Package 'MASSTIMATE'

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Title Body Mass Estimation Equations for Vertebrates

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Description Estimation equations are from a variety of sources and associated error estimation.

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Contents

MASSTIMATE-package *Body mass estimation equations for vertebrates*

Description

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Details

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Author(s)

Nicolas E. Campione

Maintainer: Nicolas E. Campione <ncampion@une.edu.au>

References

Anderson, J. F., Hall-Martin, A. and Russell, D.A. (1985) Long-bone circumference and weight in mammals, birds and dinosaurs. Journal of the Zoological Society of London A, 207, 53-61.

Campbell Jr., K.E. and Marcus, L. (1992) The relationships of hindlimb bone dimensions to body weight in birds. Natural History Museum of Los Angeles County Science Series, 36, 395-412.

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E., Evans, D. C., Brown, C. M. and Carrano, M. T. (2014) Body mass estimation in non-avian bipeds using a theoretical conversion to quadruped stylopodial proportions. Methods in Ecology and Evolution, 5(9), 913-923.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43, 693-699.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precision of body mass estimation in non-avian dinosaurs. Biological Reviews.

Christiansen, P. and Farina, R. A. (2004) Mass prediction in theropod dinosaurs. Historical Biology, 16, 85-92.

Erickson G. M. and Tumanova, T. A. (2000). Growth curve of Psittacosaurus mongoliensis Orborn (Ceratopsia; Psittacosauridae) inferred from long bone histology. Zoological Journal of the Linnean Society, 130, 551-566.

Mazzetta, G. V., Christiansen, P. and Farina, R. A. (2004) Giants and bizzares: body size of some southern South American Cretaceous dinosaurs. Historical Biology, 16, 71-83.

`AHR1985` *Body Mass Estimates Using Anderson et al. (1985)*

Description

This function estimates body mass based on humeral and/or femoral circumferences using the quadrupedal and bipedal equations of Anderson et al. (1985)

Usage

```
AHR1985(HC = NULL, FC, equation = c("bip", "quad"), data=NULL)
```

Arguments

`HC`	an optional value or vector representing humeral circumference (in mm)
`FC`	a value or vector representing femoral circumference (in mm)
`equation`	desired estimation equation. Two possible choices: `"quad"`, `"bip"`
`data`	an optional object of `class = "data.frame"` or `class = "matrix"`

Details

If `equation = "bip"` then only femoral circumference is needed. Both humeral and femoral circumference are needed to estimate body mass of a quadruped (`equation = "quad"`). If a data object is specified, the mass estiamtes will be added as a column to the data.frame or matrix within that object.

Value

`AHR1985`	A numeric value or vector representing the mass estimate(s) in grams

Author(s)

Nicolas E. Campione

References

Anderson, J. F., Hall-Martin, A. and Russell, D.A. (1985) Long-bone circumference and weight in mammals, birds and dinosaurs. Journal of the Zoological Society of London A, 207, 53-61.

See Also

QE cQE quadrupeds bipeds CM1992 CF2004 MCF2004

Examples

```
##Quadrupedal dinosaurs
data(dinos)
AHR1985(dinos$HC, dinos$FC, equation = "quad", data = dinos)

##Bipedal dinosaurs
data(dinosbip)
AHR1985(HC=NULL, dinosbip$FC, equation = "bip", data = dinosbip)
```

---

bipeds *Body Mass Estimates Using cQE, AHR1985, CF2004, and CM1992*

Description

This function returns body mass estimates for bipeds based on minimum femoral circumference using a set of five equations (intended for non-avian dinosaurs)

Usage

```
bipeds(FC, cQE.eq = "raw", cQE.cor = 2, data = NULL)
```

Arguments

FC	a value or vector representing femoral circumference (should be in mm)
cQE.eq	desired estimation equation for the cQE. Two possible choices (See cQE). "raw" is default
cQE.cor	correction factor to be used (α^2). The default is 2, as per Campione et al. (2014)
data	an optional object of class = "data.frame" or class = "matrix"

Details

This function returns estimates from five equations intented for terrestrial bipeds (in particular non-avian dinosaurs): Campione et al. (2014); Campione (in review); Anderson et al. (1985); Christiansen and Farina (2004); Campbell and Marcus (1992). For more details please see the specific functions.

If a data object is specified, the mass estiamtes and additional results will be added as columns to the data.frame or matrix within that object.

Value

Nine numeric values or columns are returned (all masses are in grams):

`cQE`	A numeric value or vector of mass estimates using cQE
`upper.cQE`	A numeric value or vector representing the upper prediction error of the cQE based on that derived for the specific equation in Campione and Evans (2012)
`lower.cQE`	A numeric value or vector representing the lower prediction error of the cQE
`qcQE`	A numeric value or vector of mass estimates using qcQE (quadratic equation)
`upper.qcQE`	A numeric value or vector representing the upper prediction error of qcQE derived for the specific equation in Campione (in review)
`lower.qcQE`	A numeric value or vector representing the lower prediction error of qcQE
`AHR1985`	A numeric value or vector of mass estimates using Anderson et al. (1985)
`CF2004`	A numeric value or vector of mass estimates using Christiansen and Farina (2004)
`CM1992`	A numeric value or vector of mass estimates using Campbell and Marcus (1992)

Author(s)

Nicolas E. Campione

References

Anderson, J. F., Hall-Martin, A. and Russell, D.A. (1985) Long-bone circumference and weight in mammals, birds and dinosaurs. Journal of the Zoological Society of London A, 207, 53-61.

Campbell Jr., K.E. and Marcus, L. (1992) The relationships of hindlimb bone dimensions to body weight in birds. Natural History Museum of Los Angeles County Science Series, 36, 395-412.

Campione, N. E., Evans, D. C., Brown, C. M. and Carrano, M. T. (2014) Body mass estimation in non-avian bipeds using a theoretical conversion to quadruped stylopodial proportions. Methods in Ecology and Evolution, 5(9), 913-923.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43, 693-699.

Christiansen, P. and Farina, R. A. (2004) Mass prediction in theropod dinosaurs. Historical Biology, 16, 85-92.

See Also

`cQE` `AHR1985` `CF2004` `CM1992`

CF2004 *Body Mass Estimates Using Christiansen and Farina (2004)*

Description

This function is meant for bipedal mass estimate (in particular theropod dinosaurs) and offers some of the body mass prediction equations published by Christiansen and Farina (2004) derived from volumetric reconstructions of theropod dinosaurs

Usage

```
CF2004(X, X2 = NULL, eqn, data = NULL)
```

Arguments

X	a value or vector representing the first variable in the equation (in mm)
X2	an optional second variable with same length as X, should the equation be multiple (see Details) in mm
eqn	a character specifying the desired prediction equation (see Details)
data	an optional object of class = "data.frame" or class = "matrix"

Details

Possible bivariate regression equations (eqn =) include: femur length ("FL"), femur circumference ("FC"), femur anteroposterior diameter ("FAP"), femur mediolateral diameter ("FML"), tibia circumference ("TC"), tibia distal mediolateral diameter ("TdistML"), fibula distal anteroposterior diameter ("FidistAP"). Multiple regression equations include femur circumference + length ("FC+FL"), femur mediolateral diameter + femur length ("FML+FL"), tibia circumference + femur length ("TC+FL"), tibia length + femur circumference ("TL+FC"), and tibia circumference + femur anteroposterior diameter ("TC+FAP"). If a multiple regression equation is chosen, X2 != NULL. See Christiansen & Farina (2004) for specific details and Campione & Evans (2020) for evaluations of the models. If a data object is specified, the mass estiamtes will be added as a column to the data.frame or matrix within that object.

Value

CF2004	A vector representing the mass estimate(s) in log grams and grams

Author(s)

Nicolas E. Campione

References

Christiansen, P. and Farina, R. A. (2004) Mass prediction in theropod dinosaurs. Historical Biology, 16, 85-92.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

See Also

cQE bipeds AHR1985 CM1992

Examples

```
##Bipedal dinosaurs
data(dinosbip)
CF2004(dinosbip$FC, eqn = "FC", data = dinosbip)
```

CM1992 *Body Mass Estimates Using Campbell and Marcus (1992)*

Description

This function estimates body mass based on femoral circumference using the avian equation of Campbell and Marcus (1992)

Usage

```
CM1992(FC, data = NULL)
```

Arguments

FC	a value of vector representing femoral circumference (in mm)
data	an optional object of class = "data.frame" or class = "matrix"

Details

If a data object is specified, the mass estiamtes will be added as a column to the data.frame or matrix within that object.

Value

CM1992	A numeric value or vector representing the mass estimate(s) in grams

Author(s)

Nicolas E. Campione

References

Campbell Jr., K.E. and Marcus, L. (1992) The relationships of hindlimb bone dimensions to body weight in birds. Natural History Museum of Los Angeles County Science Series, 36, 395-412.

See Also

cQE bipeds AHR1985 CF2004

Examples

```
##Bipedal dinosaurs
data(dinosbip)
CM1992(dinosbip$FC, data = dinosbip)
```

---

cQE *Body Mass Estimates Using Bipedal Correction Factor*

Description

This function presents equations from Campione et al. (2014) for esimating body mass in bipeds using minimum femoral circumference and based on a correction of the quadrupedal equations from Campione and Evans (2012)

Usage

```
cQE(FC, equation = "raw", cor = 2, quadratic = FALSE,
data = NULL, return_PI = FALSE)
```

Arguments

FC	a value or vector representing femoral circumference (in mm)
equation	desired estimation equation. Two possible choices (See Details)
cor	correction factor to be used (α^2). The default is 2, as per Campione et al. (2014)
quadratic	a logical indicating whether estimates based on the quadratic equation should be used (See Details)
data	an optional object of class = "data.frame" or class = "matrix"
return_PI	an optional logical value to also provide the wider prediction intervals on the estimate, currenly only works if equation = "raw"

Details

The function includes two different equations. equation = "raw" (default) applies the correction factor derived in Campione et al. (2014) to the raw (non-phylogenetically corrected) bivariate regression equation from Campione and Evans (2012). equation = "phylocor" applies the same correction factor to the phylogenetically corrected equation presented in the same study.

cor = 2 refers to the correction factor (α^2) to be used. The default (cor = 2) refers the initial derivation in Campione et al. (2014), however, this value can be modified based on the level of eccentricity of the femur. A set of values for cor corresponding to set eccentricities can be found in table S2 of Campione et al. (2014).

If quadratic = TRUE, then a second set of estimates will be returned based on a quadratic estimation equation (Campione, 2017).

If a data object is specified, the mass estiamtes and additional results will be added as columns to the data.frame or matrix within that object.

Value

Eight numeric values or columns are returned if `quadratic = TRUE` (identified by `q`):

`log.cQE`	A numeric value or vector representing the mass estimate(s) in log10 grams
`cQE`	A numeric value or vector representing the mass estimate(s) in grams
`lower.cQE`	A numeric value or vector representing the lower prediction error derived for the specific equation in Campione and Evans (2012)
`upper.cQE`	A numeric value or vector representing the upper prediction error
`log.qcQE`	A numeric value or vector representing the mass estimate(s) in log10 grams using a quadratic equation
`qcQE`	A numeric value or vector representing the mass estimate(s) in grams
`lower.qcQE`	A numeric value or vector representing the lower prediction error derived for the specific equation by Campione (2017)
`upper.qcQE`	A numeric value or vector representing the upper prediction error

Author(s)

Nicolas E. Campione

References

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E., Evans, D. C., Brown, C. M. and Carrano, M. T. (2014) Body mass estimation in non-avian bipeds using a theoretical conversion to quadruped stylopodial proportions. Methods in Ecology and Evolution, 5(9), 913-923.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43 (4), 693-699.

See Also

`QE` `bipeds` `AHR1985` `CF2004` `CM1992`

Examples

```
##Bipedal dinosaurs
data(dinosbip)

#Estimates for Tyrannosaurus (FMNH PR 2081 "Sue")
sue<-which(dinosbip$Taxon=="TyrannosaurusFMNH2081")
cQE(dinosbip$FC[sue]) #default correction factor
cQE(dinosbip$FC[sue], cor = 1.815) #based on eccentricity of the femur

##Estimates of bipedal dinosaurs using phylogeneteically corrected linear and quadratic equations
cQE(dinosbip$FC, equation = "phylocor", cor = dinosbip$cor, quadratic = TRUE, data = dinosbip)
```

dinos *Dinosaur data from Campione and Evans 2012*

Description

Humeral and Femoral circumference data for eight quadrupedal dinosaurs

Usage

```
data(dinos)
```

Format

A data frame with 8 observations and the following 3 variables.

`Taxon` a factor with levels `Brachiosaurs` `Corythosaurus` `Diplodocus` `Iguanodon` `Protoceratops` `Stegosaurus` `Styracosaurus` `Triceratops`

`HC` a numeric vector of humeral circumferences

`FC` a numeric vector of femoral circumferences

Source

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

dinosbip *Dinosaur data from Campione et al. (2014)*

Description

Femoral circumference data for 34 bipedal dinosaurs

Usage

```
data(dinosbip)
```

Format

A data frame with 34 observations and the following 3 variables.

`Taxon` a factor with the taxon names

`FC` a numeric vector of femoral circumferences

`cor` a numeric vector with the correction factor (α^2) values to be used in `cQE`

Source

Campione, N. E., Evans, D. C., Brown, C. M. and Carrano, M. T. (2014) Body mass estimation in non-avian bipeds using a theoretical conversion to quadruped stylopodial proportions. Methods in Ecology and Evolution, 5(9), 913-923.

`dino_comparisons` *Reconstruction body masses and associated limb circumference data from Campione & Evans (2020)*

Description

Metadata combining volumetric-density reconstruction mass estimates with their associated limb circumference measurements.

Usage

```
data("dino_comparisons")
```

Format

A data frame with 447 observations on the following 8 variables.

`Clade` a character vector specifying the clade to which the `Taxon` belongs.

`Taxon` a character vector specifying the genus or species name.

`Recon.Method` a character vector specifying the reconstruction method used to generate `Recon.BM`.

`Recon.BM` a numeric vector of the reconstruction body mass, in g.

`Gait` a character vector specifying whether the `Taxon` is bipedal or quadrupedal.

`HCFC` a numeric vector of the combined humeral and femoral circumferences, in mm (if `Gait = "quad"`).

`HC` a numeric vector of the humeral circumferences, in mm (if `Gait = "quad"`).

`FC` a numeric vector of the femoral circumferences, in mm.

Source

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

DME *Developmental Mass Extrapolation*

Description

This function estimates the body mass of an immature specimen based on the mass of a presumed adult and a standard measurement (e.g., femur length or circumference), as described by Erickson and Tumanova (2000).

Usage

```
DME(juv_proxy, adu_proxy, adu_mass, scale_fac = 3)
```

Arguments

juv_proxy	numeric value or vector corresponding to the measurement taken on the immature specimen(s) of interest
adu_proxy	numeric value corresponding to the measurement taken on the presumed adult representative
adu_mass	numeric value corresponding to the body mass of the adult representative
scale_fac	numeric value corresponding to the growth allometric scaling factor applied to the immature and adult specimens, defaults to 3 (i.e., isometry)

Details

It cannot be assumed that growth-related allometric scaling coefficients will be consistent with those derived from interspecific relationships of adults (e.g.,QE). DME was developed by Erickson and Tumanova (2000) in order to extrapolate the body mass of an adult to that of an immature specimen through the use of a growth-related scaling factor. Although the assumed scaling factor is that of isometry between a linear and volumetric measurement (scale_fac = 3), if an alternate scaling factor is known, then it can be incorporated by adjusting the scale_fac value.

Value

A numeric value or vector representing the mass estimate(s) in grams of the immature specimen(s).

Author(s)

Nicolas E. Campione

References

Brassey C. A., Maidment, S. C. R. & Barrett, P. M. (2015). Body mass estimates of an exceptionally complete Stegosaurus (Ornithischia: Thyreophora): comparing volumetric and linear bivariate mass estimation methods. Biology Letters, 11, 20140984.

Erickson G. M. and Tumanova, T. A. (2000). Growth curve of Psittacosaurus mongoliensis Orborn (Ceratopsia; Psittacosauridae) inferred from long bone histology. Zoological Journal of the Linnean Society, 130, 551-566.

See Also

QE cQE

Examples

```
##Based on the immature Stegosaurus from Brassey et al. (2015)

## Immature (NHMUK R36730: HC = 282, FC = 339, FL = 863
## Adult (YPM1853): HC = 352, FC = 425, FL = 1348

##DME estimate, adult extracted from dinos dataset
DME(juv_proxy = 863, adu_proxy = 1348, adu_mass = QE(352+425)[2])
```

---

extants *Extant limb data from Campione and Evans 2012*

Description

Humeral and Femoral data for 245 living tetrapods, including mammals and reptiles

Usage

```
data(extants)
```

Format

A data frame with 245 observations and the following 13 variables.

`Mon.Groups` a character vector representing the inclusive clade

`Family` a character vector representing the family level taxonomy

`Species` a character vector identifying the mammal or reptile species

`Common.Name` a character vector identifying the common species name

`SP.` a character vector specifying the specimen number (see Campione and Evans 2012 for more details)

`BM` a numeric vector of body masses (in g)

`Humerus.Length` a numeric vector of humeral lengths (in mm)

`HC` a numeric vector of humeral circumferences (in mm)

`Femur.Length` a numeric vector of femoral lengths (in mm)

`FC` a numeric vector of femoral circumferences (in mm)

`HCFC` a numeric vector of combined humeral and femoral circumferences (in mm)

`log.BM` a numeric vector of the base-10 logarithms of body masses

`log.HCFC` a numeric vector of the base-10 logarithms of combined humeral and femoral circumferences

Source

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

`MASSunite` *Body mass comparisons, projecting reconstructions onto an extant standard*

Description

The main function for projecting a body mass estimate from a reconstruction onto the limb circumference standard of accuracy, as presented by Campione & Evans (2020).

Usage

```
MASSunite(HFC = NULL, HC, FC, BM, ES.type = "QE", gait, VD.par = NULL, line = FALSE, ...)
```

Arguments

`HFC`	a numeric value or vector representing the combined humeral and femoral circumferences (in mm)
`HC`	a numeric value or vector representing humeral circumference (in mm)
`FC`	a numeric value or vector representing femoral circumference (in mm)
`BM`	a numeric value or vector associated with the limb circumferences, ideally generates by a reconstruction approach (in g)
`ES.type`	a character specifying whether a linear or quadratic equation should be used as the extant limb scaling standard, (default is linear `ES.type = "QE"`)
`gait`	a character specifying whether the reconstruction is `gait = "biped"` or `gait = "quadruped"`
`VD.par`	a list of parameters to be used when plotting. Options include: `pch`, an integer specifying a symbol or a single character to be used to project a reconstruction, `col`, a character specifying the colour to be used for the prejected recontruction(s), `names`, an optional character vector equal in length to `BM` specifying whether names are to be included in the plot (should be specified as `names = NULL`, if unwanted)
`line`	a logical value specifying whether a linear model should be run for the reconstruction (if `length(BM) > 1`)
`...`	parameter arguments passed to scaling standard plot (e.g., `mod_OLS`.

Details

This function will take a set of body masses estimated via volumetric-density (VD) approaches, their accociated limb circumference data (such as that of the humerus and femur for a quadruped), and project them onto the extant standard of accuracy (Campione & Evans, 2010, Campione et al. 2014, Campione & Evans 2020). In addition, there is an option to fit a linear model to the VD reconstructions, allowing visual comparison to the extant relationship (see `line = TRUE`).

Both the linear and quadratic extant models can be used (see Campione, 2017) and residual deviations are calculated in accordance with the specified model. Residual plot, however, will depict both the upper and lower extremes of the prediction intervals as these can vary along the regression lines, especially is `ES.type = "qQE"`.

Value

A list of variable length depending on the parameters specified. Permanent values include:

`Residual`	a numeric value or vector with the residual deviation between VD reconstructions and the ES standard
`mean.Residual`	a numeric value of the average residual value
`PPE`	a list with output of the `ppe` function

Optional values include:

`Inferred.Line`	object of class `lm` with the output from the linear model, if `line = TRUE`
`Outliers`	an optional vector specifying VD resconstruction data points that occur outside the prediction intervals of the extant standard
`Caution`	if `length(Outliers) > 0`, then a warning message will be generated

Author(s)

Nicolas E. Campione

References

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E., Evans, D. C., Brown, C. M. and Carrano, M. T. (2014) Body mass estimation in non-avian bipeds using a theoretical conversion to quadruped stylopodial proportions. Methods in Ecology and Evolution, 5(9), 913-923.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43 (4), 693-699.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

See Also

`QE` `cQE` `lm`

Examples

```
# metadata from Campione & Evans (2020)
data(dino_comparisons)

# using linear standard and quadupedal dinosaurs w/ VD reconstruction line
MASSunite(dino_comparisons$HCFC, BM = dino_comparisons$Recon.BM, gait = "quadruped",
VD.par = list(pch = 19, col = "pink", names = NULL), line = TRUE)

# using quadratic standard and bipedal dinsoaurs w/ no line
MASSunite(FC = dino_comparisons$FC, BM = dino_comparisons$Recon.BM, ES.type = "qQE", gait = "biped",
VD.par = list(pch = 19, col = "pink", names = NULL))
```

MCF2004 *Body Mass Estimates Using Mazzetta et al. (2004)*

Description

This function is meant for quadrupedal mass estimates (in particularly sauropod dinosaurs) and offers some of the body mass prediction equations published by Mazzetta et al. (2004) derived from volumetric reconstructions of sauropod dinosaurs

Usage

```
MCF2004(X, eqn, data = NULL)
```

Arguments

X	a value or vector representing the variable in the equation (in mm)
eqn	a character specifying the desired prediction equation (see Details)
data	an optional object of `class = "data.frame"` or `class = "matrix"`

Details

Possible equations (`eqn =`) include: femur length (`"FL"`), modified femur length (`"FL*"`), femur circumference (`"FC"`), tibia length (`"TL"`), and tibia circumference (`"TC"`). See Mazzetta et al. (2004) for specific details and Campione & Evans (2020) for evaluations of the models. If a data object is specified, the mass estiamtes will be added as a column to the data.frame or matrix within that object.

Value

MCF2004	A numeric value or vector representing the mass estimate(s) in grams

Author(s)

Nicolas E. Campione

References

Mazzetta, G. V., Christiansen, P. and Farina, R. A. (2004) Giants and bizzares: body size of some southern South American Cretaceous dinosaurs. Historical Biology, 16, 71-83.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

See Also

QE quadrupeds MR AHR1985

Examples

```
##Quadrupedal dinosaurs
data(dinos)
MCF2004(dinos$FC, eqn = "FC", data = dinos)
```

---

mod_OLS *Extant standard using a linear, ordinary least squares model*

Description

An internal function used by MASSunite to project a VD recontruction onto a standard of accuracy.

Usage

```
mod_OLS(xvar = extants$log.HCFC, yvar = extants$log.BM,
                  xlab = "Log Stylopodial Circumference",ylab = "Log Body Mass",
               xlim = c(1, 3.5), ylim = c(1.5, 8), cex = 0.5, pch = 4, col = "gray",
                  fit.col = "black", pred.seq = seq(from = 1, to = 4, by = 0.01),
                    PI.col = "blue", PI.lty = 2, CI.col = "red", CI.lty = 1,
                    verbose = FALSE, plot = TRUE, ...)
```

Arguments

xvar, yvar	the x and y coordinates of the model, defaults to the log combined humeral and femoral circumferences and their associated log body mass, respectively.
xlab, ylab	single character objects specifying the axes labels, as in par, defaults to xlab = "Log Stylopodial Circumference" and ylab = "Log Body Mass".
xlim, ylim	numeric vector specifying the axes ranges, as in par, defaults to xlim = c(1, 3.5) and ylim = c(1.5, 8).
cex, pch, col	main plotting parameters, as in par, defaults to cex = 0.5, pch = 4, and col = "gray".
fit.col	character object specifying the colour of the fitted line.
pred.seq	integer or numeric sequence use as newdata to generate confidence and prediction intervals.

PI.col, PI.lty	colour and line-type parameters for the prediction interval lines.
CI.col, CI.lty	colour and line-type parameters for the confidence interval lines.
verbose	a logical value indicating whether the results of the model fitting are returned.
plot	a logical value indicating whether the plot should be produced, defaults to plot = FALSE.
...	parameter arguments passed to plot.

Details

This function is mostly used internally by MASSunite to project volumetric reconstruction models onto the linear limb circumferences standard of accuracy, as presented in Campione & Evans (2020). However, the function can technically be used to generate a plot of any x-y coordinates with their fitted ordinary least squares line and associated confidence/prediction intervals. N.B. If modified, the defaults may not suite.

Value

The default function will generate a plot. If verbose = TRUE a 3 item list will be returned with:

model	the output from lm.
prediction	a 3-column matrix with the fitted, lower, and upper prediction intervals for the vector given in pred.seq.
confidence	a 3-column matrix with the fitted, lower, and upper confidence intervals for the vector given in pred.seq.

Author(s)

Nicolas E. Campione

References

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

See Also

MASSunite mod_QUAD

Examples

```
mod_OLS()
```

mod_QUAD *Extant standard using a non-linear, quadratic model*

Description

An internal function used by MASSunite to project a VD recontruction onto a standard of accuracy.

Usage

```
mod_QUAD(xvar = extants$log.HCFC, yvar = extants$log.BM,
                  xlab = "Log Stylopodial Circumference",ylab = "Log Body Mass",
               xlim = c(1, 3.5), ylim = c(1.5, 8), cex = 0.5, pch = 4, col = "gray",
                  fit.col = "black", pred.seq = seq(from = 1, to = 4, by = 0.01),
                    PI.col = "blue", PI.lty = 2, CI.col = "red", CI.lty = 1,
                    verbose = FALSE, plot = TRUE, ...)
```

Arguments

xvar, yvar	the x and y coordinates of the model, defaults to the log combined humeral and femoral circumferences and their associated log body mass, respectively.
xlab, ylab	single character objects specifying the axes labels, as in par, defaults to xlab = "Log Stylopodial Circumference" and ylab = "Log Body Mass".
xlim, ylim	numeric vector specifying the axes ranges, as in par, defaults to xlim = c(1, 3.5) and ylim = c(1.5, 8).
cex, pch, col	main plotting parameters, as in par, defaults to cex = 0.5, pch = 4, and col = "gray".
fit.col	character object specifying the colour of the fitted line.
pred.seq	integer or numeric sequence use as newdata to generate confidence and prediction intervals.
PI.col, PI.lty	colour and line-type parameters for the prediction interval lines.
CI.col, CI.lty	colour and line-type parameters for the confidence interval lines.
verbose	a logical value indicating whether the results of the model fitting are returned.
plot	a logical value indicating whether the plot should be produced, defaults to plot = FALSE.
...	parameter arguments passed to plot.

Details

This function is mostly used internally by MASSunite to project volumetric reconstruction models onto the non-linear limb circumferences standard of accuracy, as presented in Campione & Evans (2020). However, the function can technically be used to generate a plot of any x-y coordinates with their fitted quadratic line and associated confidence/prediction intervals. N.B. If modified, the defaults may not suite.

Value

The default function will generate a plot. If `verbose = TRUE` a 3 item list will be returned with:

`model`	the output from `lm`.
`prediction`	a 3-column matrix with the fitted, lower, and upper prediction intervals for the vector given in `pred.seq`
`confidence`	a 3-column matrix with the fitted, lower, and upper confidence intervals for the vector given in `pred.seq`

Author(s)

Nicolas E. Campione

References

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43 (4), 693-699.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

See Also

`MASSunite` `mod_OLS`

Examples

```
mod_QUAD()
```

MR *Body Mass Estimates Using Campione and Evans (2012)*

Description

This function presents the multiple regressions equations from Campione and Evans (2012) for esimating body mass in terretrial vertebartes using humeral and femoral circumferences

Usage

```
MR(HC, FC, equation = c("raw","phylocor"), data = NULL)
```

Arguments

`HC`	a value or vector representing humeral circumference (in mm)
`FC`	a value or vector representing femoral circumference (in mm)
`equation`	desired estimation equation. Two possible choices (See Details)
`data`	an optional object of `class = "data.frame"` or `class = "matrix"`

Details

The function includes two different equations. `equation = "raw"` applies the multiple regression based on the raw (non-phylogenetically corrected) relationship - equation 5 of Campione and Evans (2012). `equation = "phylocor"` applies the multiple regressions taking phylogenetic relationships into account - equation 6 of Campione and Evans (2012).

If a data object is specified, the mass estiamtes and additional results will be added as columns to the data.frame or matrix within that object.

Value

Four numeric values or columns are returned:

`log.masstimate`	A numeric value or vector representing the mass estimate(s) in log10 grams
`MR`	A numeric value or vector representing the mass estimate(s) in grams
`upper.MR`	A numeric value or vector representing the upper prediction error based on that derived for the specific equation by Campione and Evans (2012)
`lower.MR`	A numeric value or vector representing the lower prediction error

Author(s)

Nicolas E. Campione

References

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

See Also

`QE` `quadrupeds` `AHR1985` `MCF2004`

Examples

```
##Dinosaur data from Campione and Evans (2012) for quadrupedal dinosaurs
data(dinos)

##Combined equation based on the raw regression
MR(dinos$HC, dinos$FC, equation = "raw", data = dinos)

##Combined equation based on the phylogenetically corrected regression, data not specified
MR(dinos$HC, dinos$FC, equation = "phylocor")
```

OH2012 *Body Mass Estimates Using O'Gorman & Hone (2012)*

Description

This function is meant for dinosaur mass estimation from femoral length as presented by O'Gorman & Hone (2012)

Usage

```
OH2012(FL, eqn, data=NULL)
```

Arguments

FL	a value or vector representing femoral length (in mm)
eqn	a character specifying the desired prediction equation (see Details)
data	an optional object of class = "data.frame" or class = "matrix"

Details

Possible estimation equations (eqn =) include: "theropods", "sauropods", and "ornithischians". See O'Gorman & Hone (2012) for specific details and Campione & Evans (2020) for evaluations of the models. If a data object is specified, the mass estiamtes will be added as a column to the data.frame or matrix within that object.

Value

OH2012	A vector representing the mass estimate(s) in log grams and grams

Author(s)

Nicolas E. Campione

References

O'Gorman, E. J. and Hone, D. W. E. (2012) Body Size Distribution of the Dinosaurs. PLoS ONE 7(12): e51925.

Campione, N. E. and Evans, D. C. (2020) The accuracy and precisions of body mass estimation in non-avian dinosaurs. Biological Reviews.

See Also

cQE QE

ppe *Percent Prediction Error*

Description

This function calculates the percent prediction error of a sample based on the predicted and true values

Usage

```
ppe(true, pred, abs = TRUE)
```

Arguments

true	a numeric vector representing the true value on which a prediction (pred) will be compared
pred	a numeric vector with the predicted values, must be equal length to true
abs	a logical value indicating whether to return the absolute values for ppe, default is abs = TRUE

Details

This function calculates the percent prediction error (ppe) as a scaled residual (Smith 1980), generally based on the absolute residual, so:

$$ppe = \frac{(|true - pred|)}{pred} \times 100$$

Value

Function returns a list of results, including the a list of all the precent prediction errors, along with the mean, 95 percent confidence intervals, range, and standard deviation.

Author(s)

Nicolas E. Campione

References

Smith, R. J. (1980) Rethinking allometry. Journal of Theoretical Biology, 87, 97-111.

See Also

see

QE *Body Mass Estimates Using Combined Humeral and Femoral Circumferences*

Description

This function is based on the bivariate regression equations from Campione and Evans (2012) for esimating body mass in terretrial vertebartes using the combined humeral and femoral circumferences

Usage

```
QE(HFC = NULL, HC, FC, equation = "raw",
quadratic = FALSE, data = NULL, return_PI = FALSE)
```

Arguments

HFC	a value or vector representing the combined humeral and femoral circumferences
HC	a value or vector representing humeral circumference (in mm)
FC	a value or vector representing femoral circumference (in mm)
equation	desired estimation equation. Two possible choices (See Details)
quadratic	a logical indicating whether estimates based on the quadratic equation should be used (See Details)
data	an optional object of class = "data.frame" or class = "matrix"
return_PI	an optional logical value to also provide the wider prediction intervals on the estimate, currenly only works if equation = "raw"

Details

The function includes two different equations. equation = "raw" (default) applies the non-phylogenetically corrected regression equation - equation 1 of Campione and Evans (2012). equation = "phylocor" applies the phylogenetically corrected regression equation - equation 2 of Campione and Evans (2012).

If HFC is specified, then HC and FC are ignored.

If quadratic = TRUE, then a second set of estimates will be returned based on a quadratic view of the Campione and Evans (2012) data set (Campione, 2017).

If a data object is specified, the mass estiamtes and additional results will be added as columns to the data.frame or matrix within that object.

Value

Eight numeric values or columns are returned if `quadratic = TRUE` (identified by `q`):

`log.QE`	A numeric value or vector representing the mass estimate(s) in log10 grams
`QE`	A numeric value or vector representing the mass estimate(s) in grams
`lower.QE`	A numeric value or vector representing the lower prediction error derived for the specific equation by Campione and Evans (2012)
`upper.QE`	A numeric value or vector representing the upper prediction error
`log.qQE`	A numeric value or vector representing the mass estimate(s) in log10 grams using a quadratic equation
`qQE`	A numeric value or vector representing the mass estimate(s) in grams
`lower.qQE`	A numeric value or vector representing the lower prediction error derived for the specific equation by Campione (2017)
`upper.qQE`	A numeric value or vector representing the upper prediction error

Author(s)

Nicolas E. Campione

References

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43 (4), 693-699.

See Also

`cQE` `quadrupeds` `MR` `AHR1985` `MCF2004`

Examples

```
##Dinosaur data from Campione and Evans (2012) for quadrupedal dinosaurs
data(dinos)

##Combined equation based on the raw regression
QE(HC = dinos$HC, FC = dinos$FC, quadratic = TRUE, data = dinos, return_PI = TRUE)

##Combined equation based on the phylogenetically corrected regression, data not specified
QE(HC = dinos$HC, FC = dinos$FC, equation = "phylocor")
```

quadrupeds *Body Mass Estimates Using QE, MR, AHR1985, and MCF2004*

Description

This function returns body mass estimates for quadrupeds using humeral and/or femoral circumferences (intended for non-avian dinosaurs)

Usage

```
quadrupeds(HC, FC, QE_MR.eq = "raw", data = NULL)
```

Arguments

HC	a value or vector representing humeral circumference (in mm)
FC	a value or vector representing femoral circumference (in mm)
QE_MR.eq	desired estimation equations to used by QE and MR. Two possible choices. "raw" is default
data	an optional object of class = "data.frame" or class = "matrix"

Details

This function returns estimates from five equations intented for terrestrial quadrupeds (in particular non-avian dinosaurs): two from Campione and Evans (2012) based on bivariate and multiple regression approaches; a quadratic view of the bivariate regression (Campione in review); Anderson et al. (1985); Mazzetta et al. (2004). For more details please see the specific functions.

If a data object is specified, the mass estiamtes and additional results will be added as columns to the data.frame or matrix within that object.

Value

11 numeric values or columns are returned (all masses are in grams):

QE	A numeric value or vector of mass estimates using QE (bivariate regression)
upper.QE	A numeric value or vector representing the upper prediction error of the QE based on that derived for the specific equation by Campione and Evans (2012)
lower.QE	A numeric value or vector representing the lower prediction error of the QE
qQE	A numeric value or vector of mass estimates using qQE (quadratic equation)
upper.qQE	A numeric value or vector representing the upper prediction error of qQE derived for the specific equation in Campione (in review)
lower.qQE	A numeric value or vector representing the lower prediction error of qQE
MR	A numeric value or vector of mass estimates using MR (multiple regression)
upper.MR	A numeric value or vector representing the upper prediction error of the MR based on that derived for the specific equation by Campione and Evans (2012)

lower.MR	A numeric value or vector representing the lower prediction error of the MR
AHR1985	A numeric value or vector of mass estimates using Anderson et al. (1985)
MCF2004	A numeric value or vector of mass estimates using Mazzetta et al. (2004)

Author(s)

Nicolas E. Campione

References

Anderson, J. F., Hall-Martin, A. and Russell, D. A. (1985) Long-bone circumference and weight in mammals, birds and dinosaurs. Journal of the Zoological Society of London A, 207, 53-61.

Campione, N. E. and Evans, D. C. (2012) A universal scaling relationship between body mass and proximal limb bone dimensions in quadrupedal terrestrial tetrapods. BMC Biology, 10, 60.

Campione, N. E. (2017) Extrapolation of a universal scaling relationship for estimating body masses in extinct terrestrial vertebrates. Paleobiology, 43, 693-699.

Mazzetta, G. V., Christiansen, P. and Farina, R. A. (2004) Giants and bizzares: body size of some southern South American Cretaceous dinosaurs. Historical Biology, 16, 71-83.

See Also

QE MR AHR1985 MCF2004

---

see *Standard Error of the Estimate*

Description

This function computes the standard error of the estimate based on the actual and predicted values

Usage

```
see(true, pred)
```

Arguments

true	a numeric vector representing the true values
pred	a numeric vector representing the predicted values, must be equal length to true

Details

This function calculates the standard error of the estimate (see) as a scaled residual, so:

$$see = \sqrt{\frac{\sum (true - pred)^2}{N}}$$

Value

Function returns a length one value of the standard error of the estimate

Author(s)

Nicolas E. Campione

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