Package 'TapeR'

January 11, 2022

Type Package

Title Flexible Tree Taper Curves Based on Semiparametric Mixed Models

Version 0.5.0

Date 2022-01-11

Description Implementation of functions for fitting taper curves (a semiparametric linear mixed effects taper model) to diameter measurements along stems. Further functions are provided to estimate the uncertainty around the predicted curves, to calculate timber volume (also by sections) and marginal (e.g., upper) diameters. For cases where tree heights are not measured, methods for estimating additional variance in volume predictions resulting from uncertainties in tree height models (tariffs) are provided. The example data include the taper curve parameters for Norway spruce used in the 3rd German NFI fitted to 380 trees and a subset of section-wise diameter measurements of these trees. The functions implemented here are detailed in Kublin, E., Breidenbach, J., Kaendler, G. (2013) <doi:10.1007/s10342-013-0715-0>.

License GPL (>= 2)

LazyLoad yes

Depends nlme, splines, pracma

Suggests testthat

RoxygenNote 7.1.2

NeedsCompilation no

Author Edgar Kublin [aut],
Johannes Breidenbach [ctb],
Christian Vonderach [ctb, cre]

Maintainer Christian Vonderach <christian.vonderach@forst.bwl.de>

Repository CRAN

Date/Publication 2022-01-11 22:52:46 UTC

R topics documented:

`TapeR-package` *Flexible tree taper curves based on Semiparametric Mixed Models.*

Description

This package implements functions for fitting taper curves (a semiparametric linear mixed effects taper model) to diameter measurements along stems. Further functions are provided to estimate the variance/confidence intervals around the predicted curves, to calculate timber volume (also by sections) and marginal (e.g., upper) diameters. For cases where tree heights are not measured, methods for estimating additional variance in volume predictions resulting from uncertainties in tree height models (tariffs) are provided. The example data include the taper curve parameters for Norway spruce used in the 3rd German NFI fitted to 380 trees and a subset of section-wise diameter measurements of these trees.

Details

Package:	TapeR
Type:	Package
License:	GPL-2
LazyLoad:	yes

Fits taper models using diameter measurements along the stem. Uses fitted models and arbitrary numbers of diameter measurements to estimate diameter at any position along the stem. Estimates timber volume from the taper curve. Provides variances for all estimates.

Author(s)

Edgar Kublin

Maintainer: Johannes Breidenbach <job@skogoglandskap.no>

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

See Also

`TapeR_FIT_LME.f`, `E_DHx_HmDm_HT.f`, `DxHx.df`, `SK.par.lme`, `HT.par`

`BSplines` *builds B-Splines Matrix with appropriate knots for taper fitting*

Description

Internal function not usually called by users

Usage

```
BSplines(knots = c(seq(0, 1, 0.1)), ord = 4, der = 0, x = c(seq(0, 1, 0.01)), ...)
```

Arguments

`knots`	knot positions for spline function
`ord`	order of the spline function
`der`	derivatives
`x`	height measurements
`...`	not currently used

Details

internally splineDesign is called

Value

B-Splines matrix build using splineDesign

Author(s)

Edgar Kublin

`CdN_DHxHt.f` *percentile for estimated taper curve diameter*

Description

Internal function not usually called by users

Usage

```
CdN_DHxHt.f(Ht, Hx, qD, Hm, Dm, par.lme, Rfn, ...)
```

Arguments

Ht	tree height
Hx	Numeric vector of stem heights (m) along which to return the expected diameter.
qD	vector of quantiles, passed to pnorm
Hm	measured height of respective diameters Dm
Dm	measured diameter
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f.
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
...	not currently used

Value

percentile for estimated taper curve diameter at position Hx given Ht, Hm and Dm

Author(s)

Edgar Kublin

dN.f — *evaluate Normal distribution*

Description

Internal function not usually called by users

Usage

```
dN.f(x, mw, sd, ...)
```

Arguments

x	vector of quantiles
mw	vector of means
sd	vector of standard deviations
...	not currently used

Value

numeric density of normal distribution

Author(s)

Edgar Kublin

DxHx.df — *Example dataset of 10 trees with 10 diameter and height measurements for each tree.*

Description

Example dataset of 10 trees with 10 diameter and height measurements for each tree.

Usage

```
data(DxHx.df)
```

Format

A data frame with 172 observations on the following 4 variables.

- Id Numeric vector of tree IDs.
- Dx Numeric vector of diameter measurements.
- Hx Numeric vector of height measurements.
- Ht Numeric vector of tree height (repeated for each measurement in each tree).

Details

Measured for BWI3.

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

Examples

```
data(DxHx.df)
head(DxHx.df)
```

`EYx_ssp.f` *estimate cubic smoothing spline with linear extrapolation*

Description

Internal function not usually called by users

Usage

```
EYx_ssp.f(knt, coe, x, ...)
```

Arguments

`knt`	knots position of B-Splines
`coe`	estimated coefficient for B-Splines
`x`	position at which to evaluate B-Splines model
`...`	not currently used

Value

expected diameter given knots and coefficients at position (height) `x`.

Author(s)

Edgar Kublin

E_DHx_HmDm_HT.f *Estimate diameter and approximate confidence and prediction intervals*

Description

Calibrates a taper curve based on at least one diameter measurement and returns the expected diameters and approximate variances

Usage

```
E_DHx_HmDm_HT.f(
  Hx,
  Hm,
  Dm,
  mHt,
  sHt = 0,
  par.lme,
  Rfn = list(fn = "sig2"),
  ...
)
```

Arguments

Hx	Numeric vector of stem heights (m) along which to return the expected diameter.
Hm	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as Dm.
Dm	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as Hm.
mHt	Scalar. Tree height (m).
sHt	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error.
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f.
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
...	not currently used

Details

calibrates the tree specific taper curve and calculates approximate confidence intervals, which can be useful for plotting. Uncertainty resulting from tariff height estimates if tree height was not measured is incorporated. Using Rfn the taper curve can be forced through the measured diameters, c.f. resVar.

Value

a list holding six elements:

- DHx: Numeric vector of diameters (cm) (expected value) along the heights given by Hx.
- Hx: Numeric vector of heights (m) along which to return the expected diameter.
- MSE_Mean: Mean squared error for the expected value of the diameter.
- CI_Mean: Confidence interval. Matrix of the 95% conf. int. for the expected value of the diameter (cm). First column: lower limit, second column: mean, third column: upper limit.
- MSE_Pred: Mean squared error for the prediction of the diameter.
- CI_Mean: Prediction interval. Matrix of the 95% conf. int. for the prediction of the diameter (cm). First column: lower limit, second column: mean, third column: upper limit.
- Rfn: Function applied for estimated or assumed residual variance.

Author(s)

Edgar Kublin

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

See Also

TapeR_FIT_LME.f

Examples

```
# example data
data(DxHx.df)
# taper curve parameters based on all measured trees
data(SK.par.lme)

#select data of first tree
Idi <- (DxHx.df[,"Id"] == unique(DxHx.df$Id)[1])
(tree1 <- DxHx.df[Idi,])

## Predict the taper curve based on the diameter measurement in 2 m
## height and known height
tc.tree1 <- E_DHx_HmDm_HT.f(Hx=1:tree1$Ht[1],
                            Hm=tree1$Hx[3],
                            Dm=tree1$Dx[3],
                            mHt = tree1$Ht[1],
                            sHt = 0,
                            par.lme = SK.par.lme)
#plot the predicted taper curve
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", las=1)
#lower CI
lines(tc.tree1$Hx, tc.tree1$CI_Mean[,1], lty=2)
```

```
#upper CI
lines(tc.tree1$Hx, tc.tree1$CI_Mean[,3], lty=2)
#lower prediction interval
lines(tc.tree1$Hx, tc.tree1$CI_Pred[,1], lty=3)
#upper prediction interval
lines(tc.tree1$Hx, tc.tree1$CI_Pred[,3], lty=3)
#add measured diameter used for calibration
points(tree1$Hx[3], tree1$Dx[3], pch=3, col=2)
#add the observations
points(tree1$Hx, tree1$Dx)

## feature of forcing taper curve through measured diameters
i <- c(3, 6)
tc.tree1 <- E_DHx_HmDm_HT.f(Hx=seq(0, tree1$Ht[1], 0.1),
                            Hm=tree1$Hx[i],
                            Dm=tree1$Dx[i],
                            mHt = tree1$Ht[1],
                            sHt = 0,
                            par.lme = SK.par.lme,
                            Rfn=list(fn="sig2"))
tc.tree2 <- E_DHx_HmDm_HT.f(Hx=seq(0, tree1$Ht[1], 0.1),
                            Hm=tree1$Hx[i],
                            Dm=tree1$Dx[i],
                            mHt = tree1$Ht[1],
                            sHt = 0,
                            par.lme = SK.par.lme,
                            Rfn=list(fn="zero"))
# plot the predicted taper curve
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", las=1)
# added taper curve through measurement
points(x=tc.tree2$Hx, y=tc.tree2$DHx, type="l", lty=2)
# closer window
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", las=1, xlim=c(0, 8), ylim=c(24, 30))
# added taper curve through measurement
points(x=tc.tree2$Hx, y=tc.tree2$DHx, type="l", lty=2)
# add measured diameter used for calibration
points(tree1$Hx[i], tree1$Dx[i], pch=3, col=2)
# add the observations
points(tree1$Hx, tree1$Dx)

## apply yet another residual variance function
i <- c(1, 2, 3) # calibrating with 0.5, 1m and 2m, assuming no error in 0.5m
zrv <- tree1$Hx[1] / tree1$Ht[1] # assumed zero resiudal variance
# assumed residual variance per measurement
TapeR:::resVar(relH = tree1$Hx[i] / tree1$Ht[1], fn = "dlnorm",
               sig2 = SK.par.lme$sig2_eps, par = list(zrv=zrv))
tc.tree3 <- E_DHx_HmDm_HT.f(Hx=seq(0, tree1$Ht[1], 0.1),
                            Hm=tree1$Hx[i],
                            Dm=tree1$Dx[i],
                            mHt = tree1$Ht[1],
                            sHt = 0,
                            par.lme = SK.par.lme,
                            Rfn=list(fn="dlnorm", par=list(zrv=zrv)))
```

```
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", las=1, xlim=c(0, 4))
points(x=tc.tree3$Hx, y=tc.tree3$DHx, type="l", lty=2)
points(tree1$Hx[i], tree1$Dx[i], pch=3, col=2)
points(tree1$Hx, tree1$Dx)
```

`E_DHx_HmDm_HT_CIdHt.f` *Estimate diameter and exact confidence and prediction intervals*

Description

Calibrates a taper curve based on at least one diameter measurement and returns the expected diameters and exact variances

Usage

```
E_DHx_HmDm_HT_CIdHt.f(
  Hx,
  Hm,
  Dm,
  mHt,
  sHt,
  par.lme,
  Rfn = list(fn = "sig2"),
  ...
)
```

Arguments

`Hx`	Numeric vector of stem heights (m) along which to return the expected diameter.
`Hm`	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as `Dm`.
`Dm`	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as `Hm`.
`mHt`	Scalar. Tree height (m).
`sHt`	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error.
`par.lme`	List of taper model parameters obtained by `TapeR_FIT_LME.f`.
`Rfn`	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
`...`	not currently used

Details

calibrates the tree specific taper curve and calculates 'exact' confidence intervals, which can be useful for plotting. Attention: this function is somewhat time-consuming.

Value

a matrix with six columns:

- Hx: Numeric vector of heights (m) along which to return the expected diameter.
- q_DHx_u: Lower confidence interval (cm). (95% CI except for estimates close to the stem tip.)
- DHx: Diameter estimate (cm).
- q_DHx_o: Upper CI (cm).
- cP_DHx_u: Probability of observations <q_DHx_u.
- cP_DHx_o: Probability of observations <q_DHx_o.

Author(s)

Edgar Kublin

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

See Also

TapeR_FIT_LME.f

Examples

```
# example data
data(DxHx.df)
# taper curve parameters based on all measured trees
data(SK.par.lme)

#select data of first tree
Idi <- (DxHx.df[,"Id"] == unique(DxHx.df$Id)[1])
(tree1 <- DxHx.df[Idi,])

## Predict the taper curve based on the diameter measurement in 2 m
## height and known height
tc.tree1 <- E_DHx_HmDm_HT.f(Hx=1:tree1$Ht[1],
                            Hm=tree1$Hx[3],
                            Dm=tree1$Dx[3],
                            mHt = tree1$Ht[1],
                            sHt = 0,
                            par.lme = SK.par.lme)
#plot the predicted taper curve
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", las=1)
#lower CI
lines(tc.tree1$Hx, tc.tree1$CI_Mean[,1], lty=2)
#upper CI
lines(tc.tree1$Hx, tc.tree1$CI_Mean[,3], lty=2)
#lower prediction interval
```

```
lines(tc.tree1$Hx, tc.tree1$CI_Pred[,1], lty=3)
#upper prediction interval
lines(tc.tree1$Hx, tc.tree1$CI_Pred[,3], lty=3)
#add measured diameter used for calibration
points(tree1$Hx[3], tree1$Dx[3], pch=3, col=2)
#add the observations
points(tree1$Hx, tree1$Dx)

## Calculate "exact" CIs. Careful: This takes a while!
#library(pracma)# for numerical integration with gaussLegendre()

tc.tree1.exact <- E_DHx_HmDm_HT_CIdHt.f(Hx=1:tree1$Ht[1],
                                        Hm=tree1$Hx[3],
                                        Dm=tree1$Dx[3],
                                        mHt=tree1$Ht[1],
                                        sHt=1,
                                        par.lme=SK.par.lme)
#add exact confidence intervals to approximate intervals above - fits
#quite well
lines(tc.tree1.exact[,1], tc.tree1.exact[,2], lty=2,col=2)
lines(tc.tree1.exact[,1], tc.tree1.exact[,4], lty=2,col=2)
```

`E_HDx_HmDm_HT.f` *Estimate height of given diameter*

Description

Calibrates a taper curve based on at least one diameter measurement and returns the height of a given diameter

Usage

```
E_HDx_HmDm_HT.f(
  Dx,
  Hm,
  Dm,
  mHt,
  sHt = 0,
  par.lme,
  Rfn = list(fn = "sig2"),
  ...
)
```

Arguments

`Dx`	Scalar. Diameter for which to return height.
`Hm`	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as `Dm`.

Dm	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as Hm.
mHt	Scalar. Tree height (m).
sHt	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error.
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f.
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
...	not currently used

Details

returns the height given a certain diameter.

Value

A scalar. Estimated height (m) given a diameter.

Author(s)

Edgar Kublin

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

See Also

TapeR_FIT_LME.f

Examples

```
# example data
data(DxHx.df)
# taper curve parameters based on all measured trees
data(SK.par.lme)

#select data of first tree
Idi <- (DxHx.df[,"Id"] == unique(DxHx.df$Id)[1])
(tree1 <- DxHx.df[Idi,])

## Predict the taper curve based on the diameter measurement in 2 m
## height and known height
tc.tree1 <- E_DHx_HmDm_HT.f(Hx=1:tree1$Ht[1],
                            Hm=tree1$Hx[3],
                            Dm=tree1$Dx[3],
                            mHt = tree1$Ht[1],
                            sHt = 0,
                            par.lme = SK.par.lme)
```

```
#plot the predicted taper curve
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", las=1)

## Calculate the height given a certain diameter threshold, say 8.5 cm
ht.tree1.d8.5 <- E_HDx_HmDm_HT.f (Dx=8.5,
                                  Hm=tree1$Hx[3],
                                  Dm=tree1$Dx[3],
                                  mHt = tree1$Ht[1],
                                  sHt = 1,
                                  par.lme = SK.par.lme,
                                  Rfn=list(fn="sig2"))
# add to plot
points(x=ht.tree1.d8.5, y=8.5, pch=8, col=2, cex=2)
```

`E_VOL_AB_HmDm_HT.f` *Estimate volume for stem and sections*

Description

Estimate volume for a complete stem from bottom to tip or for a section defined by lower and upper diameter or height. Variances for estimated volumes are calculated.

Usage

```
E_VOL_AB_HmDm_HT.f(
  Hm,
  Dm,
  mHt,
  sHt = 0,
  A = NULL,
  B = NULL,
  iDH = "D",
  par.lme,
  Rfn = list(fn = "sig2"),
  IA = F,
  nGL = 51,
  ...
)
```

Arguments

`Hm`	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as `Dm`.
`Dm`	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as `Hm`.
`mHt`	Scalar. Tree height (m).

sHt	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error.
A	Numeric scalar defining the lower threshold of a stem section for volume estimation. Depends on iDH. If iDH = "D", a diameter (cm), if iDH = "H", a height (m). If NULL, section starts at lowest point.
B	Numeric scalar defining the upper threshold of a stem section for volume estimation. Depends on iDH. If iDH = "D", a diameter (cm), if iDH = "H", a height (m). If NULL, section ends at tip.
iDH	Character scalar. Either "D" or "H". Type of threshold for section volume estimation. See A or B.
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f.
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
IA	Logic scalar. If TRUE, variance calculation of height estimate based on 2-point distribution. If FALSE, variance calculation of height estimate based on Normal approximation.
nGL	Numeric scalar. Number of support points for numerical integration.
...	not currently used

Details

calculates the volume for a complete stem or sections defined by A and B, which might be defined as diameter or height. The parameter Rfn can be used to force the taper curve through the measured points (e.g. by Rfn=list(fn="zero"), cf. resVar).

Value

a list holding nine elements:

- E_VOL: Estimated volume (m^3).
- VAR_VOL: Variance of the volume estimate.
- Hm: Height of diameter measurement (m).
- Dm: Diameter measurement (cm).
- Ht: Tree height (m).
- Da: Diameter at lower section threshold (cm).
- Db: Diameter at upper section threshold (cm).
- Ha: Height at lower section threshold (m).
- Hb: Height at upper section threshold (m).
- Rfn: Function applied for estimated or assumed residual variance.

Author(s)

Edgar Kublin

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

See Also

TapeR_FIT_LME.f

Examples

```
# example data
data(DxHx.df)
# taper curve parameters based on all measured trees
data(SK.par.lme)

#select data of first tree
Idi <- (DxHx.df[,"Id"] == unique(DxHx.df$Id)[1])
(tree1 <- DxHx.df[Idi,])

## Calculate the timber volume for the whole stem
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 0, # no height variance assumed
                          par.lme = SK.par.lme)
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance
VOL$Rfn

## Calculate the timber volume for the whole stem, using Rfn="zero"
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 0, # no height variance assumed
                          par.lme = SK.par.lme,
                          Rfn = list(fn="zero"))
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance
VOL$Rfn

## Calculate the timber volume for the whole stem
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 1, # no height variance assumed
                          par.lme = SK.par.lme)
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance
VOL$Rfn

## Calculate the timber volume for the whole stem, using Rfn="zero"
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
```

```
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 1, #  height variance assumed
                          par.lme = SK.par.lme,
                          Rfn = list(fn="zero"))
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance
VOL$Rfn

## Calculate the timber volume for a selected section given a height (0.3 - 5 m)
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 1,
                          par.lme = SK.par.lme,
                          A=0.3,
                          B=5,
                          iDH = "H")
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance
VOL$Rfn

## Calculate the timber volume for a selected section given a height (0.3 - 5 m)
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 1,
                          par.lme = SK.par.lme,
                          A=0.3,
                          B=5,
                          iDH = "H",
                          Rfn=list(fn="zero"))
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance
VOL$Rfn

## Calculate the timber volume for a selected section given a diameter
## threshold (30cm - 15cm) (negative value if A<B)
VOL <- E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3],
                          Dm=tree1$Dx[3],
                          mHt = tree1$Ht[1],
                          sHt = 1,
                          par.lme = SK.par.lme,
                          A=30,
                          B=15,
                          iDH = "D")
VOL$E_VOL #' expected value
VOL$VAR_VOL #' corresponding variance

## Not run:

## The variance estimate resulting from the tree height uncertainty using
## a Normal approximation takes much longer...
```

```
ptm <- proc.time()
E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3], Dm=tree1$Dx[3], mHt = tree1$Ht[1],
                   sHt = 1, par.lme = SK.par.lme, IA=FALSE)
proc.time() - ptm


##... than the calculation using a 2-point distribution...
ptm <- proc.time()
E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3], Dm=tree1$Dx[3], mHt = tree1$Ht[1],
                   sHt = 1, par.lme = SK.par.lme, IA=TRUE)
proc.time() - ptm

##...fastest if no height variance is assumed
ptm <- proc.time()
E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3], Dm=tree1$Dx[3], mHt = tree1$Ht[1],
                   sHt = 0, par.lme = SK.par.lme, IA=FALSE)
proc.time() - ptm

## Also the number of supportive points for the numerical integration
## influences the calculation time
ptm <- proc.time()
E_VOL_AB_HmDm_HT.f(Hm=tree1$Hx[3], Dm=tree1$Dx[3], mHt = tree1$Ht[1],
                   sHt = 0, par.lme = SK.par.lme, IA=FALSE, nGL=10)
proc.time() - ptm
##' End(Not run)
```

`HT.par` *Height tariff parameters for estimating tree heights of unmeasured trees in the BWI3.*

Description

Height is only measured on a subset of the trees on a sample plots. This Height tariff is used to estimate the height of the trees with only a dbh measurement.

Usage

```
data(HT.par)
```

Format

The format is: List of 4 $ knt.mw: num [1:16] 0 0 0 0 19.6 ... $ coe.mw: num [1:12] 1.3 7.28 15.1 21.75 24.39 ... $ knt.sd: num [1:53] 0 0 0 0 7.52 ... $ coe.sd: num [1:49] 0 0.618 1.376 2.142 2.486 ...

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

Examples

```
data(HT.par)
## maybe str(HT.par) ; plot(HT.par) ...
```

`Hx_root.f` *find root (height) given diameter, measurements and fitted model*

Description

Internal function not usually called by users

Usage

```
Hx_root.f(Hx, Dx, Hm, Dm, mHt, sHt, par.lme, Rfn, ...)
```

Arguments

`Hx`	Numeric vector of stem heights (m) along which to return the expected diameter
`Dx`	expected diameter
`Hm`	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as `Dm`
`Dm`	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as `Hm`
`mHt`	Scalar. Tree height (m)
`sHt`	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error
`par.lme`	List of taper model parameters obtained by `TapeR_FIT_LME.f`.
`Rfn`	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
`...`	not currently used

Details

function is called by `uniroot` inside `E_HDx_HmDm_HT.f`

Value

deviation between observed diameter `Dx` and diameter in height `Hx`.

Author(s)

Edgar Kublin

Int_CdN_DHx_dHt.f *Int_CdN_DHx_dHt.f*

Description

Internal function not usually called by users

Usage

```
Int_CdN_DHx_dHt.f(qD, Hx, Hm, Dm, mHt, sHt, par.lme, Rfn, nGL = 51, ...)
```

Arguments

qD	vector of quantiles, finally passed to pnorm
Hx	Numeric vector of stem heights (m) along which to return the expected diameter
Hm	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as Dm
Dm	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as Hm
mHt	Scalar. Tree height (m)
sHt	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
nGL	Numeric scalar. Number of support points for numerical integration
...	not currently used

Value

Int_CdN_dN

Author(s)

Edgar Kublin

`Int_E_VOL_AB_HmDm_HT_dHt.f`
Int_E_VOL_AB_HmDm_HT_dHt.f

Description

Internal function not usually called by users

Usage

```
Int_E_VOL_AB_HmDm_HT_dHt.f(
  Hm,
  Dm,
  A = NULL,
  B = NULL,
  iDH = "D",
  mw_HtT,
  sd_HtT,
  par.lme,
  Rfn = list(fn = "sig2"),
  IA = FALSE,
  nGL = 51,
  ...
)
```

Arguments

`Hm`	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as `Dm`
`Dm`	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as `Hm`
`A`	Numeric scalar defining the lower threshold of a stem section for volume estimation. Depends on `iDH`. If `iDH` = "D", a diameter (cm), if `iDH` = "H", a height (m). If NULL, section starts at lowest point.
`B`	Numeric scalar defining the upper threshold of a stem section for volume estimation. Depends on `iDH`. If `iDH` = "D", a diameter (cm), if `iDH` = "H", a height (m). If NULL, section ends at tip.
`iDH`	Character scalar. Either "D" or "H". Type of threshold for section volume estimation. See `A` or `B`.
`mw_HtT`	Scalar. Tree height (m)
`sd_HtT`	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error
`par.lme`	List of taper model parameters obtained by `TapeR_FIT_LME.f`
`Rfn`	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions

IA	Logic scalar. If TRUE, variance calculation of height estimate based on 2-point distribution. If FALSE, variance calculation of height estimate based on Normal approximation.
nGL	Numeric scalar. Number of support points for numerical integration.
...	not currently used

Details

integrating the taper curve considering uncertainty of height measurement

Value

list with expected volume, variance of volume and squared expected value incorporating the uncertainty of height measurement

Author(s)

Edgar Kublin

`qD.rout.f` *qD.rout.f*

Description

Internal function not usually called by users

Usage

```
qD.rout.f(qD, alpha = 0.975, Hx, Hm, Dm, mHt, sHt, par.lme, Rfn, nGL = 51, ...)
```

Arguments

qD	vector of quantiles, finally passed to pnorm
alpha	quantile for which root is sought
Hx	Numeric vector of stem heights (m) along which to return the expected diameter
Hm	Numeric vector of stem heights (m) along which diameter measurements were taken for calibration. Can be of length 1. Must be of same length as Dm
Dm	Numeric vector of diameter measurements (cm) taken for calibration. Can be of length 1. Must be of same length as Hm
mHt	Scalar. Tree height (m)
sHt	Scalar. Standard deviation of stem height. Can be 0 if height was measured without error
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f.
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
nGL	Numeric scalar. Number of support points for numerical integration.
...	not currently used

Value

qD for given alpha with respect to Int_CdN_DHx_dHt.f

Author(s)

Edgar Kublin

---

resVar *Functions to put different size of uncertainty on given measurements*

Description

When estimating a tree specific taper curve based on given measurements one can modify the assumed measurement uncertainty by these functions

Usage

```
resVar(relH, fn, sig2, par = NULL)
```

Arguments

relH	relative tree height for which the assumed residual variance should be calculated
fn	name of function to be applied as character string
sig2	residual variance from fitted model, cf. TapeR_FIT_LME.f
par	either NULL or a list with parameters to the different functions. See details.

Details

When estimating a tree specific taper curve based on given measurements the residual variance of the model is taken into account to estimate the tree specific random effects. Alternatively, it is possible to make assumptions about the measurement error, eventually at specific relative heights. With that, one can e.g. force the taper curve through the given measurements. Standard behaviour not necessarily leads to passing the measurements, if more than one is given.

Different functions are available. sig2 applies the model residual variance and hence is the default behaviour. zero means assuming no residual variance and forcing the taper curve through the given measurements. Care has to be taken in this case because forcing the taper curve through a lot of measurements might result in implausible results. linear interpolates between zero and the given residual variance along the stem, i.e. from bottom to tree top. bilinear puts zero variance not at zero but at a predefined location (can be given via par). Below and above a linear interpolation is done up to the given residual variance. If zero variance position is not given, it is set at 5% of tree height (approximately height of dbh). laglinear assumes zero variance up to a predefined location (defaults to 5% of tree height) and interpolates upwards to the given residual variance of the model. quadratic function distributes residual variance according to a quadratic function along the stem. It is build so that zero variance is put at a predefined location (defaults to 5% of tree height) and model residual variance (as a default) at tree top. dnorm and dlnorm put residual variance in form

of an inverse normal or an inverse log-normal distribution along the stem with a zero-minimum at a predefined location (defaults to 5% of tree height). See examples for a visualisation.

For all functions (except `zero` and `sig2`) the point of zero residual variance is defined by `par$zrv` if given, otherwise set to 0.05. For `dnorm` one can additionally provide the parameter `sd` to determine standard deviation. By default it is set to `zrv/3`; in case of `dlnorm` one can define `lsd` (sdlog, cf. `dlnorm`), which is by default set to `1-sqrt(zrv)`. It is up to the user to define meaningful parameters and use the functions in appropriate context.

Value

vector of assumed residual variance

Author(s)

Christian Vonderach

Examples

```
curve(resVar(relH=x, fn = "sig2", 0.5))
curve(resVar(relH=x, fn = "zero", 0.5))
curve(resVar(relH=x, fn = "linear", 0.5))
curve(resVar(relH=x, fn = "bilinear", 0.5))
curve(resVar(relH=x, fn = "laglinear", 0.5))
curve(resVar(relH=x, fn = "quadratic", 0.5))
curve(resVar(relH=x, fn = "dnorm", 0.5))
curve(resVar(relH=x, fn = "dnorm", 0.5, par=list(zrv=0.2, sd=0.2/3)))
curve(resVar(relH=x, fn = "dlnorm", 0.5))
curve(resVar(relH=x, fn = "dlnorm", 0.5, par=list(zrv=0.2)))
invisible(sapply(seq(0.01, 0.99, length.out=20), function(a){
  curve(resVar(relH=x, fn = "dlnorm", 0.5, par=list(zrv=a, lsd=(1-sqrt(a)))),
  n=1000)
}))
```

SK.par.lme *Taper model parameters for spruce in Germany based on BWI3 data.*

Description

Taper model parameters for spruce in Germany based on BWI3 data obtained using `TapeR_FIT_LME.f`.

Usage

```
data(SK.par.lme)
```

Format

See Value section of `TapeR_FIT_LME.f`.

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

Examples

```
data(SK.par.lme)
```

`SK_EBLUP_LME.f` *Evaluate fitted taper curve*

Description

This is the actual function to estimate diameters according to the fitted mixed B-splines model.

Usage

```
SK_EBLUP_LME.f(xm, ym, xp, par.lme, Rfn = list(fn = "sig2"), ...)
```

Arguments

`xm`	relative heights for which measurements are available
`ym`	corresponding diameter measurements in height `xm`
`xp`	relative heights for which predictions are required
`par.lme`	Fitted model object, return of `TapeR_FIT_LME.f`
`Rfn`	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
`...`	not currently used

Details

This function is the actual working horse for prediction using the fitted taper model. Based on the model `par.lme` and the measured diameters `ym` and corresponding (relative) heights `xm` of a specific tree (there might be just one measurement), the random effect parameters and subsequently diameters are estimated. Depending on the parameter `Rfn`, the calibrated taper curve is forced through the given diameter `ym` (`Rfn = list(fn="zero")`), or calibrated using the complete residual variance-covariance information (`Rfn = list(fn="sig2")`, the default). Further assumptions are possible, see also `resVar` and Kublin et al. (2013) p. 987 for more details.

Value

a list holding nine elements:

- b_fix fixed effects parameter of taper model
- b_rnd random effects parameter given tree (posterior mean b_k)
- yp estimated diameter in height xp
- KOV_Mean variance-covariance matrix of expected value
- KOV_Pred variance-covariance matrix of prediction
- CI_Mean mean and limits of confidence interval
- MSE_Mean mean squared error of expected value
- MSE_Pred mean squared error of prediction
- CI_Pred mean and limits of prediction interval

Author(s)

Edgar Kublin

See Also

E_DHx_HmDm_HT.f, E_VOL_AB_HmDm_HT.f, resVar

Examples

```
data("SK.par.lme")
TapeR:::SK_EBLUP_LME.f(1.3/27, 30, 1.3/27, SK.par.lme)
## using empirical best linear unbiased estimator: estimate != 30
TapeR:::SK_EBLUP_LME.f(1.3/27, 30, 1.3/27, SK.par.lme, Rfn=list(fn="sig2"))$yp
## interpolate / force through given diameter: estimate  == 30
TapeR:::SK_EBLUP_LME.f(1.3/27, 30, 1.3/27, SK.par.lme, Rfn=list(fn="zero"))$yp
TapeR:::SK_EBLUP_LME.f(1.3/27, 30, c(1.3, 5)/27, SK.par.lme)
par.lme <- SK.par.lme
h <- 12 # tree height
xm <- c(1.3, 3) / h # relative measuring height
ym <- c(8, 7.5) # measured diameter
xp <- c(0.5, 1) / h # relative prediction height
TapeR:::SK_EBLUP_LME.f(xm, ym, xp, SK.par.lme)
```

SK_VOLab_EBLUP_LME.f *taper volume estimation*

Description

Internal function not usually called by users

Usage

```
SK_VOLab_EBLUP_LME.f(
  xm,
  ym,
  a = 0,
  b = 1,
  Ht,
  par.lme,
  Rfn = list(fn = "sig2"),
  IntPolOpt = TRUE,
  ...
)
```

Arguments

xm	relative heights for which measurements are available
ym	corresponding diameter measurements in height xm
a	relative height of lower threshold of stem section
b	relative height of upper threshold of stem section
Ht	tree height
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
IntPolOpt	option for method of interpolation, if TRUE using a natural interpolating spline (splinefun), if FALSE using a smoothing spline (smooth.spline); defaults to TRUE
...	not currently used

Details

with Rfn=list(fn="zero") one can decide whether the measured diameters are forced to lie exactly on the taper curve; this interferes somewhat with the IntPolOpt, which determines the method of taper curve point interpolation for integration. The default TRUE (used throughout all function calls) applies natural interpolating splines, hence this does not contradict the optional use of Rfn=list(fn="zero").

Value

List with two elements, the estimated volume and its variance

Author(s)

Edgar Kublin

`TapeR_FIT_LME.f` *Fits a taper curve model to the specified diameter-height data*

Description

Fits a taper curve model with random effects on tree-level based on B-Splines to the specified diameter-height data. Number and position of nodes and order of B-Splines can be specified.

Usage

```
TapeR_FIT_LME.f(
  Id,
  x,
  y,
  knt_x,
  ord_x,
  knt_z,
  ord_z,
  IdKOVb = "pdSymm",
  control = list(),
  ...
)
```

Arguments

`Id`	Vector of tree identifiers of same length as diameter and height measurements.
`x`	Numeric vector of height measurements (explanatory variables) along the stem relative to the tree height.
`y`	Numeric vector of diameter measurements (response) along the stem (in centimeters).
`knt_x`	Numeric vector of relative knot positions for fixed effects.
`ord_x`	Numeric scalar. Order of fixed effects Spline (4=cubic).
`knt_z`	Numeric vector of relative knot positions for random effects.
`ord_z`	Numeric scalar. Order of random effects Spline (4=cubic).
`IdKOVb`	Character string. Type of covariance matrix used by `lme`. Only "pdSymm" makes sense. Rather reduce number of knots if function does not converge.
`control`	a list of control values for the estimation algorithm to replace the default values returned by the function `lmeControl`. Defaults to an empty list.
`...`	not currently used

Details

If too few trees are given, the linear mixed model (lme) will not converge. See examples for a suggestion of node positions.

The variance parameters `theta` are stored in the natural parametrization (Pinheiro and Bates (2004), p. 93). This means log for variances and logit for covariances. `theta` is the vectorized triangle of the random effects covariance matrix + the residual variance (lSigma). Given there are 2 inner knots for random effects, the structure will be c(sig^2_b1, sig_b1 sig_b2, sig_b1 sig_b3, sig_b1 sig_b4, sig^2_b2,...,sig^2_b4, lSigma)

Value

List of model properties

- fit.lmeSummary of the fitted lme model.
- par.lmeList of model parameters (e.g., coefficients and variance-covariance matrices) needed for volume estimation and other functions in this package. Components of the `par.lme` list
  - knt_xRelative positions of the fixed effects Spline knots along the stem.
  - pad_knt_xPadded version of knt_x, as used to define B-Spline design matrix.
  - ord_xOrder of the spline.
  - knt_zRelative positions of the random effects Spline knots along the stem.
  - pad_knt_zPadded version of knt_z, as used to define B-Spline design matrix.
  - ord_zOrder of the spline.
  - b_fixFixed-effects spline coefficients.
  - KOVb_fixCovariance of fixed-effects.
  - sig2_epsResidual variance.
  - dfResResidual degrees of freedom.
  - KOVb_rndCovariance of random effects.
  - thetaVariance parameters in natural parametrization. See Details.
  - KOV_thetaApproximate asymptotic covariance matrix of variance parameters.

Author(s)

Edgar Kublin

References

Kublin, E., Breidenbach, J., Kaendler, G. (2013) A flexible stem taper and volume prediction method based on mixed-effects B-spline regression, Eur J For Res, 132:983-997.

See Also

`E_DHx_HmDm_HT.f`, `E_DHx_HmDm_HT_CIdHt.f`, `E_HDx_HmDm_HT.f`, `E_VOL_AB_HmDm_HT.f`

Examples

```
# load example data
data(DxHx.df)

# prepare the data (could be defined in the function directly)
Id = DxHx.df[,"Id"]
x = DxHx.df[,"Hx"]/DxHx.df[,"Ht"]#calculate relative heights
y = DxHx.df[,"Dx"]

# define the relative knot positions and order of splines
knt_x = c(0.0, 0.1, 0.75, 1.0); ord_x = 4 # B-Spline knots: fix effects; order (cubic = 4)
knt_z = c(0.0, 0.1       ,1.0); ord_z = 4 # B-Spline knots: rnd effects

# fit the model
taper.model <- TapeR_FIT_LME.f(Id, x, y, knt_x, ord_x, knt_z, ord_z,
                               IdKOVb = "pdSymm")

## save model parameters for documentation or dissimination
## parameters can be load()-ed and used to predict the taper
## or volume using one or several measured dbh
#spruce.taper.pars <- taper.model$par.lme
#save(spruce.taper.pars, file="spruce.taper.pars.rdata")
```

`TransKnots` *transform knot vector*

Description

Internal function not usually called by users

Usage

```
TransKnots(knots = c(seq(0, 1, 0.1)), ord = 4, ...)
```

Arguments

`knots`	knot positions for spline function
`ord`	order of the spline function
`...`	not currently used

Value

transformed knots vector, especially with repeated first and last knot given order of spline function

Author(s)

Edgar Kublin

xy0_root.f *xy0_root.f*

Description

Internal function not usually called by users

Usage

```
xy0_root.f(x, y0, SK, par.lme, ...)
```

Arguments

x	relative height
y0	diameter for which height is required
SK	return of SK_EBLUP_LME.f containing estimated fixed and the tree specific random effects of the taper model
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f
...	not currently used

Details

used in xy0_SK_EBLUP_LME.f to find the root of taper curve (i.e. height x) at given diameter y0

Value

difference between actual diameter at height x and given diameter y0

Author(s)

Edgar Kublin

xy0_SK_EBLUP_LME.f *find relative height of given diameter*

Description

Internal function not usually called by users

Usage

```
xy0_SK_EBLUP_LME.f(xm, ym, y0, par.lme, Rfn = list(fn = "sig2"), ...)
```

Arguments

xm	relative heights for which measurements are available
ym	corresponding diameter measurements in height xm
y0	given diameter for which height is required
par.lme	Fitted model object, return of TapeR_FIT_LME.f
Rfn	list with function name to provide estimated or assumed residual variances for the given measurements, optionally parameters for such functions
...	not currently used

Details

function used to transform given diameter in volume calculation into height; c.f E_VOL_AB_HmDm_HT.f; with Rfn one can decide whether the measured diameters are forced to lie exactly on the taper curve Rfn$fn="sig2" or not Rfn$fn="zero". Other options are possible, see also SK_EBLUP_LME.f and resVar.

Value

relative height of given diameter y0

Author(s)

Edgar Kublin

XZ_BSPLINE.f *construct B-Splines design matrices*

Description

Internal function not usually called by users

Usage

```
XZ_BSPLINE.f(x, knt, ord, ...)
```

Arguments

x	relative height measurements
knt	knot positions for B-Splines, usually taken from a model fit by TapeR_FIT_LME.f
ord	order of B-Splines, usually taken from a model fit by TapeR_FIT_LME.f
...	not currently used

Value

List with height measurements (x), the fixed effects B-splines matrix and the random effects B-splines matrix.

Author(s)

Edgar Kublin

See Also

TapeR_FIT_LME.f

`y2x_isp.f` *squared diameter using interpolating splines*

Description

Internal function not usually called by users

Usage

```
y2x_isp.f(x, x.grd, y.grd, ...)
```

Arguments

`x`	relative height
`x.grd`	relative heights for interpolation
`y.grd`	diameter of taper curve at relative heights `x.grd` for interpolation
`...`	not currently used

Value

squared estimated diameter based on natural interpolating spline (splinefun)

Author(s)

Edgar Kublin

y2x_ssp.f *squared diameter using smoothing splines*

Description

Internal function not usually called by users

Usage

```
y2x_ssp.f(x, x.grd, y.grd, ...)
```

Arguments

x	relative height
x.grd	relative heights for interpolation
y.grd	diameter of taper curve at relative heights x.grd for interpolation
...	not currently used

Value

squared estimated diameter based on smoothing splines (smooth.spline)

Author(s)

Edgar Kublin

yx_isp.f *diameter using interpolating splines*

Description

Internal function not usually called by users

Usage

```
yx_isp.f(x, x.grd, y.grd, ...)
```

Arguments

x	relative height
x.grd	relative heights for interpolation
y.grd	diameter of taper curve at relative heights x.grd for interpolation
...	not currently used

Value

estimated diameter based on natural interpolating spline (`splinefun`)

Author(s)

Edgar Kublin

`yx_ssp.f` *diameter using smoothing splines*

Description

Internal function not usually called by users

Usage

```
yx_ssp.f(x, x.grd, y.grd, ...)
```

Arguments

`x`	relative height
`x.grd`	relative heights for interpolation
`y.grd`	diameter of taper curve at relative heights `x.grd` for interpolation
`...`	not currently used

Value

estimated diameter based on smoothing splines (`smooth.spline`)

Author(s)

Edgar Kublin

Index