Statistical Models for estimating Forest Parameters using Airborne Laser Scanner Data

Johannes.Breidenbach@forst.bwl.de

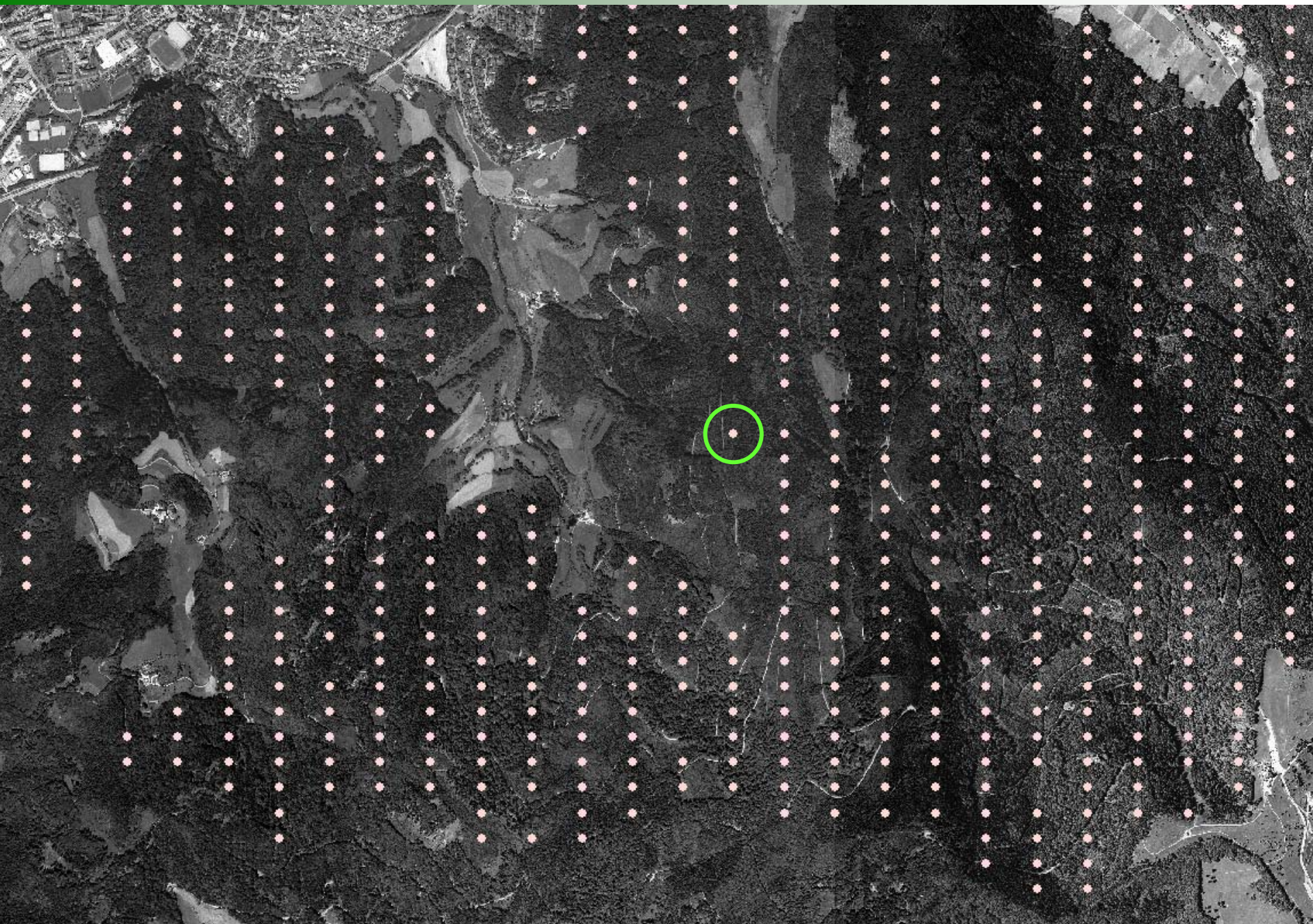
Forstliche Versuchs- und Forschungsanstalt
Baden-Württemberg

Abteilung Biometrie
und Informatik

Outline

- Introduction
- Lidar
- Methods for analysing lidar data
- Fitting of regression models
  - Diameter distributions (Ger.)
  - Stem volume
- Application of regression models
  - Biomass

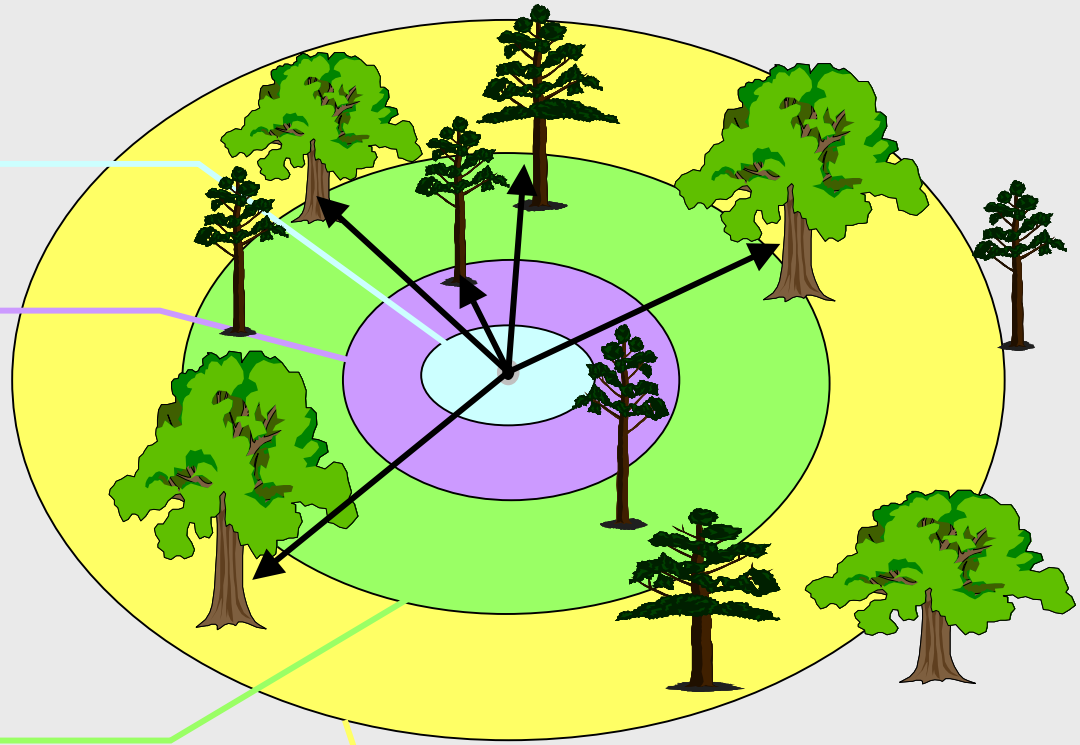
Systematic sample plot inventory



Introduction

r = 2 m; > 7 cm

r = 3 m; > 10 cm



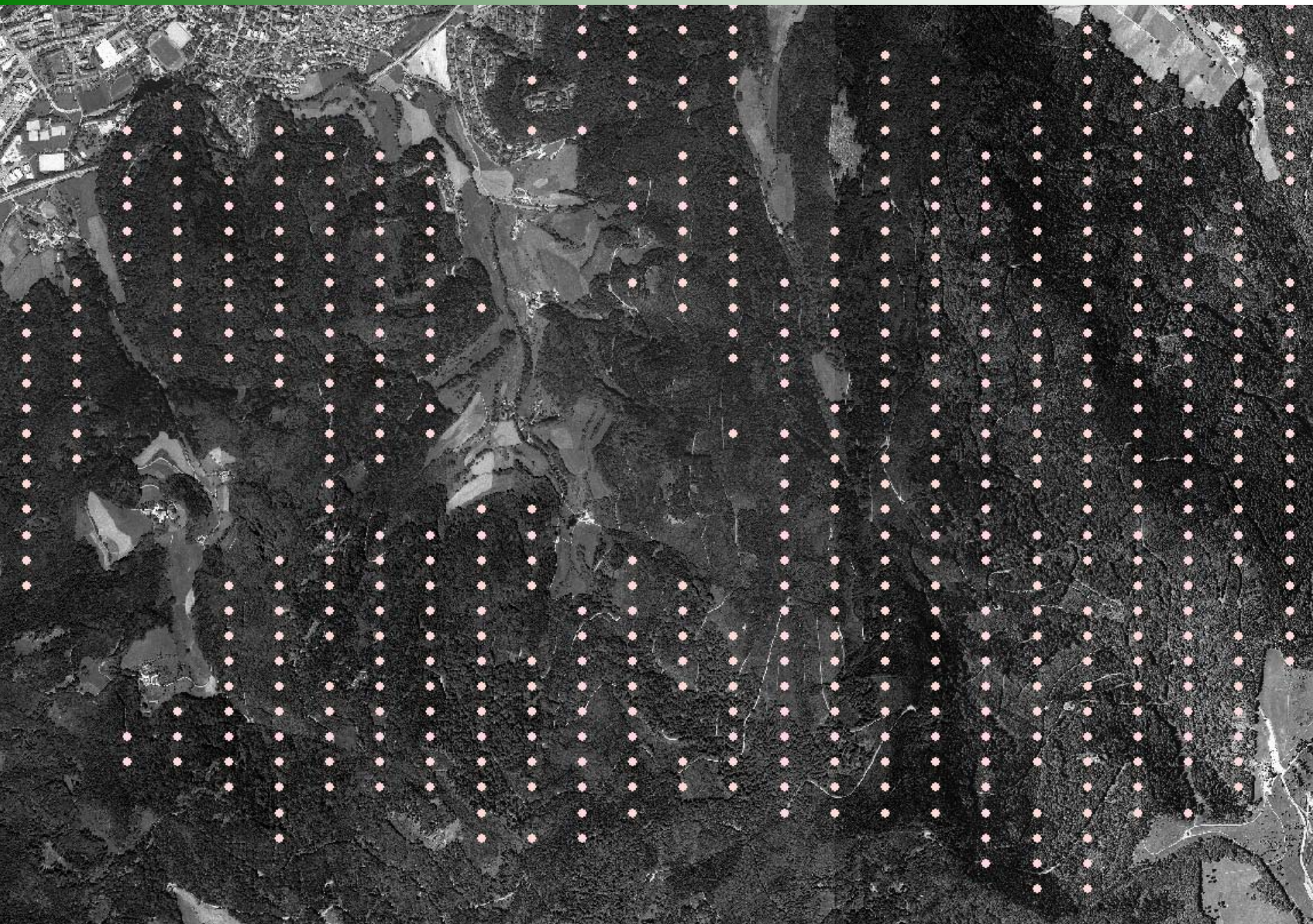
r = 6 m; > 15 cm

r =12 m; > 30 cm

Mapping of forest characteristics with Lidar data

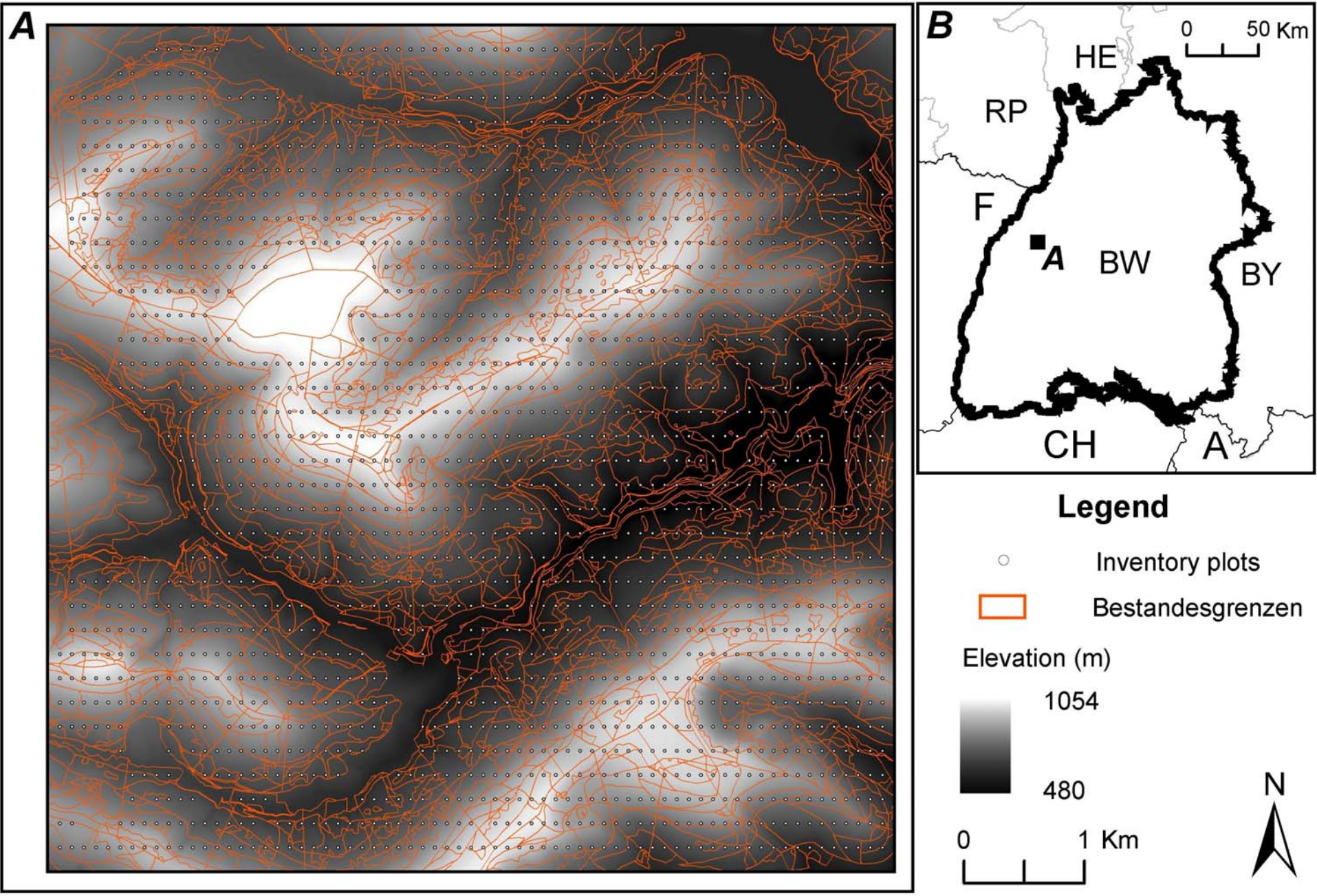
1. Preprocessing of data
2. Fitting of statistical models (Lidar+sample plots)
3. Application of statistical models (Lidar only)

Introduction



Introduction

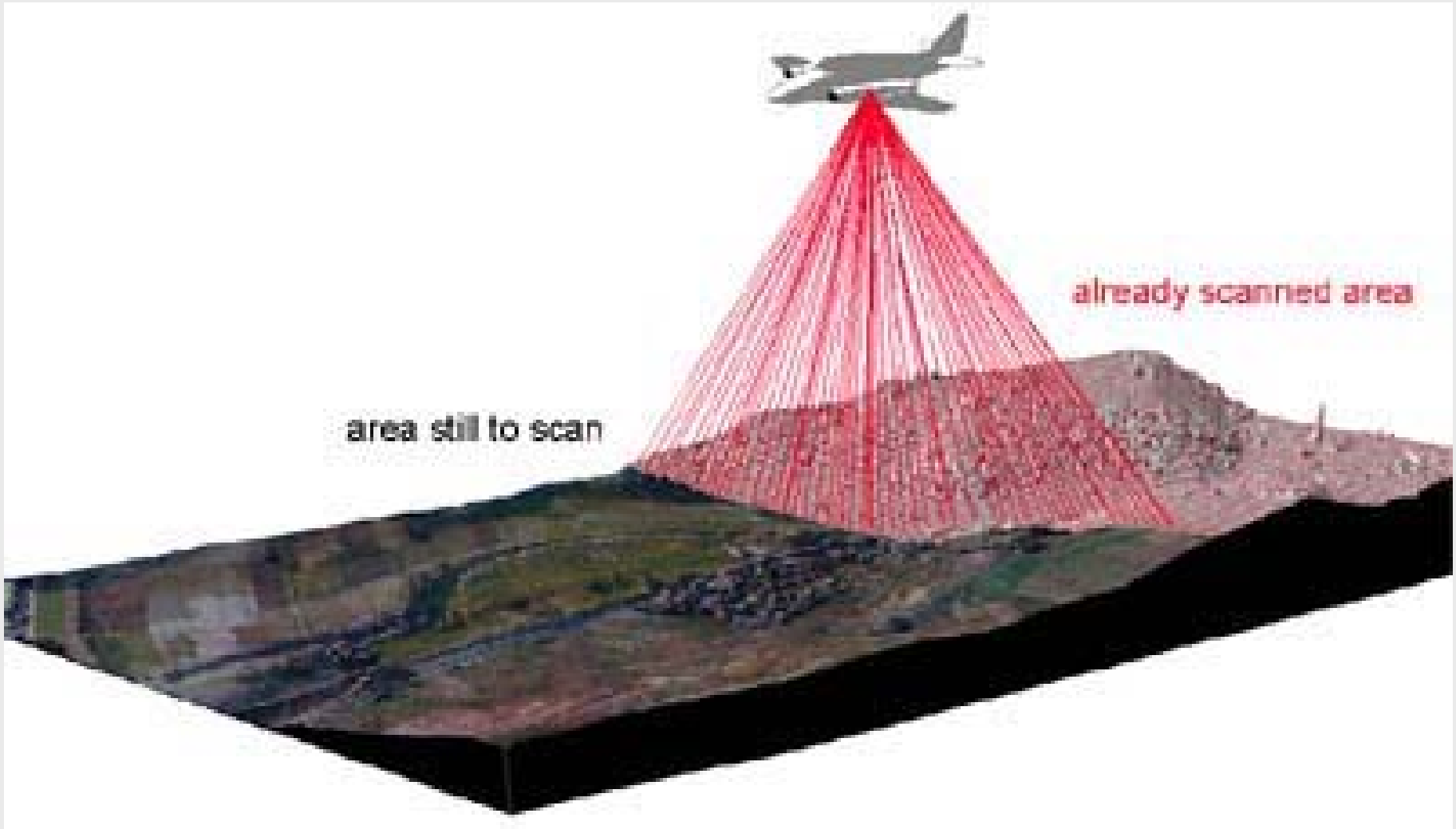
G Ökologie et al. 2007, Günzburg


A
B
0
50 Km
HE
RP
F
A
BW
BY
CH
A
Legend
Inventory plots
Bestandesgrenzen
Elevation (m)
1054
480
0
1 Km
N

Outline

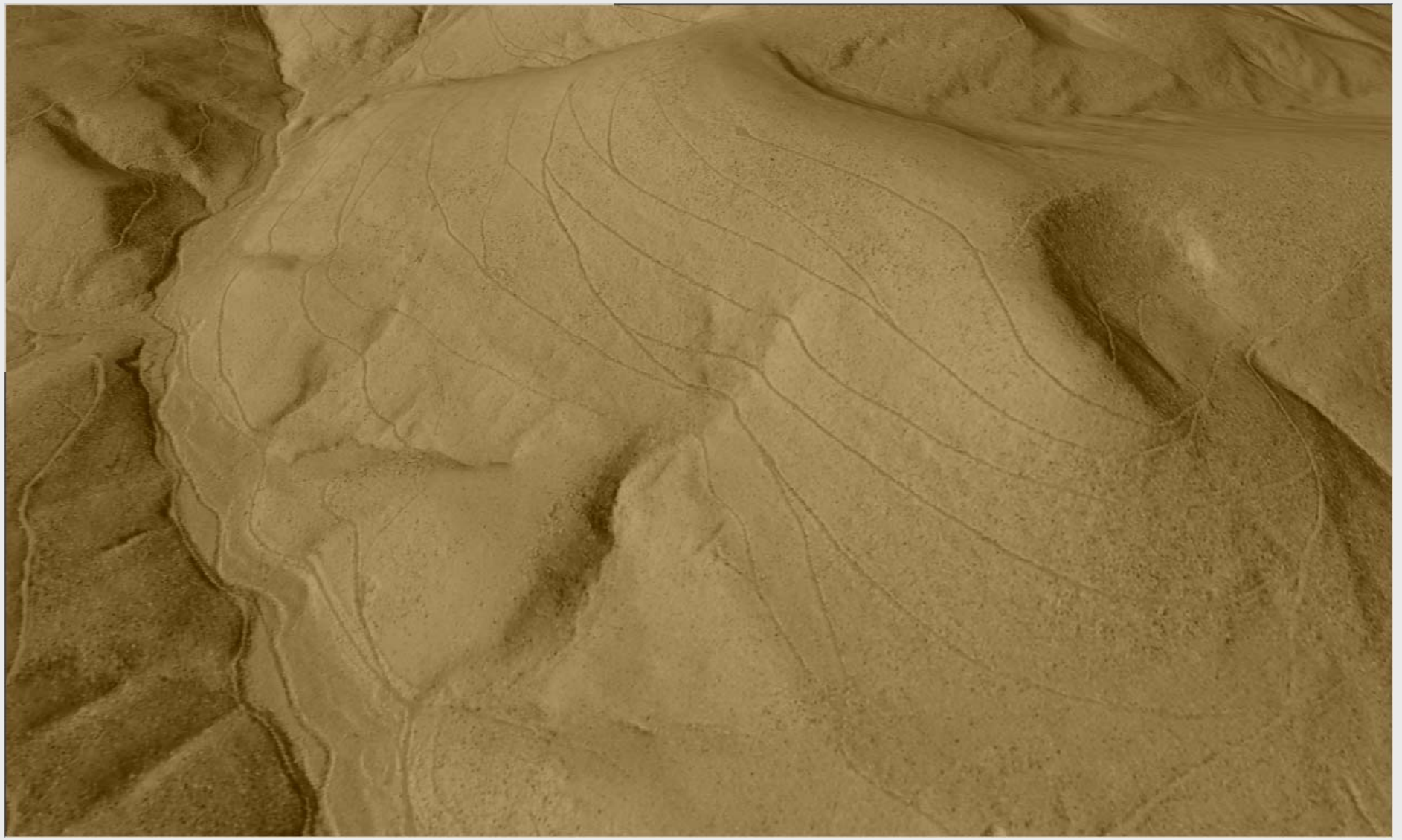
- Introduction
- Lidar
- Methods for analysing lidar data
- Fitting of regression models
  - Diameter distributions (Ger.)
  - Stem volume (US + Ger.)
- Application of regression models
  - Biomass (Ger.)

Lidar



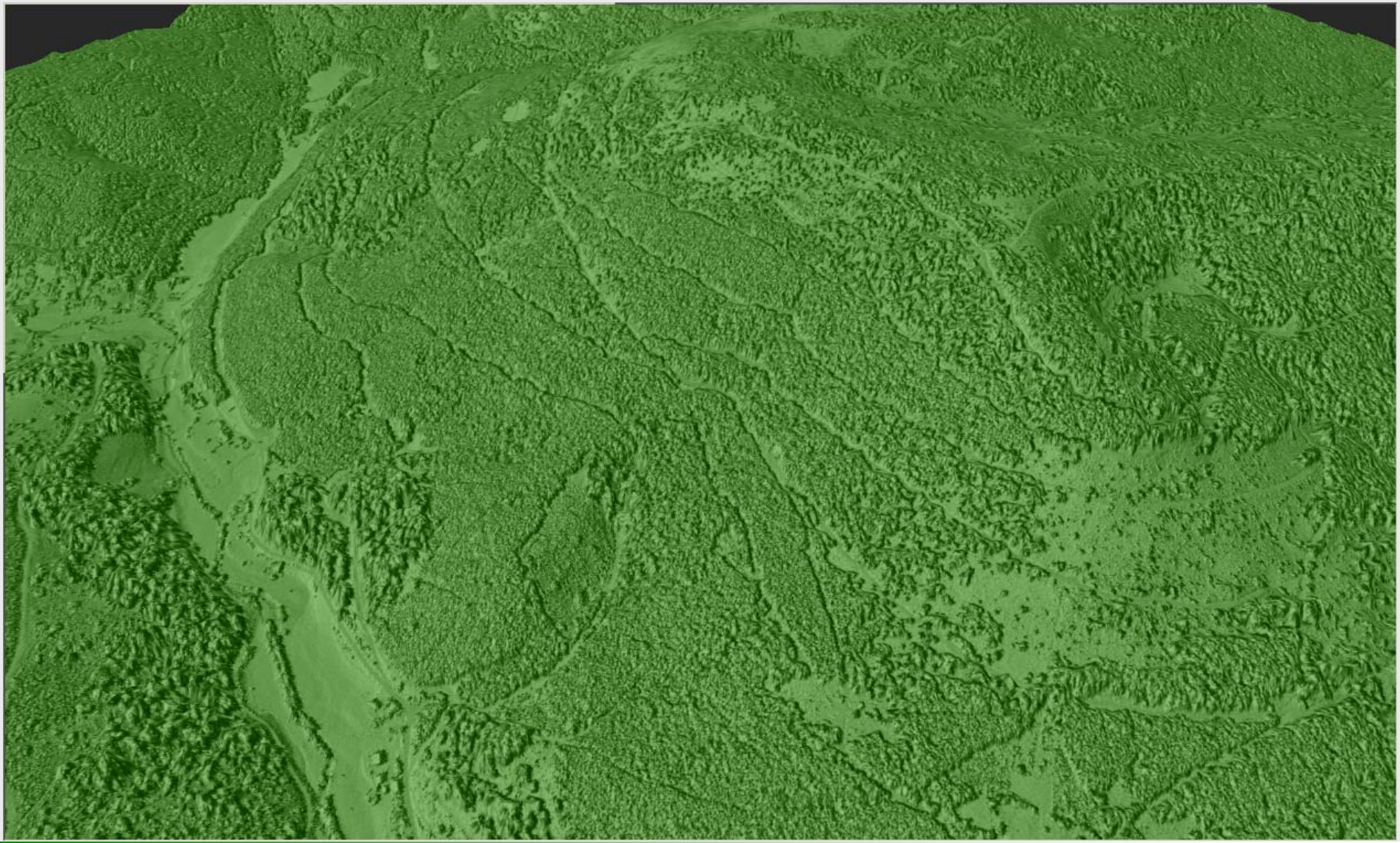
Source: TopoSys

Lidar



AG Ökologie et al. 2007, Günzburg

Lidar

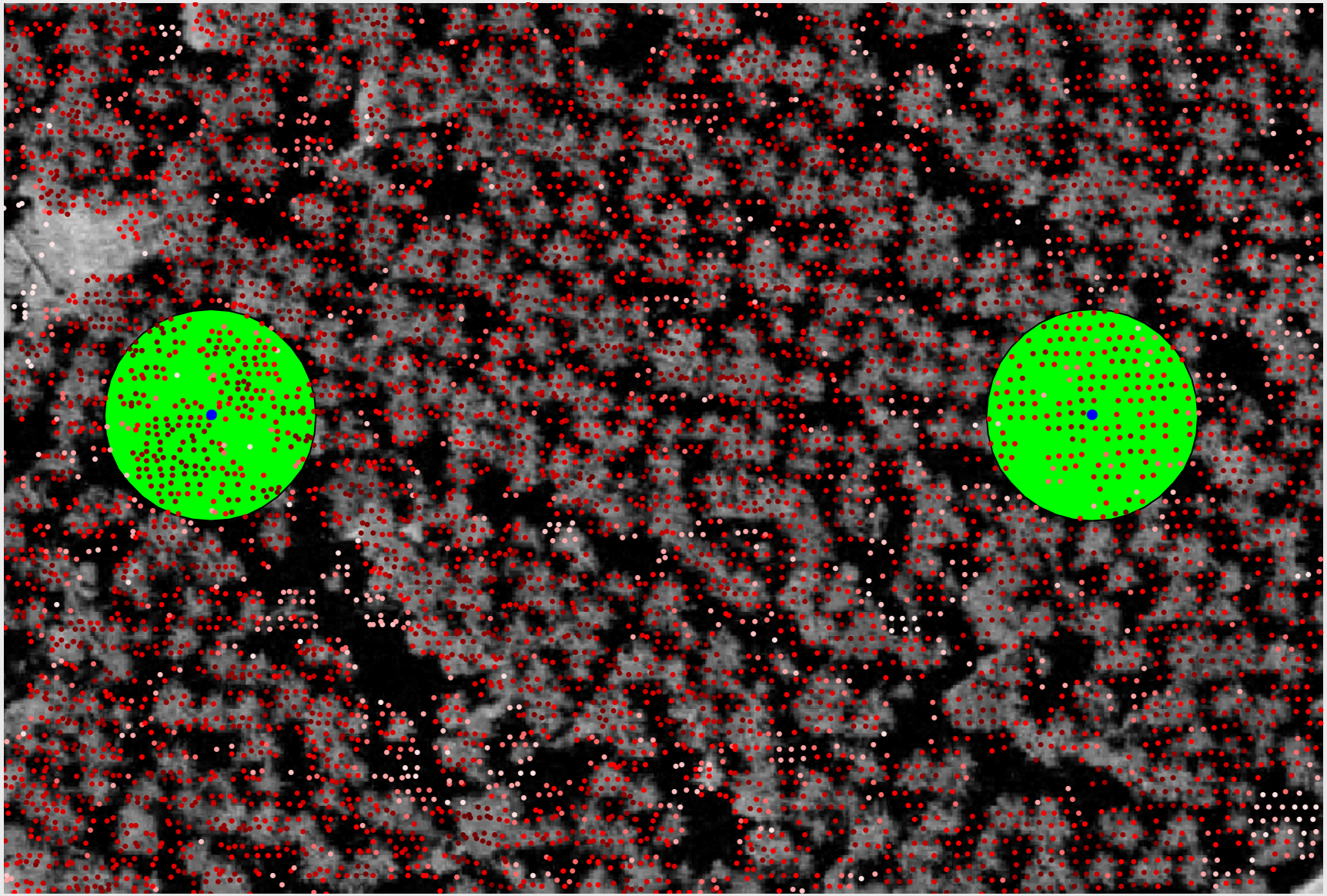


AG Ökologie et al. 2007, Günzburg

Outline

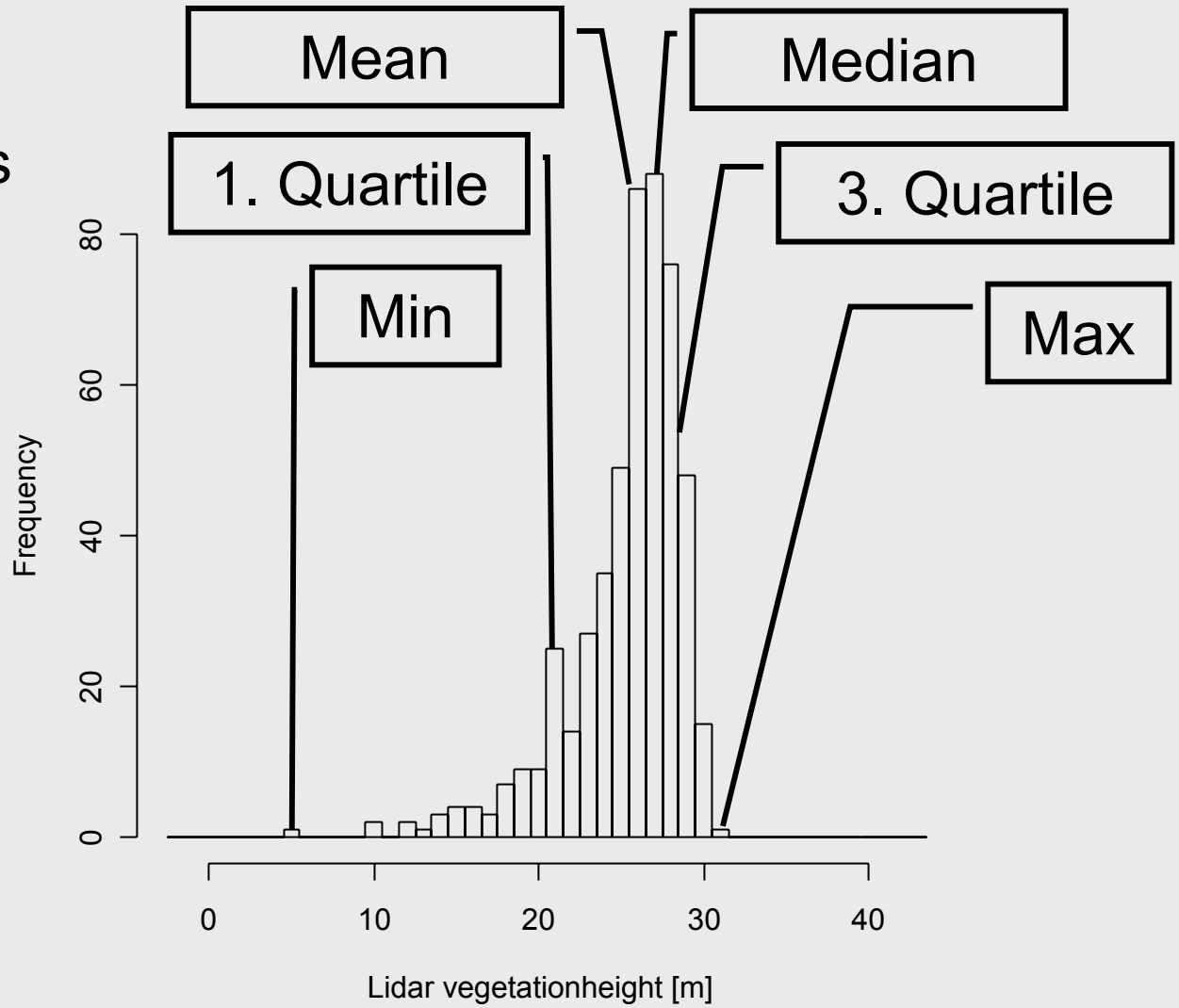
- Introduction
- Lidar
- Methods for analysing lidar data
- Fitting of regression models
  - Diameter distributions (Ger.)
  - Stem volume (US + Ger.)
- Application of regression models
  - Biomass (Ger.)

Methods



Methods

Height metrics



Additional covariates

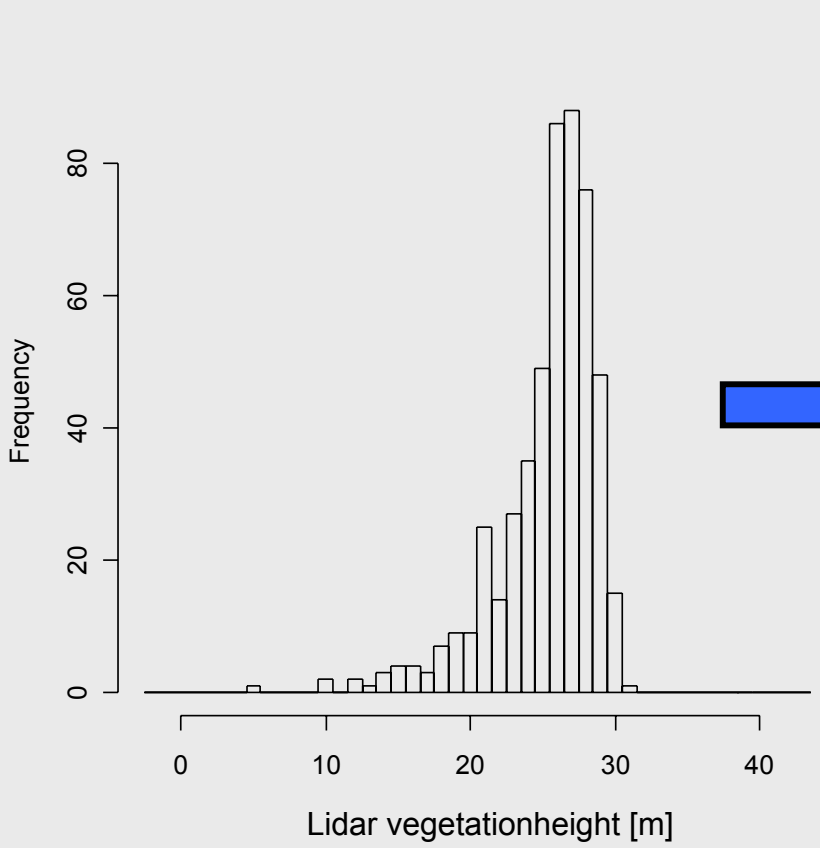
- Coniferous proportion (CP) = $(CHM_F - CHM_L)/ CHM_F > 0.3$

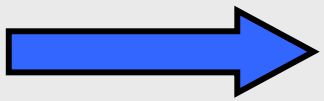
- Crown cover (CC) = $CHM_F > 1$ m

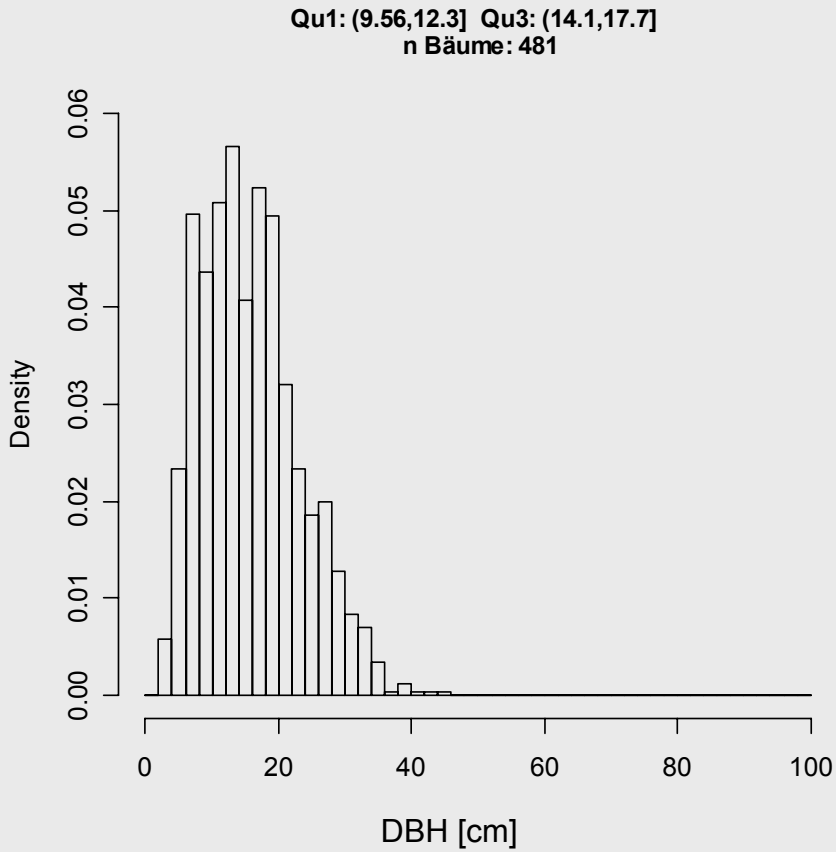
Outline

- Introduction
- Lidar
- Methods for analysing lidar data
- Fitting of regression models
  - Diameter distributions (Ger.)
  - Stem volume (US + Ger.)
- Application of regression models
  - Biomass (Ger.)

Estimation of diameter distributions







$$y \sim Weibull(a,b,c) \qquad a = 7, \quad b,c > 0$$

$$f(y \mid a,b,c) = \frac{c}{b}\left(\frac{y-a}{b}\right)^{c-1} \exp\left[-\left(\frac{y-a}{b}\right)^{c}\right]$$

$$LLH = \sum_{i=1}^{n} \log\left[f\left(y_i \mid a,b,c\right)\right]$$

$$b_i = g_1^{-1}\left(\eta_{1i}\right) \qquad c_i = g_2^{-1}\left(\eta_{2i}\right)$$

$$LLH = \sum_{i=1}^{n} \log\left[f\left(y_i \mid a,b_i,c_i\right)\right]$$

$$g_A(y_i \mid a, b_i, c_i) = \frac{f(y_i \mid a, b_i, c_i)}{F(10 \mid a, b_i, c_i) - F(7 \mid a, b_i, c_i)}$$

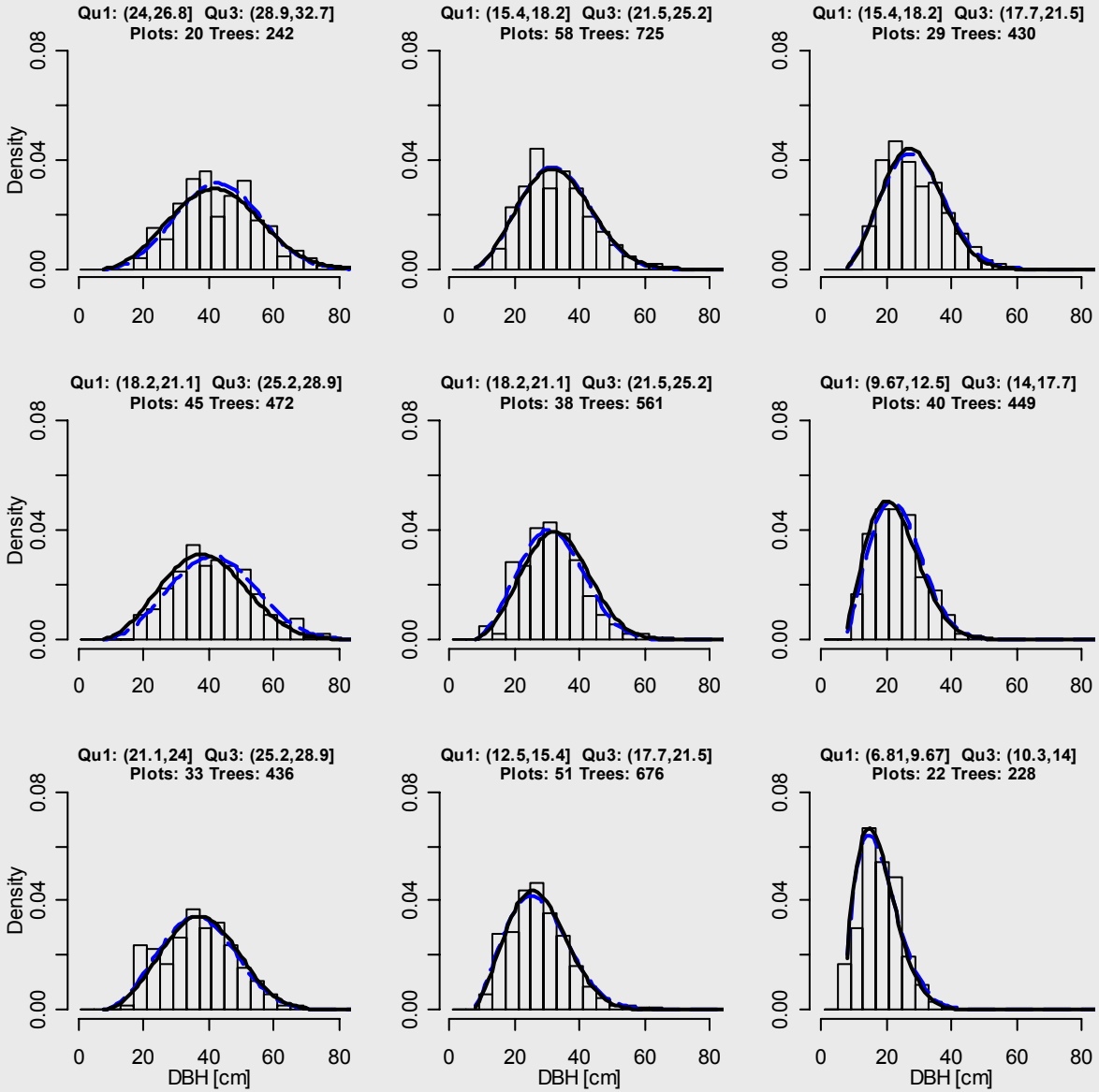
$$g_B(y_i \mid a, b_i, c_i) = \frac{f(y_i \mid a, b_i, c_i)}{F(15 \mid a, b_i, c_i) - F(10 \mid a, b_i, c_i)}$$

$$g_C(y_i \mid a, b_i, c_i) = \frac{f(y_i \mid a, b_i, c_i)}{F(30 \mid a, b_i, c_i) - F(15 \mid a, b_i, c_i)}$$

$$g_D(y_i \mid a, b_i, c_i) = \frac{f(y_i \mid a, b_i, c_i)}{1 - F(30 \mid a, b_i, c_i)} \qquad F(x \mid a, b_i, c_i) = 1 - \exp\left[\left(\frac{x-a}{b_i}\right)^{c_i}\right]$$

$$LLH = \sum_{i=1}^{n} \ln \begin{array}{l} (g_A(y_i \mid a, b_i, c_i) 1_A(y_i) + g_B(y_i \mid a, b_i, c_i) 1_B(y_i) + \\ g_C(y_i \mid a, b_i, c_i) 1_C(y_i) + g_D(y_i \mid a, b_i, c_i)\ 1_D(y_i)) \end{array}$$

DBH


Qu1: (24,26.8] Qu3: (28.9,32.7]
Plots: 20 Trees: 242
Qu1: (15.4,18.2] Qu3: (21.5,25.2]
Plots: 58 Trees: 725
Qu1: (15.4,18.2] Qu3: (17.7,21.5]
Plots: 29 Trees: 430
Qu1: (18.2,21.1] Qu3: (25.2,28.9]
Plots: 45 Trees: 472
Qu1: (18.2,21.1] Qu3: (21.5,25.2]
Plots: 38 Trees: 561
Qu1: (9.67,12.5] Qu3: (14,17.7]
Plots: 40 Trees: 449
Qu1: (21.1,24] Qu3: (25.2,28.9]
Plots: 33 Trees: 436
Qu1: (12.5,15.4] Qu3: (17.7,21.5]
Plots: 51 Trees: 676
Qu1: (6.81,9.67] Qu3: (10.3,14]
Plots: 22 Trees: 228
Density
0.00
0.04
0.08
0
20
40
60
80
DBH [cm]

Outline

- Introduction
- Lidar
- Methods for analysing lidar data
- Fitting of regression models
  - Diameter distributions (Ger.)
  - Stem volume (US + Ger.)
- Application of regression models
  - Biomass (Ger.)

Modeling steps

1. Local models for each study site

Volume

$$y \sim Normal(\mu, \sigma = \phi\, Mean.L^{\delta})$$

E(μ) = ***Mean.L*** + ***CP*** + ***CC*** + ***Mean.L*** * ***CP*** + ***Mean.L*** * ***CC***

Ger.:

R^2 0.70; RMSE 120 m³/ha (~34%)

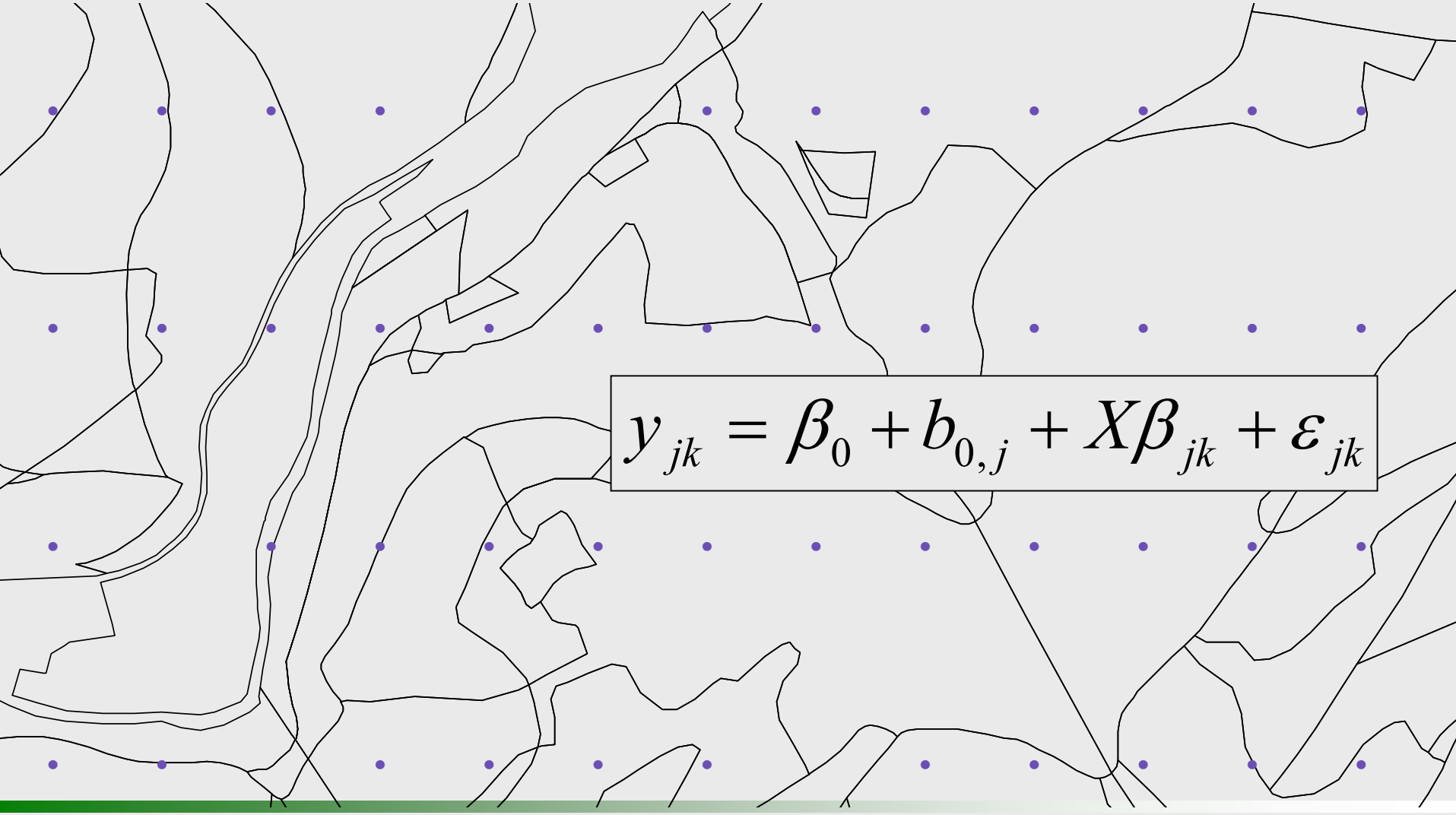
US:

R^2 0.86; RMSE 109 m³/ha (~19%)

Modeling steps

1. Local models for each study site
2. Local mixed-effects models

Volume



$$y_{jk} = \beta_0 + b_{0,j} + X\beta_{jk} + \varepsilon_{jk}$$

Modeling steps

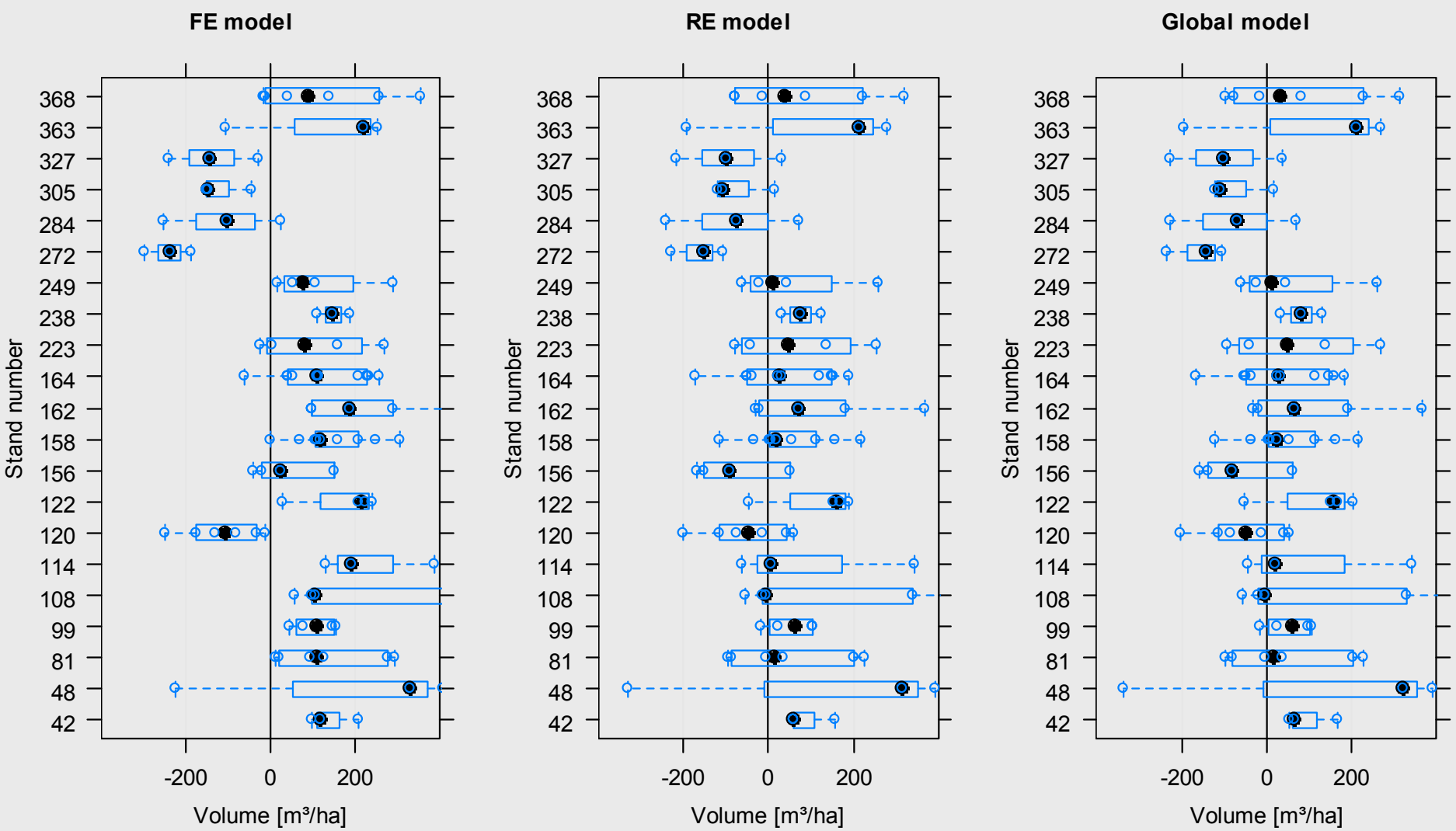
1. Local models for both study sites
2. Local mixed-effects models
3. Global mixed-effects model combining both study sites

Volume

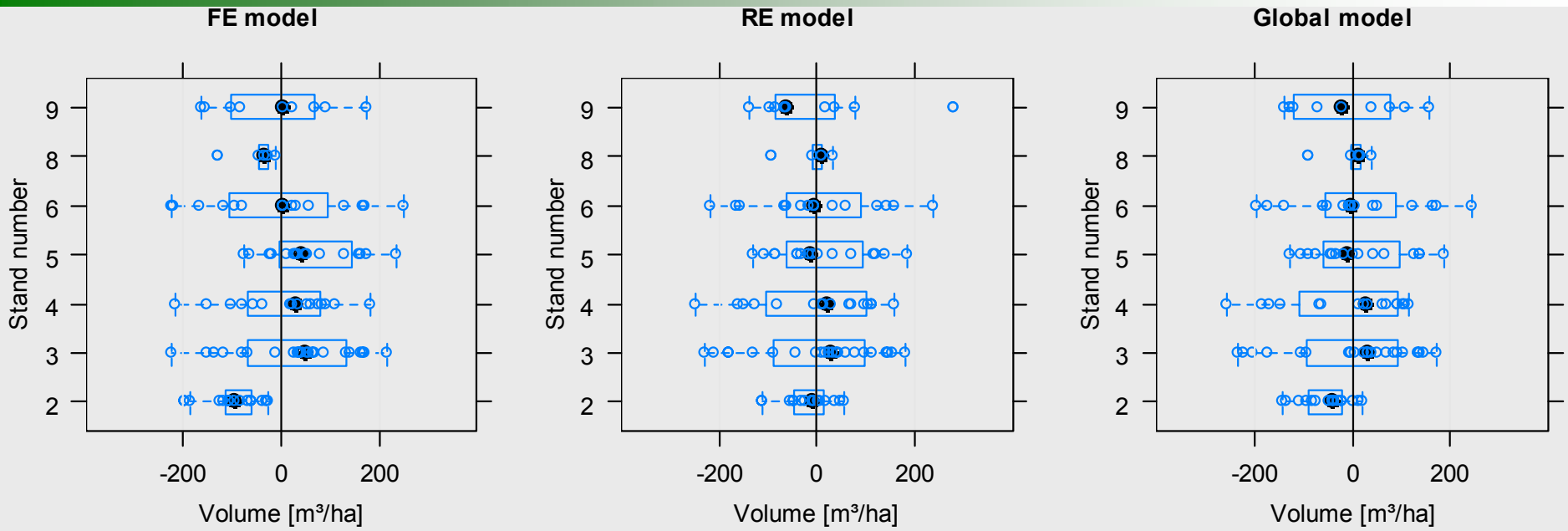
+

$$y_{ijk} = \beta_0 + b_{0,i} + b_{0,ij} + (b_{1,i} + \beta)X_{ijk} + \varepsilon_{ijk}$$

Volume


FE model
RE model
Global model
Stand number
368
363
327
305
284
272
249
238
223
164
162
158
156
122
120
114
108
99
81
48
42
-200
0
200
Volume [m³/ha]

Volume

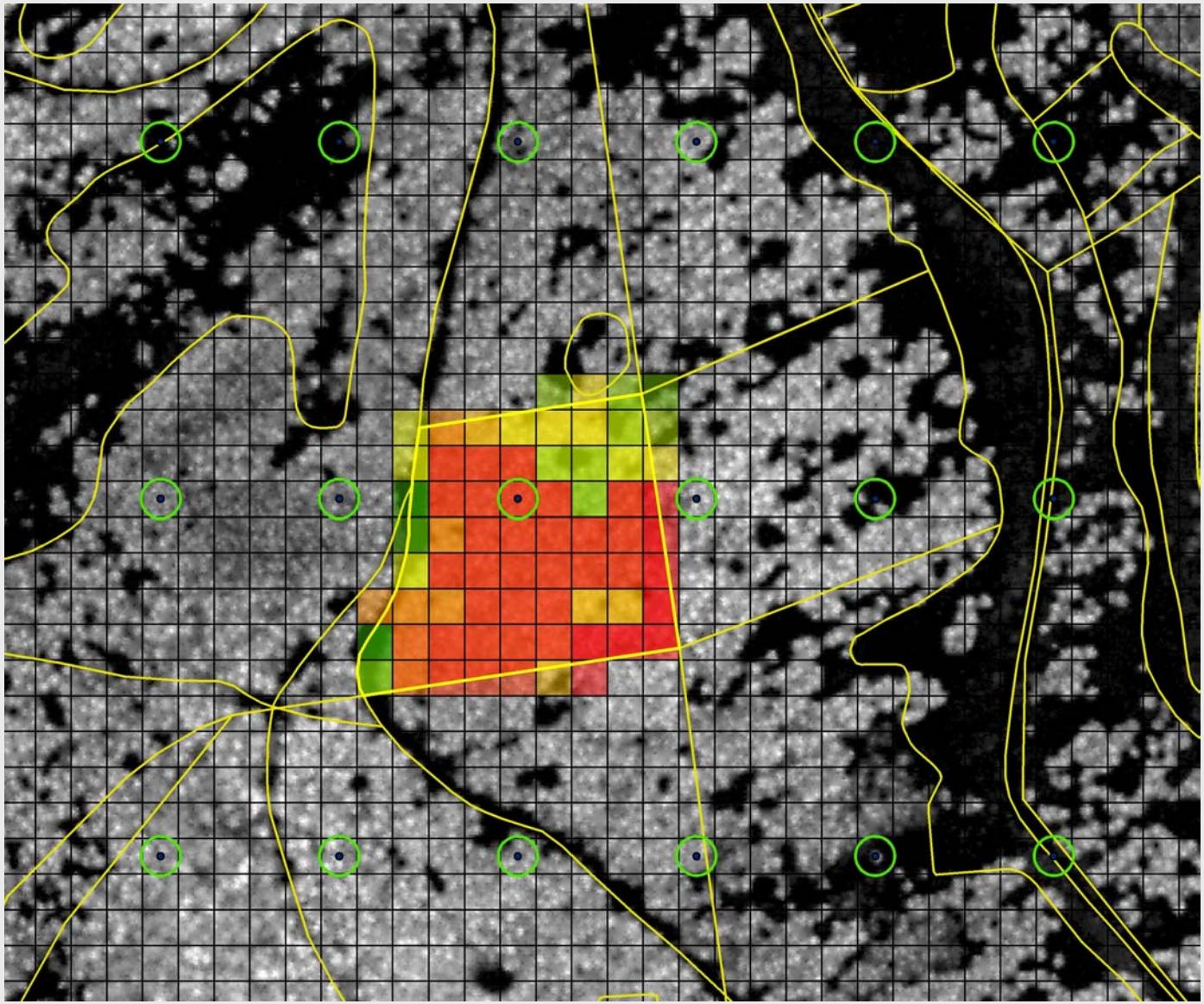


	German models		American models		Both
	FE model	RE model	FE model	RE model	Global model
RMSE [m^3 ha^{-1}]	120.33	103.12	108.96	95.51	103.00
German study site					
RMSE [%]	34.67	29.71			29.76
RMSE.CV [%]	34.90	34.40			34.43
American study site					
RMSE [%]			19.19	16.82	17.58
RMSE.CV [%]			19.95	18.49	18.69
Both					
RMSE [%]					28.16
RMSE.CV [%]					32.35
R^2	0.70	0.78	0.86	0.89	0.81

Outline

- Introduction
- Lidar
- Methods for analysing lidar data
- Fitting of regression models
  - Diameter distributions (Ger.)
  - Stem volume (US + Ger.)
- Application of regression models
  - Biomass (Ger.)

Biomass



AG Ökologie et al. 2007, Günzburg

Biomass

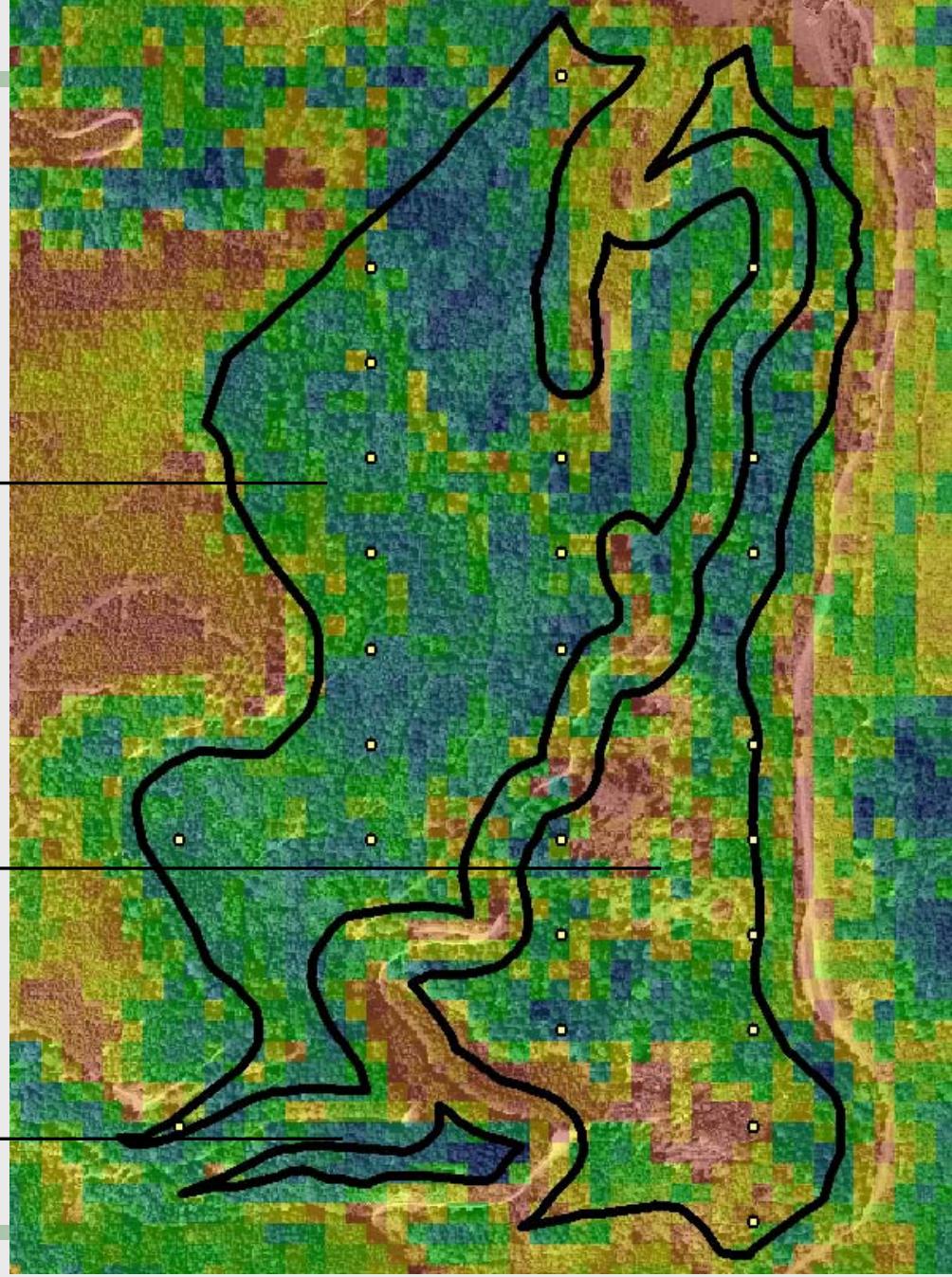
Nature reserve Ridis

Area: 31,5 ha
Estimated biomass (inventory):
8491 t, 300 t/ha, 8% Error[1]
Estimated biomass (Lidar):
8681 t, 276 t/ha, 2% Error[1]

Area: 18,5 ha
Estimated biomass (inventory):
3796 t, 186 t/ha, 17% Error[2]
Estimated biomass (Lidar):
4082 t, 221 t/ha, 3% Error[2]

Area: 1 ha
Estimated biomass (Lidar):
329 t, 10% Error

[1,2] difference not significant



Abteilung Biometrie
und Informatik

AG Ökologie et al. 2007, Günzburg

- Previous work
  - Estimation of mean tree heights
  - Estimation of diameter distributions

- Future work
  - Influence of plot location errors
  - Non-parametric methods

- **BREIDENBACH, J., et al.:** A mixed effects model to estimate stand volume by means of small footprint airborne lidar data for an american and german study site. Proceedings of the ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007.
- **ANDERSEN, H.-E., BREIDENBACH, J.:** Statistical properties of mean stand biomass estimators in a lidar-based double sampling forest survey design. Proceedings of the ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007.
- **BREIDENBACH, J., SCHMIDT, M., KÄNDLER, G.:** Schätzung von oberirdischen Biomassevorräten aus Flugzeuggetragenen Laserscannerdaten. Veröffentlichung im Rahmen der Tagung des Verbands Deutscher Forstlicher Forschungsanstalten, Sektion Biometrie und Informatik. Trippstadt 25. – 27. September 2006.
- **BREIDENBACH, J., SCHMIDT, M.:** Laserscannerdaten als Hilfsmittel zur Regionalisierung von Durchmesserverteilungen in Stichprobeninventuren. Tagung des Verbands Deutscher Forstlicher Forschungsanstalten, Sektion Ertragskunde. Staufen, 29. – 31. Mai 2006. Online unter `http://www.nw-fva.de/~nagel/SektionErtragskunde/band2006/Tag2006_11.pdf`
- **BREIDENBACH, J., KOCH, B., KÄNDLER, G., KLEUSBERG, A.:** Quantifying the influence of slope, aspect, crown shape and stem density on the estimation of tree height at plot level using lidar and InSAR data. Int. J. of Remote Sensing. (Accepted)