Package 'TapeR'

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Type Package

Title Flexible Tree Taper Curves Based on Semiparametric Mixed Models

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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 the following publication: 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.

License GPL (>= 2)

LazyLoad yes

Depends nlme, splines, pracma

NeedsCompilation no

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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)

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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`

`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)
```

`E_DHx_HmDm_HT.f` *Calibrates a taper curve based on at least one diameter measurement and returns the expected diameters and their variances, volumes for parts or the complete stem and threshold heights given a diameter.*

Description

Calibrates a taper curve based on e.g., dbh and upper diameter measurements and returns the expected diameter and its approximate variance given relative heights and taper model parameters. Confidence intervals are calculated using exact or approximate methods. Supportive functions return the volume for parts or the complete stem and threshold heights given a diameter as well as variances of all estimates.

Usage

```
E_DHx_HmDm_HT.f(Hx, Hm, Dm, mHt, sHt=0, par.lme, ...)
E_DHx_HmDm_HT_CIdHt.f(Hx, Hm, Dm, mHt, sHt, par.lme, ...)
E_HDx_HmDm_HT.f (Dx, Hm, Dm, mHt, sHt=0, par.lme, ...)
E_VOL_AB_HmDm_HT.f(Hm, Dm, mHt, sHt=0, A=NULL, B=NULL, iDH, par.lme, IA, nGL, ...)
```

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.
Dx	Scalar. Diameter for which to return height.
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.
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.
...	currently unused

Details

E_DHx_HmDm_HT.f returns the calibrated taper curve and approximate confidence intervals which can be useful for plotting. Uncertainty resulting from triff height estimates if tree height was not measured is incorporated.

E_DHx_HmDm_HT_CIdHt.f returns the calibrated taper curve and "exact" confidence intervals. Attention: this function is somewhat time-consuming.

E_HDx_HmDm_HT.f returns the height given a certain diameter.

E_VOL_AB_HmDm_HT.f calculates the volume for a complete stem or sections.

Value

—————————E_DHx_HmDm_HT.f—————————

`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.

—————————E_DHx_HmDm_HT_CIdHt.f—————————

Named matrix with the following 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`.

—————————E_HDx_HmDm_HT.f—————————

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

—————————E_VOL_AB_HmDm_HT.f—————————

`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).

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

```
## Let's take a look on the taper curve of the first tree in the
## example data set if it is only calibrated using the diameter
## measurement in 2m height.

#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]); DxHx.df[Idi,]
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")
#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
points(tree1$Hx[3], tree1$Dx[3], pch=3, col=2)
#add the observations
points(tree1$Hx, tree1$Dx)

## Add the population average taper curve (without calibration) to the
## plot (not of high practical interest but good to know how to get it).
Ht  = tree1$Ht[1]
Hx  = tree1$Hx
#get fixed-effects design matrix for the Splines
X = TapeR:::XZ_BSPLINE.f(x=Hx/Ht, par.lme = SK.par.lme)$X
#Calculate population average taper curve
DHx_PA = X %*% SK.par.lme$b_fix
```

```
#add to plot
lines(tree1$Hx, DHx_PA, lwd=2, lty=4)

## Let's see how CI's change if there's some uncertainty in the height
## measurement
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 = 1, par.lme = SK.par.lme)

#plot the predicted taper curve
plot(tc.tree1$Hx, tc.tree1$DHx, type="l", xlab="Height (m)",
ylab="Diameter (cm)")
#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
points(tree1$Hx[3], tree1$Dx[3], pch=3, col=2)
#add the observations
points(tree1$Hx, tree1$Dx)

## Not run:
## 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)


## 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)
#add to above created plot
abline(v=ht.tree1.d8.5)

## Calculate the timber volume
#for the whole stem
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)

#Calculate the timber volume for a selected section given a height
#threshold (0.3 - 5 m)
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")

#Calculate the timber volume for a selected section given a diameter
```

```
#threshold (30 cm - 15 cm) (negative value if A<B)
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")

#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) ...
```

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)
```

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",
...)
```

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.
`...`	Currently unused

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.lme`	Summary of the fitted lme model.
`par.lme`	List 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_x`	Relative positions of the fixed effects Spline knots along the stem.
`ord_x`	Order of the spline.
`knt_z`	Relative positions of the random effects Spline knots along the stem.
`ord_z`	Order of the spline.
`b_fix`	Fixed-effects spline coefficients.
`KOVb_fix`	Covariance of fixed-effects.
`sig2_eps`	Residual variance.
`dfRes`	Residual degrees of freedom.
`KOVb_rnd`	Covariance of random effects.
`theta`	Variance parameters in natural parametrization. See Details.
`KOV_theta`	Approximate 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

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")
```

---

yx_ssp.f *Internal funtions not usually called by users.*

Description

Internal funtions 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)), ...)
CdN_DHxHt.f(Ht, Hx, qD, Hm, Dm, par.lme, ...)
dN.f(x, mw, sd, ...)
```

```
EYx_ssp.f(knt, coe, x, ...)
Hx_root.f(Hx, Dx, Hm, Dm, mHt, sHt, par.lme, ...)
Int_CdN_DHx_dHt.f(qD, Hx, Hm, Dm, mHt, sHt, par.lme, nGL = 51, ...)
Int_E_VOL_AB_HmDm_HT_dHt.f(Hm, Dm, A = NULL, B = NULL, iDH = "D",
mw_HtT, sd_HtT, par.lme, IA = F, nGL = 51, ...)
qD.rout.f(qD, alpha = 0.975, Hx, Hm, Dm, mHt, sHt, par.lme,
nGL = 51, ...)
SK_EBLUP_LME.f(xm, ym, xp, par.lme, ...)
SK_VOLab_EBLUP_LME.f(xm, ym, a = 0, b = 1, Ht, par.lme, IntPolOpt = T,
...)
TransKnots(knots = c(seq(0, 1, 0.1)), ord = 4, ...)
xy0_root.f(x, y0, SK, par.lme, ...)
xy0_SK_EBLUP_LME.f(xm, ym, y0, par.lme, ...)
XZ_BSPLINE.f(x, par.lme, ...)
y2x_isp.f(x, x.grd, y.grd, ...)
y2x_ssp.f(x, x.grd, y.grd, ...)
yx_isp.f(x, x.grd, y.grd, ...)
yx_ssp.f(x, x.grd, y.grd, ...)
```

Arguments

knots	Vector of knots
ord	Scalar - order of spline
der	der
x	x
Ht	Height
Hx	Numeric vector of stem heights (m) along which to return the expected diameter.
Dx	Scalar. Diameter for which to return height.
qD	
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.
par.lme	List of taper model parameters obtained by TapeR_FIT_LME.f.
mw	
sd	
knt	
coe	
mHt	
sHt	
nGL	
A	Height from which to calculate
B	Height to which to calculate

`iDH`

`mw_HtT`

`sd_HtT`

`IA`

`alpha`

`xm`

`ym`

`xp`

`a`

`b`

`IntPolOpt`

`y0`

`SK`

`x.grd`

`y.grd`

`...` Currently unused

Details

Internal funtions not usually called by users.

BSplines: Calculates BSplines

CdN_DHxHt.f:

dN.f:

EYx_ssp.f:

Hx_root.f:

Int_CdN_DHx_dHt.f:

Int_E_VOL_AB_HmDm_HT_dHt.f:

qD.rout.f:

SK_EBLUP_LME.f:

SK_VOLab_EBLUP_LME.f:

TransKnots:

xy0_root.f:

xy0_SK_EBLUP_LME.f:

XZ_BSPLINE.f:

y2x_isp.f:

y2x_ssp.f:

yx_isp.f:

yx_ssp.f:

Value

Depends on the specific function.

Author(s)

Edgar Kublin

See Also

TapeR_FIT_LME.f, E_DHx_HmDm_HT.f

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