Package ‘devRate’

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Type Package

Title Quantify the Relationship Between Development Rate and Temperature in Ectotherms

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Description A set of functions to quantify the relationship between development rate and temperature and to build phenological models. The package comprises a set of models and estimated parameters borrowed from a literature review in ectotherms. The methods and literature review are described in Rebaudo et al. (2018) <doi:10.1111/2041-210X.12935>, Rebaudo and Rabhi (2018) <doi:10.1111/eea.12693>, and Regnier et al. (2021) <doi:10.1093/ee/nvab115>. An example can be found in Rebaudo et al. (2017) <doi:10.1007/s13355-017-0480-5>.

License GPL-2

Encoding UTF-8

LazyData TRUE

Depends R (>= 4.3.0)

RoxygenNote 7.3.2

Suggests knitr, rmarkdown, testthat, minpack.lm (>= 1.2-1)

VignetteBuilder knitr

URL https://github.com/frareb/devRate/

BugReports https://github.com/frareb/devRate/issues

NeedsCompilation no

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`analytis_77` *Analytis equation of development rate as a function of temperature.*

Description

Analytis, S. (1977) Uber die Relation zwischen biologischer Entwicklung und Temperatur bei phytopathogenen Pilzen. Journal of Phytopathology 90(1): 64-76.

Usage

```
analytis_77
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa * (T - Tmin)^{bb} * (Tmax - T)^{cc}$$

where rT is the development rate, T the temperature, Tmin the minimum temperature, Tmax the maximum temperature, and aa, bb, and cc constants.

References

doi:10.1111/j.14390434.1977.tb02886.x

`bayoh_03` *Bayoh and Lindsay equation of development rate as a function of temperature.*

Description

Bayoh, M.N., Lindsay, S.W. (2003) Effect of temperature on the development of the aquatic stages of Anopheles gambiae sensu stricto (Diptera: Culicidae). Bulletin of entomological research 93(5): 375-81.

Usage

```
bayoh_03
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa + bb * T + cc * e^T + dd * e^{-T}$$

where rT is the development rate, T the temperature, and aa, bb, cc, and dd empirical constant parameters.

References

doi:10.1079/BER2003259

`beta_16` *Beta2 equation of development rate as a function of temperature.*

Description

Yin, X., Kropff, M.J., McLaren, G., and Visperas, R.M. (1995) A nonlinear model for crop development as a function of temperature. Agricultural and Forest Meteorology 77(1): 1-16.

Shi, P. J., Chen, L., Hui, C., & Grissino-Mayer, H. D. (2016). Capture the time when plants reach their maximum body size by using the beta sigmoid growth equation. Ecological Modelling, 320, 177-181.

Shi, P. J., Reddy, G. V., Chen, L., and Ge, F. (2015). Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (I) empirical models. Annals of the Entomological Society of America, 109(2), 211-215.

Usage

```
beta_16
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = rm * (\frac{T2 - T}{/}T2 - Tm) * (\frac{T - T1}{/}Tm - T1)^{\frac{Tm - T1}{/}T2 - Tm}$$

where rT is the development rate, T the temperature, T1, T2, and Tm the model parameters.

References

doi:10.1016/j.ecolmodel.2015.09.012

---

beta_95 — *Beta equation of development rate as a function of temperature.*

Description

Yin, X., Kropff, M.J., McLaren, G., and Visperas, R.M. (1995) A nonlinear model for crop development as a function of temperature. Agricultural and Forest Meteorology 77(1): 1-16.

Usage

```
beta_95
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = e^{mu} * (T - Tb)^{aa} * (Tc - T)^{bb}$$

where rT is the development rate, T the temperature, mu, aa, and bb the model parameters, Tb the base temperature, and Tc the ceiling temperature.

References

doi:10.1016/01681923(95)02236Q

bieri1_83 *Bieri equation 1 of development rate as a function of temperature.*

Description

Bieri, M., Baumgartner, J., Bianchi, G., Delucchi, V., Arx, R. von. (1983) Development and fecundity of pea aphid (Acyrthosiphon pisum Harris) as affected by constant temperatures and by pea varieties. Mitteilungen der Schweizerischen Entomologischen Gesellschaft, 56, 163-171.

Kumar, S., and Kontodimas, D.C. (2012). Temperature-dependent development of Phenacoccus solenopsis under laboratory conditions. Entomologia Hellenica, 21, 25-38.

Usage

```
bieri1_83
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa * (T - Tmin) - (bb * e^{T - Tm})$$

where rT is the development rate, T the temperature, Tmin the minimum temperature, and aa, bb, and Tm fitted coefficients.

References

http://www.e-periodica.ch

`briere1_99` *Briere et al equation 1 of development rate as a function of temperature.*

Description

Briere, J.F., Pracros, P., le Roux, A.Y. and Pierre, S. (1999) A novel rate model of temperature-dependent development for arthropods. Environmental Entomology, 28, 22-29.

Usage

```
briere1_99
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa * T * (T - Tmin) * (Tmax - T)^{\frac{1}{2}}$$

where rT is the development rate, T the temperature, Tmin the low temperature developmental threshold, Tmax the lethal temperature, and aa an empirical constant.

References

doi:10.1093/ee/28.1.22

`briere2_99`	*Briere et al equation 2 of development rate as a function of temperature.*

Description

Briere, J.F., Pracros, P., le Roux, A.Y. and Pierre, S. (1999) A novel rate model of temperature-dependent development for arthropods. Environmental Entomology, 28, 22-29.

Usage

```
briere2_99
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa * T * (T - Tmin) * (Tmax - T)^{\frac{1}{bb}}$$

where rT is the development rate, T the temperature, Tmin the low temperature developmental threshold, Tmax the lethal temperature, and aa and bb empirical constants.

References

doi:10.1093/ee/28.1.22

`campbell_74` *Campbell et al. equation of development rate as a function of temperature.*

Description

Campbell, A., Frazer, B. D., Gilbert, N. G. A. P., Gutierrez, A. P., & Mackauer, M. (1974). Temperature requirements of some aphids and their parasites. Journal of applied ecology, 431-438. <doi:10.2307/2402197>

Usage

```
campbell_74
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa + bb * T$$

where rT is the development rate, T the temperature, bb the slope, and aa the point at which the line crosses the rT axis when T = 0.

damos_08 *Simplified beta type equation of development rate as a function of temperature.*

Description

Damos, P.T., and Savopoulou-Soultani, M. (2008). Temperature-dependent bionomics and modeling of Anarsia lineatella (Lepidoptera: Gelechiidae) in the laboratory. Journal of economic entomology, 101(5), 1557-1567.

Usage

```
damos_08
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa * (bb - \frac{T}{10}) * (\frac{T}{10})^{cc}$$

where rT is the development rate, T the temperature, and aa, bb, and cc empirical constant parameters.

References

doi:10.1093/jee/101.5.1557

`damos_11` *Inverse second-order polynomial equation of development rate as a function of temperature.*

Description

Damos, P., and Savopoulou-Soultani, M. (2011) Temperature-driven models for insect development and vital thermal requirements. Psyche: A Journal of Entomology, 2012.

Usage

```
damos_11
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{aa}{1 + bb * T + cc * T^2}$$

where rT is the development rate, T the temperature, and aa, bb, and cc empirical constant parameters.

References

doi:10.1155/2012/123405

`davidson_44` *Davidson equation of development rate as a function of temperature.*

Description

Davidson, J. (1944). On the relationship between temperature and rate of development of insects at constant temperatures. The Journal of Animal Ecology:26-38. <doi:10.2307/1326>

Usage

```
davidson_44
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{K}{1 + e^{aa+bb*T}}$$

where rT is the development rate, T the temperature, K the distance between the upper and lower asymptote of the curve, aa the relative position of the origin of the curve on the abscissa, bb the degree of acceleration of development of the life stage in relation to temperature.

`devRate` *devRate: A package to quantify the relationship between development rate and temperature in ectotherms.*

Description

The devRate package allows quantifying the relationship between development rate and temperature in ectotherm organisms.

Citation

Please use `citation("devRate")` to cite the devRate package and/or Rebaudo F, Struelens Q, Dangles O. Modelling temperature-dependent development rate and phenology in arthropods: The devRate package for r. Methods Ecol Evol. 2017;00:1-7. https://doi.org/10.1111/2041-210X.12935.

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Overview

The devRate package provides three categories of functions:

- to find development rate information about a specific organism (Order, Family, Genus, species): which equations were used and what are the associated parameters (e.g., helpful to estimate starting values for your empirical data sets);

- to relate development rate and temperature; and

- to plot your empirical datasets and the associated fitted model, and/or to plot development curves from the literature.

Usage

You can use the package:

- to get development rate curves as a function of temperature for a specific organism (hundred of examples from the literature are included in the package);

- to know which equations exists and which are most used in the literature; and

- to relate development rate with temperature from your empirical data, using the equations from the package database.

Installation instructions

```
install.packages("devRate")
```

Documentation

The package includes two vignettes (long-form documentation):

- quickUserGuide: Using devRate package to fit development rate models to an empirical dataset

- modelEvaluation: Model evaluation using Shi et al. 2016 study

Author(s)

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- Baptiste Regnier (PhD; 2019-2020)

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- Camila Benavides (M2 student; 2018) [contributor]
- Tanusson Selvarajah (L2 student; 2018) [contributor]
- Nicolas Bonnal (M1 student; 2018) [contributor]
- Badre Rabhi (L2 student; 2017) [contributor]
- Quentin Struelens (VIA; 2016) [contributor]

See Also

Useful links:

- https://github.com/frareb/devRate/
- Report bugs at https://github.com/frareb/devRate/issues

`devRateEqList` *The list of all available equations of development rate as a function of temperature.*

Description

The list of all available equations of development rate as a function of temperature.

Usage

```
devRateEqList
```

Format

An object of class `list` of length 37.

`devRateEqStartVal` *Default starting values for each equation listed in the devRateEqList object.*

Description

Default starting values for each equation listed in the devRateEqList object.

Usage

```
devRateEqStartVal
```

Format

An object of class `list` of length 37.

`devRateFind` *Find models for species*

Description

Find models for species

Usage

```
devRateFind(orderSP = "", familySP = "", species = "")
```

Arguments

`orderSP`	Find models by Order.
`familySP`	Find models by Family.
`species`	Find models by species (Genus species).

Details

The function looks for the species in the database and returns the number of occurrences for each model.

Value

A data.frame with the name of the equations, the number of occurrences in the database, and the number of parameters for each equation.

Examples

```
devRateFind(orderSP = "Lepidoptera")
devRateFind(familySP = "Gelechiidae")
## detailed example:
devRateFind(species = "Tuta absoluta")
## campbell_74 model has been used for T. absoluta
## Parameters from the campbell equation can be accessed by:
## campbell_74$startVal[campbell_74$startVal["genSp"] == "Tuta absoluta",]
```

---

devRateIBM *Forecast ectotherm phenology as a function of temperature and development rate models*

Description

Forecast ectotherm phenology as a function of temperature and development rate models

Usage

```
devRateIBM(tempTS, timeStepTS, models, numInd = 100, stocha, timeLayEggs = 1)
```

Arguments

tempTS	The temperature time series (a vector).
timeStepTS	The time step of the temperature time series (a numeric in days).
models	The models for development rate (a list with objects of class nls).
numInd	The number of individuals for the simulation (an integer).
stocha	The standard deviation of a Normal distribution centered on development rate to create stochasticity among individuals (a numeric). Either a single number (same stochasticity for all stages) or a vector of length corresponding to the number of models used (different stochasticity for the phenological stages).
timeLayEggs	The delay between emergence of adults and the time where females lay eggs in time steps (a numeric).

Value

A list with three elements: the table of phenology for each individual, the models used (nls objects), and the time series for temperature.

Examples

```
data(exTropicalMoth)
forecastTsolanivora <- devRateIBM(
   tempTS = rnorm(n = 100, mean = 15, sd = 1),
   timeStepTS = 1,
   models = exTropicalMoth[[2]],
   numInd = 100,
```

```
    stocha = c(0.015, 0.005, 0.01),
    timeLayEggs = 1)
```

---

devRateIBMdataBase *Forecast ectotherm phenology as a function of temperature and development rate models available in the package database*

Description

Forecast ectotherm phenology as a function of temperature and development rate models available in the package database

Usage

```
devRateIBMdataBase(
  tempTS,
  timeStepTS,
  eq,
  species,
  lifeStages,
  numInd = 10,
  stocha,
  timeLayEggs = 1
)
```

Arguments

`tempTS`	The temperature time series (a vector).
`timeStepTS`	The time step of the temperature time series (a numeric with 1 = one day).
`eq`	The name of the equation (e.g., lactin2_95).
`species`	The species for the model (e.g., "Sesamia nonagrioides").
`lifeStages`	The life stages available for the species and the model.
`numInd`	The number of individuals for the simulation (an integer).
`stocha`	The standard deviation of a Normal distribution centered on development rate to create stochasticity among individuals (a numeric).
`timeLayEggs`	The delay between emergence of adults and the time where females lay eggs in time steps (a numeric).

Value

A list with three elements: the table of phenology for each individual, the models used (nls objects), and the time series for temperature.

Examples

```
forecastLactin2_95 <- devRateIBMdataBase(
  tempTS = rnorm(n = 20, mean = 20, sd = 1),
  timeStepTS = 10,
  eq = lactin2_95,
  species = "Sesamia nonagrioides",
  lifeStages = c("eggs", "larva", "pupa"),
  numInd = 10,
  stocha = 0.015,
  timeLayEggs = 1
)
```

---

devRateIBMgen *Number of generations*

Description

Computes the number of generations from the individual-based model fit.

Usage

```
devRateIBMgen(ibm)
```

Arguments

ibm	The phenology model returned by devRateIBM function.

Value

The simulated number of generations.

Examples

```
data(exTropicalMoth)
forecastTsolanivora <- devRateIBM(
   tempTS = rnorm(n = 100, mean = 15, sd = 1),
   timeStepTS = 1,
   models = exTropicalMoth[[2]],
   numInd = 10,
   stocha = 0.015,
   timeLayEggs = 1)
devRateIBMgen(ibm = forecastTsolanivora)
```

devRateIBMparam — *Forecast ectotherm phenology as a function of temperature and development rate models using known parameters*

Description

Forecast ectotherm phenology as a function of temperature and development rate models using known parameters

Usage

```
devRateIBMparam(
  tempTS,
  timeStepTS,
  eq,
  myParam,
  numInd = 10,
  stocha,
  timeLayEggs = 1,
  adultLifeStage = 0
)
```

Arguments

`tempTS`	The temperature time series (a vector).
`timeStepTS`	The time step of the temperature time series (a numeric with 1 = one day).
`eq`	The name of the equation provided in the package (e.g., lactin2_95). For backward compatibility, the name of equation can be used, however, it is preferable to use a list object containing the names of the various equations in character format (e.g., list("campbell_74", "lactin2_95"). See examples below.
`myParam`	The known parameters for the equation (a list of list for each life stage).
`numInd`	The number of individuals for the simulation (an integer).
`stocha`	The standard deviation of a Normal distribution centered on development rate to create stochasticity among individuals (a numeric).
`timeLayEggs`	The delay between emergence of adults and the time where females lay eggs in time steps (a numeric).
`adultLifeStage`	An integer to specify when the adult life stage is tacking place so that timeLayEggs is applied. Default to 0 for backwards compatibility with previous versions of the package.

Details

Please note that this function is experimental and only works for the briere2_99 equation.

Value

A list with three elements: the table of phenology for each individual, the models used (nls objects), and the time series for temperature.

Examples

```
# with only one life stage
forecastX <- devRateIBMparam(
  tempTS = rnorm(n = 20, mean = 20, sd = 1),
  timeStepTS = 10,
  eq = briere2_99,
  myParam = list(
    list(
      aa = 0.0002,
      Tmin = 10,
      Tmax = 36.1,
      bb = 2.84)
  ),
  numInd = 10,
  stocha = 0.015,
  timeLayEggs = 1
)
# with two life stages
forecastXX <- devRateIBMparam(
  tempTS = rnorm(n = 20, mean = 20, sd = 1),
  timeStepTS = 10,
  eq = briere2_99,
  myParam = list(
    lifeStage01 = list(
      aa = 0.0002,
      Tmin = 10,
      Tmax = 36.1,
      bb = 2.84),
    lifeStage02 = list(
      aa = 0.0004,
      Tmin = 8,
      Tmax = 35,
      bb = 2.8)
  ),
  numInd = 10,
  stocha = 0.015,
  timeLayEggs = 1
)
# with three life stages, adult stage tacking place after the pupal stage,
# so that adultLifeStage = 2. Adult longevity was exacerbated at 15 days
# to highlight the impact on function output.
forecastXXX <- devRateIBMparam(
  tempTS = rnorm(n = 120, mean = 20, sd = 1),
  timeStepTS = 1, eq = briere2_99,
  myParam = list(
   lifeStage_larva = list(
     aa = 0.0002,
```

```
      Tmin = 10,
      Tmax = 36.1,
      bb = 2.84),
    lifeStage_pupa = list(
      aa = 0.0004,
      Tmin = 8,
      Tmax = 35,
      bb = 2.8),
    lifeStage_egg = list(
      aa = 0.0002,
      Tmin = 8,
      Tmax = 35,
      bb = 2.8)
  ),
  numInd = 5, stocha = 0.015,
  timeLayEggs = 15, adultLifeStage = 2
)
# with three life stages, and a different model equation for each life stage.
forecastXXXX <- devRateIBMparam(
  tempTS = rnorm(n = 60, mean = 20, sd = 1),
  timeStepTS = 1,
  eq = list("briere2_99", "lactin2_95", "campbell_74"),
  myParam = list(
    list(
      aa = 0.0002,
      Tmin = 10,
      Tmax = 36.1,
      bb = 2.84
    ),
    list(
      aa = 0.009,
      Tmax = 35.299,
      deltaT = 0.201,
      bb = -1.049
    ),
    list(
      aa = -0.0459,
      bb = 0.0044
    )
  ),
  numInd = 10,
  stocha = 0.015,
  timeLayEggs = 1
)
```

`devRateIBMPlot` *Plot phenology table*

Description

Plot phenology table

Usage

```
devRateIBMPlot(ibm, typeG = "density", threshold = 0.1)
```

Arguments

ibm	The phenology model returned by devRateIBM function.
typeG	The type of plot ("density" or "hist").
threshold	The threshold rate of individuals for being represented in a density plot (a numeric between 0 and 1).

Value

Nothing.

Examples

```
data(exTropicalMoth)
forecastTsolanivora <- devRateIBM(
   tempTS = rnorm(n = 100, mean = 15, sd = 1),
   timeStepTS = 1,
   models = exTropicalMoth[[2]],
   numInd = 10,
   stocha = 0.015,
   timeLayEggs = 1)
devRateIBMPlot(ibm = forecastTsolanivora, typeG = "density", threshold = 0.1)
devRateIBMPlot(ibm = forecastTsolanivora, typeG = "hist")
```

---

devRateInfo *Display information about an equation*

Description

Display information about an equation

Usage

```
devRateInfo(eq)
```

Arguments

eq	The name of the equation.

Value

Nothing.

Examples

```
devRateInfo(eq = davidson_44)
devRateInfo(eq = campbell_74)
devRateInfo(eq = taylor_81)
devRateInfo(eq = wang_82)
```

---

devRateMap — *Predict development rate from a matrix of temperatures*

Description

Create a map from a temperature matrix and a development rate curve

Usage

```
devRateMap(nlsDR, tempMap)
```

Arguments

`nlsDR`	The result returned by the `devRateModel` function.
`tempMap`	A matrix containing temperatures in degrees.

Details

The `devRateMap` function is designed for a single ectotherm life stage, but the resulted matrix of development rate can be performed for each life stage in order to obtain the whole organism development. Input temperatures should preferably cover the organism development period rather than the whole year.

Value

A matrix with development rates predicted from the model.

Examples

```
myT <- 5:15
myDev <- -0.05 + rnorm(n = length(myT), mean = myT, sd = 1) * 0.01
myNLS <- devRateModel(eq = campbell_74, temp = myT, devRate = myDev,
  startValues = list(aa = 0, bb = 0))
myMap <- devRateMap(nlsDR = myNLS, tempMap = matrix(rnorm(100, mean = 12, sd = 2), ncol=10))
```

devRateModel — *Compute non-linear regression*

Description

Determine the nonlinear least-squares estimates of the parameters of a nonlinear model, on the basis of the `nls` function from package `stats`.

Usage

```
devRateModel(eq, temp, devRate, startValues, dfData = NULL, algo = "GN", ...)
```

Arguments

`eq`	The name of the equation. See `devRateEqList` for the list of equations
`temp`	The temperature (vector).
`devRate`	The development rate `(days)^-1` (vector).
`startValues`	Starting values for the regression (list).
`dfData`	A data.frame with the temperature in the first column and the development rate in the second column (alternative to the use of temp and devRate).
`algo`	The abbreviated name of the algorithm used for model fitting ("GN" for Gauss-Newton algorithm, "LM" for Levenberg-Marquardt algorithm; "GN" is the default value).
`...`	Additional arguments for the `nls` function.

Details

`startValues` for equations by Stinner et al. 1974 and Lamb 1992 are composed of two equations: one for the temperatures below the optimal temperature and another for the temperatures above the optimal temperature. For these equations, `startValues` should be a list of two lists, where the second element only contain starting estimates not specified in the first element, e.g., for Stinner et al.: `startValues <- list(list(C = 0.05, k1 = 5, k2 = -0.3), list(Topt = 30))`, and for Lamb 1992: `startValues <- list(list(Rm = 0.05, Tmax = 35, To = 15), list(T1 = 4))`

The temperature should be provided as a vector in argument `temp` and development rate in another vector in argument `devRate`. However, it is possible to use the function with a data.frame containing the temperature in the first column and the development rate in the sceond column, using the argument `dfData`

NULL is returned when an unknown algorithm is entered.

Value

An object of class `nls` (except for Stinner et al. 1974 and Lamb 1992 where the function returns a list of two objects of class `nls`).

Examples

```
## Example with a linear model (no starting estimates)
myT <- 5:15
myDev <- -0.05 + rnorm(n = length(myT), mean = myT, sd = 1) * 0.01
myNLS <- devRateModel(
  eq = campbell_74,
  temp = myT,
  devRate = myDev)
## Example with a non-linear model (starting estimates)
myT <- seq(from = 0, to = 50, by = 10)
myDev <- c(0.001, 0.008, 0.02, 0.03, 0.018, 0.004)
myNLS <- devRateModel(
  eq = stinner_74,
  temp = myT,
  devRate = myDev,
  startValues = list(
    list(C = 0.05, k1 = 5, k2 = -0.3),
    list(Topt = 30)))
## Example with a data.frame instead of two vectors for temperature and
## development rate
myDF <- data.frame(myT, myDev)
myNLS <- devRateModel(
  eq = campbell_74,
  dfData = myDF)
```

---

devRateModelAll — *Fitting all models listed in devRateEqList to a development rate dataset*

Description

This function fits all models listed in devRateEqList to a development rate dataset and then calculates a series of indices of goodness-of-fit for each fitted model.

Usage

```
devRateModelAll(
  dfData,
  eqList = devRate::devRateEqList,
  eqStartVal = devRate::devRateEqStartVal,
  propThresh = 0.01,
  interval = c(0, 50),
  ...
)
```

Arguments

`dfData`	A data.frame with the temperature in the first column and the development rate in the second column.

`eqList`	A list of models that can be retrieved from the object devRateEqList. The default value is the object devRateEqList.
`eqStartVal`	A list of sarting values for each model. The default value is the object devRateEqStartVal.
`propThresh`	The proportion of maximal development rate used as a threshold for estimating XTmin and XTmax for asymptotic equations (default value is 0.01)
`interval`	A vector containing the lower and upper boundaries of the interval of temperatures in which metrics are searched.
`...`	Additional arguments for the `devRateModel` function.

Details

Equations stinner_74 and lamb_92 are fitted and the resulting nls objects are showed in the first element of the returned list, however indices of goodness-of-fit are not provided. Equation campbell_74 is not fitted (simple linear model).

Value

An object of class `list` with two elements. The first element is a `list` with all the nls objects. The second element is a `data.frame`. In the `data.frame`, the first column corresponds to model names and the second column to the number of parameters. The columns 3 to 6 correspond to the results of the function `devRateQlStat`, i.e. RSS, RMSE, AIC, and BIC. The columns 7 to 11 correspond to the results of the function `devRateQlBio`, i.e. CTmin, CTmax, Topt, XTmin, and XTmax.

Examples

```
myDf <- exTropicalMoth$raw$egg
devRateModelAll(dfData = myDf)
```

`devRatePlot` *Plot the empirical points and the regression*

Description

Plot the empirical points and the regression

Usage

```
devRatePlot(eq, nlsDR, rangeT = 10, optText = TRUE, spe = TRUE, ...)
```

Arguments

`eq`	The name of the equation.
`nlsDR`	The result returned by the `devRateModel` function.
`rangeT`	The range of temperatures over which the regression is plotted. This argument may be overwritten depending on the equation.

optText	A logical indicating whether the name of the equation should be written in the topright corner of the plot.
spe	A logical indicating if special plotting rules from literature should apply.
...	Additional arguments for the plot.

Value

Nothing.

Examples

```
myT <- 5:15
myDev <- -0.05 + rnorm(n = length(myT), mean = myT, sd = 1) * 0.01
myNLS <- devRateModel(eq = campbell_74, temp = myT, devRate = myDev,
  startValues = list(aa = 0, bb = 0))
devRatePlot(eq = campbell_74, nlsDR = myNLS,
  spe = TRUE, pch = 16, lwd = 2, ylim = c(0, 0.10))
```

---

devRatePlotInfo *Plot thermal performance curves from the literature*

Description

Plot thermal performance curves from the literature

Usage

```
devRatePlotInfo(eq, sortBy = "genSp", stage = "all", ...)
```

Arguments

eq	The name of the equation.
sortBy	The filter to separate species ("ordersp", "familysp", "genussp", "species", "genSp").
stage	The life stage of the organism ("all", "eggs", "L1", "L2", "L3", "L4", "L5", "larva", "pupa", "prepupa", "female", "male", ...)
...	Aditional arguments for the plot.

Value

Nothing.

Examples

```
devRatePlotInfo(eq = davidson_44, sortBy = "genSp", xlim = c(0, 40), ylim = c(0, 0.05))
devRatePlotInfo(eq = campbell_74, sortBy = "familysp", xlim = c(-10, 30), ylim = c(0, 0.05))
devRatePlotInfo(eq = taylor_81, sortBy = "ordersp", xlim = c(-20, 60), ylim = c(0, 0.2))
devRatePlotInfo(eq = wang_82, sortBy = "ordersp", xlim = c(0, 50), ylim = c(0, 0.06))
devRatePlotInfo(eq = stinner_74, sortBy = "ordersp", xlim = c(0, 50), ylim = c(0, 0.06))
```

`devRatePrint` *Report model output from the NLS fit*

Description

Provide a custom output of the NLS fit.

Usage

```
devRatePrint(myNLS, doPlots = FALSE)
```

Arguments

`myNLS`	An object of class NLS
`doPlots`	A boolean to get the residual plot (default = FALSE)

Value

A list of six objects (summary of the NLS fit; confidence intervals for the model parameters; test of normality; test of independence; AIC, BIC)

Examples

```
myT <- 5:15
myDev <- -0.05 + rnorm(n = length(myT), mean = myT, sd = 1) * 0.01
myNLS <- devRateModel(
  eq = campbell_74,
  temp = myT,
  devRate = myDev,
  startValues = list(aa = 0, bb = 0))
devRatePrint(myNLS)

rawDevEggs <- matrix(c(10, 0.031, 10, 0.039, 15, 0.047, 15, 0.059, 15.5, 0.066,
   13, 0.072, 16, 0.083, 16, 0.100, 17, 0.100, 20, 0.100, 20, 0.143, 25, 0.171,
   25, 0.200, 30, 0.200, 30, 0.180, 35, 0.001), ncol = 2, byrow = TRUE)
mEggs <- devRateModel(
  eq = taylor_81,
  temp = rawDevEggs[,1],
  devRate = rawDevEggs[,2],
  startValues = list(Rm = 0.05, Tm = 30, To = 5))
devRatePrint(myNLS = mEggs)
```

`devRateQlBio` *Biological likelihood of nls fits*

Description

Return a table of 5 metrics of development (CTmin, CTmax, Topt, XTmin, XTmax)

Usage

```
devRateQlBio(nlsDR, propThresh = 0.01, eq, interval = c(0, 50))
```

Arguments

`nlsDR`	A list of nls objects.
`propThresh`	The proportion of maximal development rate used as a threshold for estimating XTmin and XTmax for asymptotic equations (default value is 0.01)
`eq`	A list of equations used for nls fitting.
`interval`	A vector containing the lower and upper boundaries of the interval of temperatures in which metrics are searched.

Details

NULL is returned when nlsDR or eq are not a list.

Value

An object of class `data.frame` with development metrics (CTmin, Ctmax, Topt, XTmin, XTmax) in columns and nls objects in rows.

Examples

```
myDf <- data.frame(temp = seq(from = 0, to = 50, by = 10),
 rT = c(0.001, 0.008, 0.02, 0.03, 0.018, 0.004))
myNLS <- list(
 devRateModel(
   eq = janisch_32,
   df = myDf,
   startValues = list(aa = 0.2, bb = 0.1, Dmin = 10, Topt = 30),
   algo = "LM"),
 devRateModel(
   eq = kontodimas_04,
   df = myDf,
   startValues = list(aa = 1, Tmin = 7, Tmax = 40),
   algo = "LM"),
 devRateModel(
   eq = poly2,
   df = myDf,
   startValues = list(a0 = 1, a1 = 1, a2 = 1),
```

```
  algo = "LM"))
devRateQlBio(
  nlsDR = myNLS,
  eq = list(janisch_32, kontodimas_04, poly2),
  propThresh = 0.1)
```

---

devRateQlStat *Statistical indices of the nls goodness-of-fit*

Description

Return a table of multiple statistical indices of goodness-of-fit

Usage

```
devRateQlStat(nlsDR)
```

Arguments

nlsDR	A list of `nls` objects.

Details

NULL is returned when nlsDR is not of type list. AIC and BIC are calculated using the RSS (Burnham and Anderson, 2002).

Value

A `data.frame` with statistical indices in columns (RSS, RMSE, AIC, BIC) and nls objects in rows.

Examples

```
myDf <- data.frame(
  temp = seq(from = 0, to = 50, by = 10),
  rT = c(0.001, 0.008, 0.02, 0.03, 0.018, 0.004))
damos_08Fit <- devRateModel(
  eq = damos_08,
  dfData = myDf,
  startValues = list(aa = 1, bb = 1, cc = 1),
  algo = "LM")
kontodimas_04Fit <- devRateModel(
  eq = kontodimas_04,
  dfData = myDf,
  startValues = list(aa = 1, Tmin = 7, Tmax = 40),
  algo = "LM")
poly2Fit <- devRateModel(
  eq = poly2,
  dfData = myDf,
  startValues = list(a0 = 1, a1 = 1, a2 = 1),
  algo = "LM")
```

```
devRateQlStat(
  nlsDR = list(damos_08Fit, kontodimas_04Fit, poly2Fit)
)
```

---

dRGetMetrics *Life traits from Thermal Performance Curve*

Description

Compute life traits from a Thermal Performance Curve

Usage

```
dRGetMetrics(
  nlsDR,
  prec = 0.1,
  lowTempLim = 0,
  highTempLimit = 60,
  devLimit = 0.01,
  printOut = FALSE
)
```

Arguments

nlsDR	The object obtained from the devRateModel function.
prec	The precision for the temperature (default = 0.1 degree celsius).
lowTempLim	The minimum temperature for the metrics (default = 0 degree celsius).
highTempLimit	The maximum temperature for the metrics (default = +60 degree celsius).
devLimit	The development rate considered as null (default = 0.01).
printOut	A logical to print the result (default = FALSE).

Value

A matrix with one column and one row for each metric. The metrics names are the row names.

Examples

```
rawDevEggs <- matrix(
   c(10, 0.031, 10, 0.039, 15, 0.047, 15, 0.059, 15.5,
   0.066, 13, 0.072, 16, 0.083, 16, 0.100, 17, 0.100, 20, 0.100, 20,
   0.143, 25, 0.171, 25, 0.200, 30, 0.200, 30, 0.180, 35, 0.001
), ncol = 2, byrow = TRUE)
mEggs <- devRateModel(
   eq = taylor_81,
   temp = rawDevEggs[,1],
   devRate = rawDevEggs[,2],
   startValues = list(Rm = 0.05, Tm = 30, To = 5)
)
myMetrics <- dRGetMetrics(nlsDR = mEggs, printOut = TRUE)
```

dRGetMetricsInfo *Life traits from the ectotherm database*

Description

Life traits from the ectotherm database

Usage

```
dRGetMetricsInfo(
  eq,
  prec = 0.1,
  lowTempLim = 0,
  highTempLimit = 60,
  devLimit = 0.01,
  devThresh = 0.1,
  lifeStage = "all",
  colId = "genSp",
  printOut = FALSE
)
```

Arguments

eq	The name of the equation.
prec	The precision for the temperature (default = 0.1 degree celsius).
lowTempLim	The minimum temperature for the metrics (default = 0 degree celsius).
highTempLimit	The maximum temperature for the metrics (default = +60 degree celsius).
devLimit	The development rate considered as null (default = 0.01).
devThresh	The threshold in development rate to compute min and max temperature (default = 0.1).
lifeStage	The life stage on which the life traits should be computed (default = "all"; specify "" to take into account all life stages).
colId	The organism information for each column (default = genSp; choices = "ordersp" for Order, "familysp" for Family, "genussp" for Genus, "species" for species, and "gensp" for Genus and species).
printOut	A logical to print the result (default = FALSE).

Value

A matrix with one column per organism and one row for each metric. The metrics names are the names of each row.

Examples

```
dRGetMetricsInfo(eq = taylor_81)
dRGetMetricsInfo(eq = taylor_81, devThresh = 0.1)
```

exTropicalMoth *Tropical moth development rate at constant temperatures.*

Description

This is a sample dataset to be used in the package examples. In this example, we used data from Crespo-Perez et al. (2011) on the potato tuber moth Tecia solanivora (Lepidoptera: Gelechiidae), a major crop pest in the central Andes of Ecuador. We used Web Plot Digitizer (Rohatgi 2015) to extract the data on development rate as a function of temperature.

Crespo-Perez, V., Rebaudo, F., Silvain, J.-F. & Dangles, O. (2011). Modeling invasive species spread in complex landscapes: the case of potato moth in Ecuador. Landscape ecology, 26, 1447-1461.

Rohatgi, A. (2015). WebPlotDigitalizer: HTML5 based online tool to extract numerical data from plot images.

Usage

```
exTropicalMoth
```

Format

A list of two elements with a list of three elements.

- **raw** The raw data extracted from Crespo-Perez et al. 2011.
  - **eggs** raw temperatures and development rates
  - **larva** raw temperatures and development rates
  - **pupa** raw temperatures and development rates
- **model** The nls object returned by the devRateModel function.
  - **eggs** nls object
  - **larva** nls object
  - **pupa** nls object

harcourtYee_82 *Harcourt and Yee equation of development rate as a function of temperature.*

Description

Harcourt, D. and Yee, J. (1982) Polynomial algorithm for predicting the duration of insect life stages. Environmental Entomology, 11, 581-584.

Usage

```
harcourtYee_82
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).
eqAlt The equation (string).
name The name of the equation.
ref The equation reference.
refShort The equation reference shortened.
startVal The parameters found in the literature with their references.
com An optional comment about the equation use.
id An id to identify the equation.

Details

Equation:

$$rT = a0 + a1 * T + a2 * T^2 + a3 * T^3$$

where rT is the development rate, T the temperature, and a0, a1, a2, and a3 are constants.

References

doi:10.1093/ee/11.3.581

`ha_ahmad2024_ls` *Ahmad linear thermal performance curve for the development of Helicoverpa armigera*

Description

Linear development performance curve from four experimental temperatures (14, 16, 18, 20, 22, 25, 27, 30, 32, 35 and 36 degrees Celsius).

Usage

```
ha_ahmad2024_ls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Ahmad S. (2024) Temperature dependent survivorship and development of Helicoverpa armigera (Hubner) (Lepidoptera-Noctuidae) on chickpea. Preprint. https://doi.org/10.21203/rs.3.rs-4845823/v1

Examples

```
mymodel <- ha_ahmad2024_ls(plotfig = FALSE)
```

---

ha_bartekova2006 *Bartekova and Praslicka linear thermal performance curve for the developmentof Helicoverpa armigera*

Description

Linear development performance curve for eggs, larvae and pupae from three experimental temperatures (20, 25, and 30 degrees Celsius).

Usage

```
ha_bartekova2006(plotfig = TRUE)
```

Arguments

plotfig	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Bartekova, A., and Praslicka, J. (2006). The effect of ambient temperature on the development of cotton bollworm (Helicoverpa armigera Hubner, 1808). Plant Protection Science, 42(4), 135. https://doi.org/10.17221/2768-PPS

Examples

```
mymodel <- ha_bartekova2006(plotfig = FALSE)
```

`ha_foley1981` *Foley linear thermal performance curve for the post-diapausing and non-diapausing pupae development of Helicoverpa armigera*

Description

Linear development performance curve for post-diapausing and non-diapausing pupae from 3 to 4 experimental temperatures (20, 24, 28, and 32 degrees Celsius).

Usage

```
ha_foley1981(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Foley, D. H. (1981). Pupal development rate of Heliothis armiger (Hubner)(Lepidoptera: Noctuidae) under constant and alternating temperatures. Australian Journal of Entomology, 20(1), 13-20. https://doi.org/10.1111/j.1440-6055.1981.tb00993.x

Examples

```
mymodel <- ha_foley1981(plotfig = FALSE)
```

`ha_jallow2001` *Jallow and Matsumura linear thermal performance curve for the development of Helicoverpa armigera*

Description

Linear development performance curve for eggs, larvae and pupae from nine experimental temperatures (10, 13.3, 16.4, 20, 22.5, 25, 27.9, 30.5, and 32.5 degrees Celsius).

Usage

```
ha_jallow2001(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Jallow, M. F., and Matsumura, M. (2001). Influence of temperature on the rate of development of Helicoverpa armigera (Hubner)(Lepidoptera: Noctuidae). Applied Entomology and Zoology, 36(4), 427-430. https://doi.org/10.1303/aez.2001.427

Examples

```
mymodel <- ha_jallow2001(plotfig = FALSE)
```

ha_kay1981_ls *Kay linear thermal performance curve for the egg development of Helicoverpa armigera*

Description

Linear development performance curve for eggs from ten experimental temperatures (8, 10, 13.3, 17.8, 20.8, 24.4, 27.2, 31.4, 35, 39.4 degrees Celsius).

Usage

```
ha_kay1981_ls(plotfig = TRUE)
```

Arguments

plotfig	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Kay, I. R. (1981). The effect of constant temperatures on the development time of eggs of Heliothis armiger (Hubner) (Lepidoptera: Noctuidae). Australian Journal of Entomology, 20(2), 155-156. https://doi.org/10.1111/j.1440-6055.1981.tb01020.x

Examples

```
mymodel <- ha_kay1981_ls(plotfig = FALSE)
```

`ha_kay1981_nls` *Kay non-linear Davidson thermal performance curve for the egg development of Helicoverpa armigera*

Description

Non-linear development performance curve for eggs from ten experimental temperatures (8, 10, 13.3, 17.8, 20.8, 24.4, 27.2, 31.4, 35, 39.4 degrees Celsius), using Davidson equation.

Usage

```
ha_kay1981_nls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Kay, I. R. (1981). The effect of constant temperatures on the development time of eggs of Heliothis armiger (Hubner) (Lepidoptera: Noctuidae). Australian Journal of Entomology, 20(2), 155-156. https://doi.org/10.1111/j.1440-6055.1981.tb01020.x

Examples

```
mymodel <- ha_kay1981_nls(plotfig = FALSE)
```

`ha_mironidis2008_ls` *Mironidis and Savopoulou-Soultani linear thermal performance curve for the development of Helicoverpa armigera*

Description

Linear development performance curve for eggs, larvae and pupae from twelve experimental temperatures (10, 12.5, 15, 17.5, 20, 25, 27.5, 30, 32.5, 35, 37.5, and 40 degrees Celsius).

Usage

```
ha_mironidis2008_ls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Mironidis, G. K., and Savopoulou-Soultani, M. (2008). Development, survivorship, and reproduction of Helicoverpa armigera (Lepidoptera: Noctuidae) under constant and alternating temperatures. Environmental Entomology, 37(1), 16-28. https://doi.org/10.1093/ee/37.1.16

Examples

```
mymodel <- ha_mironidis2008_ls(plotfig = FALSE)
```

ha_mironidis2008_nls — *Mironidis and Savopoulou-Soultani non-linear Lactin-2 thermal performance curve for the development of Helicoverpa armigera*

Description

Non-linear development performance curve for eggs, larvae and pupae from twelve experimental temperatures (10, 12.5, 15, 17.5, 20, 25, 27.5, 30, 32.5, 35, 37.5, and 40 degrees Celsius), using Lactin2 model (Lactin, 1995).

Usage

```
ha_mironidis2008_nls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Mironidis, G. K., and Savopoulou-Soultani, M. (2008). Development, survivorship, and reproduction of Helicoverpa armigera (Lepidoptera: Noctuidae) under constant and alternating temperatures. Environmental Entomology, 37(1), 16-28. https://doi.org/10.1093/ee/37.1.16

Examples

```
mymodel <- ha_mironidis2008_nls(plotfig = FALSE)
```

`ha_noorulane2018_ls` *Noor-ul-Ane et al. linear thermal performance curve for the development of Helicoverpa armigera*

Description

Linear development performance curve from ten experimental temperatures (10, 15, 17.5, 20, 25, 27.5, 30, 35, 37.5 and 40 degrees Celsius). Experimental development data were retrieve from Figure 1 using plotdigitizer.com.

Usage

```
ha_noorulane2018_ls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Noor-ul-Ane M., Mirhosseini M. A., Crickmore N., Saeed S., Noor I., Zalucki M. P. (2018). Temperature-dependent development of Helicoverpa armigera (Hubner) (Lepidoptera: Noctuidae) and its larval parasitoid, Habrobracon hebetor (Say) (Hymenoptera: Braconidae): implications for species interactions. Bulletin of Entomological Research 108, 295–304. https://doi.org/10.1017/S0007485317000724

Examples

```
mymodel <- ha_noorulane2018_ls(plotfig = FALSE)
```

`ha_noorulane2018_nls` *Noor-ul-Ane et al. non-linear thermal performance curve for the development of Helicoverpa armigera*

Description

Non-linear Briere2 development performance curve from ten experimental temperatures (10, 15, 17.5, 20, 25, 27.5, 30, 35, 37.5 and 40 degrees Celsius). Experimental development data were retrieve from Figure 1 using plotdigitizer.com.

Usage

```
ha_noorulane2018_nls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Noor-ul-Ane M., Mirhosseini M. A., Crickmore N., Saeed S., Noor I., Zalucki M. P. (2018). Temperature-dependent development of Helicoverpa armigera (Hubner) (Lepidoptera: Noctuidae) and its larval parasitoid, Habrobracon hebetor (Say) (Hymenoptera: Braconidae): implications for species interactions. Bulletin of Entomological Research 108, 295–304. https://doi.org/10.1017/S0007485317000724

Examples

```
mymodel <- ha_noorulane2018_nls(plotfig = FALSE)
```

`ha_qureshi1999_ls` *Qureshi et al. linear thermal performance curve for the development of Helicoverpa armigera*

Description

Linear development performance curve from four experimental temperatures (15, 20, 25, and 30 degrees Celsius).

Usage

```
ha_qureshi1999_ls(plotfig = TRUE)
```

Arguments

`plotfig`	A Boolean used to return the experimental points and the equation fitted in the article.

Details

This work is part of the ACOMPLI project. The ACOMPLI project is part of the Strategic Action Plan for the anticipation of the potential European withdrawal of active substances and the development of alternative crop protection techniques (PARSADA). It is financed by ecological planning funds. The French Ministry of Agriculture cannot be held responsible for the content of this package.

Value

A list with the equation used, and a list of model parameters for the different life stages considered in the article.

See Also

Qureshi, M. H., T. Murai, H. Yoshida, T. Shiraga and H. Tsumuki (1999) Effects of photoperiod and temperature on development and diapause induction in the Okayama population of Helicoverpa armigera (Hb) (Lepidoptera: Noctuidae). Appl. Entomol. Zool. 34: 327–331. https://doi.org/10.1303/aez.34.327

Examples

```
mymodel <- ha_qureshi1999_ls(plotfig = FALSE)
```

`hilbertLogan_83` *Holling type III equation of development rate as a function of temperature.*

Description

Hilbert, DW, y JA Logan (1983) Empirical model of nymphal development for the migratory grasshopper, Melanoplus sanguinipes (Orthoptera: Acrididae). Environmental Entomology 12(1): 1-5.

Usage

```
hilbertLogan_83
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = phi * ((\frac{(T - Tb)^2}{(T - Tb)^2 + aa^2}) - e^{-\frac{Tmax - (T - Tb)}{deltaT}})$$

where rT is the development rate, T the temperature, Tb the minimum temperature for development, deltaT the width of high temperature boundary area, Tmax the maximum temperature, and aa a constant.

References

doi:10.1093/ee/12.1.1

`janisch_32` *Janisch equation of development rate as a function of temperature (Analytis modification).*

Description

Janisch, E. (1932) The influence of temperature on the life-history of insects. Transactions of the Royal Entomological Society of London 80(2): 137-68.

Analytis, S. (1977) Uber die Relation zwischen biologischer Entwicklung und Temperatur bei phytopathogenen Pilzen. Journal of Phytopathology 90(1): 64-76.

Analytis, S. (1981). Relationship between temperature and development times in phytopathogenic fungus and in plant pests: a mathematical model. Agric. Res.(Athens), 5, 133-159.

Kontodimas, D.C., Eliopoulos, P.A., Stathas, G.J. and Economou, L.P. (2004) Comparative temperature-dependent development of Nephus includens (Kirsch) and Nephus bisignatus (Boheman)(Coleoptera: Coccinellidae) preying on Planococcus citri (Risso)(Homoptera: Pseudococcidae): evaluation of a linear and various nonlinear models using specific criteria. Environmental Entomology 33(1): 1-11.

Usage

```
janisch_32
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = (\frac{Dmin}{2} * (e^{aa*(T-Topt)} + e^{-bb*(T-Topt)}))^{-1}$$

where rT is the development rate, T the temperature, Topt the optimum temperature, Dmin, aa, and bb constants.

References

doi:10.1111/j.13652311.1932.tb03305.x

kontodimas_04 *Kontodimas et al. equation of development rate as a function of temperature.*

Description

Kontodimas, D.C., Eliopoulos, P.A., Stathas, G.J. and Economou, L.P. (2004) Comparative temperature-dependent development of Nephus includens (Kirsch) and Nephus bisignatus (Boheman)(Coleoptera: Coccinellidae) preying on Planococcus citri (Risso)(Homoptera: Pseudococcidae): evaluation of a linear and various nonlinear models using specific criteria. Environmental Entomology 33(1): 1-11.

Usage

```
kontodimas_04
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = aa * (T - Tmin)^2 * (Tmax - T)$$

where rT is the development rate, T the temperature, Tmin the minimum temperature, Tmax the maximum temperature, and aa a constant.

References

doi:10.1603/0046225X33.1.1

`lactin1_95` *Lactin et al. equation 1 of development rate as a function of temperature.*

Description

Lactin, Derek J, NJ Holliday, DL Johnson, y R Craigen (995) Improved rate model of temperature-dependent development by arthropods. Environmental Entomology 24(1): 68-75.

Usage

```
lactin1_95
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = e^{aa*T} - e^{aa*Tmax - \frac{Tmax-T}{deltaT}}$$

where rT is the development rate, T the temperature, and aa, Tmax, and deltaT fitted parameters.

References

doi:10.1093/ee/24.1.68

`lactin2_95` *Lactin et al. equation 2 of development rate as a function of temperature.*

Description

Lactin, Derek J, NJ Holliday, DL Johnson, y R Craigen (995) Improved rate model of temperature-dependent development by arthropods. Environmental Entomology 24(1): 68-75.

Usage

```
lactin2_95
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = e^{aa*T} - e^{aa*Tmax - \frac{Tmax-T}{deltaT}} + bb$$

where rT is the development rate, T the temperature, and aa, bb, Tmax, and deltaT fitted parameters.

References

doi:10.1093/ee/24.1.68

`lamb_92` *Lamb equation of development rate as a function of temperature.*

Description

Lamb, R. J., Gerber, G. H., & Atkinson, G. F. (1984). Comparison of developmental rate curves applied to egg hatching data of Entomoscelis americana Brown (Coleoptera: Chrysomelidae). Environmental entomology, 13(3), 868-872.

Lamb, RJ. (1992) Developmental rate of Acyrthosiphon pisum (Homoptera: Aphididae) at low temperatures: implications for estimating rate parameters for insects. Environmental Entomology 21(1): 10-19.

Usage

```
lamb_92
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = Rm * e^{-\frac{1}{2}*(\frac{T-Tmax}{To})^2}$$

and

$$rT = Rm * e^{-\frac{1}{2}*(\frac{T-Tmax}{T1})^2}$$

where rT is the development rate, T the temperature, Rm the maximum development rate, Tmax the optimum temperature, and To and T1 the shape parameter giving the spread of the curve.

References

doi:10.1093/ee/21.1.10

logan10_76	*Logan et al. equation 10 of development rate as a function of temperature.*

Description

Logan, J. A., Wollkind, D. J., Hoyt, S. C., and Tanigoshi, L. K. (1976). An analytic model for description of temperature dependent rate phenomena in arthropods. Environmental Entomology, 5(6), 1133-1140.

Usage

```
logan10_76
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = alpha * (\frac{1}{1 + cc * e^{-bb*T}} - e^{-\frac{Tmax-T}{deltaT}})$$

where rT is the development rate, T the temperature, Tmax the maximum temperature, deltaT the width of the high temperature boundary layer, and alpha and bb constants.

References

doi:10.1093/ee/5.6.1133

logan6_76 *Logan et al. equation 6 of development rate as a function of temperature.*

Description

Logan, J. A., Wollkind, D. J., Hoyt, S. C., and Tanigoshi, L. K. (1976). An analytic model for description of temperature dependent rate phenomena in arthropods. Environmental Entomology, 5(6), 1133-1140.

Usage

```
logan6_76
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = phi * (e^{bb*T} - e^{bb*Tmax - \frac{Tmax-T}{deltaT}})$$

where rT is the development rate, T the temperature, Tmax the maximum temperature, deltaT the width of the high temperature boundary layer, phi the developmental rate at some base temperature above developmental threshold, and bb a constant.

References

doi:10.1093/ee/5.6.1133

perf2_11 *Performance-2 equation of development rate as a function of temperature.*

Description

Shi, P., Ge, F., Sun, Y., and Chen, C. (2011) A simple model for describing the effect of temperature on insect developmental rate. Journal of Asia-Pacific Entomology 14(1): 15-20.

Wang, L., P. Shi, C. Chen, and F. Xue. 2013. Effect of temperature on the development of Laodelphax striatellus (Homoptera: Delphacidae). J. Econ. Entomol. 106: 107-114.

Shi, P. J., Reddy, G. V., Chen, L., and Ge, F. (2016). Comparison of Thermal Performance Equations in Describing Temperature-Dependent Developmental Rates of Insects:(I) Empirical Models. Annals of the Entomological Society of America, 109(2), 211-215.

Usage

```
perf2_11
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = cc * (T - T1) * (1 - e^{k*(T-T2)})$$

where rT is the development rate, T the temperature, T1 and T2 the conceptual lower and upper developmental thresholds at which development rates equal zero, and cc and k constants.

References

doi:10.1016/j.aspen.2010.11.008

`poly2` *Second-order polynomial equation of development rate as a function of temperature.*

Description

A simple second-order polynomial equation.

Usage

```
poly2
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = a0 + a1 * T + a2 * T^2$$

where rT is the development rate, T the temperature, and a0, a1, and a2 are constants.

`poly4` *Fourth-order polynomial equation of development rate as a function of temperature.*

Description

A simple fourth-order polynomial equation.

Usage

```
poly4
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = a0 + a1 * T + a2 * T^2 + a3 * T^3 + a4 * T^4$$

where rT is the development rate, T the temperature, and a0, a1, a2, a3, and a4 are constants.

`ratkowsky_82` *Ratkowsky equation of development rate as a function of temperature (Shi modification).*

Description

Ratkowsky, D.A., Olley, J., McMeekin, T.A., and Ball, A. (1982) Relationship between temperature and growth rate of bacterial cultures. Journal of Bacteriology 149(1): 1-5.

Ratkowsky, D.A., R.K. Lowry, T.A. McMeekin, A.N. Stokes, and R.E. Chandler. 1983. Model for bacterial culture growth rate throughout the entire biokinetic temperature range. Journal of Bacteriology 154: 1222-1226.

Shi, P., Ge, F., Sun, Y., and Chen, C. (2011) A simple model for describing the effect of temperature on insect developmental rate. Journal of Asia-Pacific Entomology 14(1): 15-20.

Usage

```
ratkowsky_82
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = (\sqrt{cc} * k1 * (T - T1) * (1 - e^{k2*(T-T2)}))^2$$

where rT is the development rate, T the temperature, T1 and T2 the minimum and maximum temperatures at which rate of growth is zero, sqrt(cc) * k1 the slope of the regression as in the rootsq_82 equation, and k2 a constant. The Ratkowsky model designed for microorganisms has been modified by Shi et al. 2011 to describe the temperature-dependent development rates of insects.

References

doi:10.1128/jb.149.1.15.1982

doi:10.1128/jb.154.3.12221226.1983

`ratkowsky_83` *Ratkowsky equation of development rate as a function of temperature (Shi 2016 modification).*

Description

Ratkowsky, D.A., Olley, J., McMeekin, T.A., and Ball, A. (1982) Relationship between temperature and growth rate of bacterial cultures. Journal of Bacteriology 149(1): 1-5.

Ratkowsky, D.A., R.K. Lowry, T.A. McMeekin, A.N. Stokes, and R.E. Chandler. 1983. Model for bacterial culture growth rate throughout the entire biokinetic temperature range. Journal of Bacteriology 154: 1222-1226.

Shi, P. J., Reddy, G. V., Chen, L., and Ge, F. (2015). Comparison of thermal performance equations in describing temperature-dependent developmental rates of insects: (I) empirical models. Annals of the Entomological Society of America, 109(2), 211-215.

Usage

```
ratkowsky_83
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = (cc * (T - T1) * (1 - e^{k*(T-T2)}))^2$$

where rT is the development rate, T the temperature, T1 and T2 the minimum and maximum temperatures at which rate of growth is zero, cc the slope of the regression as in the rootsq_82 equation, and k a constant. The Ratkowsky model designed for microorganisms has been modified by Shi et al. 2016 to describe the temperature-dependent development rates of insects.

References

doi:10.1093/aesa/sav121

---

regniere_12 *Regniere equation of development rate as a function of temperature.*

Description

Regniere, J., Powell, J., Bentz, B., and Nealis, V. (2012) Effects of temperature on development, survival and reproduction of insects: experimental design, data analysis and modeling. Journal of Insect Physiology 58(5): 634-47.

Usage

```
regniere_12
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = phi * (e^{bb*(T-Tb)} - \frac{Tm-T}{Tm-Tb} * e^{-bb*\frac{T-Tb}{deltab}} - \frac{T-Tb}{Tm-Tb} * e^{\frac{bb*(Tm-Tb)-(Tm-T)}{deltam}})$$

where rT is the development rate, T the temperature, Tb the minimum temperature, Tm the maximum temperature and phi, bb, deltab, and deltam constants (see source for more details).

References

doi:10.1016/j.jinsphys.2012.01.010

`rootsq_82` *Root square equation of development rate as a function of temperature.*

Description

Ratkowsky, D.A., Olley, J., McMeekin, T.A., and Ball, A. (1982) Relationship between temperature and growth rate of bacterial cultures. Journal of Bacteriology 149(1): 1-5.

Usage

```
rootsq_82
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = (bb * (T - Tb))^2$$

where rT is the development rate, T the temperature, bb the slope of the regression line, and Tb a conceptual temperature of no metabolic significance.

References

doi:10.1128/jb.149.1.15.1982

`schoolfieldHigh_81` *Schoolfield et al. equation of development rate as a function of temperature for intermediate to high temperatures only.*

Description

Schoolfield, R., Sharpe, P. & Magnuson, C. (1981) Non-linear regression of biological temperature-dependent rate models based on absolute reaction-rate theory. Journal of theoretical biology, 88, 719-731. Wagner, T.L., Wu, H.I., Sharpe, P.S.H., Schoolfield, R.M., Coulson, R.N. (1984) Modeling insect development rates: a literature review and application of a biophysical model. Annals of the Entomological Society of America 77(2): 208-20.

Usage

```
schoolfieldHigh_81
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{p25 * \frac{T+273.16}{298} * e^{\frac{aa}{1.987} * (\frac{1}{298} - \frac{1}{T+273.16})}}{1 + e^{\frac{dd}{1.987} * (\frac{1}{ee} - \frac{1}{T+273.16})}}$$

where rT is the development rate, T the temperature, p25 the development rate at 25 degrees Celsius assuming no enzyme inactivation, aa the enthalpy of activation of the reaction that is catalyzed by the enzyme, bb the change in enthalpy associated with low temperature inactivation of the enzyme, cc the the temperature at which the enzyme is 1/2 active and 1/2 low temperature inactive, dd the cange in enthalpy associated with high temperature inactivation of the enzyme, and ee the temperature at which the enzyme is 1/2 active and 1/2 high temperature inactive.

References

doi:10.1016/00225193(81)902460

`schoolfieldLow_81` *Schoolfield et al. equation of development rate as a function of temperature for intermediate to low temperatures only.*

Description

Schoolfield, R., Sharpe, P. & Magnuson, C. (1981) Non-linear regression of biological temperature-dependent rate models based on absolute reaction-rate theory. Journal of theoretical biology, 88, 719-731. Wagner, T.L., Wu, H.I., Sharpe, P.S.H., Schoolfield, R.M., Coulson, R.N. (1984) Modeling insect development rates: a literature review and application of a biophysical model. Annals of the Entomological Society of America 77(2): 208-20.

Usage

```
schoolfieldLow_81
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{p25 * \frac{T+273.16}{298} * e^{\frac{aa}{1.987}*(\frac{1}{298}-\frac{1}{T+273.16})}}{1 + e^{\frac{bb}{1.987}*(\frac{1}{cc}-\frac{1}{T+273.16})}}$$

where rT is the development rate, T the temperature, p25 the development rate at 25 degrees Celsius assuming no enzyme inactivation, aa the enthalpy of activation of the reaction that is catalyzed by the enzyme, bb the change in enthalpy associated with low temperature inactivation of the enzyme, cc the the temperature at which the enzyme is 1/2 active and 1/2 low temperature inactive, dd the cange in enthalpy associated with high temperature inactivation of the enzyme, and ee the temperature at which the enzyme is 1/2 active and 1/2 high temperature inactive.

References

doi:10.1016/00225193(81)902460

`schoolfield_81` *Schoolfield et al. equation of development rate as a function of temperature.*

Description

Schoolfield, R., Sharpe, P. & Magnuson, C. (1981) Non-linear regression of biological temperature-dependent rate models based on absolute reaction-rate theory. Journal of theoretical biology, 88, 719-731.

Usage

```
schoolfield_81
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{p25 * \frac{T+273.16}{298} * e^{\frac{aa}{1.987}*(\frac{1}{298}-\frac{1}{T+273.16})}}{1 + e^{\frac{bb}{1.987}*(\frac{1}{cc}-\frac{1}{T+273.16})} + e^{\frac{dd}{1.987}*(\frac{1}{ee}-\frac{1}{T+273.16})}}$$

where rT is the development rate, T the temperature, p25 the development rate at 25 degree Celsius assuming no enzyme inactivation, aa the enthalpy of activation of the reaction that is catalyzed by the enzyme, bb the change in enthalpy associated with low temperature inactivation of the enzyme, cc the temperature at which the enzyme is 1/2 active and 1/2 low temperature inactive, dd the change in enthalpy associated with high temperature inactivation of the enzyme, and ee the temperature at which the enzyme is 1/2 active and 1/2 high temperature inactive.

References

doi:10.1016/00225193(81)902460

`sharpeDeMichele_77` *Sharpe and DeMichele equation of development rate as a function of temperature.*

Description

Sharpe, P.J. & DeMichele, D.W. (1977) Reaction kinetics of poikilotherm development. Journal of Theoretical Biology, 64, 649-670.

Usage

```
sharpeDeMichele_77
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).

eqAlt The equation (string).

name The name of the equation.

ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{(T + 273.16) * e^{\frac{aa - \frac{bb}{T+273.16}}{1.987}}}{1 + e^{\frac{cc - \frac{dd}{T+273.16}}{1.987}} + e^{\frac{ff - \frac{gg}{T+273.16}}{1.987}}}$$

where rT is the development rate, T the temperature, and aa, bb, cc, dd, ff, and gg thermodynamic parameters.

References

doi:10.1016/00225193(77)90265X

`shi_11` *Shi equation of development rate as a function of temperature.*

Description

Shi, P., Ge, F., Sun, Y., and Chen, C. (2011) A simple model for describing the effect of temperature on insect developmental rate. Journal of Asia-Pacific Entomology 14(1): 15-20.

Usage

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shi_11
```

Format

A list of eight elements describing the equation.

eq The equation (formula object).
eqAlt The equation (string).
name The name of the equation.
ref The equation reference.
refShort The equation reference shortened.
startVal The parameters found in the literature with their references.
com An optional comment about the equation use.
id An id to identify the equation.

Details

Equation:
$$rT = cc * (1 - e^{-k1*(T-T1)}) * (1 - e^{k2*(T-T2)})$$

where rT is the development rate, T the temperature, T1 and T2 the conceptual lower and upper developmental thresholds at which development rates equal zero, and cc k1, and k2 constants.

References

doi:10.1016/j.aspen.2010.11.008

`stinner_74` *Stinner et al equation of development rate as a function of temperature.*

Description

Stinner, R., Gutierrez, A. & Butler, G. (1974) An algorithm for temperature-dependent growth rate simulation. The Canadian Entomologist, 106, 519-524.

Usage

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stinner_74
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Format

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Details

Equation:

$$rT = \frac{C}{1 + e^{k1 + k2 * T}}$$

and

$$rT = \frac{C}{1 + e^{k1 + k2 * (2 * Topt - T)}}$$

where rT is the development rate, T the temperature, Topt the optimum temperature, k1 and k2 constants. "[...] the relationship [is] inverted when the temperature is above an optimum [...] T = 2 * Topt - T for T >= Topt." Stinner et al. 1974.

References

doi:10.4039/Ent1065195

---

taylor_81 *Taylor equation of development rate as a function of temperature.*

Description

Taylor, F. (1981) Ecology and evolution of physiological time in insects. American Naturalist, 1-23.

Lamb, RJ. (1992) Developmental rate of Acyrthosiphon pisum (Homoptera: Aphididae) at low temperatures: implications for estimating rate parameters for insects. Environmental Entomology 21(1): 10-19.

Usage

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taylor_81
```

Format

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ref The equation reference.

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id An id to identify the equation.

Details

Equation:

$$rT = Rm * e^{-\frac{1}{2}*(\frac{T-Tm}{To})^2}$$

where rT is the development rate, T the temperature, Rm the maximum development rate, Tm the optimum temperature, and To the rate at which development rate falls away from Tm.

---

wagner_88 — *Hagstrum et Milliken equation of development rate as a function of temperature retrieved from Wagner 1984.*

Description

Hagstrum, D.W., Milliken, G.A. (1988) Quantitative analysis of temperature, moisture, and diet factors affecting insect development. Annals of the Entomological Society of America 81(4): 539-46.

Wagner, T.L., Wu, H.I., Sharpe, P.S.H., Schoolfield, R.M., Coulson, R.N. (1984) Modeling insect development rates: a literature review and application of a biophysical model. Annals of the Entomological Society of America 77(2): 208-20.

Usage

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wagner_88
```

Format

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ref The equation reference.

refShort The equation reference shortened.

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id An id to identify the equation.

Details

Equation:

$$rT = \frac{1}{\frac{1+e^{\frac{cc}{1.987}*(\frac{1}{dd}-\frac{1}{T+273.16})}}{aa*\frac{T+273.16}{298.15}*e^{\frac{bb}{1.987}*(\frac{1}{298.15}-\frac{1}{T+273.16})}}}$$

where rT is the development rate, T the temperature, and aa, bb, cc, and dd are thermodynamic parameters.

References

doi:10.1093/aesa/77.2.208

doi:10.1093/aesa/81.4.539

`wangengel_98` *Wang and Engel equation of development rate as a function of temperature.*

Description

Wang, E., and Engel, T. (1998) Simulation of phenological development of wheat crops. Agricultural systems 58(1): 1-24.

Usage

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wangengel_98
```

Format

A list of eight elements describing the equation.

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ref The equation reference.

refShort The equation reference shortened.

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com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{2 * (T - Tmin)^{aa} * (Topt - Tmin)^{aa} - (T - Tmin)^{2*aa}}{(Topt - Tmin)^{2*aa}}$$

where rT is the development rate, T the temperature, Tmin the minimum temperature, Topt the optimum temperature, and aa a constant.

References

doi:10.1016/S0308521X(98)000286

wang_82 *Wang et al. equation of development rate as a function of temperature.*

Description

Wang, R., Lan, Z. and Ding, Y. (1982) Studies on mathematical models of the relationship between insect development and temperature. Acta Ecol. Sin, 2, 47-57.

Usage

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wang_82
```

Format

A list of eight elements describing the equation.

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ref The equation reference.

refShort The equation reference shortened.

startVal The parameters found in the literature with their references.

com An optional comment about the equation use.

id An id to identify the equation.

Details

Equation:

$$rT = \frac{K}{1 + e^{-r*(T-T0)}} * (1 - e^{-\frac{T-TL}{aa}}) * (1 - e^{-\frac{TH-T}{aa}})$$

where rT is the development rate, T the temperature, and K, r, T0, TH, and TL constants.

References

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