing body temperature measurements.

tset_low	Lower boundary of a species or population set-point range that was determined through thermal preference trials in a temperature gradient. This may be a named double vector containing the lower boundary value, or simply the value itself.
tset_up	Upper boundary of the set-point range.
index	Either 'hertz' or 'blouin'.
n	The desired number of samples drawn with replacement.

Value

The mean E and its 95 percent confidence interval obtained through resampling with replacement n times.

References

Blouin-Demers, G., & Weatherhead, P. J. (2001). Thermal ecology of black rat snakes (Elaphe obsoleta) in a thermally challenging environment. Ecology, 82 (11), 3025-3043.
Hertz, P. E., Huey, R. B., & Stevenson, R. D. (1993). Evaluating temperature regulation by field-active ectotherms: the fallacy of the inappropriate question. The American Naturalist, 142(5), 796-818.

See Also

calculate_E_hertz and calculate_E_blouin.

Examples

```
te <- na.omit(bufbuf[,"te"])
tb <- na.omit(bufbuf[,"tb"])
E_bootstrapped <- bootstrap_E(te, tb,
                              19.35, 26.44,
                              'hertz',
                              1000)
```

---

bufbuf *Common toad body temperatures and associated operative temperatures*

Description

Active field body temperature data of Belgian common toads (*Bufo bufo*) and associated operative temperature data from agar models, collected during nocturnal surveys in spring. Data are in degrees Celsius.

Usage

```
data(bufbuf)
```

Format

An object of class `data.frame` with 99 rows and 2 columns.

Source

Wouter Beukema <wouter.beukema@gmail.com>

`calculate_db` *Calculate accuracy of temperature regulation*

Description

This function determines the degree to which ectotherms experience body temperatures outside their set-point range, better known as the accuracy of temperature regulation (db) as described by Hertz et al. (1993). Descriptive statistics are automatically computed as well.

Usage

```
calculate_db(tb, tset_low, tset_up)
```

Arguments

`tb`	A vector containing body temperature measurements.
`tset_low`	Lower boundary of a species or population set-point range that was determined through thermal preference trials in a temperature gradient.
`tset_up`	Upper boundary of the set-point range.

Value

Degree to which ectotherms experience body temperatures outside their set-point range (db), and associated descriptive statistics.

References

Hertz, P. E., Huey, R. B., & Stevenson, R. D. (1993). Evaluating temperature regulation by field-active ectotherms: the fallacy of the inappropriate question. The American Naturalist, 142(5), 796-818.

Examples

```
tb <- na.omit(bufbuf[,"tb"])
db_stats <- calculate_db(tb, 19.35, 26.44)
```

calculate_de — *Calculate thermal quality of the habitat*

Description

This function calculates the thermal quality of the habitat (de) from the perspective of the focal species or population as described by Hertz et al. (1993). Descriptive statistics are automatically computed as well.

Usage

```
calculate_de(te, tset_low, tset_up)
```

Arguments

`te`	A vector containing operative temperatures.
`tset_low`	Lower boundary of a species or population set-point range that was determined through thermal preference trials in a temperature gradient.
`tset_up`	Upper boundary of the set-point range.

Value

Thermal quality of the habitat (de) and associated descriptive statistics.

References

Hertz, P. E., Huey, R. B., & Stevenson, R. D. (1993). Evaluating temperature regulation by field-active ectotherms: the fallacy of the inappropriate question. The American Naturalist, 142(5), 796-818.

Examples

```
te <- na.omit(bufbuf[,"te"])
de_stats <- calculate_de(te, 19.35, 26.44)
```

calculate_Ex — *Exploitation of the thermal environment*

Description

This function determines the extent to which organisms exploit their thermal environment (indexed by Ex) following Christian and Weavers (1996). Ex is given by the amount of time when field body temperatures (Tb) are within the set-point range, relative to the total amount of time during which this could have been possible as indicated by operative temperatures (Te). The higher the Ex value, the more an organism exploits its thermal environment when the environment is permissive. The user-supplied vectors containing Te and Tb data are assumed to use the same time unit.

Usage

```
calculate_Ex(te, tb, tset_low, tset_up)
```

Arguments

te	A vector containing operative temperatures. These data should be in the same time unit as the tb data.
tb	A vector containing body temperature measurements.
tset_low	Lower boundary of a species or population set-point range that was determined through thermal preference trials in a temperature gradient. This may be a named double vector containing the lower boundary value, or simply the value itself.
tset_up	Upper boundary of the set-point range.

Value

Ex index, indicating thermal exploitation of the environment during a user-determined period of time.

References

Christian, K. A., & Weavers, B. W. (1996). Thermoregulation of monitor lizards in Australia: an evaluation of methods in thermal biology. Ecological monographs, 66(2), 139-157.

Examples

```
te <- na.omit(ichalp[,"te"])
tb <- na.omit(ichalp[,"tb"])
Ex <- calculate_Ex(te, tb, 14.44, 18.33)
```

---

calculate_E_blouin *Thermoregulation effectiveness sensu Blouin-Demers & Weatherhead*

Description

This function calculates an often-used variant of the original formula to determine effectiveness of temperature regulation of Hertz et al. (1993). The concerning variant was proposed by Blouin-Demers & Weatherhead (2001), who argued that interpretation of the formula of Hertz et al. (1993) is confounded by the fact that different combinations of the mean thermal quality of the habitat (de) and mean accuracy of temperature regulation (db) might lead to similar E values. As such, Blouin-Demers & Weatherhead (2001) proposed use of E = de - db, which quantifies the extent of departure from perfect thermoconformity. Positive E values indicate active temperature regulation, negative values represent active avoidance of suitable thermal habitat, and values around 0 suggest thermoconformity. The thermal quality of the habitat (de) and accuracy of temperature regulation (db) are calculated as part of this formula, so it is not necessary to run `calculate_de` and `calculate_db` before running this function.

Usage

```
calculate_E_blouin(te, tb, tset_low, tset_up)
```

Arguments

`te`	A vector containing operative temperatures.
`tb`	A vector containing body temperature measurements.
`tset_low`	Lower boundary of a species or population set-point range that was determined through thermal preference trials in a temperature gradient. This may be a named double vector containing the lower boundary value, or simply the value itself.
`tset_up`	Upper boundary of the set-point range.

Value

Effectiveness of temperature regulation (E) sensu Blouin-Demers and Weatherhead (2001).

References

Blouin-Demers, G., & Weatherhead, P. J. (2001). Thermal ecology of black rat snakes (Elaphe obsoleta) in a thermally challenging environment. Ecology, 82 (11), 3025-3043.

See Also

`calculate_E_hertz`.

Examples

```
te <- na.omit(bufbuf[,"te"])
tb <- na.omit(bufbuf[,"tb"])
E <- calculate_E_blouin(te, tb, 19.35, 26.44)
```

`calculate_E_hertz` *Calculate thermoregulation effectiveness sensu Hertz, Huey & Stevenson*

Description

This function calculates the effectiveness of temperature regulation (E = 1 - (mean db / mean de)) as described by Hertz et al. (1993). The thermal quality of the habitat (de) and accuracy of temperature regulation (db) are calculated as part of this formula, so it is not necessary to run `calculate_de` and `calculate_db` before running this function.

Usage

```
calculate_E_hertz(te, tb, tset_low, tset_up)
```

Arguments

te	A vector containing operative temperatures.
tb	A vector containing body temperature measurements.
tset_low	Lower boundary of a species or population set-point range that was determined through thermal preference trials in a temperature gradient. This may be a named double vector containing the lower boundary value, or simply the value itself.
tset_up	Upper boundary of the set-point range.

Value

Effectiveness of temperature regulation (E)

References

Hertz, P. E., Huey, R. B., & Stevenson, R. D. (1993). Evaluating temperature regulation by field-active ectotherms: the fallacy of the inappropriate question. The American Naturalist, 142(5), 796-818.

See Also

calculate_de and calculate_db.

Examples

```
te <- na.omit(bufbuf[,"te"])
tb <- na.omit(bufbuf[,"tb"])
E <- calculate_E_hertz(te, tb, 19.35, 26.44)
```

---

compare_E — *Compare E between species or populations using permutation*

Description

To test whether or not distinct species or populations (hereafter 'entity') differed in their effectiveness of thermoregulation, Hertz et al. (1993) suggested comparing paired estimates of E obtained through bootstrapping. However, because sample sizes of active body temperatures (Tb) or operative temperatures (Te) may be small and could differ in size and variance, possibly leading to non-normality, we propose to use two-sided permutation testing instead of bootstrapping to build and compare distributions of E values.

Usage

```
compare_E(
  datasp1,
  datasp2,
  tset_lowsp1,
  tset_upsp1,
  tset_lowsp2,
  tset_upsp2,
  index,
  n
)
```

Arguments

datasp1	A dataframe with two columns named 'te' (containing operative temperatures) and 'tb' (containing body temperature measurements) of entity 1. Do not use capitals in column names.
datasp2	A dataframe for entity 2 structured as indicated above.
tset_lowsp1	Lower boundary of the set-point range of entity 1 that was determined through thermal preference trials in a temperature gradient. This may be a named double vector containing the lower boundary value, or simply the value itself.
tset_upsp1	Upper boundary of the set-point range of entity 1.
tset_lowsp2	Lower boundary of the set-point range of entity 2.
tset_upsp2	Upper boundary of the set-point range of entity 2.
index	Either 'hertz' or 'blouin'.
n	The desired number of samples drawn without replacement.

Value

Permutation testing results including a graphical overview which displays the empirical (actual) difference in E between two entities, along with a null distribution of differences in permuted E values constructed from pooled data of both entities.

References

Blouin-Demers, G., & Weatherhead, P. J. (2001). Thermal ecology of black rat snakes (Elaphe obsoleta) in a thermally challenging environment. Ecology, 82 (11), 3025-3043.
Hertz, P. E., Huey, R. B., & Stevenson, R. D. (1993). Evaluating temperature regulation by field-active ectotherms: the fallacy of the inappropriate question. The American Naturalist, 142(5), 796-818.

See Also

calculate_E_hertz and calculate_E_blouin.

Examples

```
bufbuf <- bufbuf
ichalp <- ichalp
E_diff <- compare_E(bufbuf, ichalp,
                    19.35, 26.44,
                    14.44, 18.33,
                    'blouin',
                    1000)
```

`ichalp` *Alpine newt body temperatures and associated operative temperatures*

Description

Active field body temperature data of Belgian alpine newts (*Ichthyosaura alpestris*) and associated operative temperature data from agar models, collected during nocturnal surveys in spring. Data are in degrees Celsius.

Usage

```
data(ichalp)
```

Format

An object of class `data.frame` with 99 rows and 2 columns.

Source

Wouter Beukema <wouter.beukema@gmail.com>

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