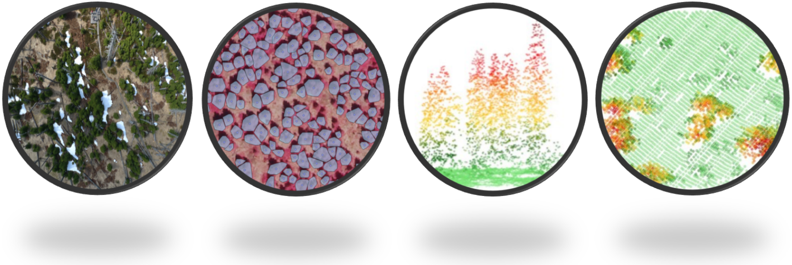
Predicting the Forest Development after Natural Disturbance using Airborne LiDAR



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Content

Introduction

Forest Dynamics

- Forests are dynamic ecosystems shaped by anthropogene 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

[image removed]

[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

[image removed]

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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[image removed]

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Natural disturbances

[image removed]

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

[image removed]

[Heurich et al., 2012]

Forest Structure

- Forest structure is *'the physical and temporal distribution of trees in a forest stand'* (Oliver1996)
- Important factor in the analysis and management of forest ecosystems
- Indicator für ecosystem functions
- Basis for biodiversity evaluation

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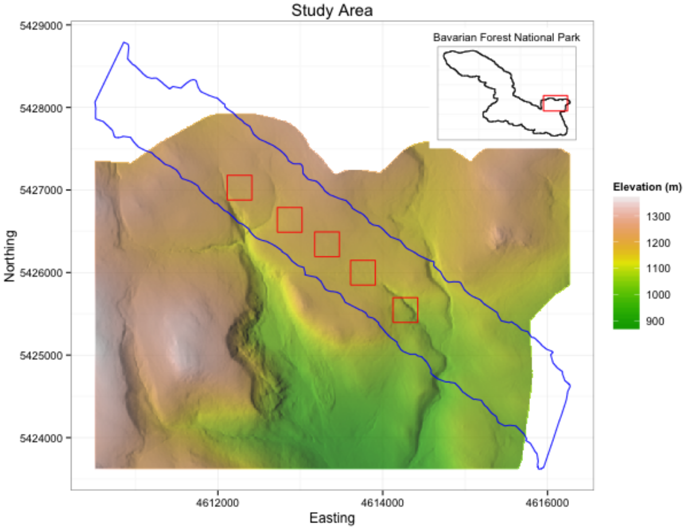
Research Area



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

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Remote sensing

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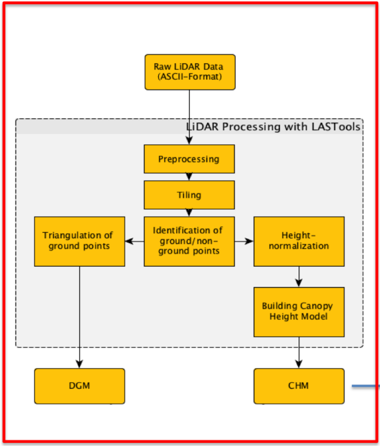
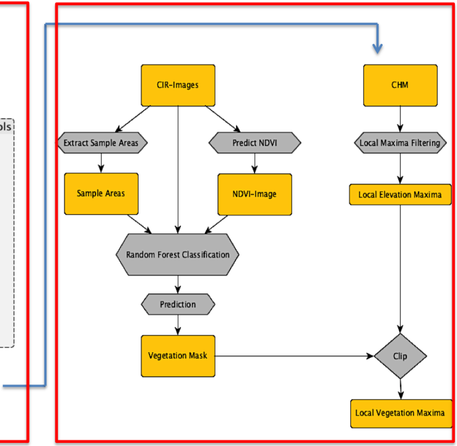
http://www.ucanr.edu

Single Tree Extraction

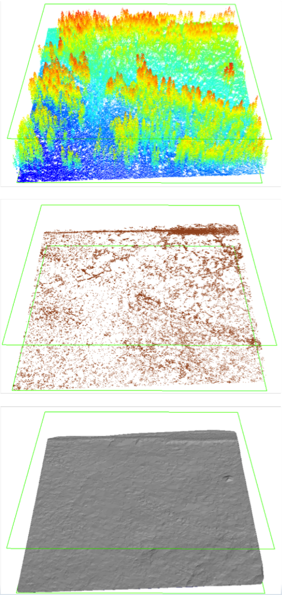
LiDAR-Processing

Extraction of singel tree positions





Ground Extraction

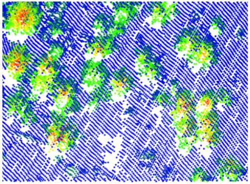


Identification of
Ground Points

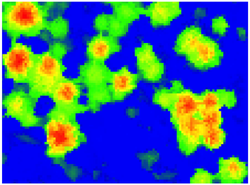
Triangulation of
Ground Points

Single Tree Positions

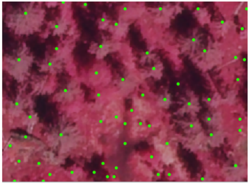
LiDAR-Point Cloud



Canopy Height Model

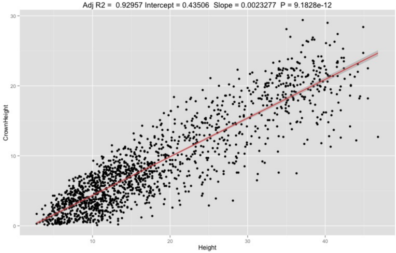


Single Tree Positions



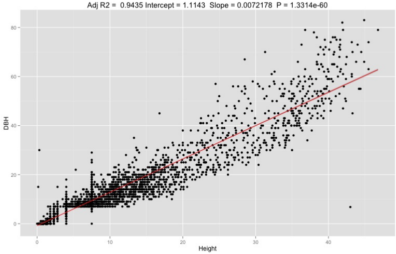
Modelling Tree attributes

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

[image removed]

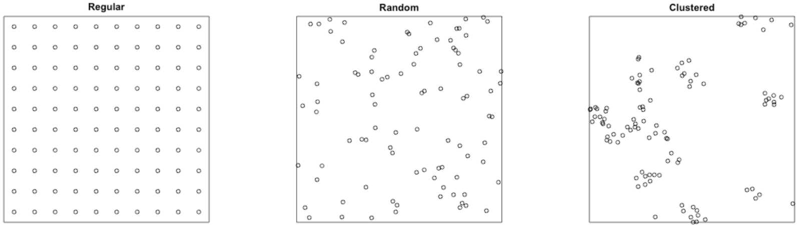
Spatial Analysis

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

- **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



$\rightarrow$ Aim: comparing te 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

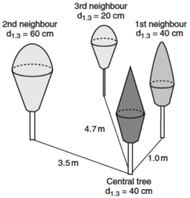
  1. The number of points in any region B follows the Poisson distribution with mean $\lambda v(B)$ (i.e. the intensity of events will not vary across the region)
  2. Given n trees in B, their positions behave as an independent sample from the uniform distribution in B (i.e. there is no interaction between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

$$p_n = \frac{\lambda^n}{n!} * e^{-\lambda} \tag{1}$$

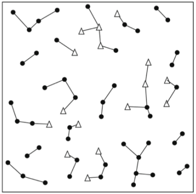
Aggregation index of Clark and Evans

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



$$R = \frac{\overline{r}_{observed}}{E(r)} \text{ where } E(r) = \frac{1}{2 * \sqrt{\frac{N}{A}}} \qquad (2)$$



PRETZSCH (2009)

$R > 1$: tendency towards regularity

$R < 1$ clustered pattern

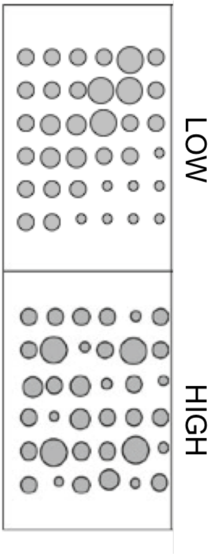
Diameter differentiation index

Diameter differentiation index

- Describes the size difference between the tree *i* and its *n* nearest neighbor *j* (j = 1,...,n)

$$T_{ji} = 1 - \frac{min(DBH_i, DBH_j)}{max(DBH_i, DBH_j)} \quad (3)$$

$0 \leq T < 0.3$ 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

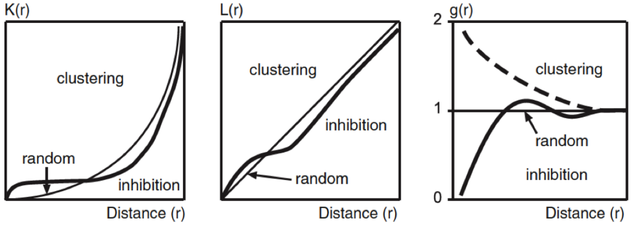


Second-order statistics

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

Ripleys K-Function

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

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

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 fallin inside circle
3. Increment r and repeat computation

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

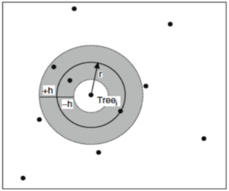
$$L(r) = \sqrt{\frac{K(r)}{\pi}} \text{ for } r \leq 0 \tag{5}$$

PairCorrelation-Function

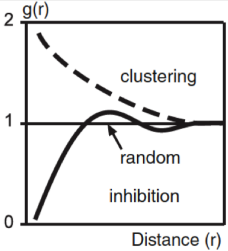
- Uses rings instead of cumulative circles
- After each increment trees located within a ring are counted and weighted more heavily the closer they are to the mean radius r
- allows to identify the distance at which deviations from the random distribution occur

$$g(r) = \frac{\frac{dK(r)}{dr}}{2\pi r} \tag{6}$$

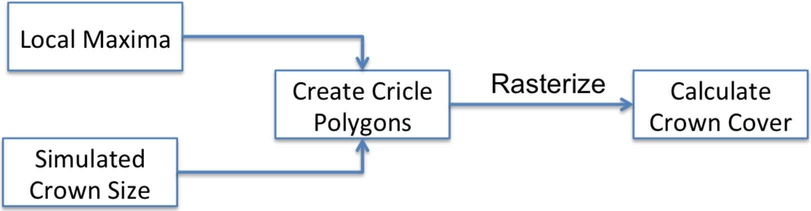
- $g(r) = 1$: trees are distributed random
- $g(r) < 1$: tendency towards regularity
- $g(r) > 1$: tendency towards clustering

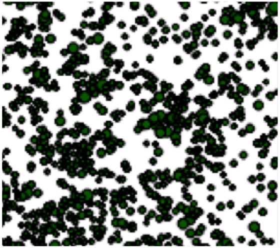


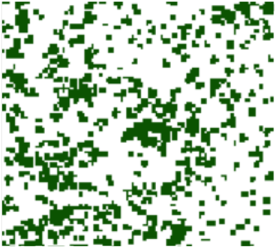
PRETZSCH (2009)



Crown Cover

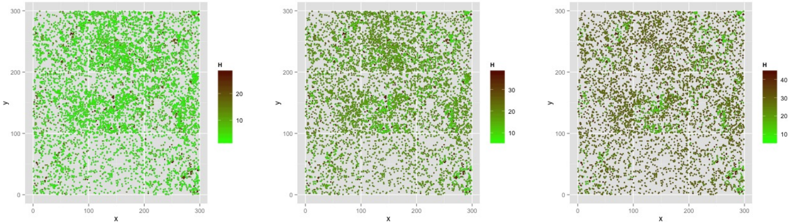

Local Maxima
Create Cricle Polygons
Rasterize
Calculate Crown Cover
Simulated Crown Size



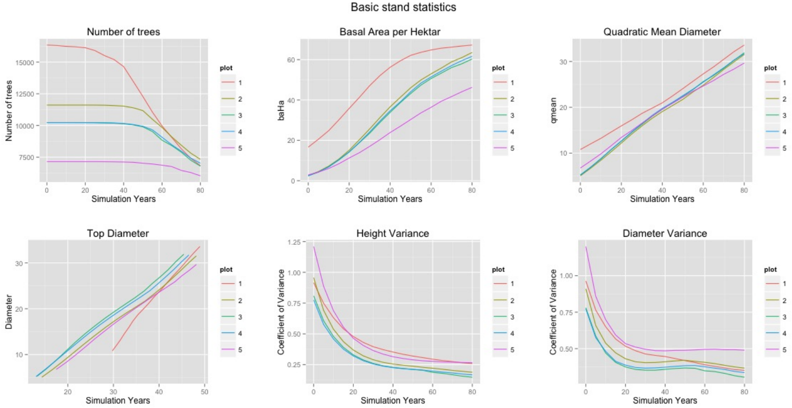


Results

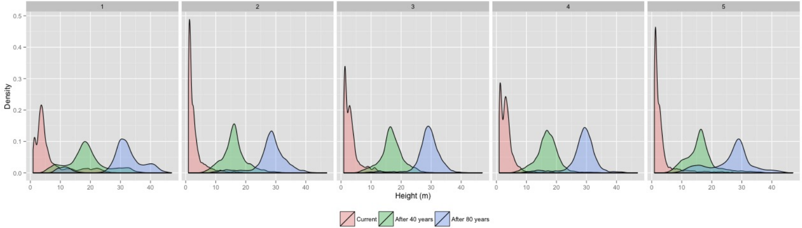
Single tree Positions



Basic Statistics



Tree height


1
2
3
4
5
Density
Height (m)
Current
After 40 years
After 80 years

Single tree Positions

	Site	Number of Trees	Basa Areal	Mean DBH	Mean Height	Height Variation	R	TD1
Initial Values	1	16,343	16.61	7.77	6.42	4.30	1.52	0.25
	2	11,611	2.59	3.74	3.03	1.87	1.46	0.26
	3	10,227	2.46	4.14	3.43	1.92	1.42	0.26
	4	10,231	2.42	4.12	3.44	1.67	1.46	0.29
	5	7,146	2.84	4.32	3.47	2.49	1.40	0.30
Sim. Values	1	6,830	67.22	31.69	30.50	5.28	1.50	0.25
	2	7,327	63.54	29.60	28.25	3.63	1.52	0.31
	3	6,793	60.31	30.52	28.94	2.81	1.48	0.27
	4	7,020	61.63	30.07	28.65	3.17	1.52	0.29
	5	6,029	46.27	26.64	26.40	5.39	1.42	0.32

Table: Initial and simulated stand statistics for each test site

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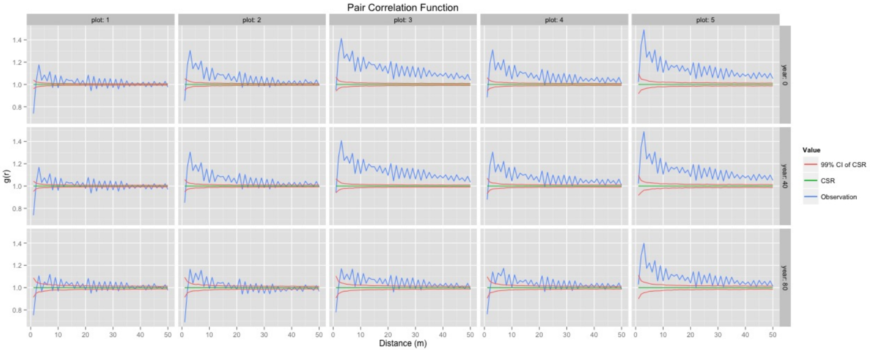
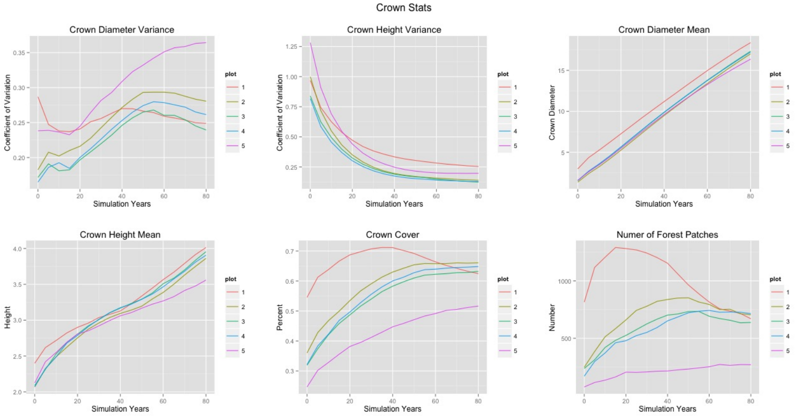
PairCorellation-Function



Further Statistics



The findings of the study revealed that the post-disturbed sites in the BFNP

- 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

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Thank you for your attention!