



Universität für Bodenkultur Wien
University of Natural Resources
and Life Sciences, Vienna

Moderne Waldinventur mittels Laserscanner Technologien (ALS, TLS, PLS)

Christoph Gollob, Andreas Tockner, Tim Ritter, Ralf Kraßnitzer,
Sarah Witzmann, Valentin Sarkleti, Tobias Ofner-Graff,
Andreas Holzinger, Karl Stampfer, Arne Nothdurft

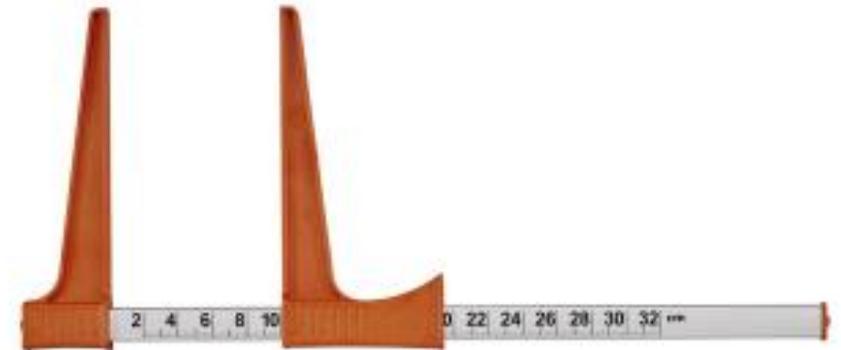
Universität für Bodenkultur
Department für Wald und Bodenwissenschaften
Institut für Waldwachstum

07.11.2023

Forstökonomische Tagung 2023

Traditionelle Verfahren

- Traditionell mit mechanischen und optischen Geräten
- Gebrochener Informationsfluss:
 - Messung (mit traditionellen Geräten)
 - analoge Erfassung (manuelle Eingabe)
 - elektronische Verarbeitung
- Selten volle Reproduzierbarkeit
- Geringer Detailierungsgrad



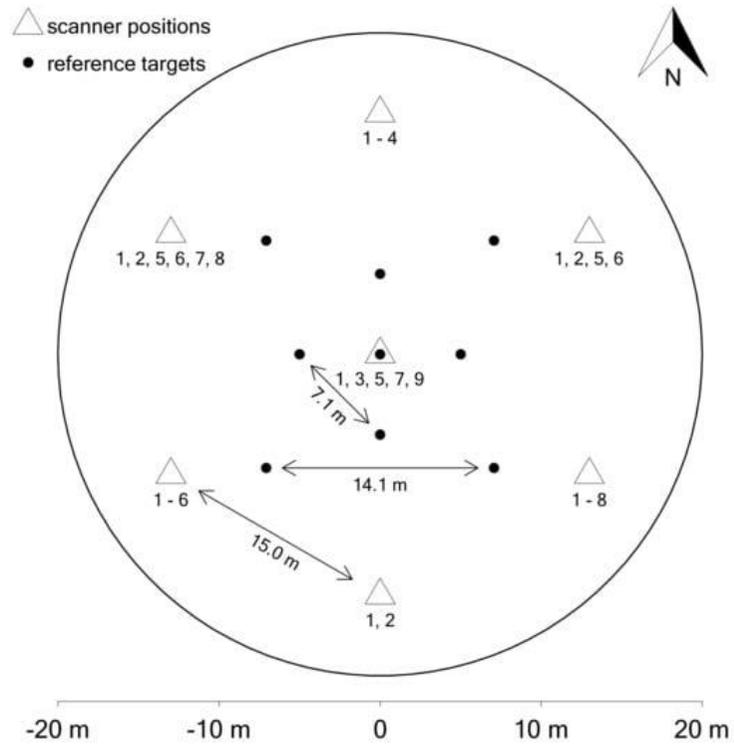
Entwicklung von Laserscanning-Systemen in den letzten Jahren

- Terrestrisches Laser Scanning (TLS)
- Personengetragenes Laser Scanning (PLS)
- Consumer-level Laser Scanning (iPad/iPhone)

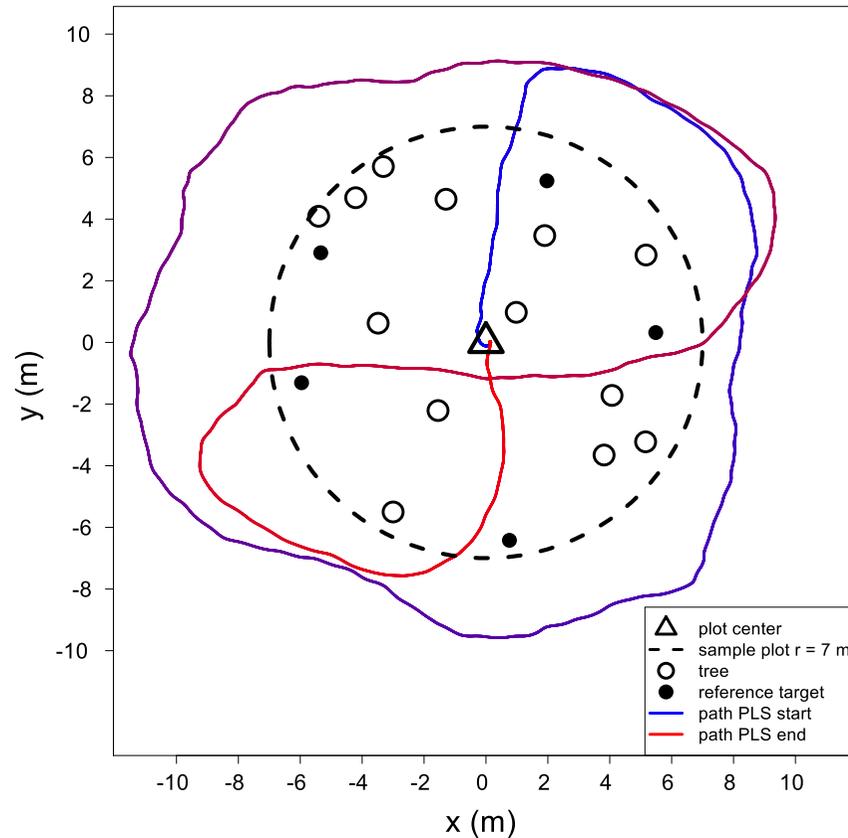


Datenaufnahme mit TLS, PLS, iPad

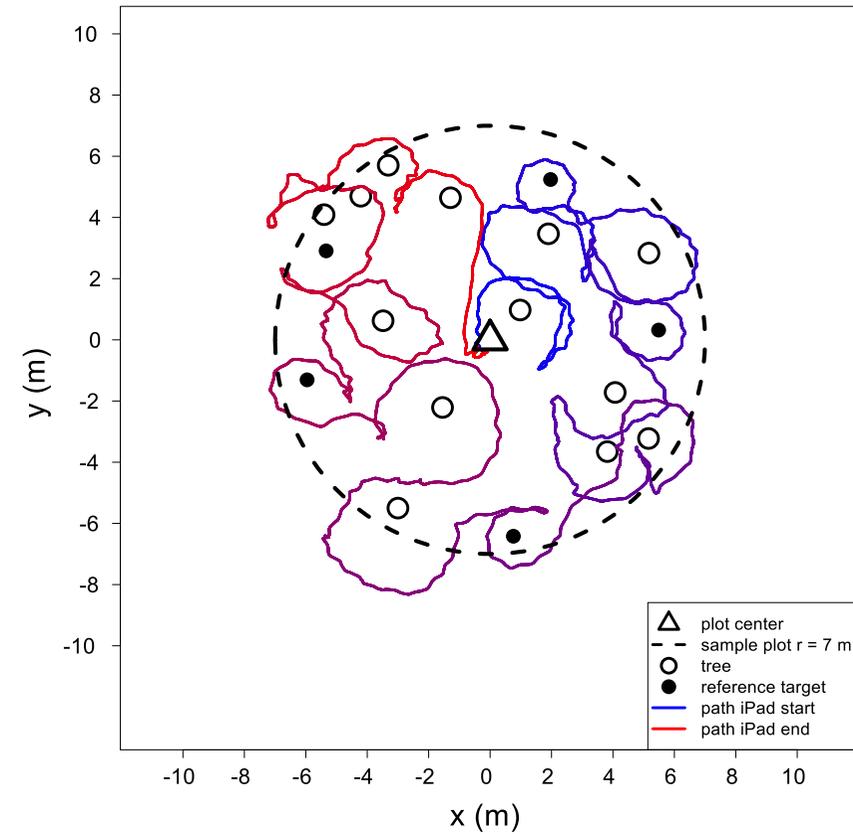
TLS



PLS

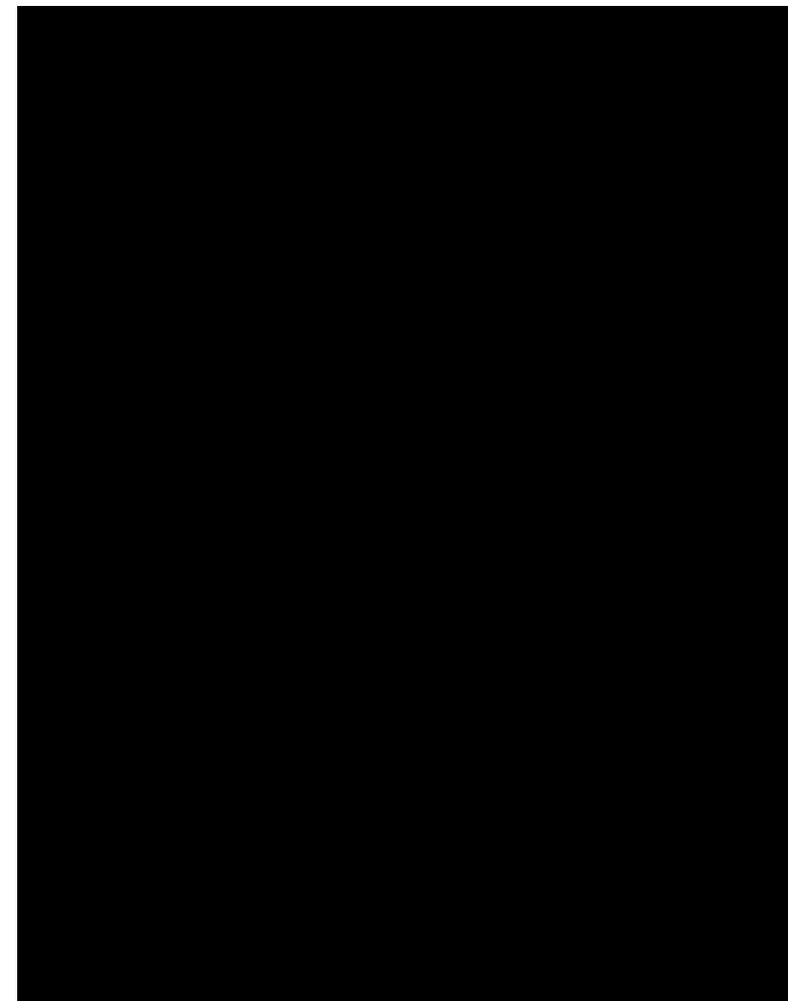


iPad

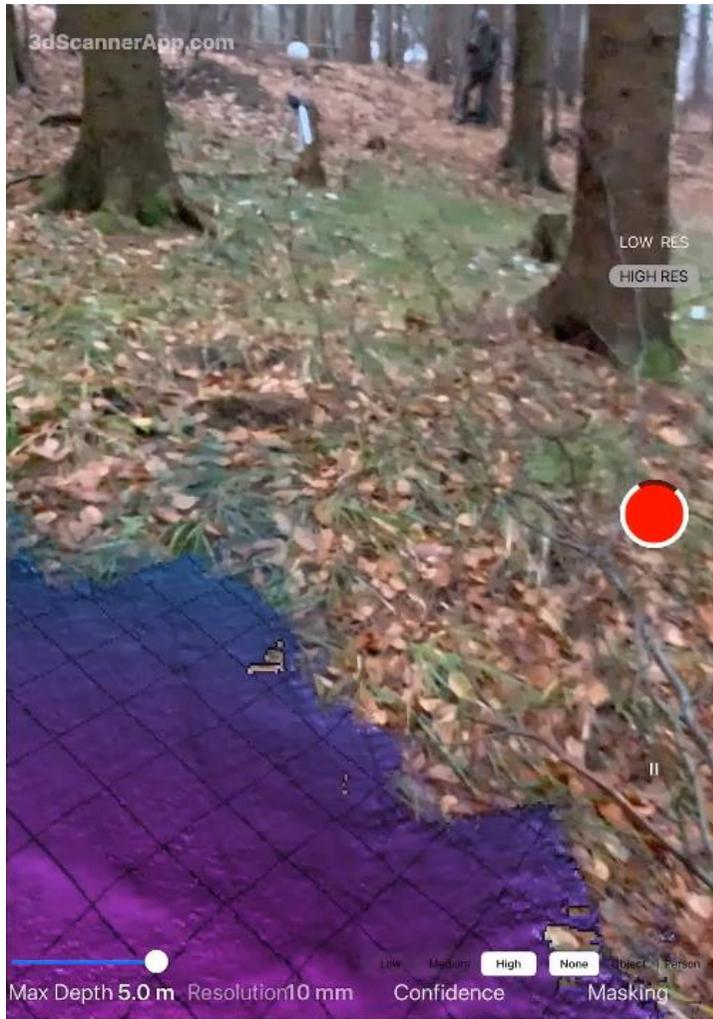


3D Punktwolke - TLS

| | X | Y | Z |
|---------|----------|---------|---------|
| 1: | -9.2252 | -4.1865 | 8.5578 |
| 2: | -9.9358 | -4.2528 | 8.5620 |
| 3: | -9.3412 | -4.5497 | 9.2935 |
| 4: | -9.0552 | -4.2395 | 8.3706 |
| 5: | -10.0568 | -4.1968 | 8.0218 |
| --- | | | |
| 563175: | -7.9320 | -7.0758 | -2.2360 |
| 563176: | -7.9013 | -7.0836 | -1.8388 |
| 563177: | -7.9439 | -7.0723 | -1.8388 |
| 563178: | -7.9732 | -7.0491 | -1.8356 |
| 563179: | -8.0261 | -7.0465 | -1.8379 |



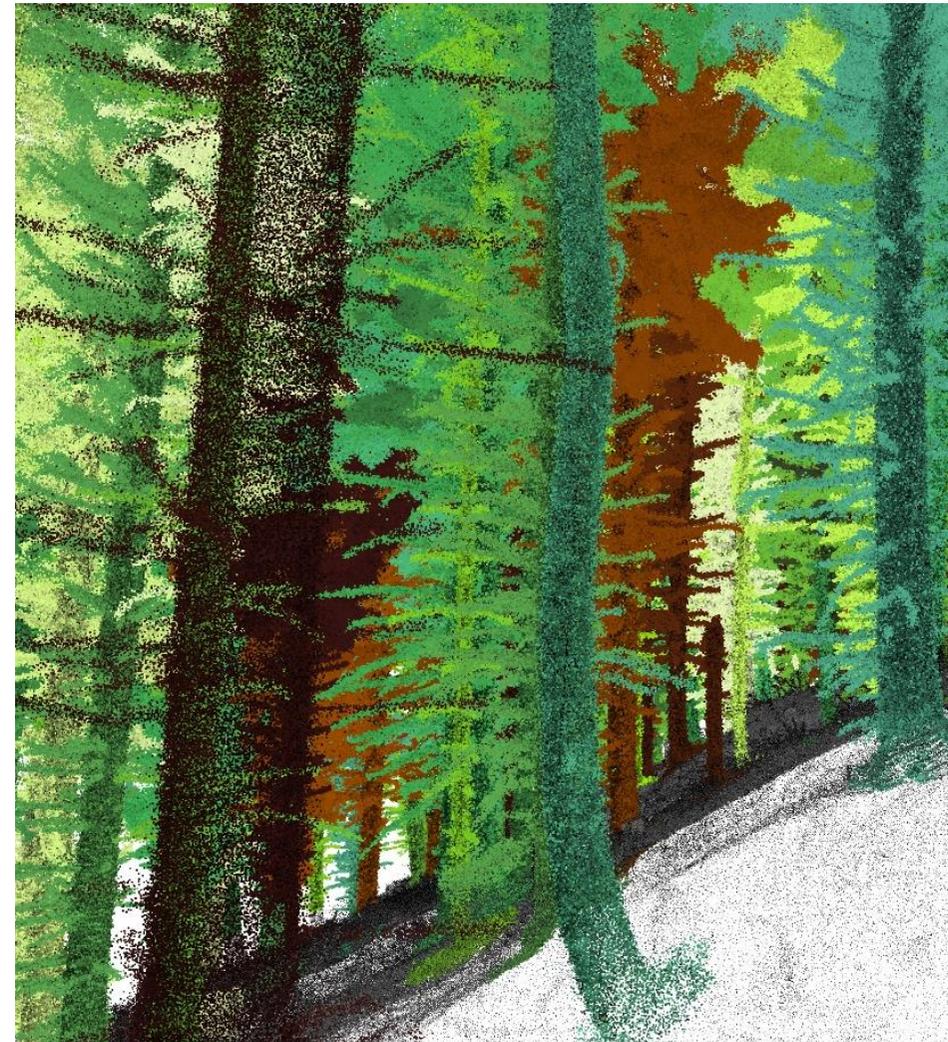
3D Punktwolke - iPad



Digitale Zwillinge



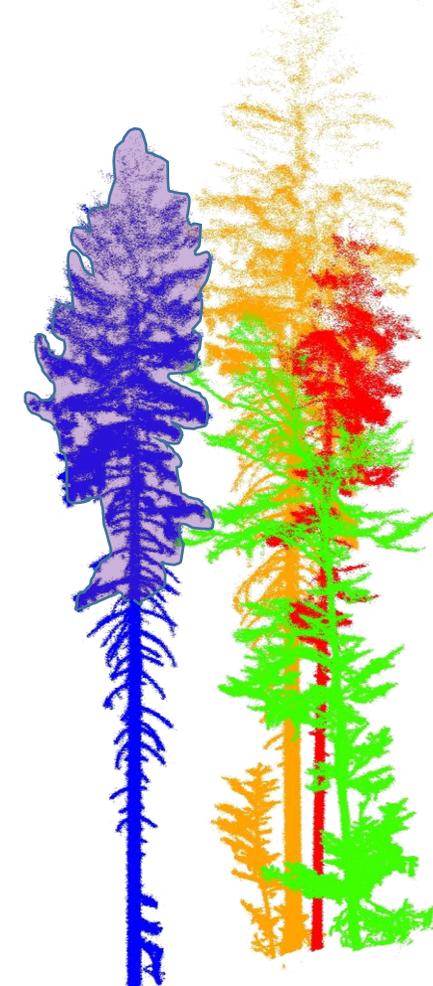
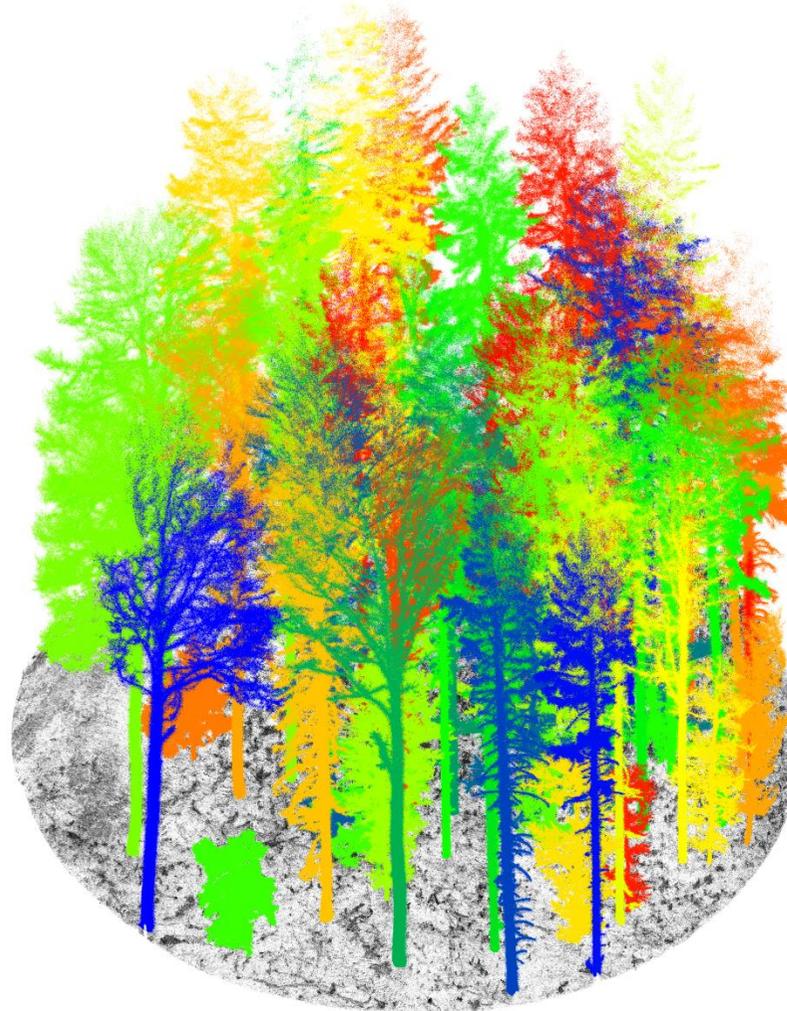
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Digitale Zwillinge



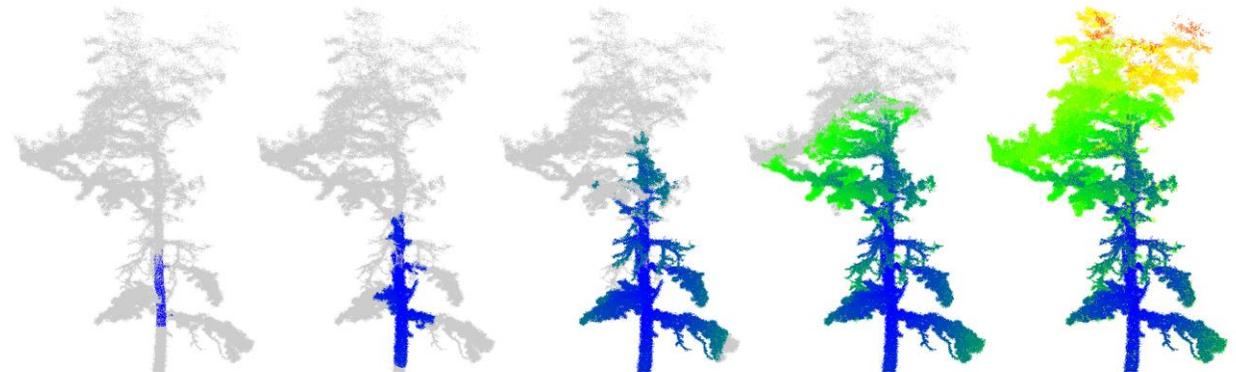
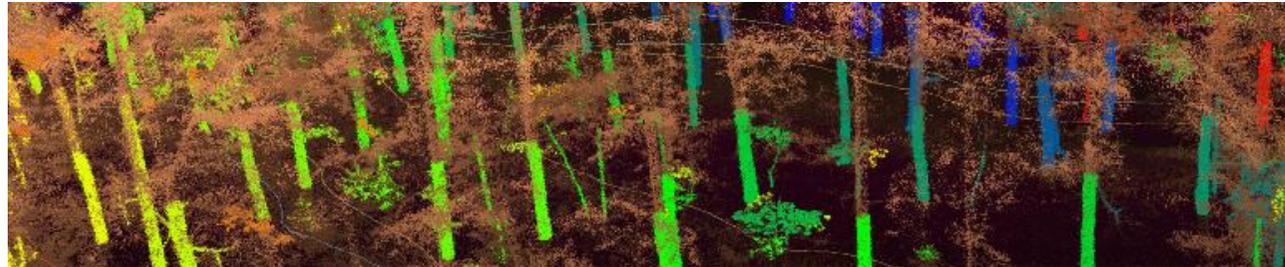
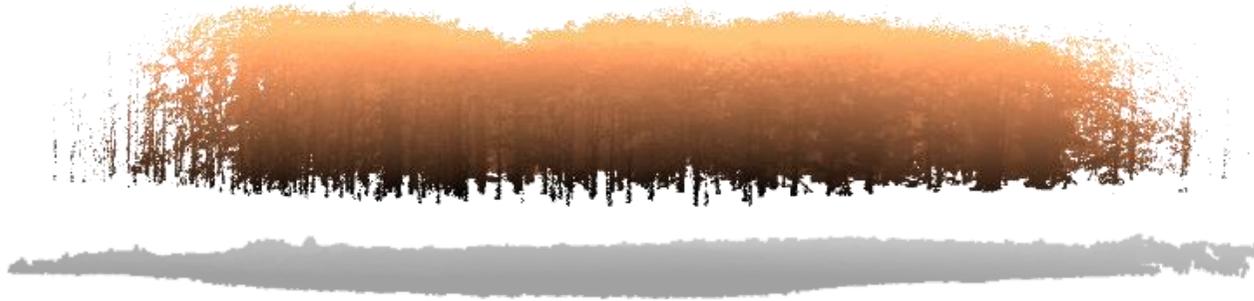
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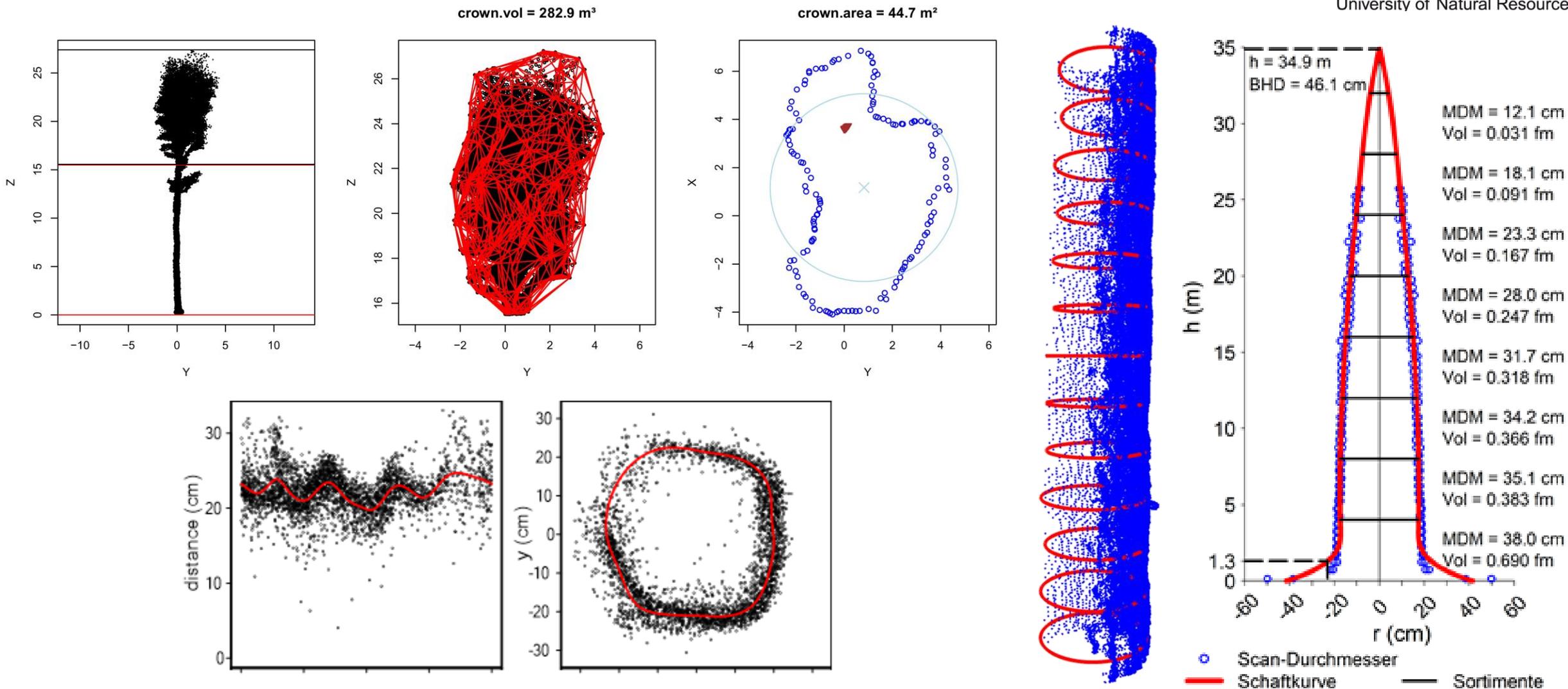
Automatische Abgrenzung der Bäume



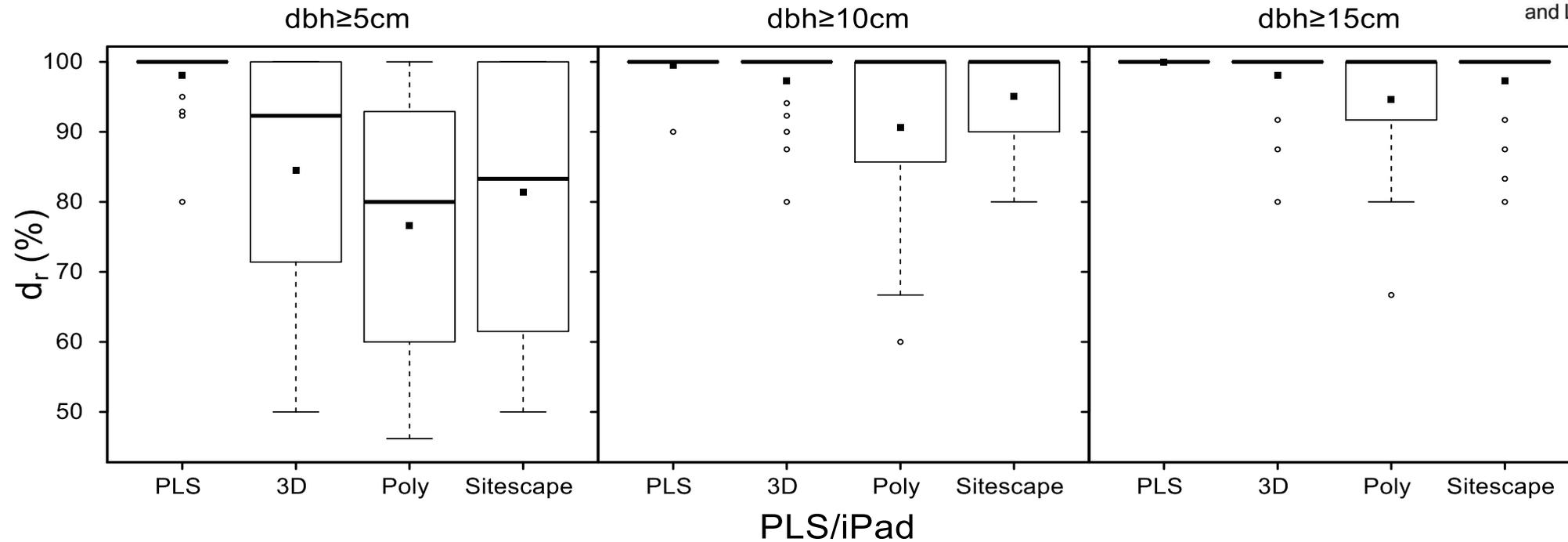
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Automatische Vermessung der Bäume



Baum-Entdeckungsrate PLS/iPad



Open Access Article

Forest Inventory with Long Range and High-Speed Personal Laser Scanning (PLS) and Simultaneous Localization and Mapping (SLAM) Technology

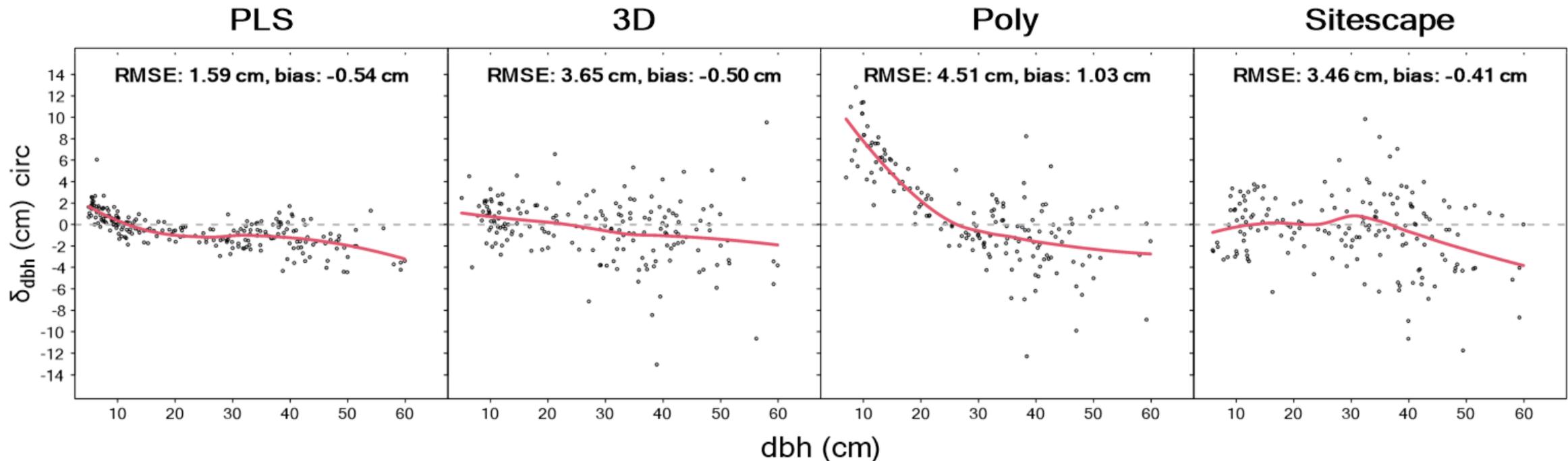
by  Christoph Gollob*  ,  Tim Ritter   and  Arne Nothdurft  



Durchmesser Genauigkeit PLS/iPad



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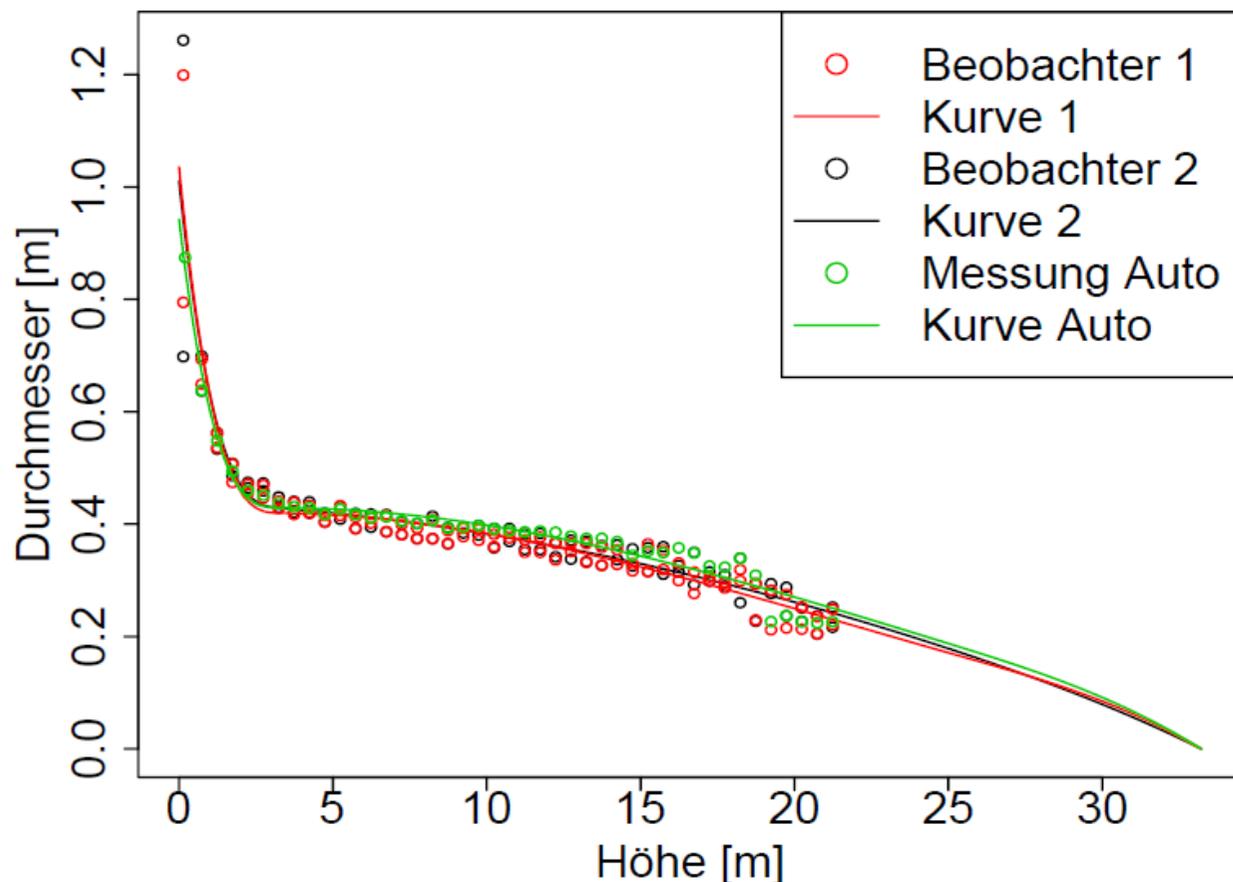
Open Access Article

Measurement of Forest Inventory Parameters with Apple iPad Pro and Integrated LiDAR Technology

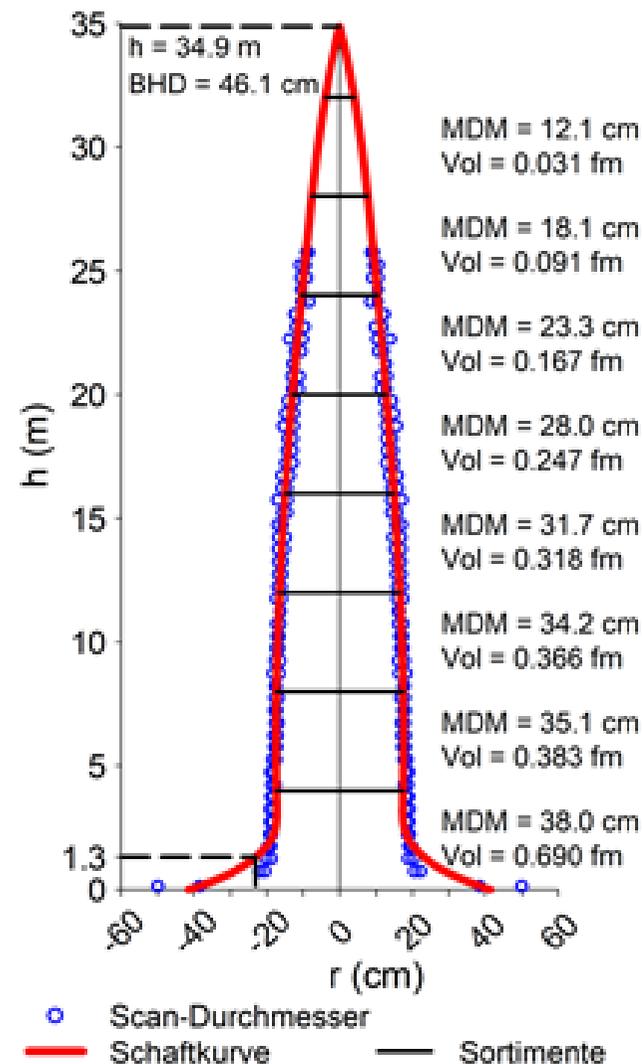
by Christoph Gollob * , Tim Ritter , Ralf Kraßnitzer , Andreas Tockner and Arne Nothdurft



Durchmesser Genauigkeit PLS

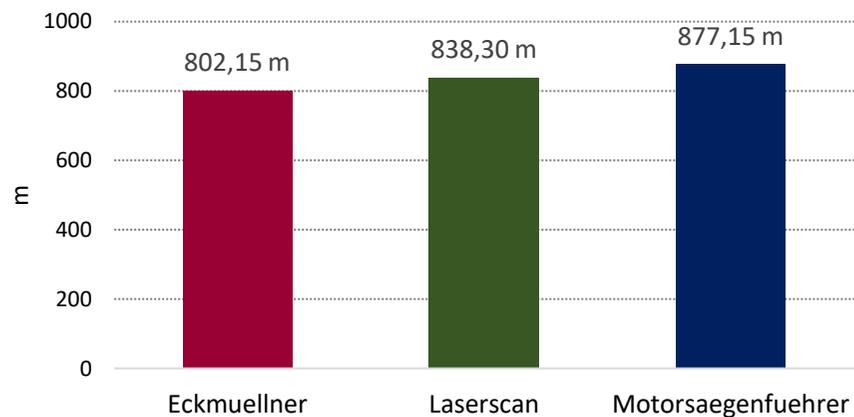


Vergleich der manuellen und automatischen Messungen

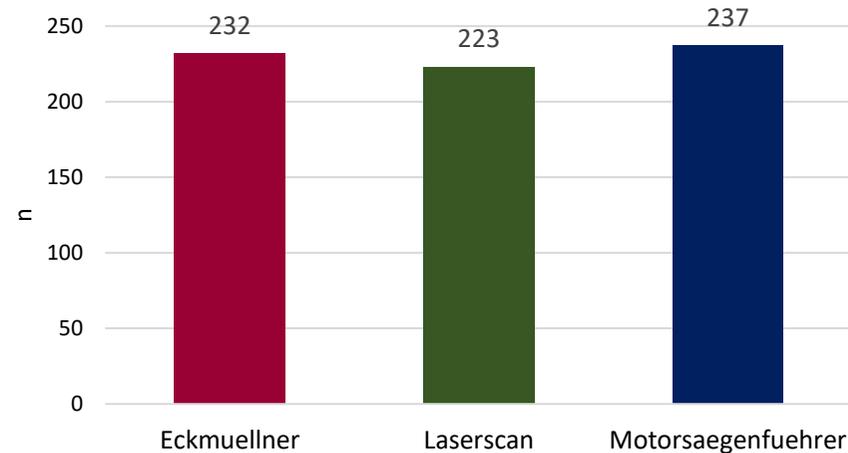


Ausformung – Sortiment - Erlöse

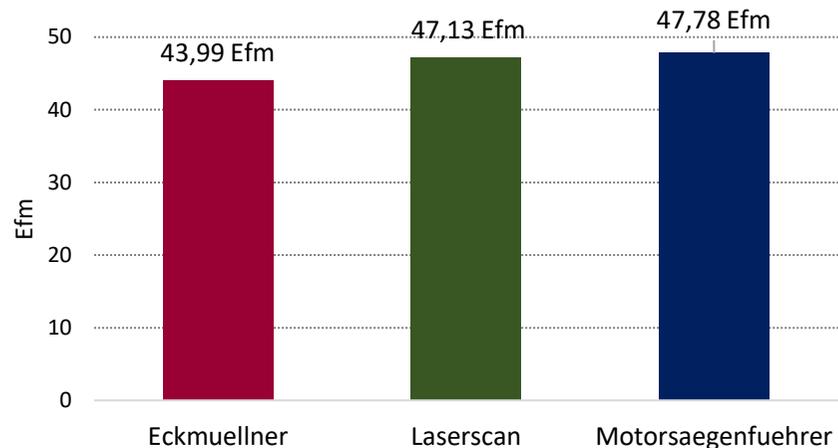
Nominallaenge



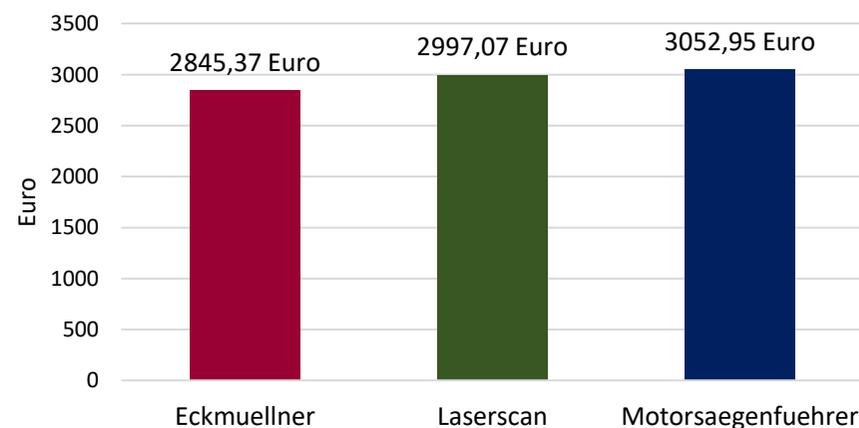
Ausgeformte Bloche



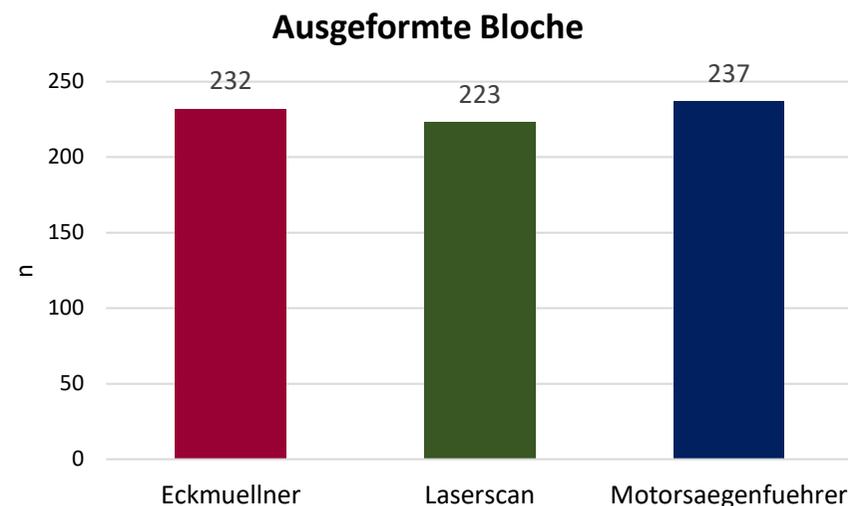
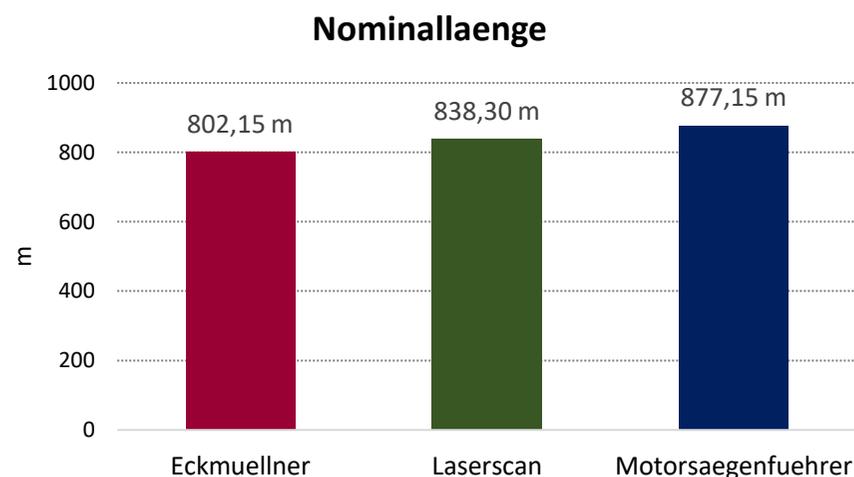
Erntevolumen



Erloes



Ausformung – Sortiment - Erlöse



Open access

Original scientific paper

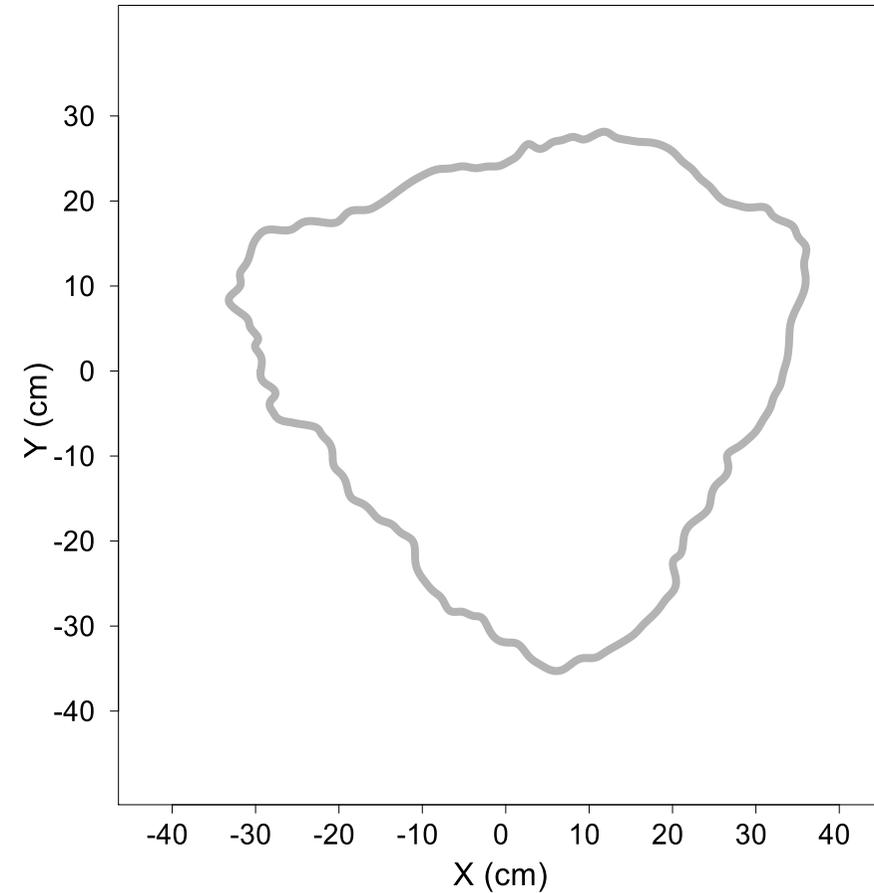
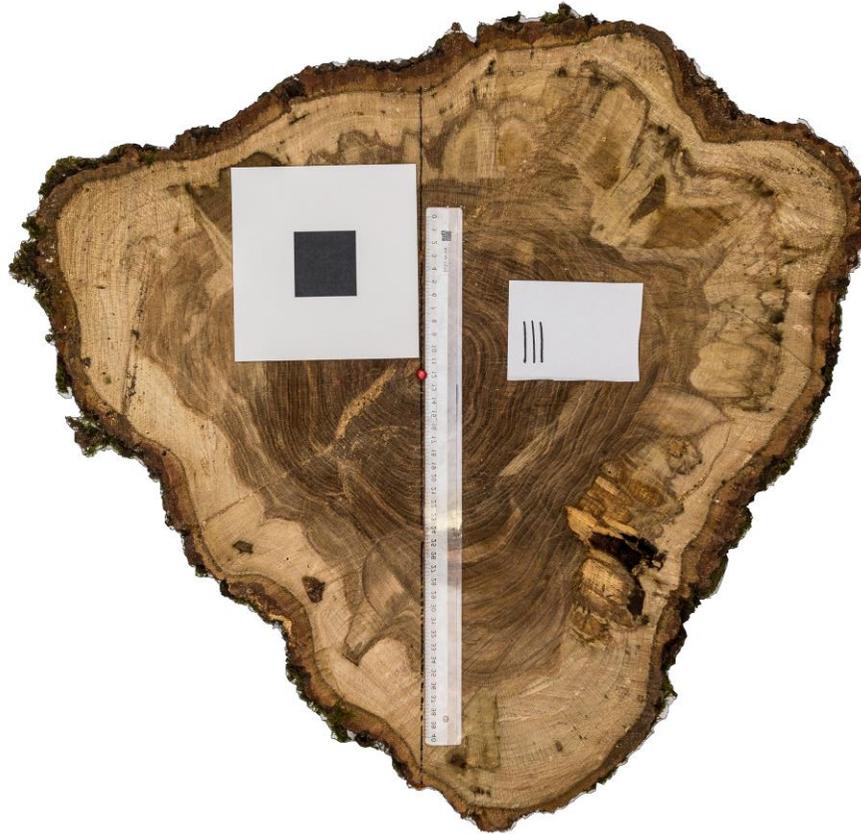
<https://doi.org/10.5552/crojfe.2022.1596>

Stem-Level Bucking Pattern Optimization in Chainsaw Bucking Based on Terrestrial Laser Scanning Data

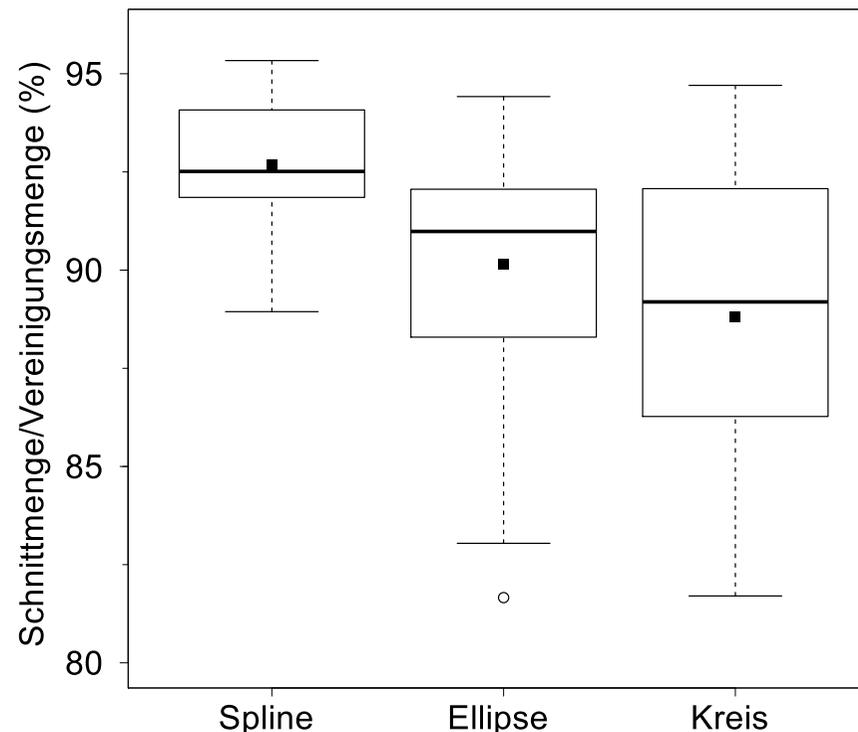
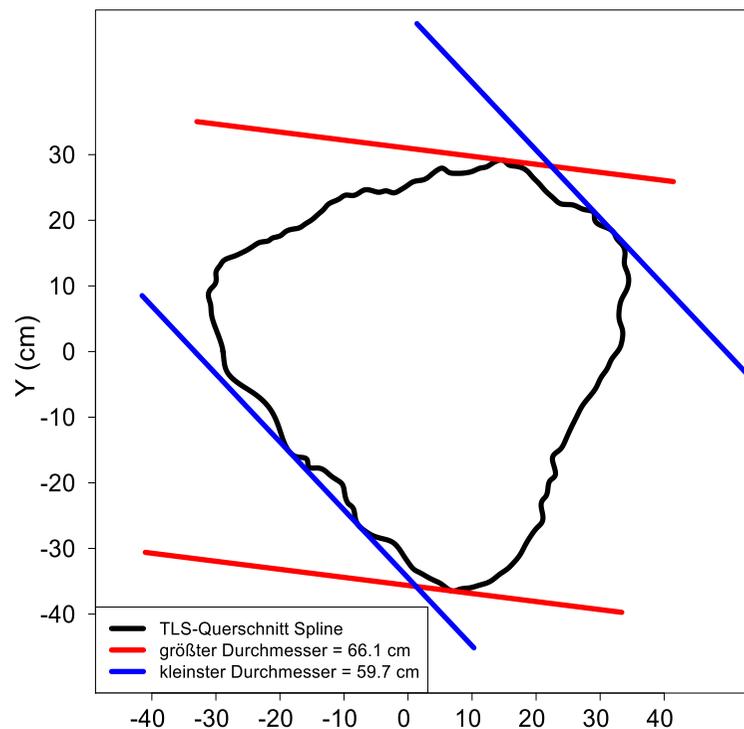
Gernot Erber, Christoph Gollob, Ralf Krassnitzer, Arne Nothdurft, Karl Stampfer



Was ist der richtige Durchmesser?



Was ist der richtige Durchmesser?



Open Access Article

Accuracy and Precision of Stem Cross-Section Modeling in 3D Point Clouds from TLS and Caliper Measurements for Basal Area Estimation

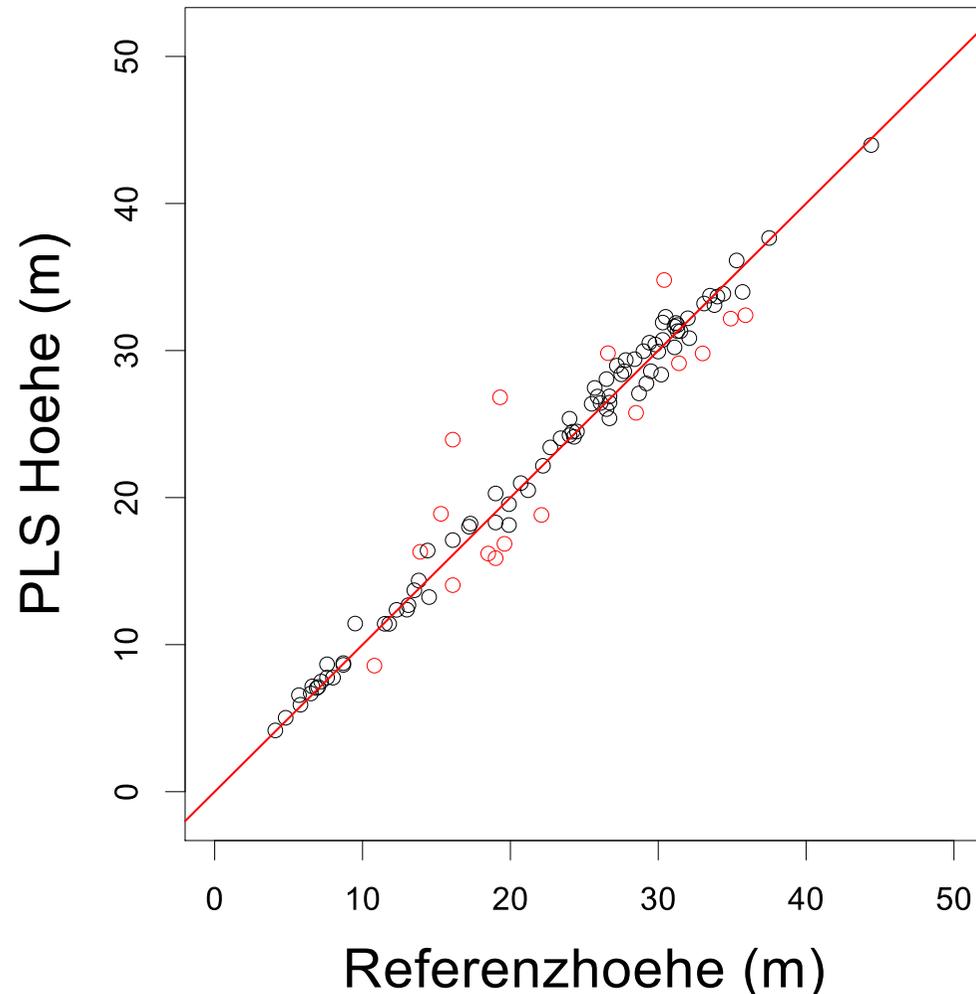
by  Sarah Witzmann ^{1,*} ,  Laura Matitz ² ,  Christoph Gollob ¹  ,  Tim Ritter ¹  ,
 Ralf Kraßnitzer ¹ ,  Andreas Tockner ¹  ,  Karl Stampfer ²  and  Arne Nothdurft ¹  



Höhen / Kronenparameter Genauigkeit PLS



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| Parameter | RMSE |
|--------------------|---------------------|
| Höhe | 1,21 m |
| Kronenansatz | 3,15 m |
| Kronendurchmesser | 1,11 m |
| Kronenschirmfläche | 5,25 m ² |



Contents lists available at [ScienceDirect](#)
International Journal of Applied Earth Observation and
Geoinformation
journal homepage: www.elsevier.com/locate/jag



Automatic tree crown segmentation using dense forest point clouds from
Personal Laser Scanning (PLS)

Andreas Tockner*, Christoph Gollob, Ralf Kraßnitzer, Tim Ritter, Arne Nothdurft



Baumartenerkennung

- Gesamtgenauigkeit: 89.8 %
- Intensität der oberen Krone wichtigster Faktor

andere wichtige Faktoren: BHD / Kronenbreite und Kronenhüllvolumen / Kronenzylindervolumen

Fichte



Tanne



Lärche



Kiefer



Eiche



Buche



Hainbuche



Ahorn



Birke



Baumartenerkennung

- Referenzdaten: 7.000 Bäume (9 Baumarten)
- > 7 cm BHD
- Für jeden Einzelbaum:
 - Intensitäts Werte
 - Verhältnisse von Messwerten (Kronengeometrie)



Baumartenerkennung

```

> ptab
      truth
pred Bu  Ei  Bi  Ah  Fi  Ki  La  Ta
Bu  332  2  4  5  4  0  1  7
Ei   2 123  1  0  1  6  0  0
Bi   0  0 16  0  0  0  0  0
Ah   1  0  0  7  0  0  0  0
Fi  16  8  7  0 521 13 11 32
Ki   2  5  7  0   3 195  4  1
La   0  0  0  0   0  1  2  0
Ta   0  1  0  0  12  0  0 19

> round( diag(ptab) / colSums(ptab), 3)
      Bu  Ei  Bi  Ah  Fi  Ki  La  Ta
0.941 0.885 0.457 0.583 0.963 0.907 0.111 0.322
  
```

Laubholz

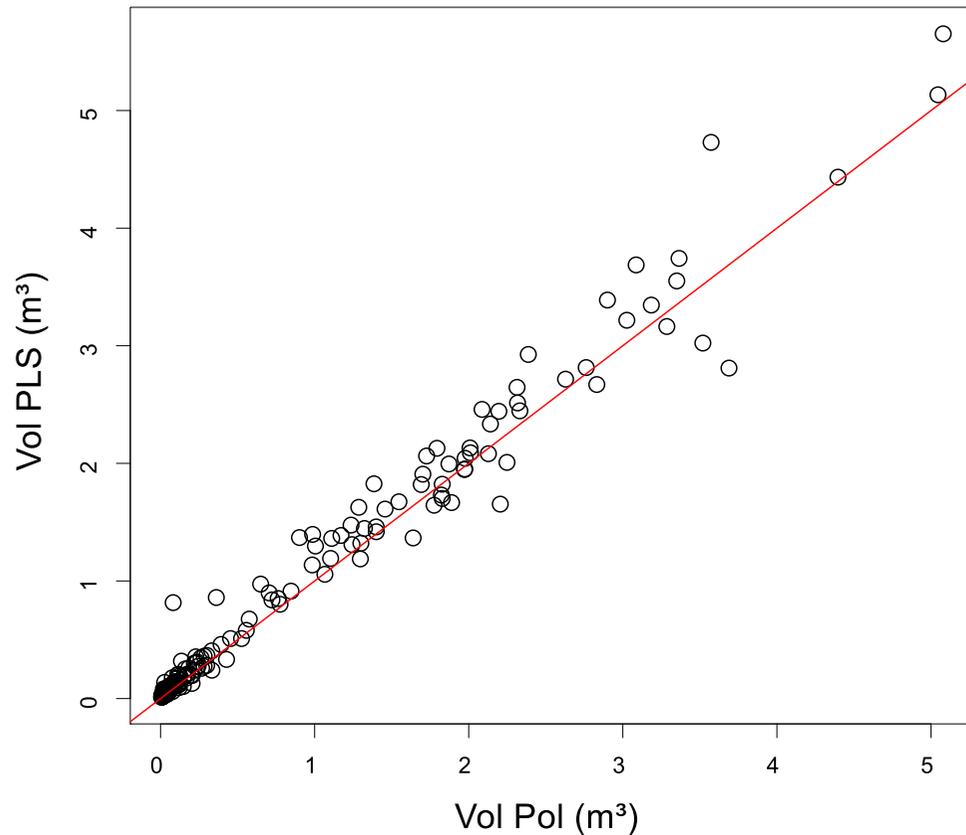
Nadelholz

Genauigkeit Einzelbaumvolumen PLS

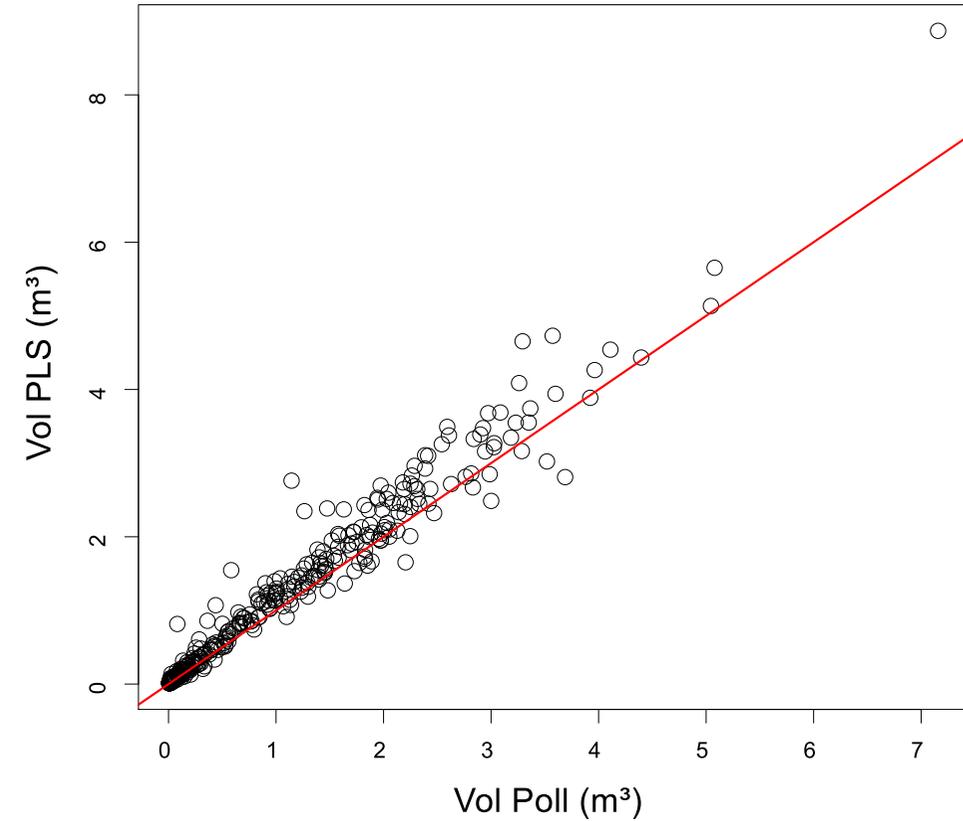


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Vergleich Buchen Vol Poll / Vol PLS 0.3
RMSE: 0.203, bias: -0.069



Vergleich V Poll / V PLS 0.3
RMSE: 0.302, bias: 0.148



WAF0 trees for KLEINARL 1 ha

3 trees selected, total 4.36 Vfm (0.4 %), dbh 30.4 cm, h/d 105.7

OUT 0.24 Vfm from tree 314, "Fi", DBH=14.9 cm, h=19.99 m, h/d=134.16

status/statistics

color = tree species
reference diameter

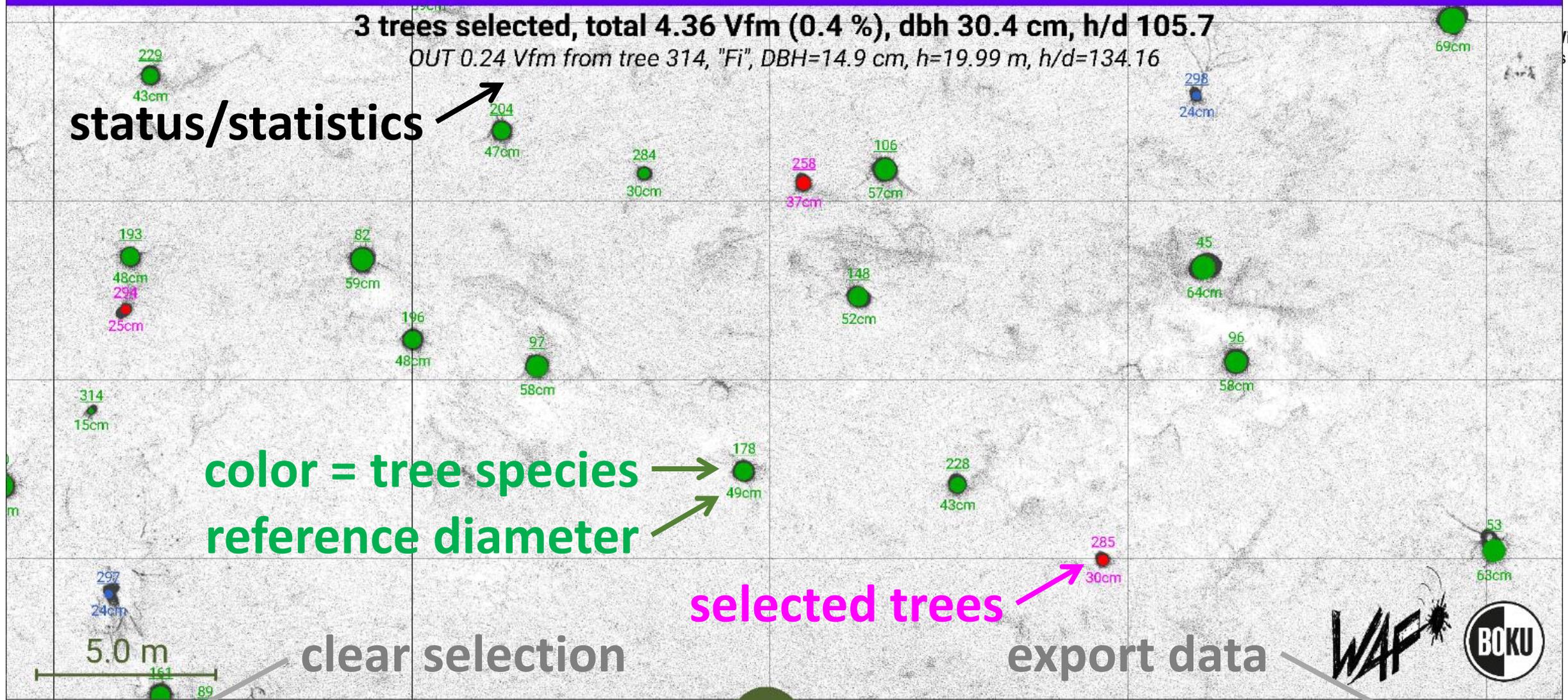
selected trees

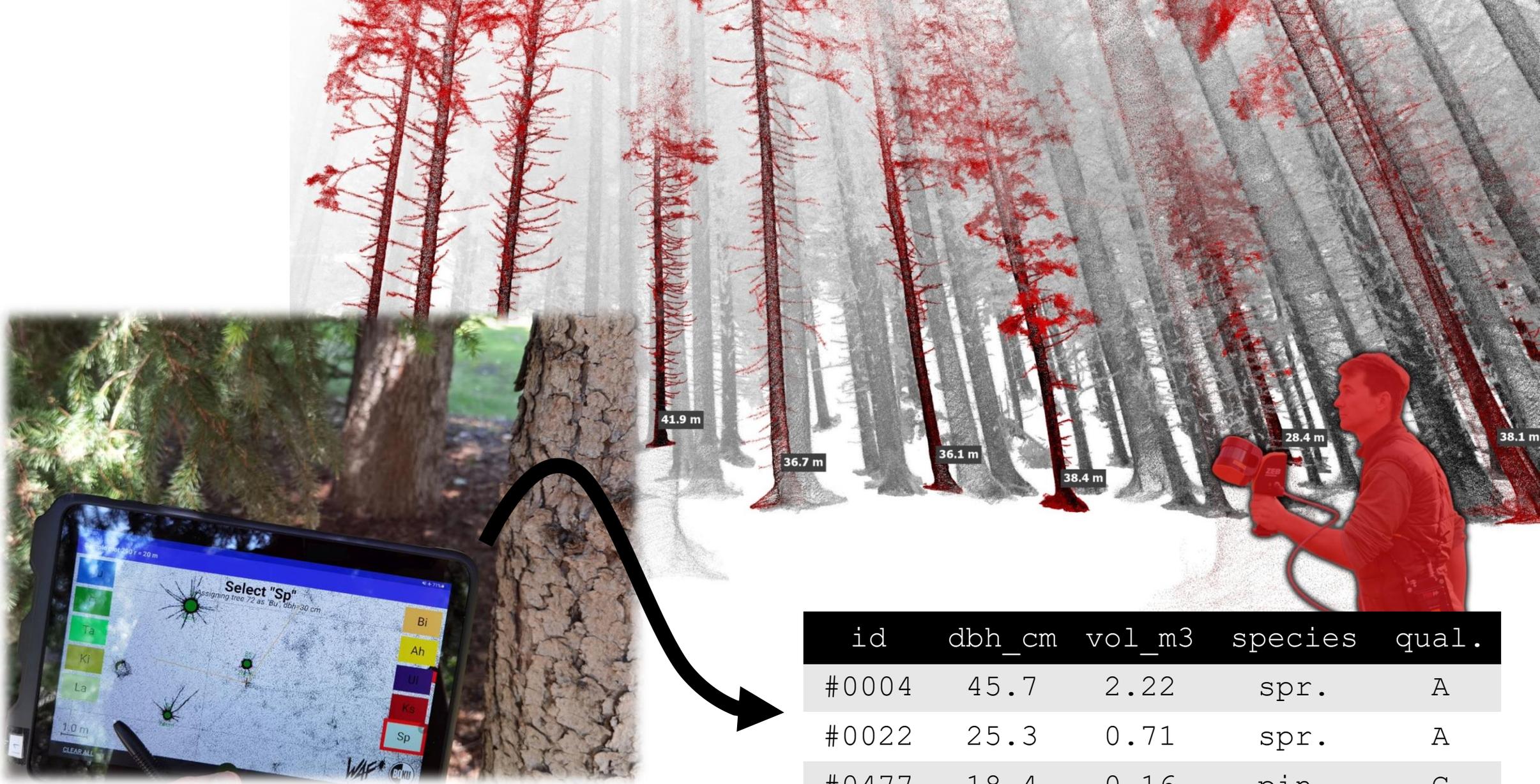
clear selection

export data

CLEAR ALL

EXPORT ALL





| id | dbh_cm | vol_m3 | species | qual. |
|-------|--------|--------|---------|-------|
| #0004 | 45.7 | 2.22 | spr. | A |
| #0022 | 25.3 | 0.71 | spr. | A |
| #0477 | 18.4 | 0.16 | pin. | C |

Fusion verschiedener Sensoren für flächige Prognosen

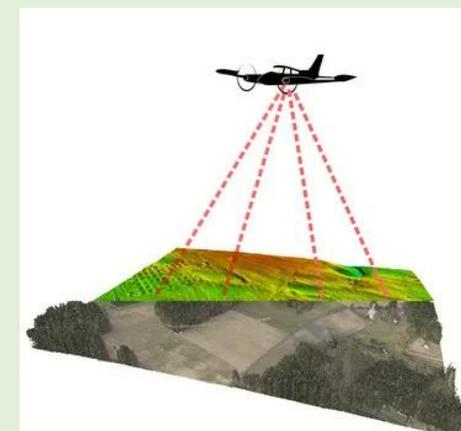
Personengetragene Laserscanner



LiDAR-Technologie in „günstigen“ elektronischen Produkten

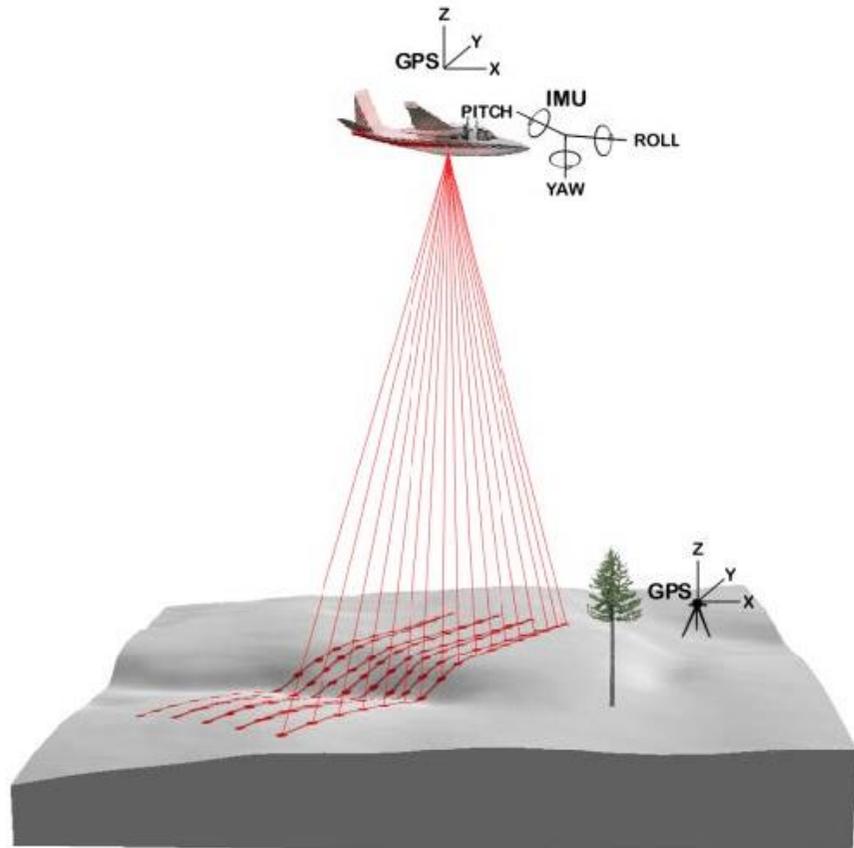


Airborne Sensing

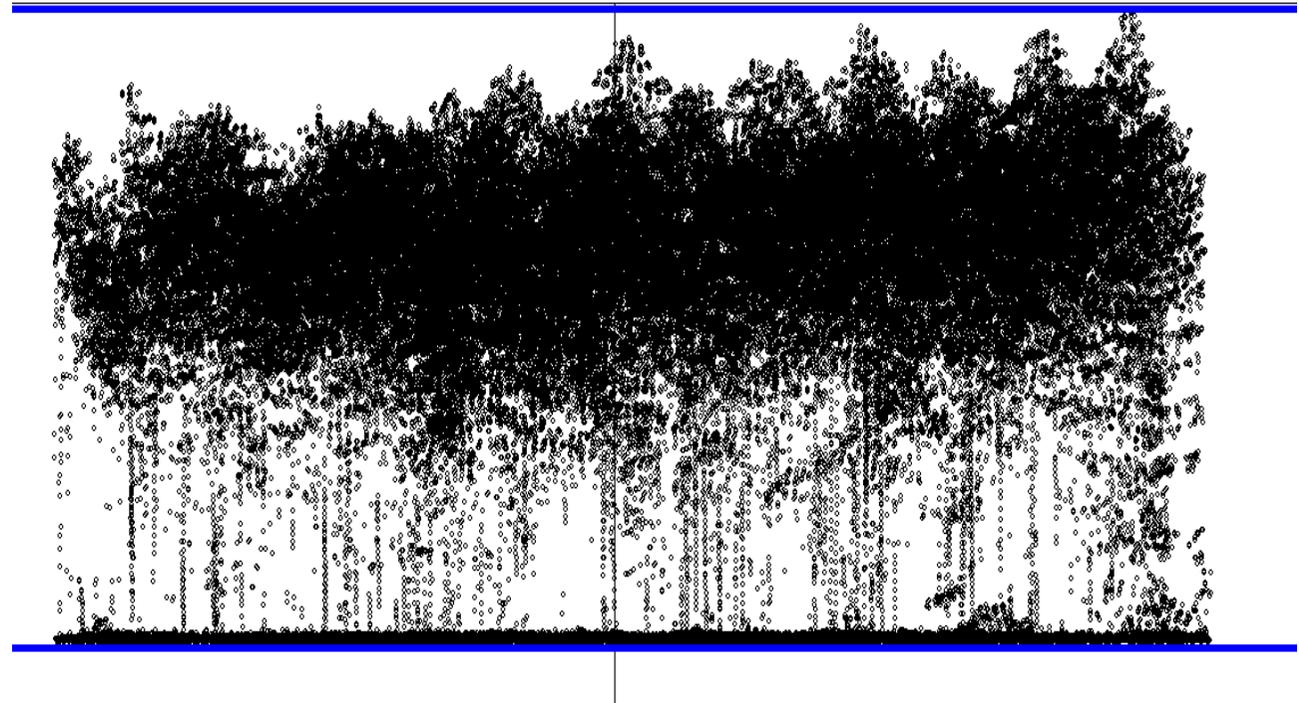


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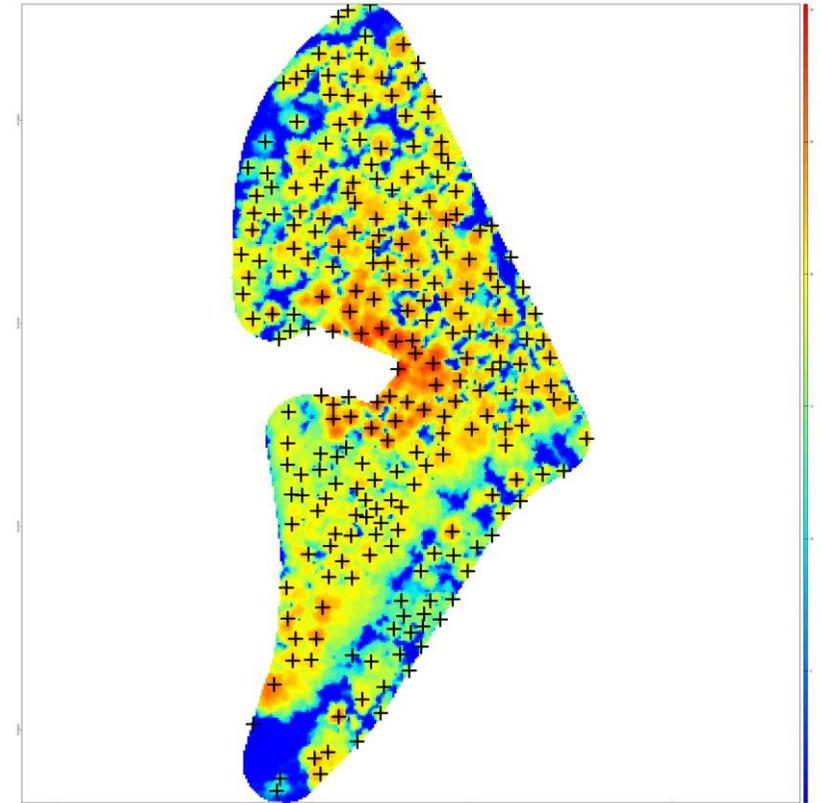
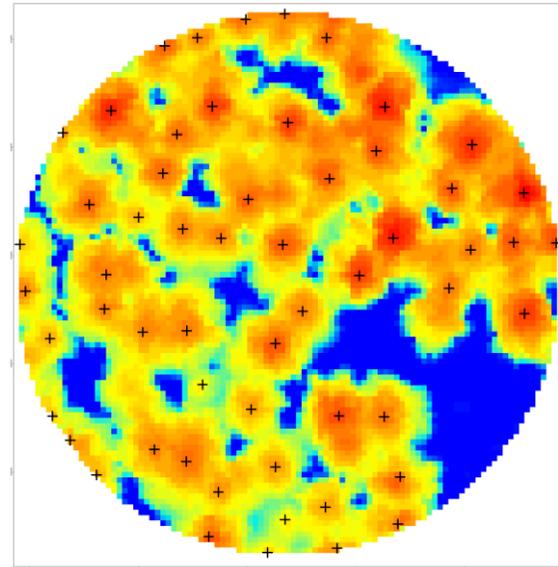
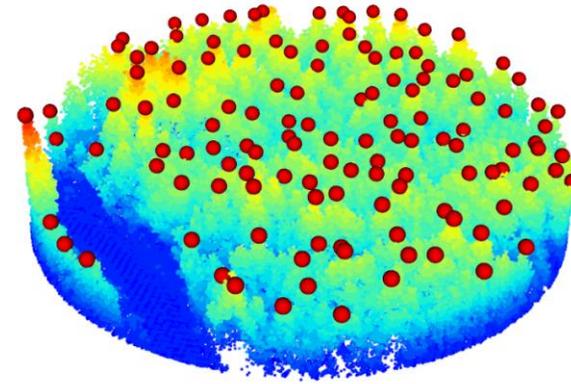
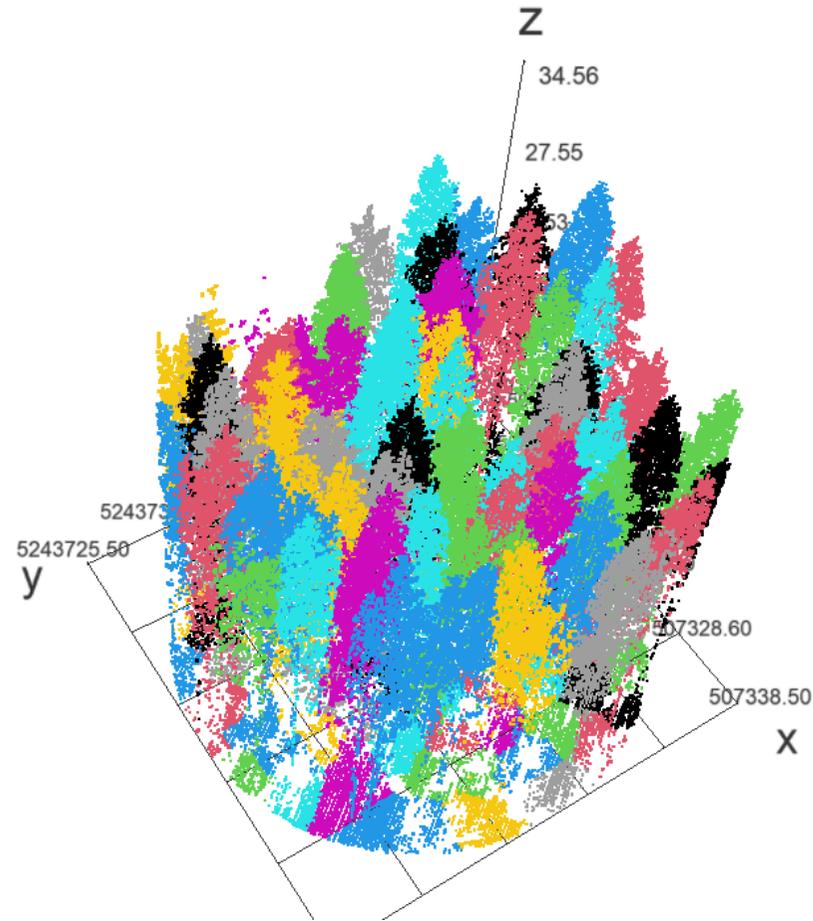
ALS Punktwolke



©Mcgaughey (2014)

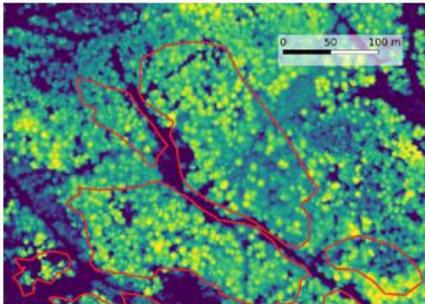


Vegetationshöhenmodell und Baumfindung aus ALS Daten



Räumliche Interpolation von Holzvorräten

Flugzeug-
getragenes
Laserscanning
(ALS)
vor dem Sturm

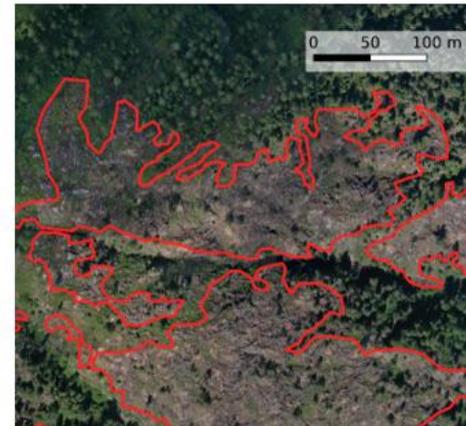


Personengetragenes Laserscanning (PLS)
in unversehrten Beständen



Räumliches
Statistisches
Modell

Flächenscharfe Schätzung
der Holzvorräte
vor dem Windwurf



Forest Ecology and Management
Volume 502, 15 December 2021, 119714



Estimating timber volume loss due to storm damage in Carinthia, Austria, using ALS/TLS and spatial regression models

Arne Nothdurft ^a, Christoph Gollob ^a, Ralf Kraßnitzer ^a, Gernot Erber ^b, Tim Ritter ^a, Karl Stampfer ^b, Andrew O. Finley ^c

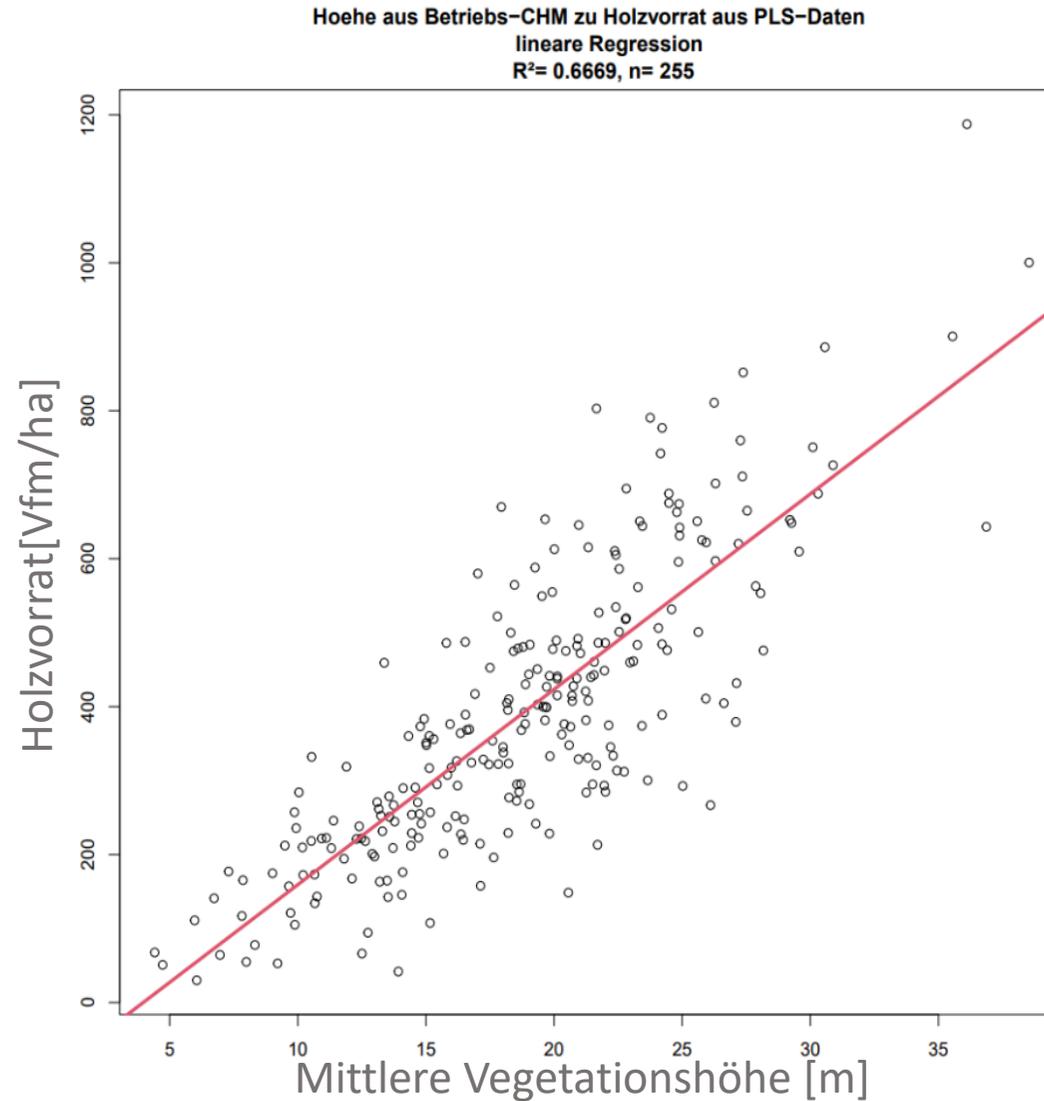


Projekt Digitalisierung in der Forsttechnik (Digi4+)

Zusammenhang ALS Vegetationshöhe/ PLS Vorrat



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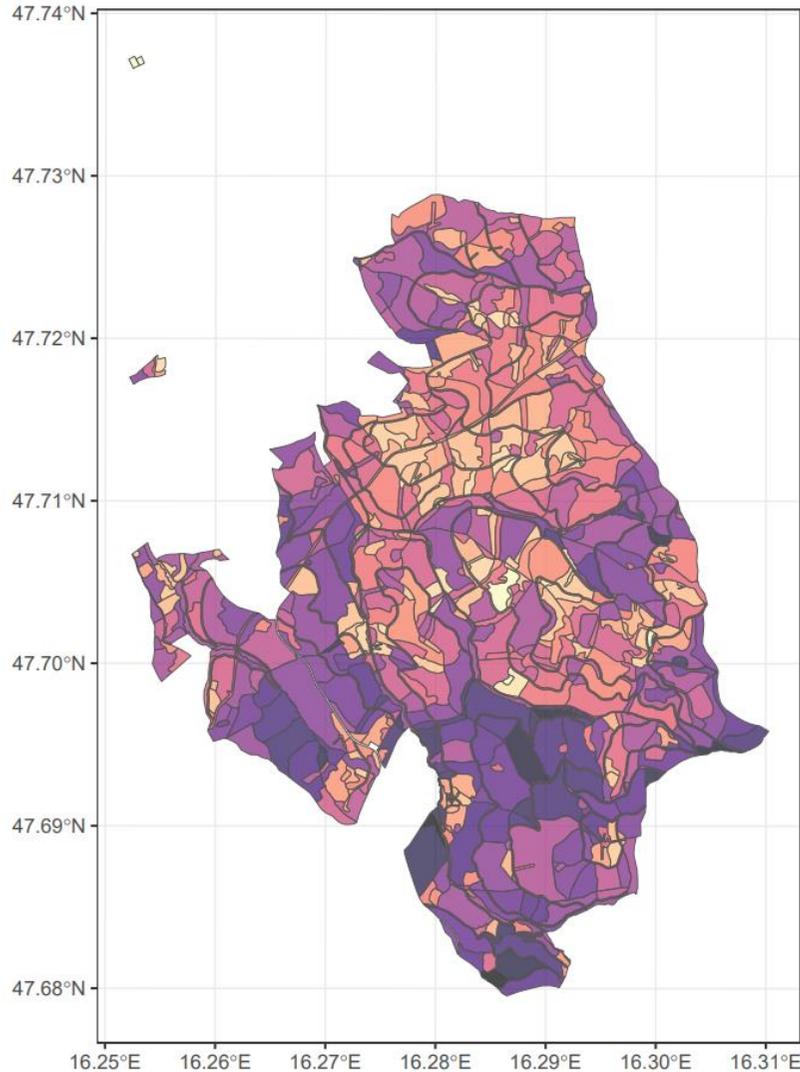


Prognose Vorrat BOKU Lehrforst

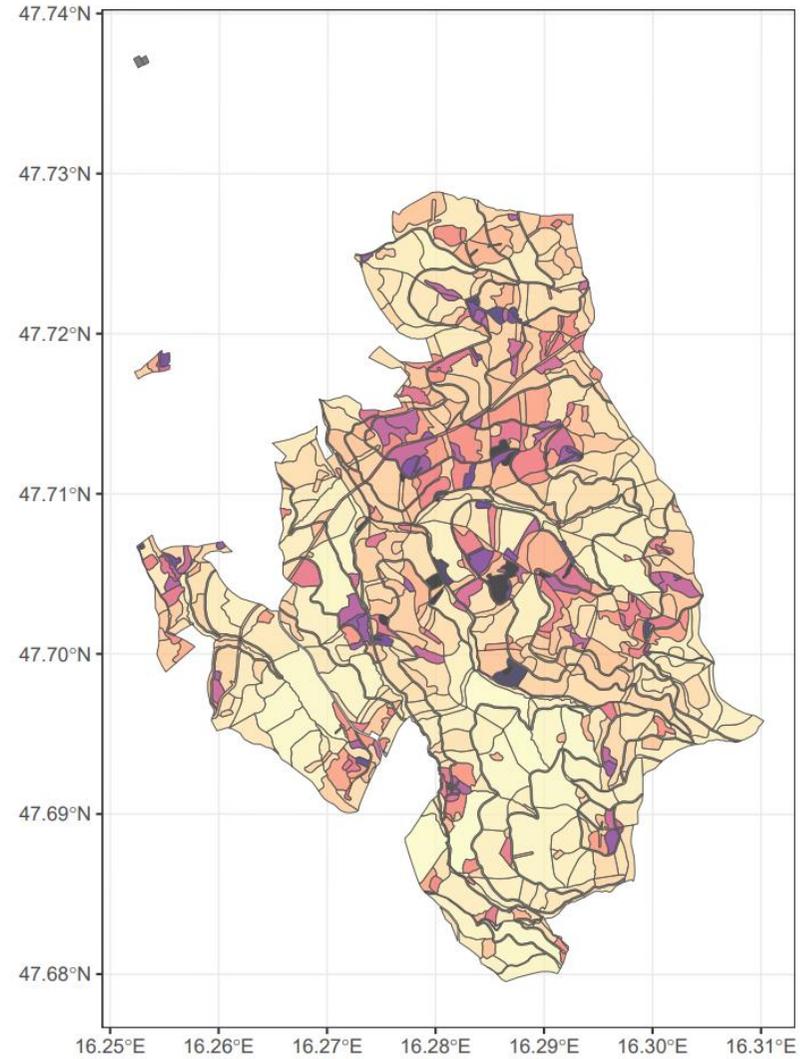


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BOKU-Lehrforst Vorratskarte



BOKU-Lehrforst Fehlerkarte

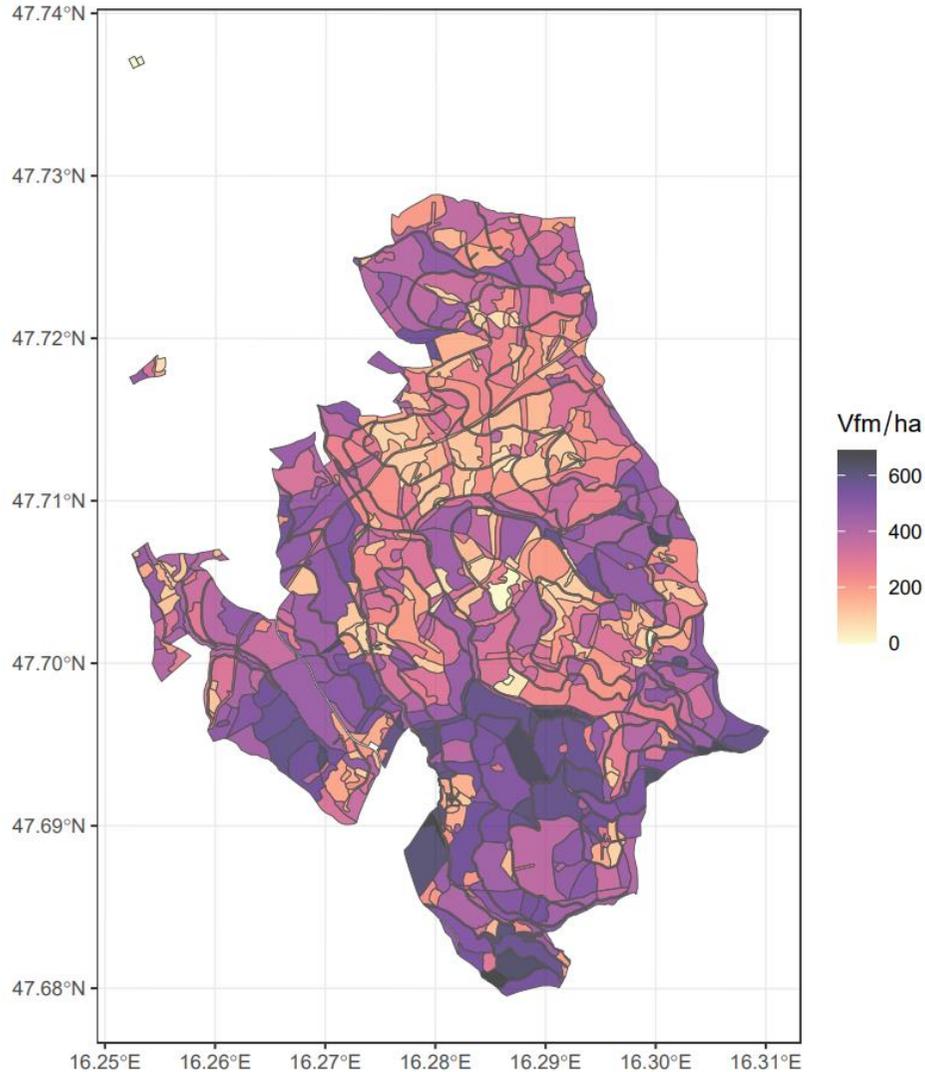


Prognose Vorrat BOKU Lehrforst

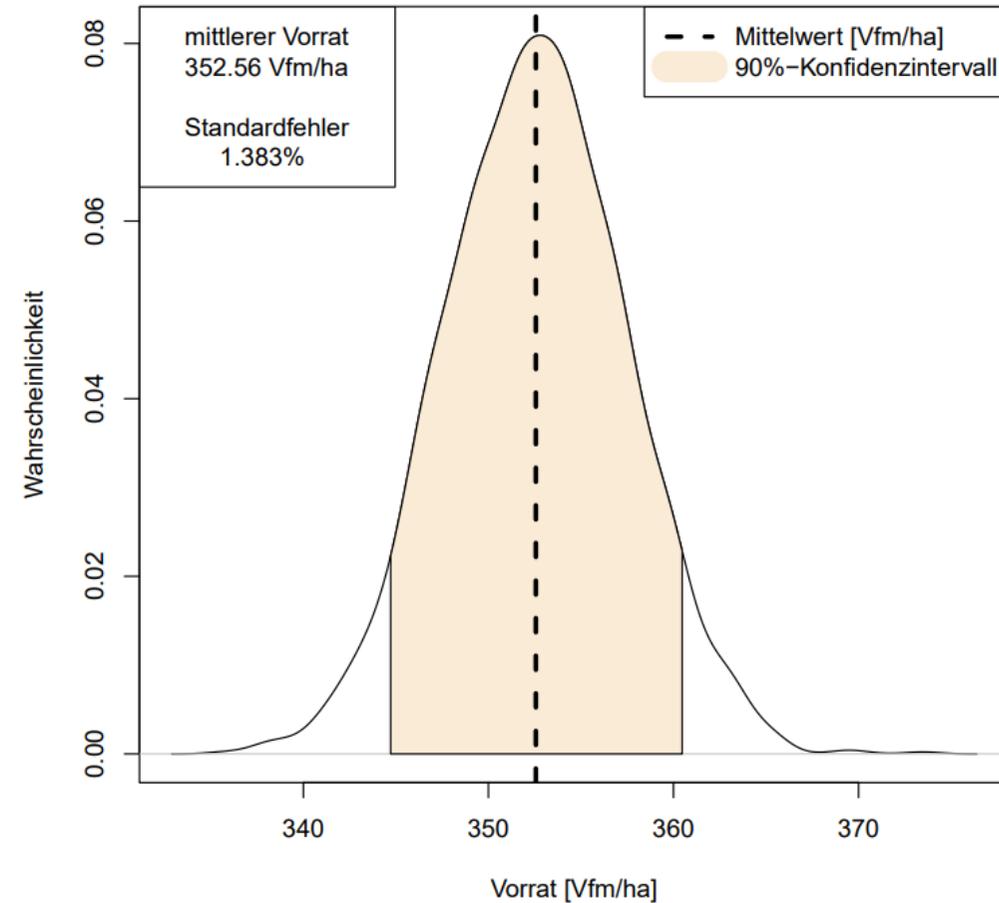


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BOKU-Lehrforst Vorratskarte



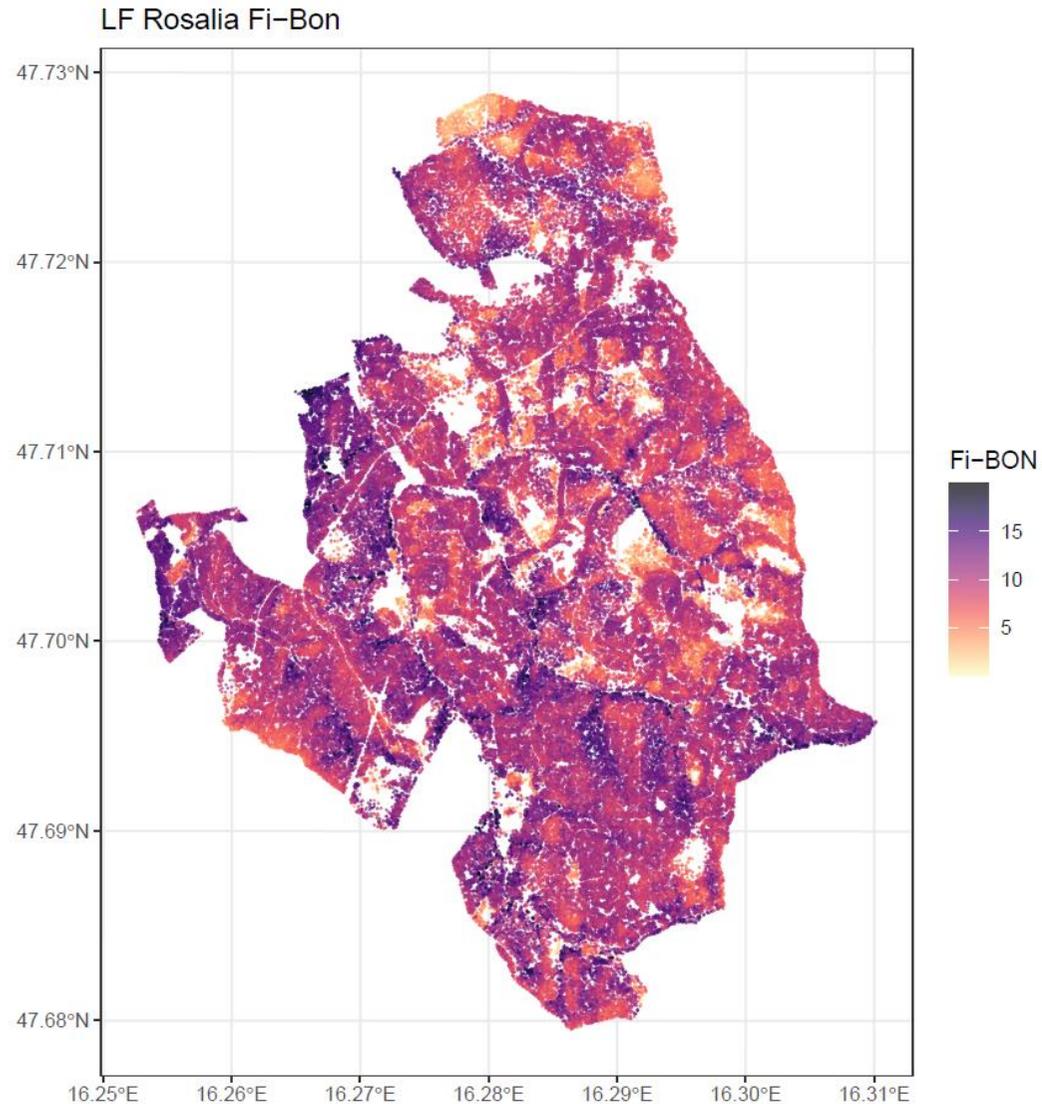
Boku-Lehrforst Holzvorrat je Hektar



Prognose Bonität BOKU Lehrforst



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| Baumart | Probestämme [n] | RMSE [Vfm/ha/a] |
|------------|--------------------|--------------------|
| Buche | 1969 | 1,92 |
| Fichte | 1731 | 1,87 |
| Weißkiefer | 875 | 1,19 |
| Lärche | 202 | 0,67 |
| Tanne | 132 | 0,93 |

Zusammenfassung – praktischer Nutzen für Inventur, Monitoring, Forsteinrichtung

- 100% Baumentdeckung
- 1,6 cm Fehler Durchmessermessung
- 1,2 m Fehler Höhenmessung
- 90% Genauigkeit Baumartenerkennung
- 0,2 Vfm Fehler Einzelbaumvolumen
- 1,4 % Fehler Betriebsvorrat
- 1,8 EKL Fehler Fi-Bonität
- ...

A large blue bracket on the right side of the slide groups the list of metrics. It starts at the top of the list and extends down to the bottom, with a small horizontal bar pointing towards the text 'Wichtige Inputgrößen'.

Wichtige Inputgrößen

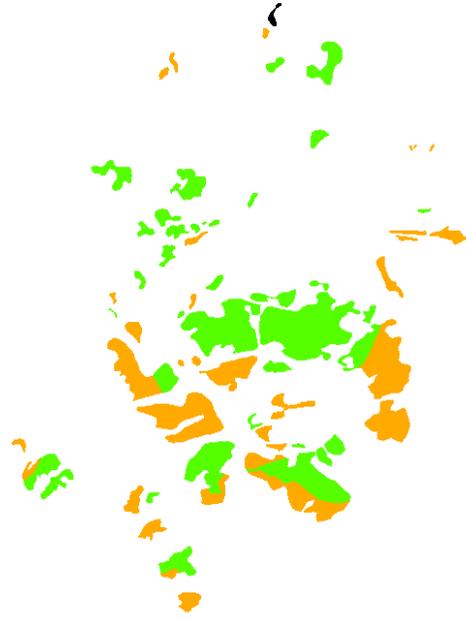
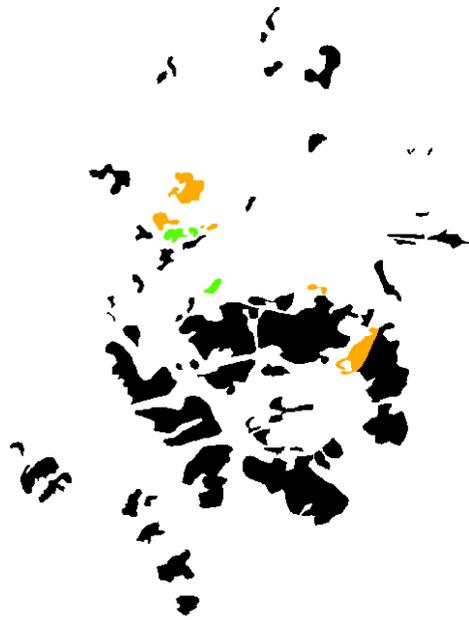
Exkurs: Planung der Holzernte



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Harvester/Forwarder

Seilkran



nicht geeignet
 mäßig geeignet
 gut geeignet

Table 8. Capacity plan for harvesters.

| | Plots (n) | Area (ha) | Timber Volume (m ³) | Machine Hours (h) | Man-Hours (h) | Productivity (m ³ /h) |
|--------------------------------------|-----------|-----------|---------------------------------|-------------------|---------------|----------------------------------|
| No harvesting | 74 | 15.64 | 7341 | - | - | - |
| Chainsaw-Cable yarder | 406 | 158.85 | 101,401 | 16,488 | 49,464 | 6.15 |
| Relocation of cable yarder | - | - | - | 577 | 577 | - |
| Forwarder | 127 | 37.82 | 22,015 | 906 | 906 | 24.31 |
| Relocation of forwarder (self) | - | - | - | 18 | 18 | - |
| Relocation of forwarder (low-loader) | - | - | - | 40 | 40 | - |



Article

Capacity Planning of Timber Harvesting in Windthrow Areas

Martin Kühmaier ^{1,*}, Christoph Gollob ², Arne Nothdurft ², Maximilian Lackner ³ and Karl Stampfer ¹



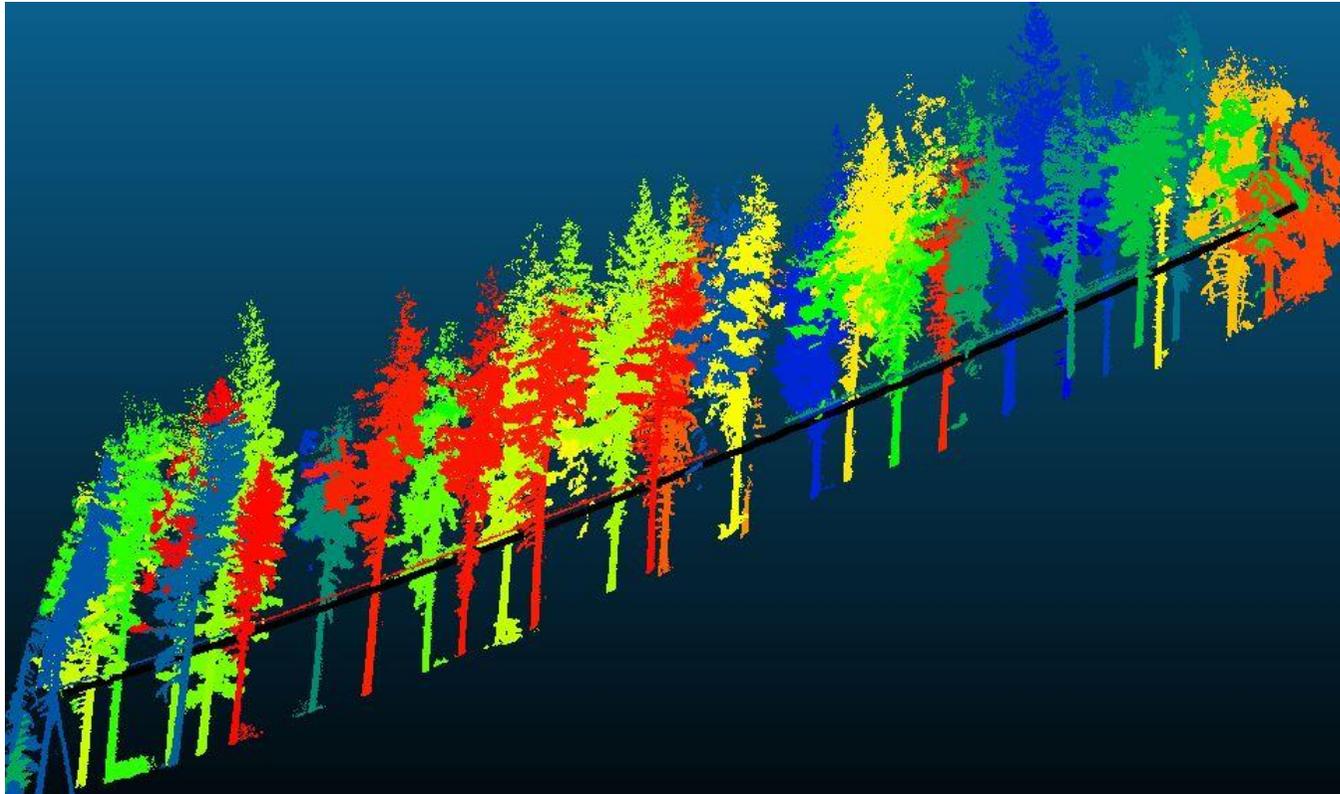
Exkurs: Seilkran mit Laserscanner



Exkurs: Seilkran mit Laserscanner



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Open access

Original scientific paper

<https://doi.org/10.5552/crojfe.2023.2252>

Measurement of Individual Tree Parameters with Carriage-Based Laser Scanning in Cable Yarding Operations

Christoph Gollob, Ralf Krassnitzer, Tim Ritter, Andreas Tockner, Gernot Erber, Martin Kühmaier, Ferdinand Hönigsberger, Thomas Varch, Andreas Holzinger, Karl Stampfer, Arne Nothdurft



Exkurs: autonomes Waldmonitoring



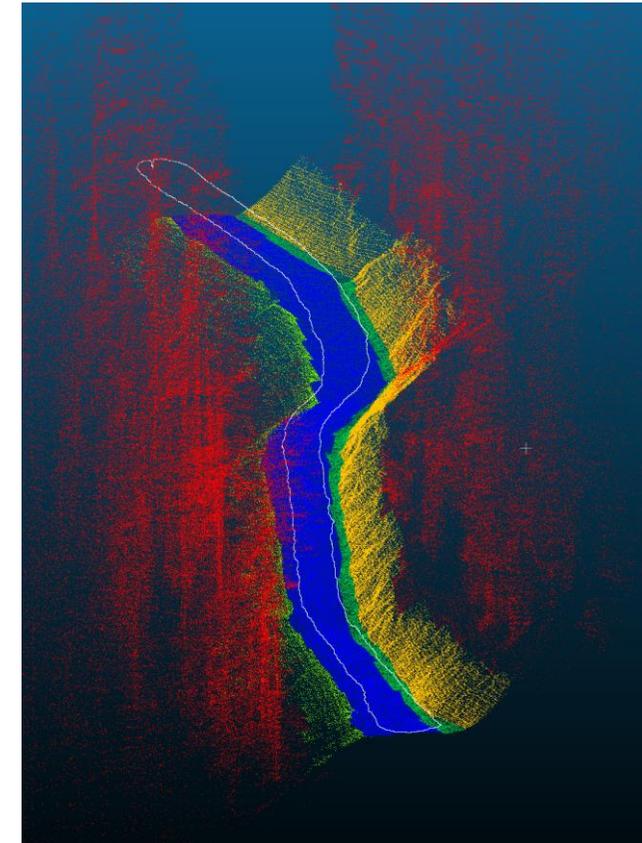
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Exkurs: Digitaler Zwilling Forststraße



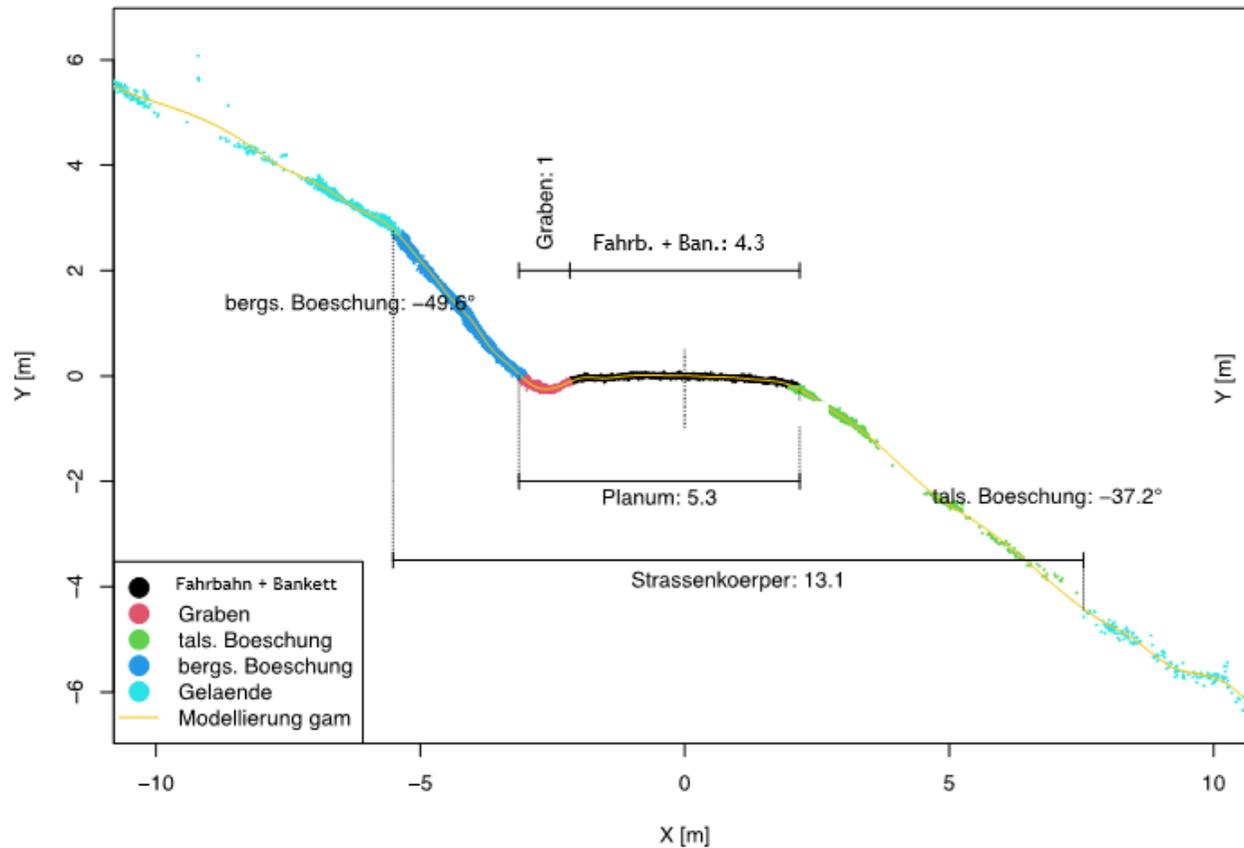
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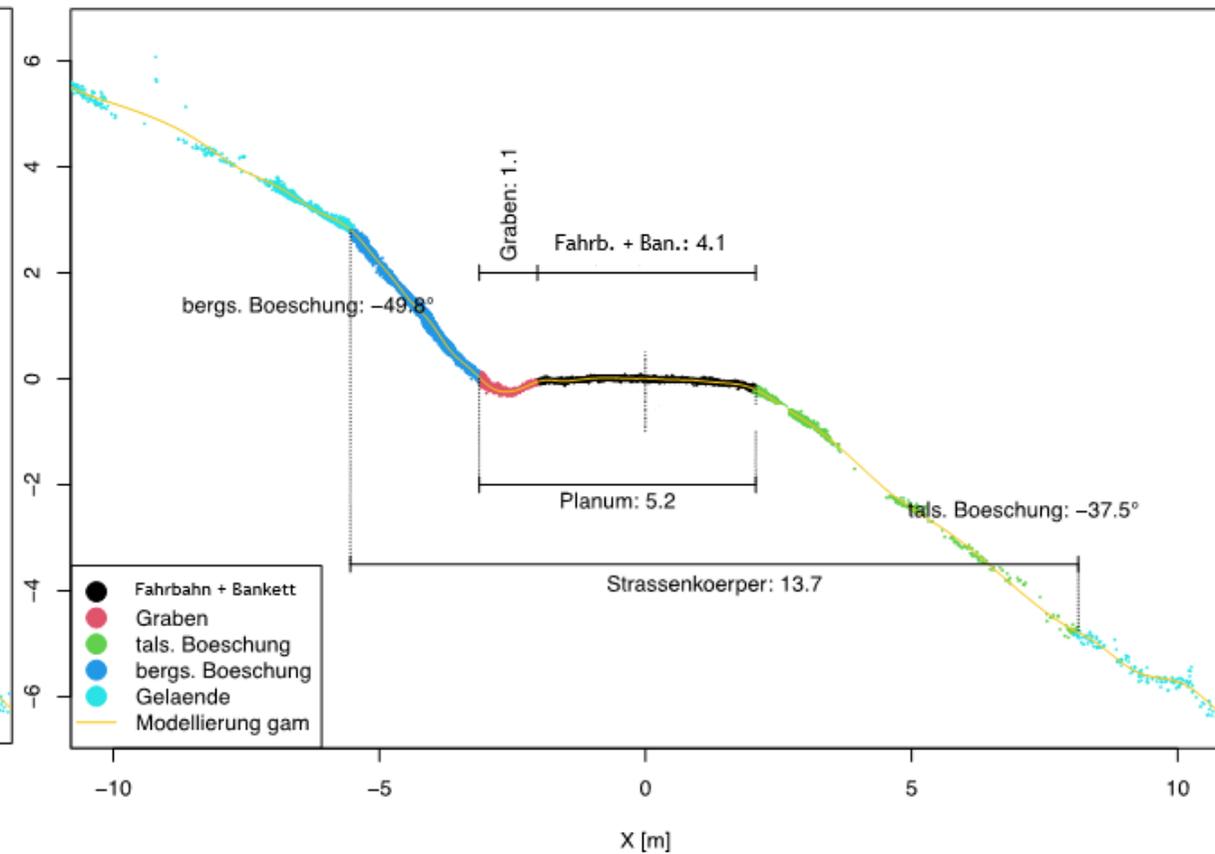
Exkurs: Digitaler Zwilling Forststraße



Referenzprofil bei m: 110

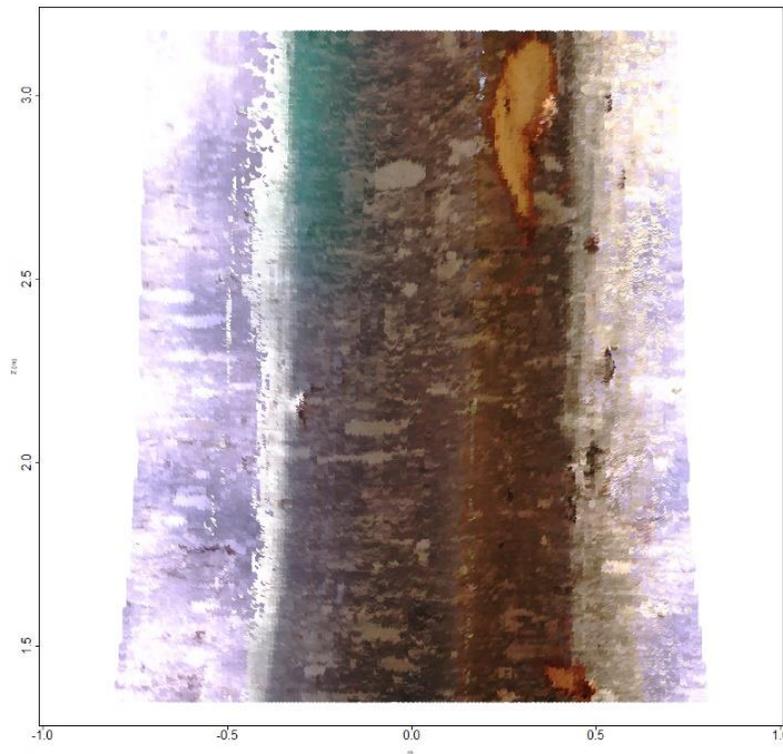


autom. Profil bei m: 110

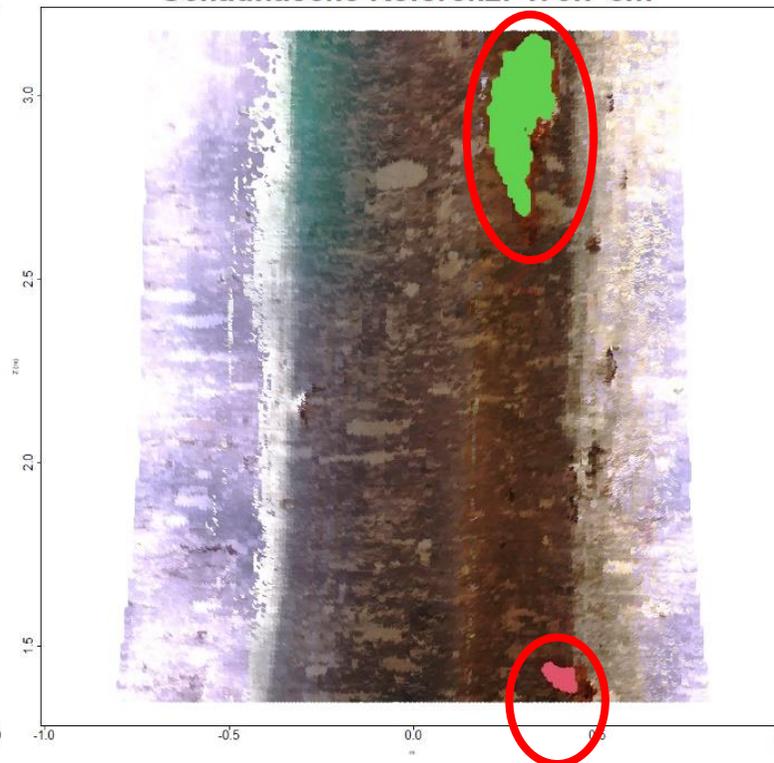


Exkurs: Holzernteschäden

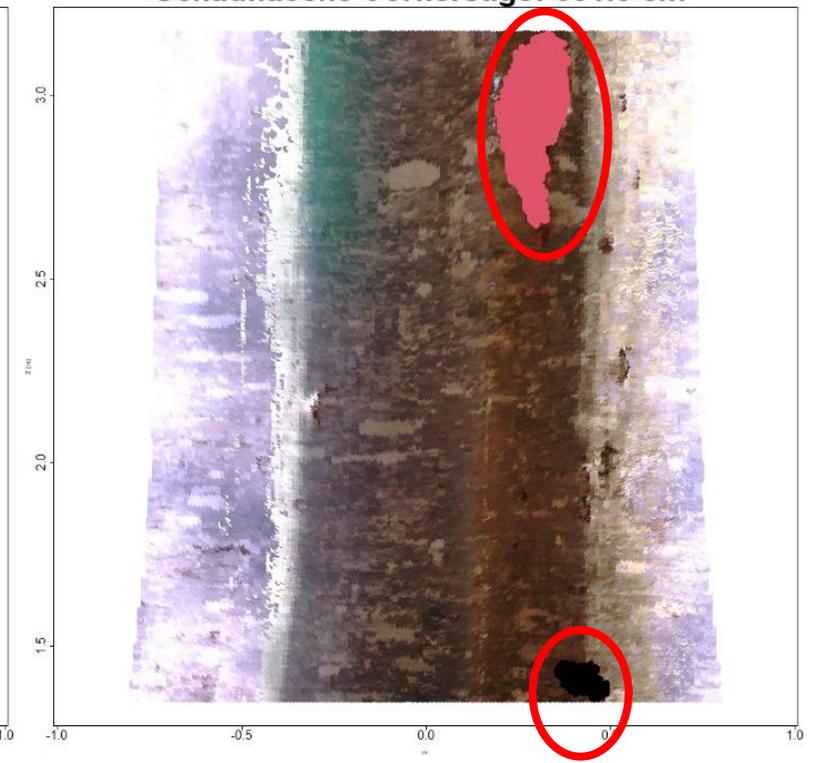
“Abgerollter” Stammabschnitt mit Schaden aus
der eingefärbten 3D Punktwolke



Schadflaeche Referenz: 478.7 cm²



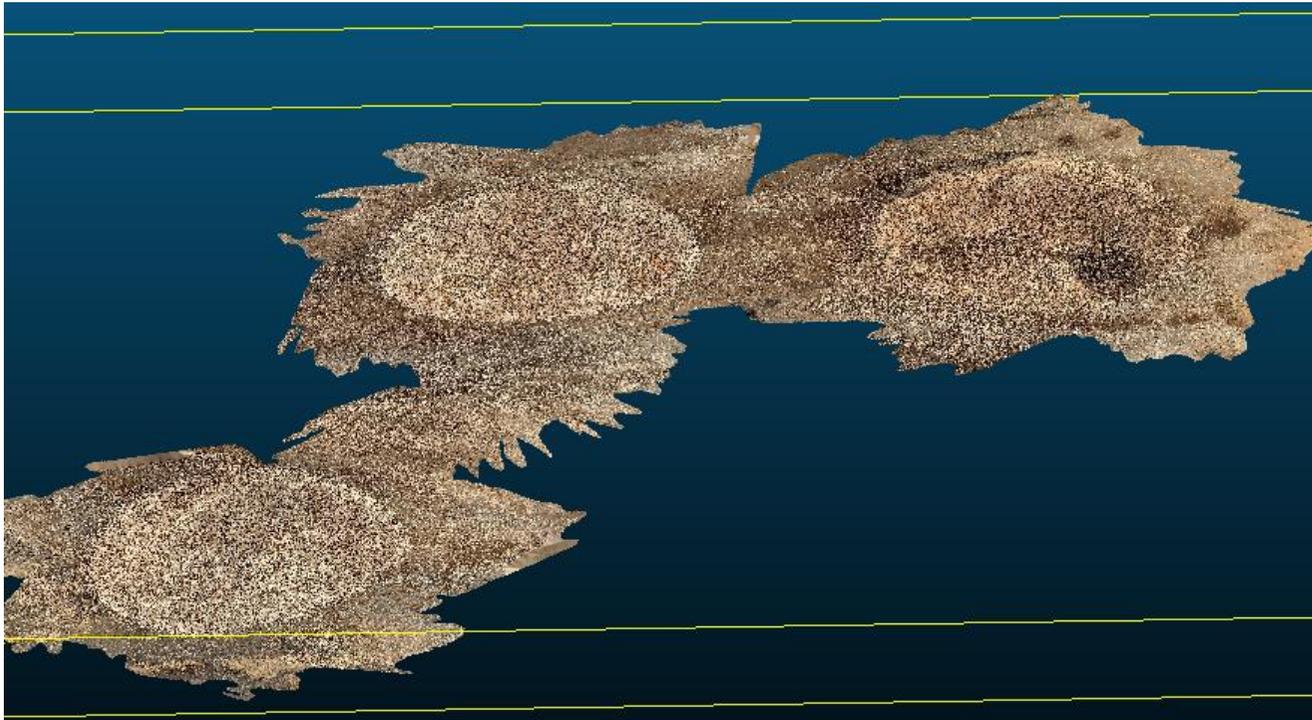
Schadflaeche Vorhersage: 681.8 cm²



Exkurs: Hackgutvermessung

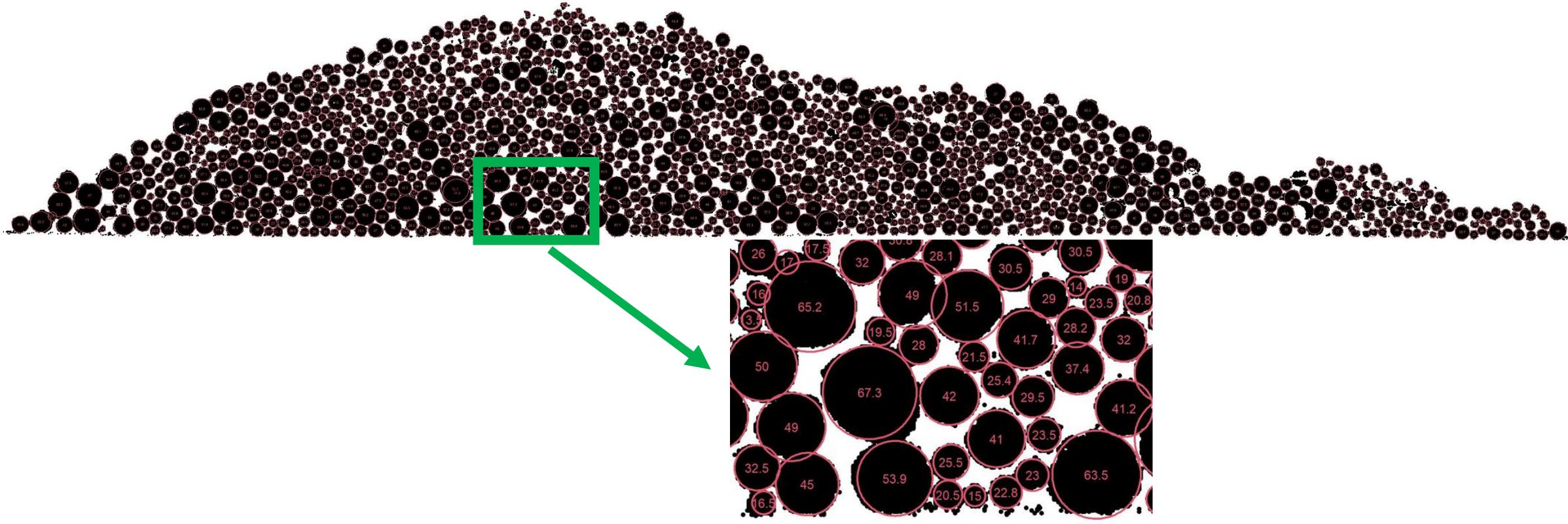


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| Technologie | mean RMSE Raster [%] | mean RMSE GAM mN [%] | mean RMSE GAM oN [%] |
|-------------|----------------------|----------------------|----------------------|
| PLS | 3,27 | 3,32 | 3,29 |
| TLS | 6,35 | 4,25 | 4,21 |
| 3DScan | 14,82 | 5,64 | 5,66 |
| Sitescape | 7,26 | 5,69 | 5,51 |
| Polycam | 3,39 | 2,81 | 2,76 |

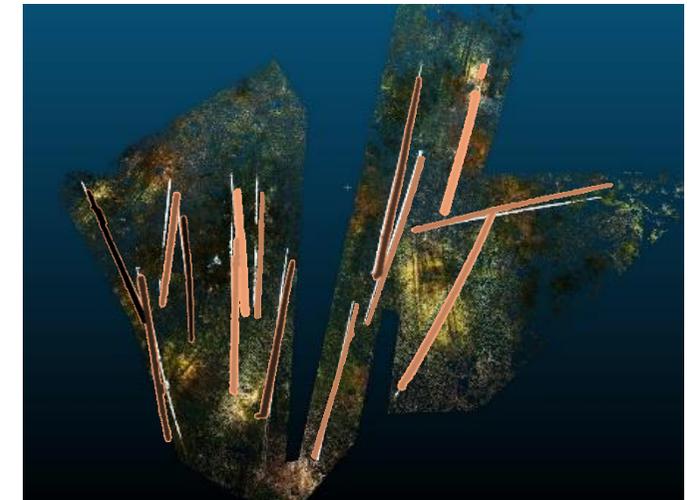
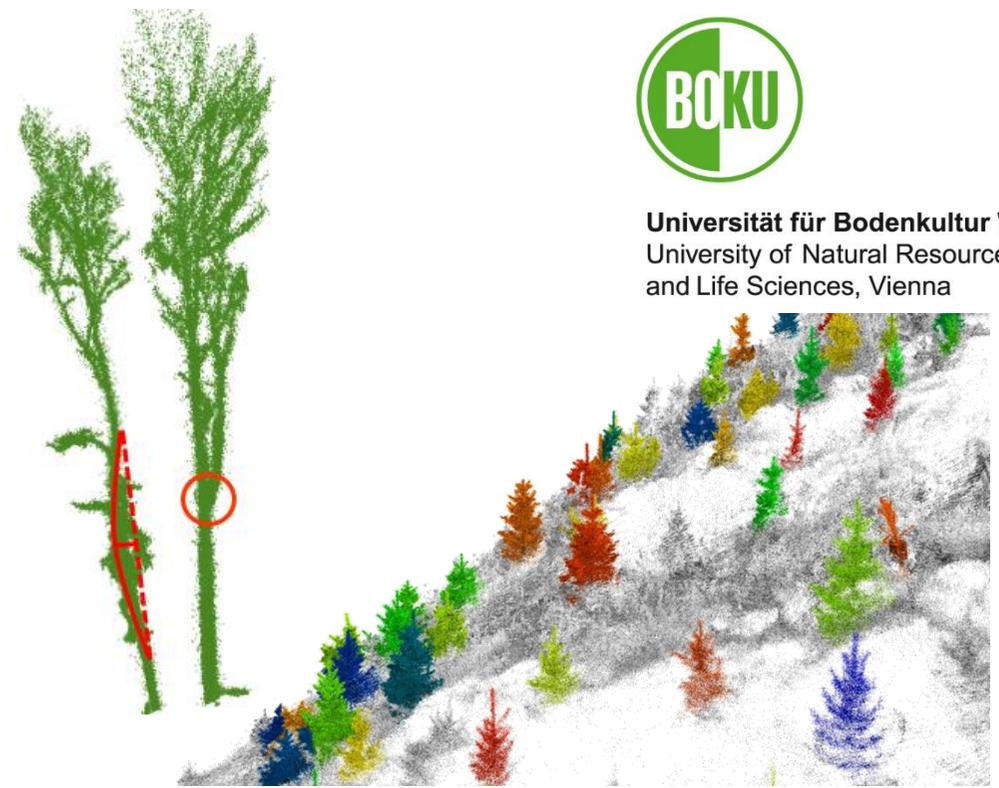
Exkurs: Poltervermessung



| Kennziffer | Abmaßliste Sägewerk | Scan vorne | Scan hinten |
|-------------------------|---------------------|------------|-------------|
| Stämme gefunden | 1420 | 1377 | 1384 |
| Falsch pos. Stämme | 0 | 14 | 9 |
| Richtig erkannte Stämme | 100% | 96% | 96,8% |

Weiterer Forschungsbedarf

- Mobile Anwendung (iPad) für jedermann
- Totholz
- Biodiversität
- Qualitätsansprache
- Verjüngung
- Harvestergassen und Seillinienoptimierung
- Erschließungsplanung
- ...



Zusammenfassung - Fazit

- **Hardware (Scanner)** funktioniert auch im Wald
- **Software** wird laufend erweitert und verbessert
- **Vollautomatisierte** Auswertung
- Detailgetreues, nahezu **verlustfreies Abbild** der **Wirklichkeit**
→ **digitale Archivierung** für spätere Aufgaben/Auswertungen.
- **Gesamtpaket** für digitale Waldinventur, -monitoring und Forsteinrichtung ist allmählich am entstehen
- Viele interessante Fragestellungen neben dem klassischen „Bäume messen“
- Viel weiterer Forschungsbedarf

Vielen Dank für die Aufmerksamkeit!

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