Predicting the Forest Development after Natural Disturbance using Airborne LiDAR

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1 Introduction
2 Remote Sensing
3 Spatial Analysis
4 Results
5 Conclusion
Introduction
- Forests are dynamic ecosystems shaped by anthropogenic and natural drivers.
- Changes have effects on the ecological, economical and social value of forest ecosystems.
- Increased public demands for forest services as well as climate change present new challenges for forest management.

[Pretzsch, 2009]
Natural disturbances

- Integral part of forest ecosystems
- Strongly influence the structure, composition and functioning of forest ecosystems
- Influence the spatial and temporal patterns of forested landscapes

Throughout the 20th century the number of disturbance events from wind, wild fires and bark beetles increased in Europe [Schelhaas et al., 2003, Seidl et al., 2014]
Natural disturbances

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Throughout the 20th century the number of disturbance events from wind, wild fires and bark beetles increased in Europe [Schelhaas et al., 2003, Seidl et al., 2014]
Increasing forest disturbance damage in Europe [Seidl et al., 2014], Nature
Research needs

Natural forest development post-disturbed sites in Central Europe is only insufficiently documented

Questions:

- How do natural forest evolve after natural disturbances?
- How is forest regeneration affected
- Ecological importance of early seral forests
- Effects on forest biodiversity, carbon sequestration, vitality ....
Bavarian Forest National Park

[Heurich et al., 2012]
Forest structure is *the physical and temporal distribution of trees in a forest stand* (Oliver 1996)

- Important factor in the analysis and management of forest ecosystems
- Indicator für ecosystem functions
- Basis for biodiversity evaluation
Research Area
Framework

Extraction of the three dimensional forest structure using remote sensing

Detection of single tree positions

Simulation of future tree development

Spatio-temporal analysis of current and simulated forest structure
Framework

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Remote sensing
http://www.ucanr.edu
Single Tree Extraction

LiDAR-Processing

Extraction of single tree positions

Diagram:
- Raw LiDAR Data (ASCII-Format)
- Preprocessing
- Tiling
- Identification of ground/non-ground points
- Height-normalization
- Building Canopy Height Model
- DGM
- CHM
- CIR-Images
- Extract Sample Areas
- Predict NDVI
- Sample Areas
- NDVI-Image
- Random Forest Classification
- Prediction
- Vegetation Mask
- Clip
- Local Vegetation Maxima
- Local Maxima Filtering
- Local Elevation Maxima
- CHM
Ground Extraction

Identification of Ground Points

Triangulation of Ground Points
Modelling Tree attributes

DBH

Adj R2 = 0.9435  Intercept = 1.1143  
Slope = 0.0072178  P = 1.3314e-60

Crown base height

Adj R2 = 0.92957  Intercept = 0.43506  
Slope = 0.0023277  P = 9.1828e-12
Forest Growth Simulator: SILVA

Start values
Management, Site conditions

Data missing?

yes → Stand structure generator

no → Site dependent growth potential

3D-Competition analysis
Mortality model
Thinning model
Increment model

Classical tree and stand information for forest management

Timber grading
Monetary yield

Structure analysis
Indices for diversity

Output

$t = 0 \quad t = 20 \quad t = 40$

$t = 0 \ldots n$

Output

$t = 0 \ldots n$

Output

$t = 0 \ldots n$
Spatial Analysis
Objective of spatial analysis

- Arrangement of plants in natural vegetation is usually not random
- Spatial patterns formed by (i) morphological, (ii) environmental and (iii) phytosociological factors [Dale, 2002].
- Spatial statistics allow the identification and analysis of these spatial patterns
- Does a spatial pattern exhibit a tendency towards clustering or regularity?
- Over what spatial scales do patterns exist?
**Point Pattern:** data set consisting of locations $x_i$ of all events of a particular kind within a given region [Diggle, 2014]

**Point Process:** underlying stochastic model

→ Aim: comparing the observed data to the null hypothesis of complete *spatial randomness (CSR)*
Complete spatial randomness

- **Complete spatial randomness (CSR)**: the points are independently distributed in space.

- CSR assumes that points follow a **homogeneous Poisson-process** over the study area.

1. The number of points in any region $B$ follows the Poisson distribution with mean $\lambda v(B)$ (i.e. the intensity of events will not vary across the region).
2. Given $n$ trees in $B$, their positions behave as an independent sample from the uniform distribution in $B$ (i.e. there is no interaction between events).

$$p_n = \frac{\lambda^n}{n!} \cdot e^{-\lambda}$$  \hspace{1cm} (1)
Clark and Evans index [Clark and Evans, 1954]

- based on the distances of each tree to its nearest neighbor
- observed distance to the nearest neighbor is related to the expected mean distance

\[ R = \frac{r_{observed}}{E(r)} \text{ where } E(r) = \frac{1}{2 \sqrt{\frac{N}{A}}} \]  

\( R > 1 \): tendency towards regularity  
\( R < 1 \) clustered pattern
Diameter differentiation index

Describes the size difference between the tree $i$ and its $n$ nearest neighbor $j$ ($j = 1, \ldots, n$)

\[
T_{ji} = 1 - \frac{\min(DBH_i, DBH_j)}{\max(DBH_i, DBH_j)}
\]  

$0 \leq T < 0.3$ smallest tree diameter at breast height is 70% or more of neighboring tree’s size

$0.3 \leq T < 0.5$ 50-70% or more of neighboring tree’s size

$0.5 \leq T < 0.7$ 30-50% or more of neighboring tree’s size

$0.7 \leq T < 1$ less than 30% of neighboring tree’s size
Second-order statistics

**Limitation of nearest neighbor method**: Considers only variation in an area defined by next neighbours

**Second-order statistics**

- Exploration of spatial patterns at multiple distances
- Information about the tendentious changes in the surrounding structure
- Assumes isotropy over the region

[ Pretzsch, 2009 ]
K-, L-Function

Ripley's K-Function

\[ K(r) = \lambda^{-1} E[\text{number of extra events within distance of a randomly chosen event}] \]

\[ K_{\text{est}}(r) = \lambda^{-1} \sum_{i=1}^{n} \sum_{j \neq 1} w(l_i, l_j) \frac{I(d_{ij} < r)}{N} \]  \hspace{1cm} (4)

Under the assumption of CSR: \( K(r) = \pi * r^2 \)

Basic idea

1. Construct a circle of radius \( r \) around each point
2. Count the number of other points falling inside circle
3. Increment \( r \) and repeat computation

- L-function by Besag (1977) is a transformation of the Ripley’s K-function

\[ L(r) = \sqrt{\frac{K(r)}{\pi}} \quad \text{for } r \leq 0 \]  \hspace{1cm} (5)
PairCorrelation-Function

- Uses rings instead of cumulative circles.
- After each increment, trees located within a ring are counted and weighted more heavily the closer they are to the mean radius $r$.
- Allows to identify the distance at which deviations from the random distribution occur.

$$g(r) = \frac{dK(r)}{2\pi r}$$

- $g(r) = 1$: trees are distributed random.
- $g(r) < 1$: tendency towards regularity.
- $g(r) > 1$: tendency towards clustering.
Crown Cover

Local Maxima → Create Circle Polygons → Rasterize → Calculate Crown Cover

Simulated Crown Size
Results
Basic Statistics

Basic stand statistics

Number of trees
Basal Area per Hektar
Quadratic Mean Diameter

Top Diameter
Height Variance
Diameter Variance

Simulation Years
Simulation Years
Simulation Years

Simulation Years
Simulation Years
Simulation Years

Number oftrees
bH

Number of trees
Basal Area
Quadratic Mean Diameter

Top Diameter
Height Variance
Diameter Variance

Plot
Plot
Plot

Plot
Plot
Plot
Tree height

![Graph showing distributions of tree heights over time](image)
### Table: Initial and simulated stand statistics for each test site

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PairCorrelation-Function
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- show a high degree of natural regeneration

- exhibited a heterogenous tree arrangement, characterized by a diverse structure of neighboring patches of juvenile and few old-growth trees

- show regular pattern at very small distances and clustering of tree patterns up to 5 m in all test sites (2 sites show clumped patterns even up to 50 m)

- tendency towards regular patterns with increasing distance

- exhibit different succession pathways

- aggregated regeneration patterns indicated a concentration of tree individuals on favorable microsites

- patterns may arise from the strong linkage between spruce regeneration and coarse woody debris
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Conclusion

- Results confirmed the usefulness of airborne LiDAR data to investigate forest structural attributes.
- Structure is not only the result of the past disturbance events, but also a major factor influencing the regeneration process.
- Under certain conditions early-seral forest can establish complex structures normally associated with old-growth forests.
- There is no single succession pathway.
Distance to nearest neighbor as a measure of spatial relationships in populations.

*Spatial Pattern Analysis in Plant Ecology.*
Cambridge University Press.

Spatial point pattern.
Berichte aus dem Nationalpark., 8/12.

Forest Dynamics, Growth and Yield: From Measurement to Model.
Springer.

Natural disturbances in the european forests in the 19th and 20th centuries.

Forest and woodland systems.


Increasing forest disturbances in europe and their impact on carbon storage.

Thank you for your attention!