A site index model for Norway spruce in Bavaria

Susanne Brandl, Wolfgang Falk, Dr. Hans-Joachim Klemmt
Bayerische Landesanstalt für Wald und Forstwirtschaft

LWF Bayerische Landesanstalt für Wald und Forstwirtschaft

BAYERISCHE FORSTVERWALTUNG

ZENTRUM WALD FORST HOLZ WEIHENSTEPHAN

Structure

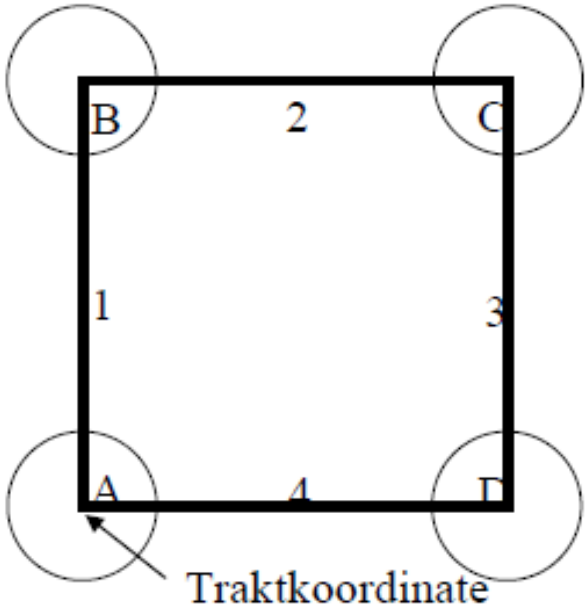
- Aims
- Database
- Height-diameter model
- Diameter-age model
- Predicition of site index
- Alternative approaches

Aims

- Investigating the relationship between growth and site -> statistical model
- Site index (height at age 100) to compare site productivity
- Regionalisation -> maps for Bavaria
- Predictions for changing environmental conditions

Data

- Data of the National Forest Inventories BWI 1 (1987) and BWI 2 (2002): height, BHD (diameter at breast height), age…
- Environmental data with high resolution (water balance, physical and chemical soil variables, monthly means of climatic variables, relief parameters)
- Regionalised daily surfaces of climatic variables (temperature, precipitation, evaporation)



Height-Diameter-Model

- Based on an approach of Albert & Schmidt (Albert, Matthias; Schmidt, Matthias (2009): Ein longitudinales Höhen-Durchmesser-Modell für Fichte in Deutschland, Tagungsband der Jahrestagung der Sektion Ertragskunde im DVFFA, S. 69-82)
- Basis: Korf function

$$\ln(height) = A - B \cdot BHD^{-C}$$

- modification

$$\ln(height) = A - B \cdot xBHD$$

$$xBHD = \frac{(BHD + \lambda)^{-C} - (30 + \lambda)^{-C}}{(10 + \lambda)^{-C} - (30 + \lambda)^{-C}}$$

-> biological interpretation and reduction of correlation between parameters

- A: expected value for ln(height) for trees with a diameter of 30 cm
- B: expected difference between ln(height) of trees with a diameter of 10 cm

Height-Diameter-Model

- Linearisation of the Korf function
  - 4 parameters are too many
  - direct application of GAM-method on the parameters
- Iterative identification of the optimal combination for λ and C in a GAM:

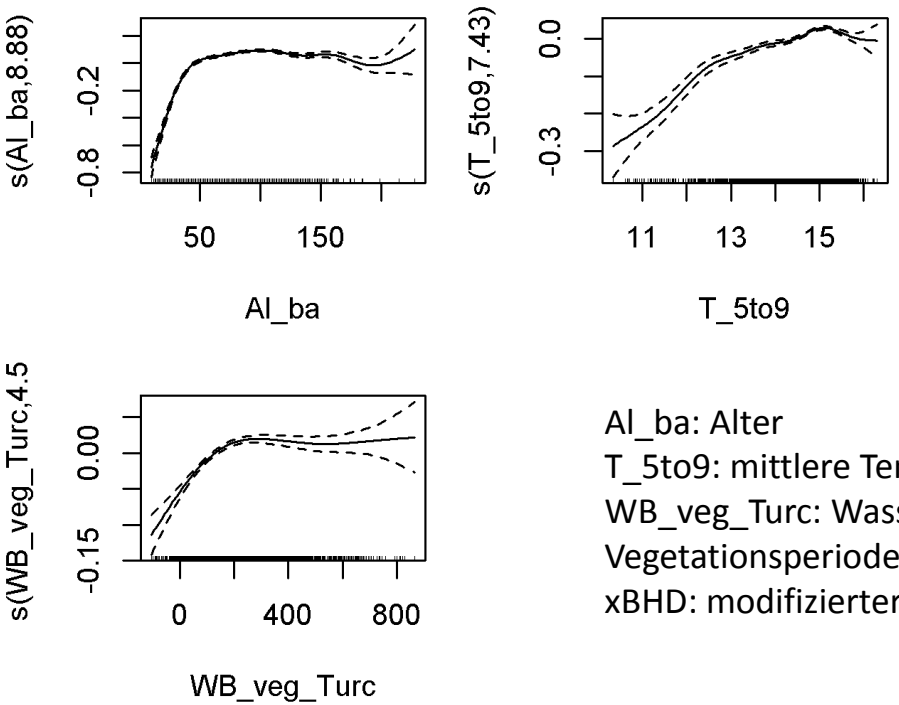
  gam(log(height) ~ s(age) + te(x,y) + s(elevation) + xBhd + age:xBhd + elevation:xBhd)
- Selection criterion: BIC

  λ = 6.6 and C = 1.535
- -> linear function with two parameters A and B

  $$\ln(height) = A - B \cdot xBHD$$

Effect of environmental variables on the parameter A of the Korf function

- $gam(Höhe \sim s(Al\_ba) + s(T\_5to9) + s(WB\_veg\_Turc) + xBHD + Al\_ba{:}\,xBHD + T\_5to9{:}\,xBHD, data = Fichte, family = gaussian(link = log))$

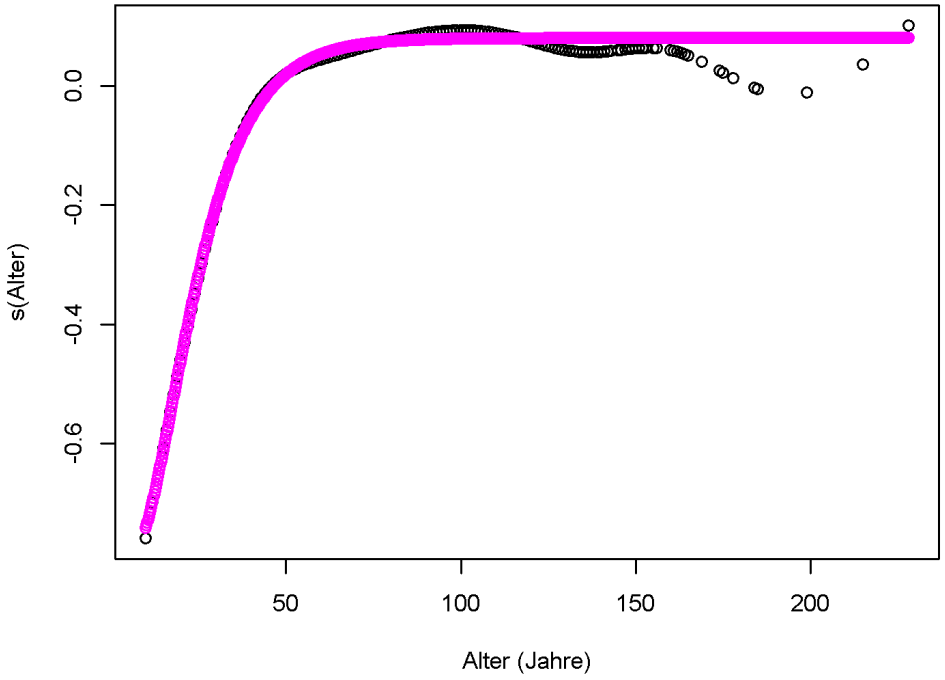


BIC = 25949.08
GCV = 8.5293

Al_ba: Alter
T_5to9: mittlere Temperatur Mai bis September
WB_veg_Turc: Wasserbilanz während der Vegetationsperiode
xBHD: modifizierter BHD

Replacing smooth terms by parametric functions

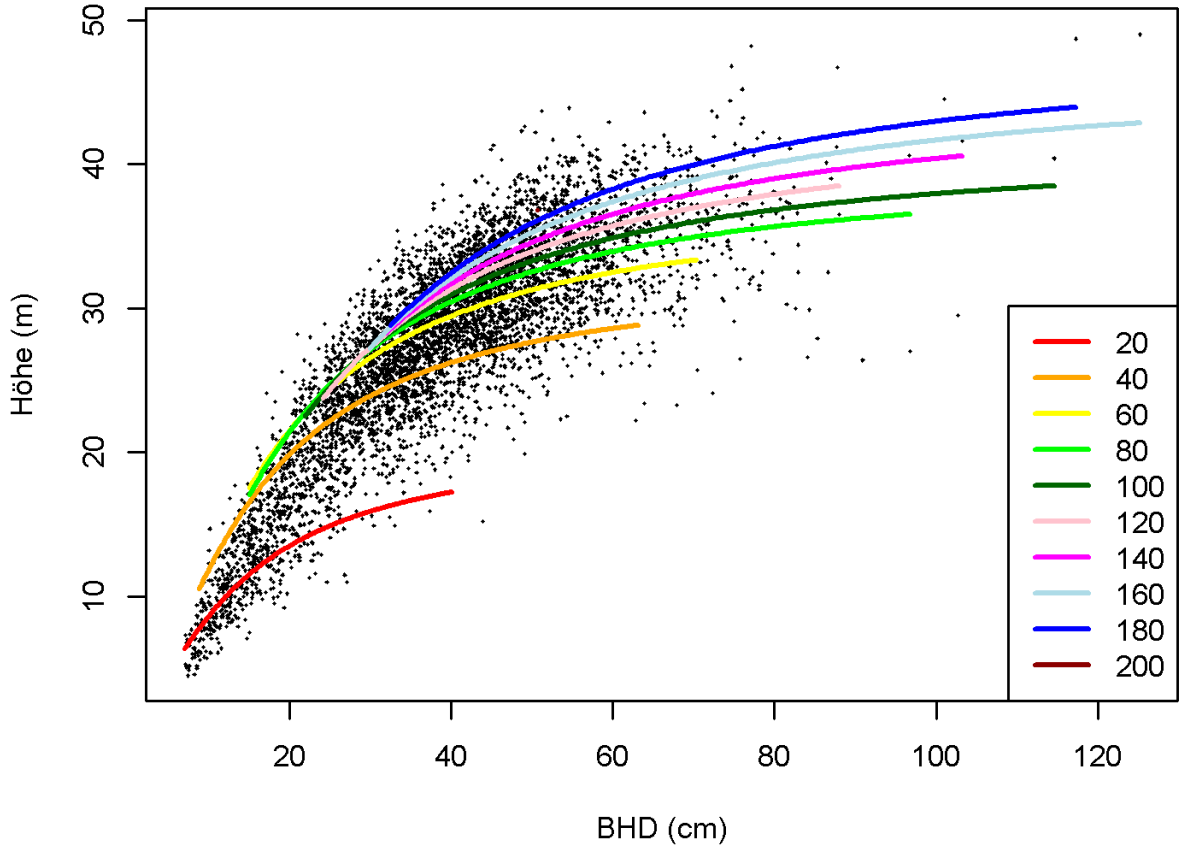
- glm_rep <- glm(Hoehe ~ I((1 - exp(-0.08311921*Al_ba))^4.145161) + I(0.3814*T_5to9 + -0.01233*T_5to9^2) + I(0.02306-(0.07282 * exp(-0.008566*WB_veg_Turc))) + xBhd + Al_ba:xBhd + T_5to9:xBhd, data = Fichte, family = gaussian(link = log))



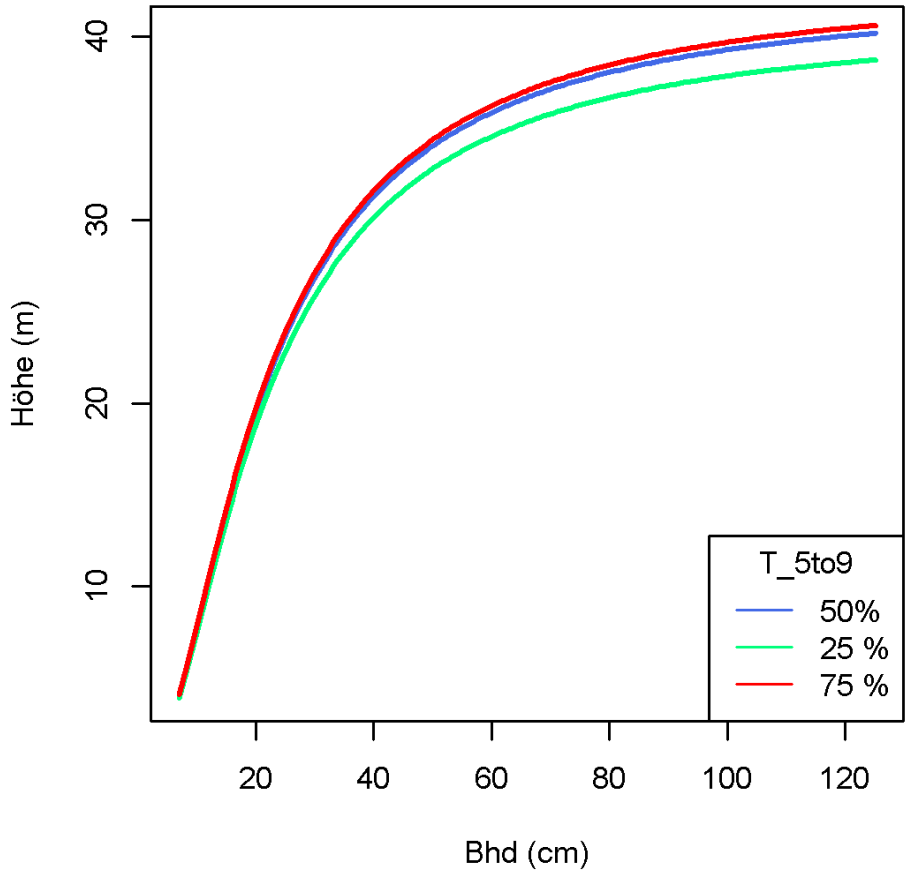
Influence of diameter, age and environment

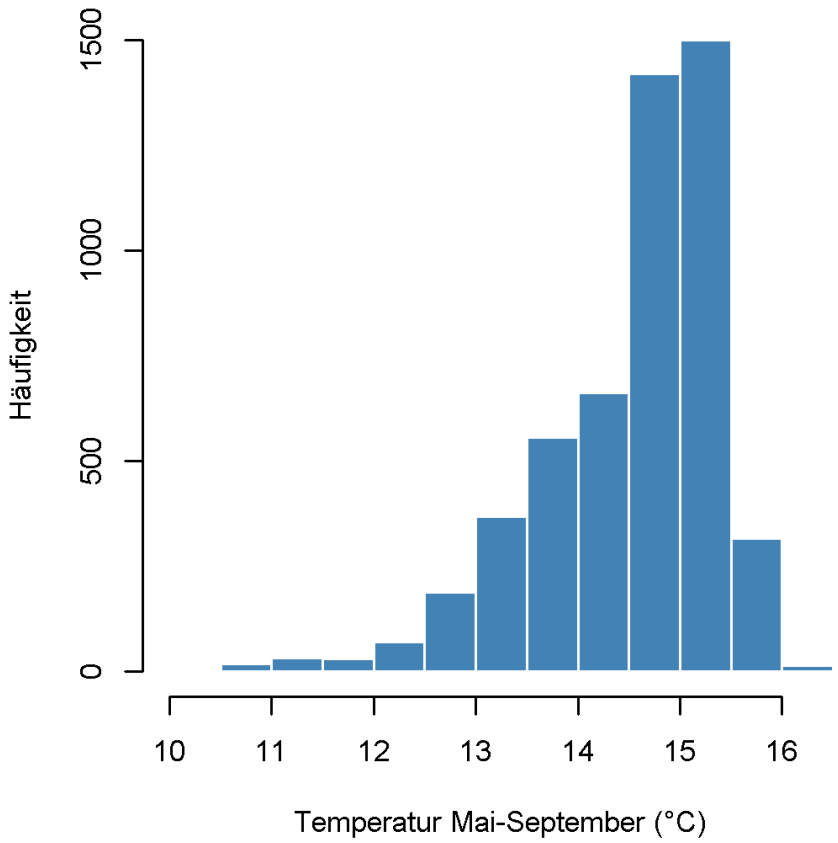
- A model with diameter and/or age alone already explains a great part of the variance
  - gam1 <- gam(log(height) ~ s(xBhd)) R^2 86 %
  - gam2 <- gam(log(height) ~ s(Al_ba)) R^2 80 %
  - gam3 <- gam(log(height) ~ s(Al_ba) + xBhd + Al_ba:xBhd) R^2 88.9 %
  - Selected GAM with environmental variables R^2 89.8 %

Effect of age on height-diameter-model



Effect of temperature on height-diameter-model





Determination of Site Index

$$\ln(height) = A + f(age) + f(temperature) + f(water\ balance) \\ -(B + \beta_1 \cdot age + \beta_2 \cdot temperature) * xBHD$$

- Age = 100
- Diameter at age 100
  - Diameter at age 100 has to be predicted -> Diameter-Age-Model
  - Site specific: a tree has a bigger diameter at a favourable site than at an unfavourable site under otherwise equal conditions

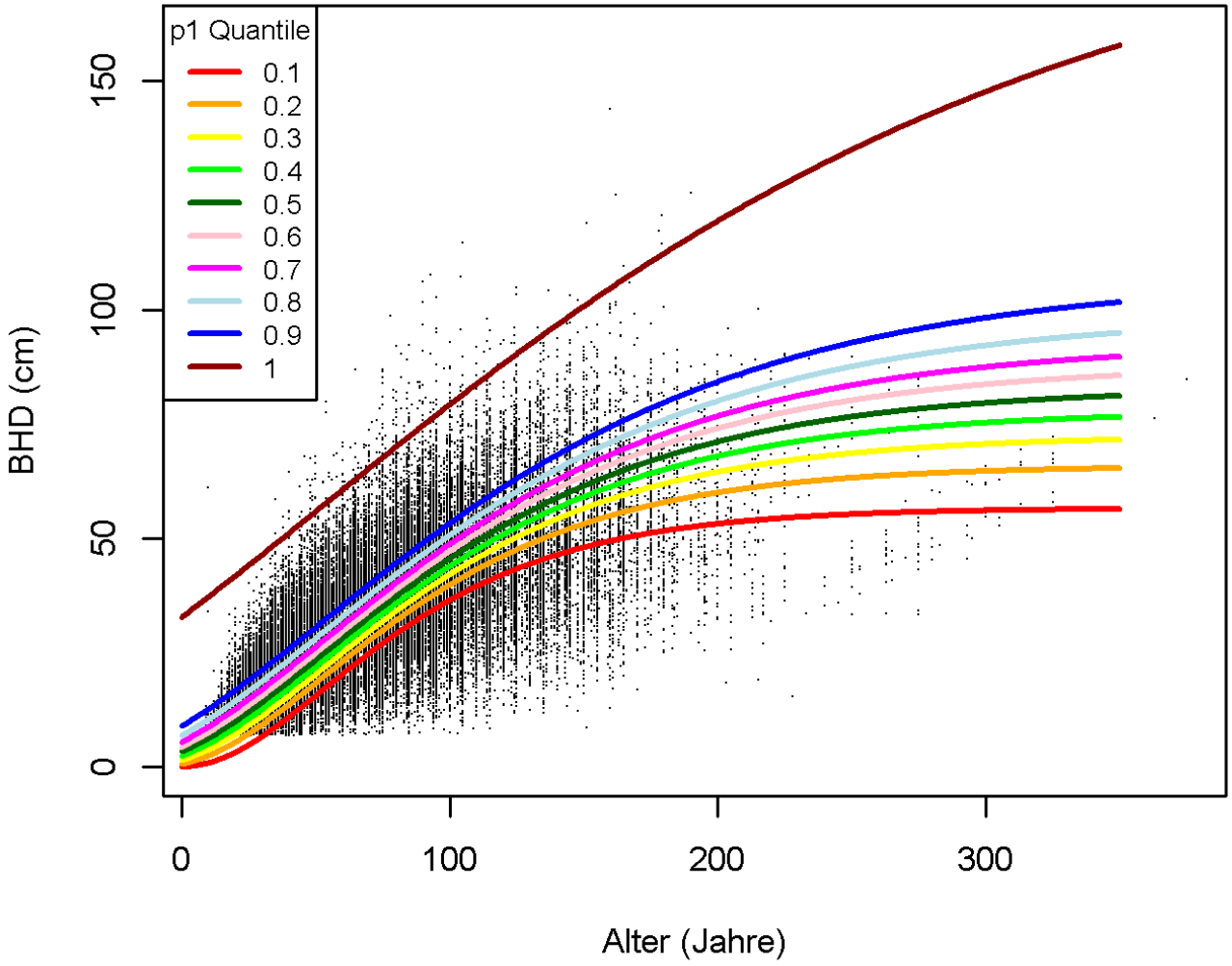
Diameter-Age-Model

- Based on an approach of Albert & Schmidt (NW-FVA)
- Basis: Bertalanffy function as a nonlinear mixed model (nlme)
- Modified version

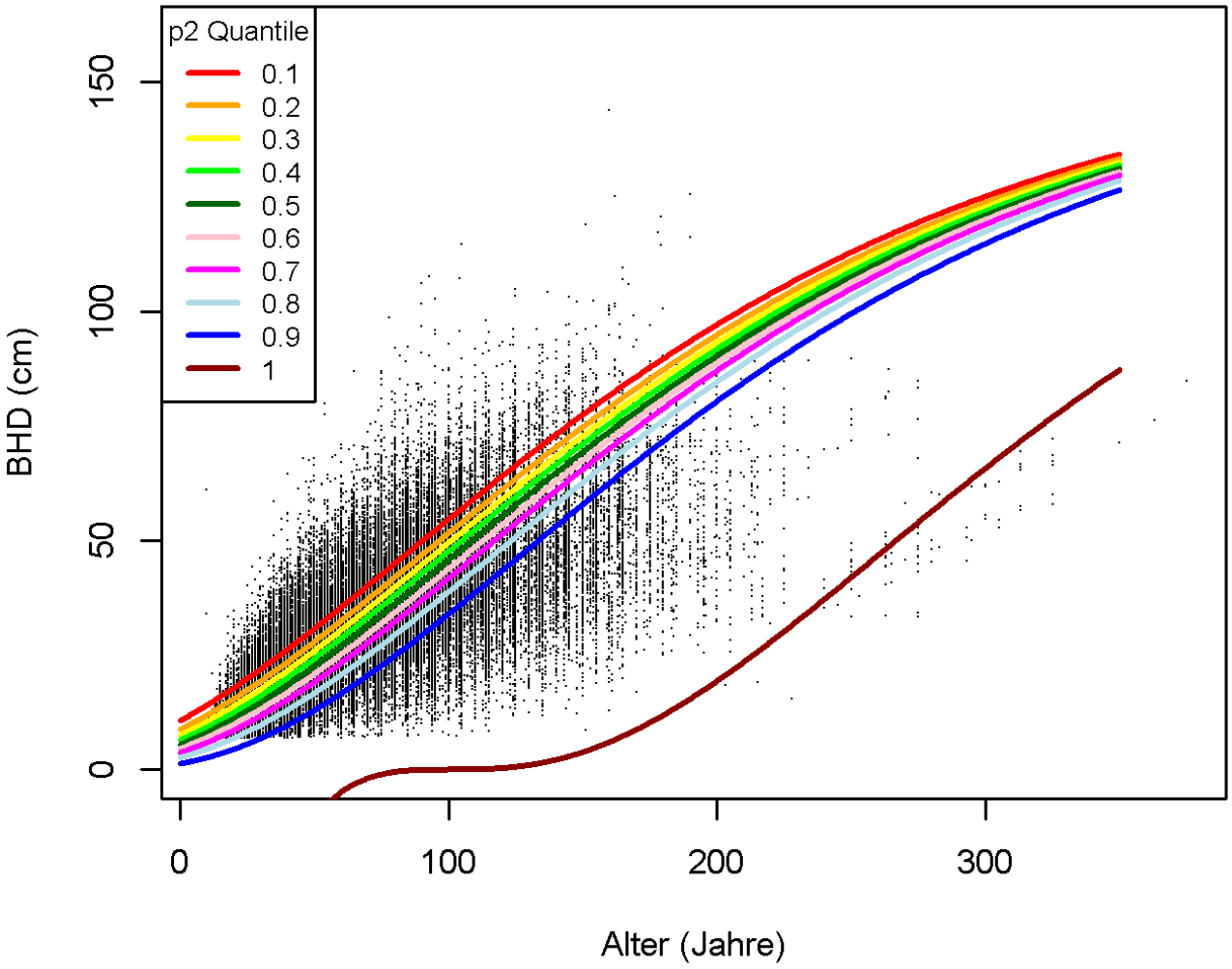
$$BHD_{ijk} = p_{1i} \cdot \left(1 - \frac{1}{3} \cdot e^{\left(\frac{p_3}{p_{1i}} \cdot (p_2 - Alter_{ijk}) \cdot \frac{9}{4}\right)}\right)^3$$

p_1: Asymptote (cm)
p_2: point in time of maximum diameter growth (a)
p_3: maximum diameter growth (cm/a)

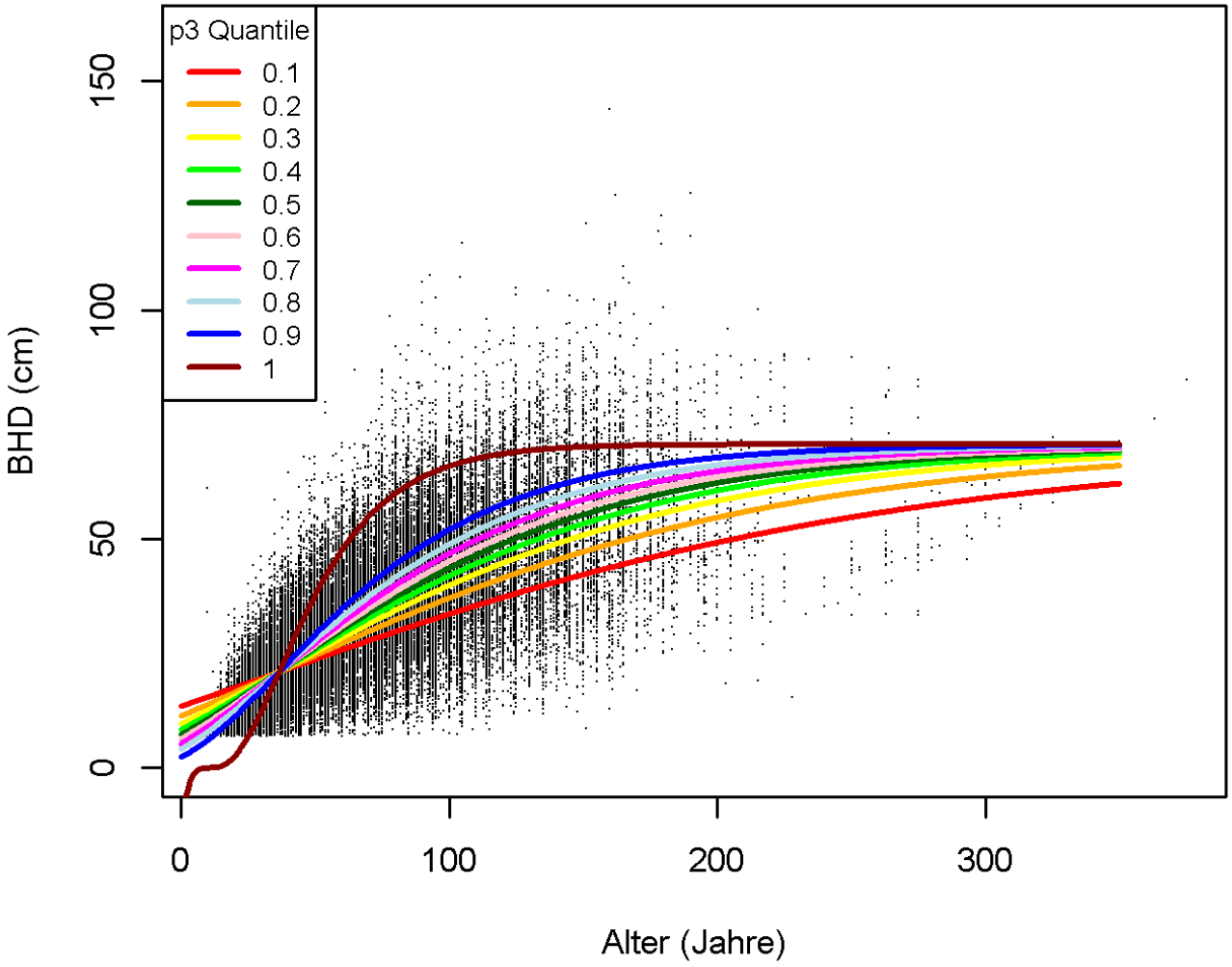
Curves of the quantiles of the BLUP for p1 (asymptote (cm))



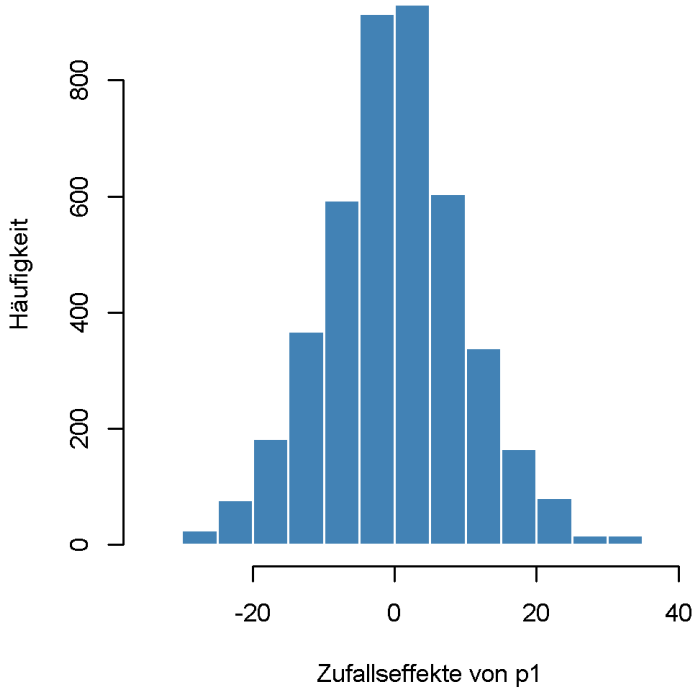
Curves of the quantiles of the BLUP for p2 (point in time of maximum diameter growth (a))



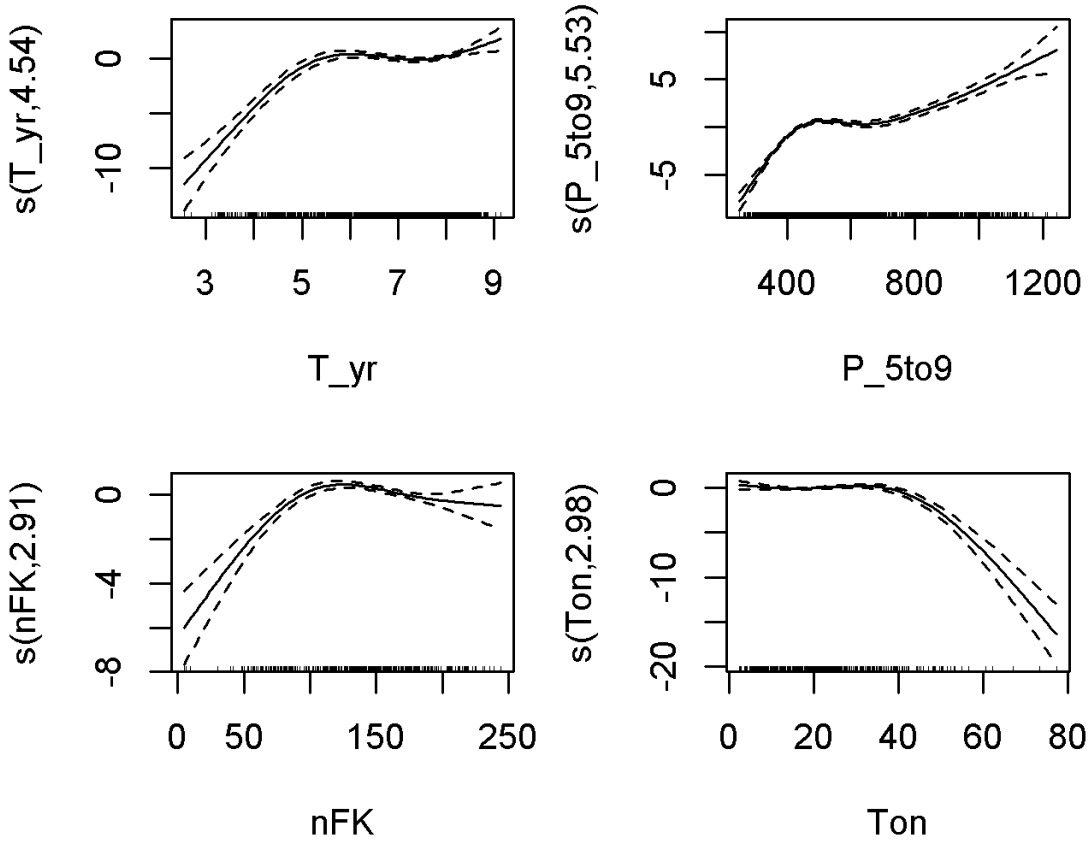
Curves of the quantiles of the BLUP for p3 (maximum diameter growth (cm/a))



Random effects of p1



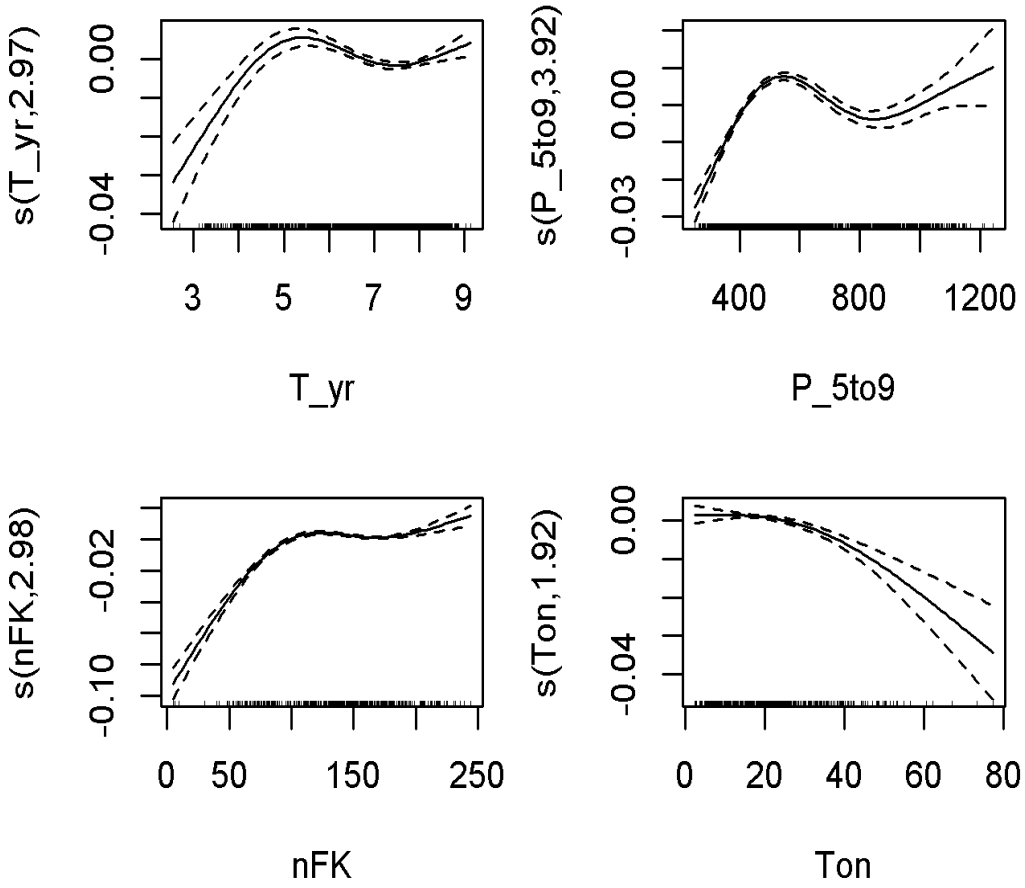
Effects of environmental variables on random parameter p1



T_yr: Jahresmitteltemperatur
P_5to9: Niederschlagssumme von Mai bis September
nFK: nutzbare Feldkapazität

R^2 = 4.12 %

Effects of environmental variables on random parameter p3



T_yr: Jahresmitteltemperatur
P_5to9: Niederschlagssumme von Mai bis September
nFK: nutzbare Feldkapazität

R^2 = 3.75 %

Integration of environmental effects in the Bertalanffy-Model

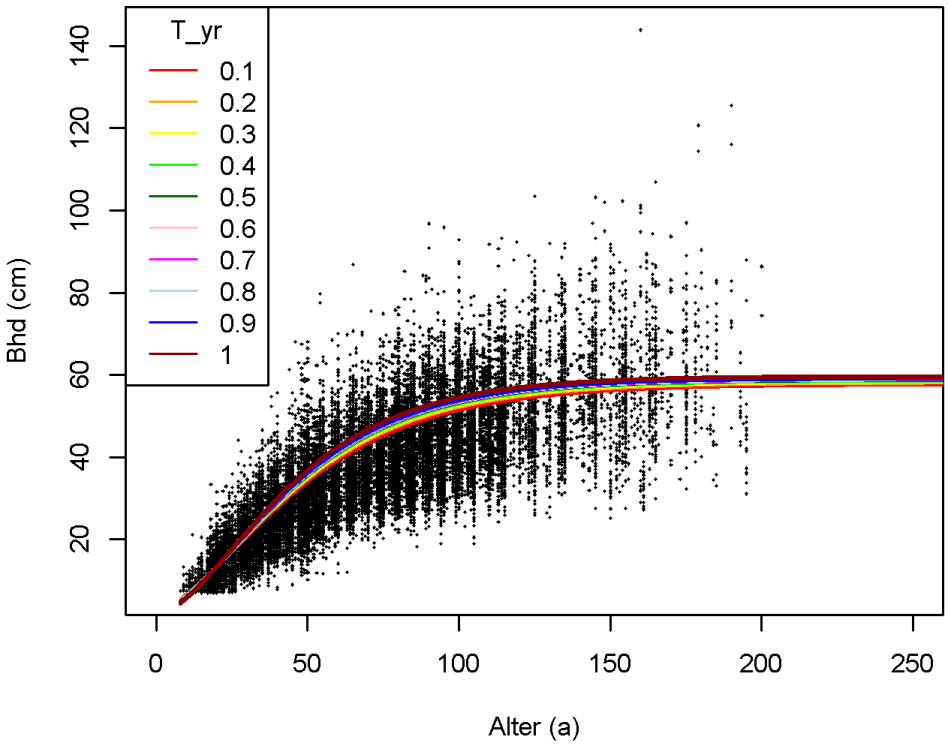
- Reestimation of the model parameters

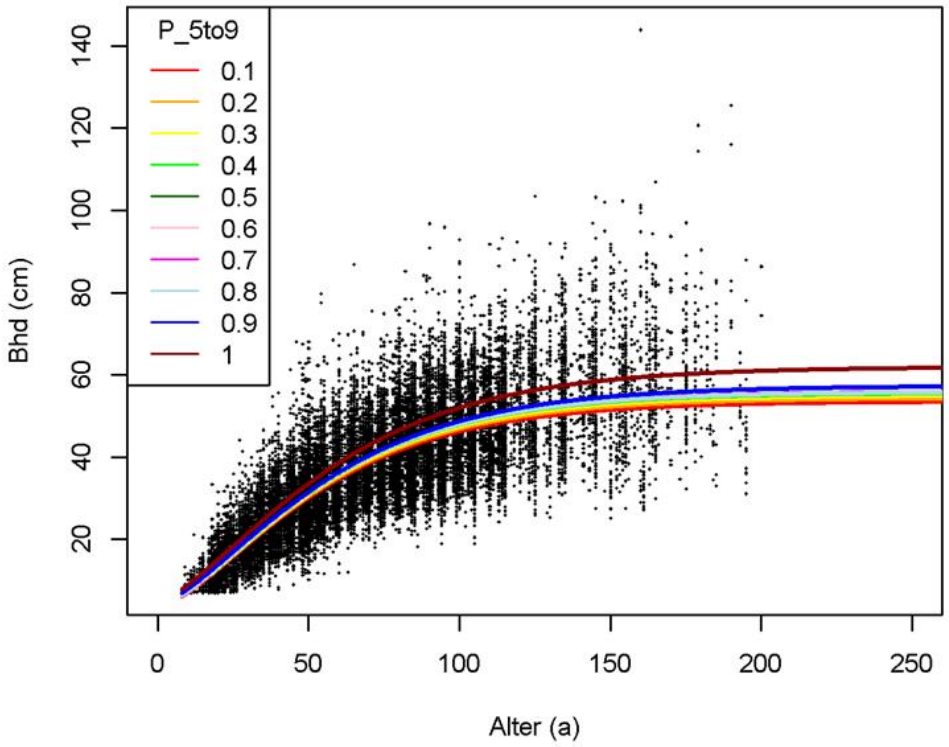
$$BHD_{ijk} = p_{1i} \cdot \left(1 - \frac{1}{3} \cdot e^{\left(\frac{p_{3i}}{p_{1i}} \cdot (p_2 - Alter_{ijk}) \cdot \frac{9}{4}\right)}\right)^3$$

$$p_1 = \alpha_{0i} + \alpha_1 \cdot s_{T_{yr}} + \alpha_2 \cdot s_{P_{5to9}} + \alpha_3 \cdot s_{nFK} + \alpha_4 \cdot s_{Ton}$$

$$p_3 = \beta_{0i} + \beta_1 \cdot s_{T_{yr}} + \beta_2 \cdot s_{P\_5to9} + \beta_3 \cdot s_{nFK} + \beta_4 \cdot s_{Ton}$$

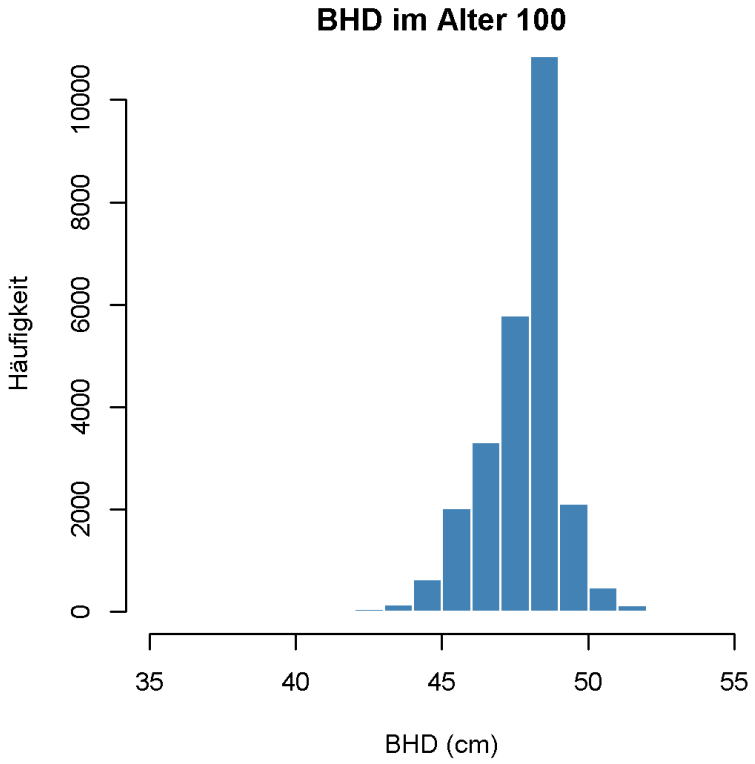
Effect of temperature and precipitation on diameter-age-model

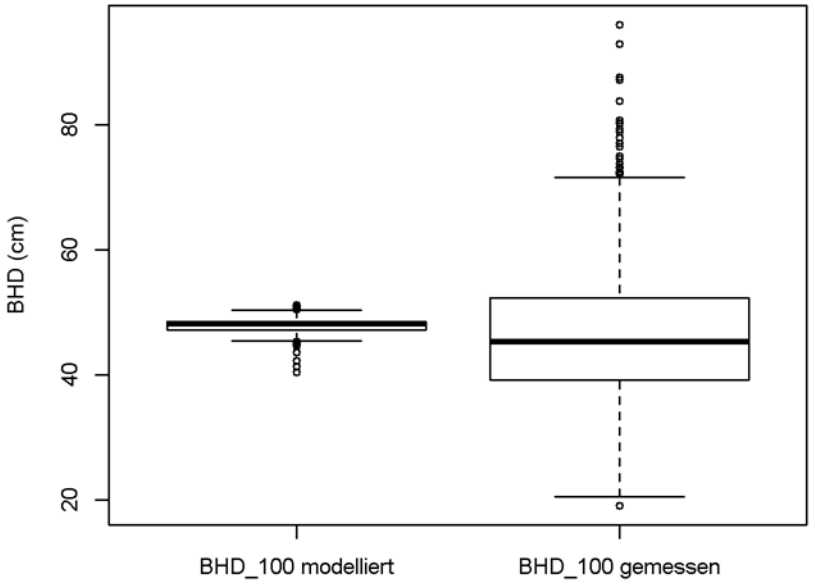




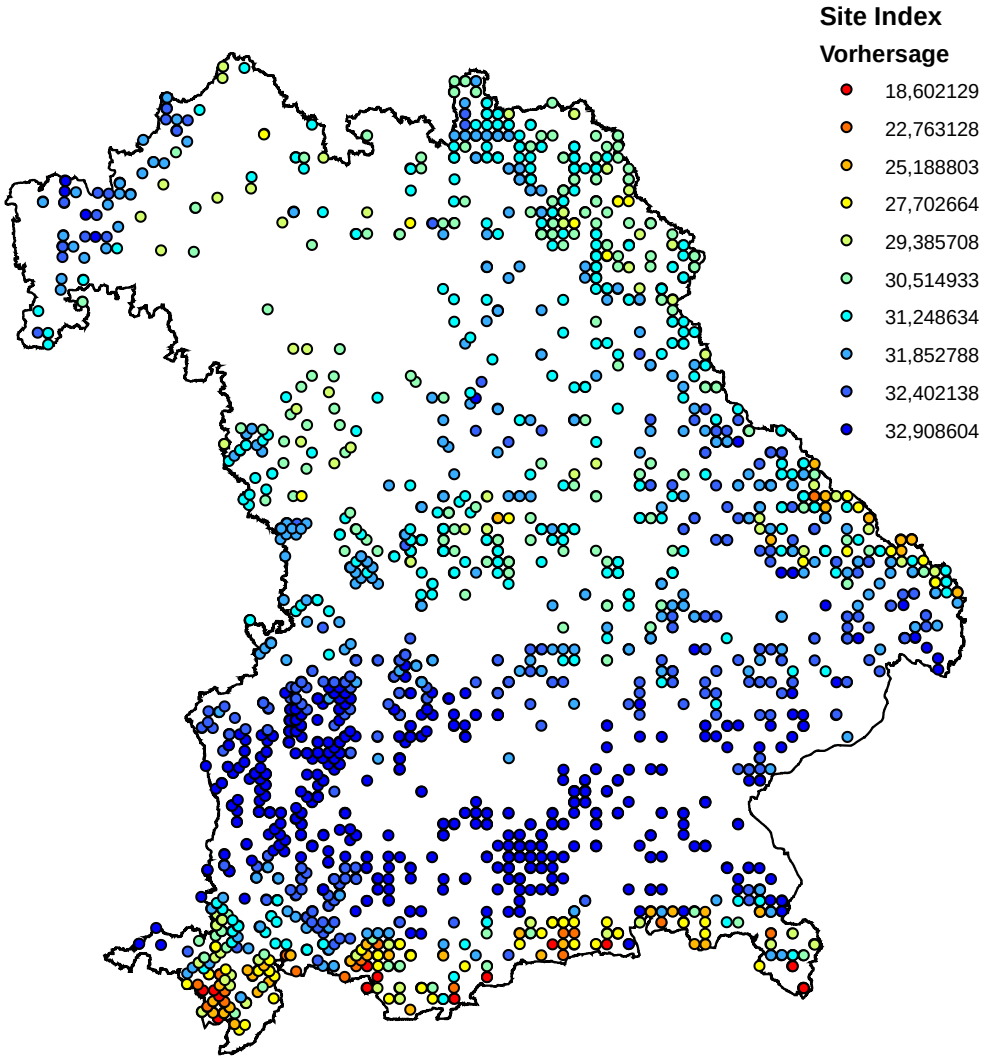
T_yr: Jahresmitteltemperatur
P_5to9: Niederschlagssumme von Mai bis September

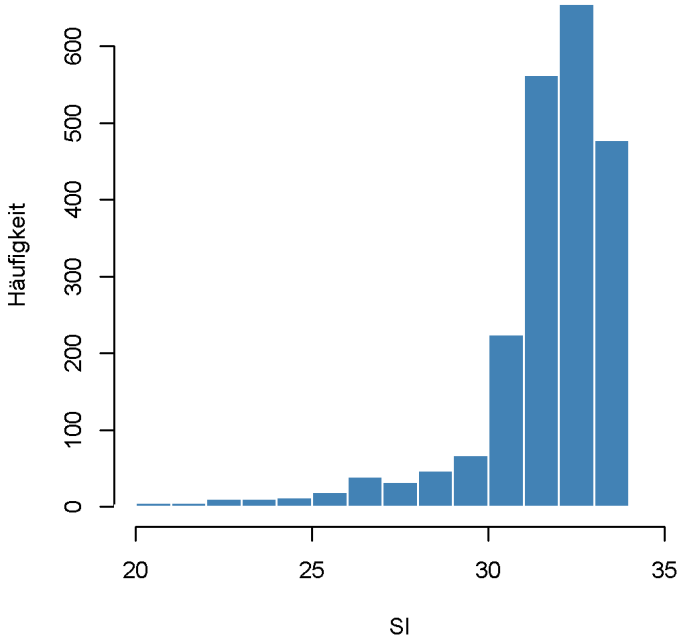
Predicted diameters at age 100 (only fixed effects)





Site Index Predictions





Method: Combining two models

- diameter-age-Model
  - Bertalanffy function
  - Response: DBH
  - Target variable: DBH at age 100 = input variable for height-diameter-model
- height-diameter-Model
  - Korf function
  - Response: height
  - Target variable: height at age 100 = Site Index

Reasons for modeling in two steps

- Height as response variable and measure for site potential as it is less affected by management than diameter
- Why not modeling the relationship between height and age? (instead of first modeling the relationship between height and diameter and then the relationship between diameter and age)
  - The relationship between height and diameter is better than the relationship between height and age, because trees of the same age can differ very much in height
  - DBH is measured quite exactly for all trees, whereas age is a rough estimation

  -> main model: height-diameter-model
  - Not only height but also diameter depends on environmental conditions

Next steps

- Focus on environmental variables -> better explanatory variables
- Integrating interactions
- Allowing for management effects in Diameter-Age-Model
- Direct calculation of SI from BWI-data and subsequent use as response variable in a regression model with environmental conditions as explanatory variables (Nothdurft et al. 2012)

  -> comparison of the results