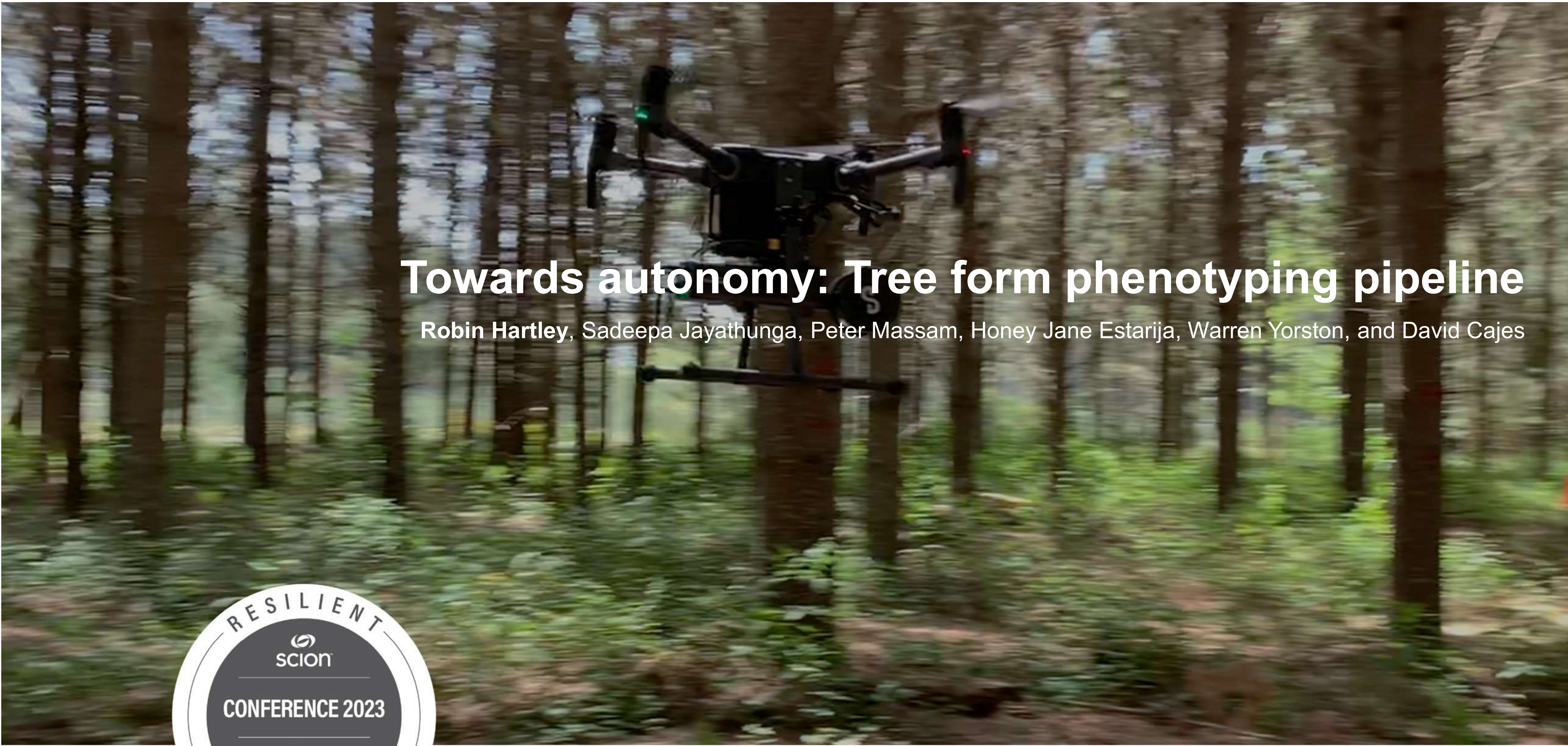

Towards autonomy: Tree form phenotyping pipeline

Robin Hartley, Sadeepa Jayathunga, Peter Massam, Honey Jane Estarija, Warren Yorston, and David Cajes

RESILIENT FORESTS
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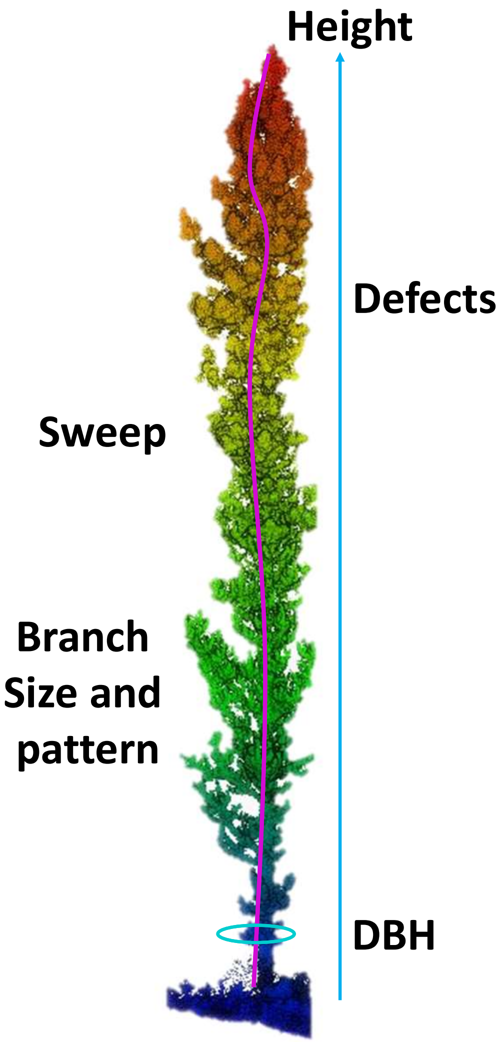
FOREST GROWERS RESEARCH
Resilient Forests Research Programme

What is Phenotyping and why should we automate it?



- Compare tree form with genetics, environment and silviculture (GxExS) to identify optimal trees for a given situation.
- Uses: Tree breeding and Forest Management (Right Tree, Right Place, Right Purpose).

Traditional Measurement

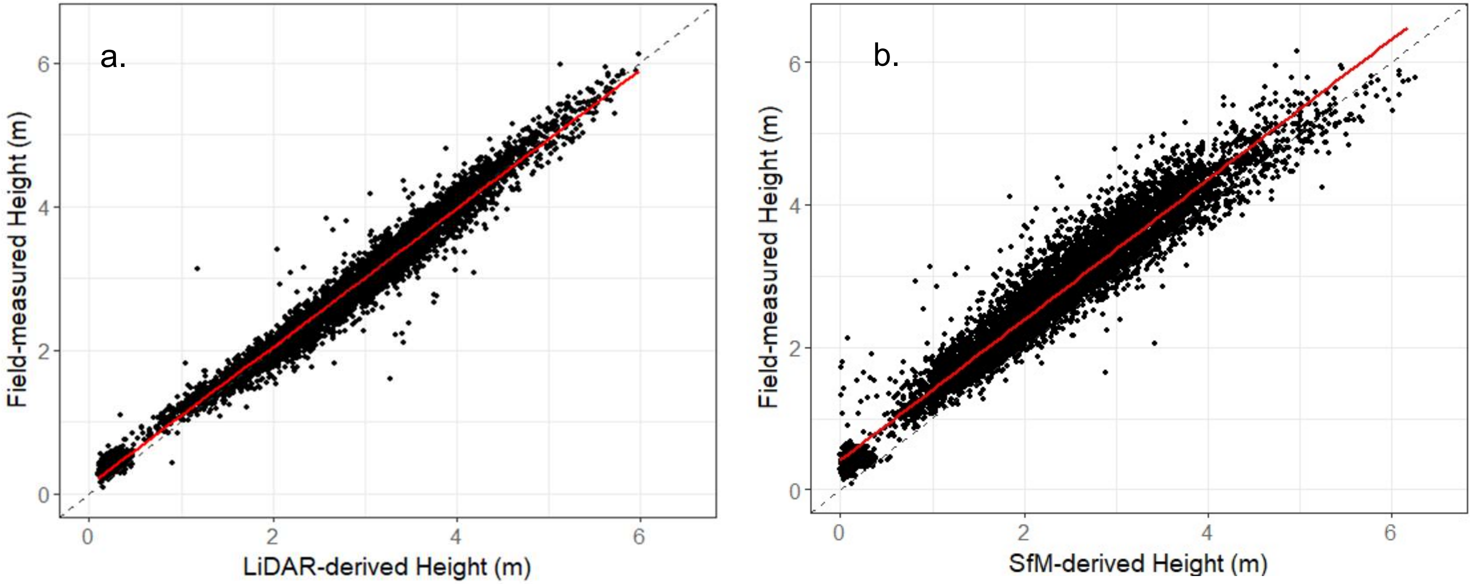
- Time consuming/costly,
- Subjective
- Plot-based metrics - Averaging
- Bias (tree heights - occlusion, terrain effects, tree lean…)
- Low throughput

Automated

- Rapid
- Objective
- Individual tree
- Less-biased
- High throughput

Backstory:

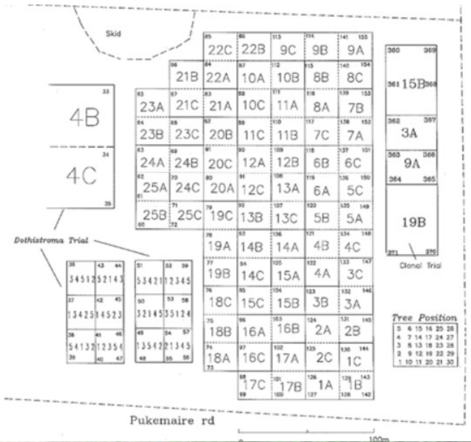
- GCFF: can we measure trees with UAVs?
  - UAV laser scanning (ULS) (MiniVUX1-UAV)
  - Photogrammetry (SfM) (DJI Phantom 4 pro – used by industry)
- 6 trial sites across NZ North Island, age 4 months to age 3.
- SfM and ULS both highly accurate for heights in young trials



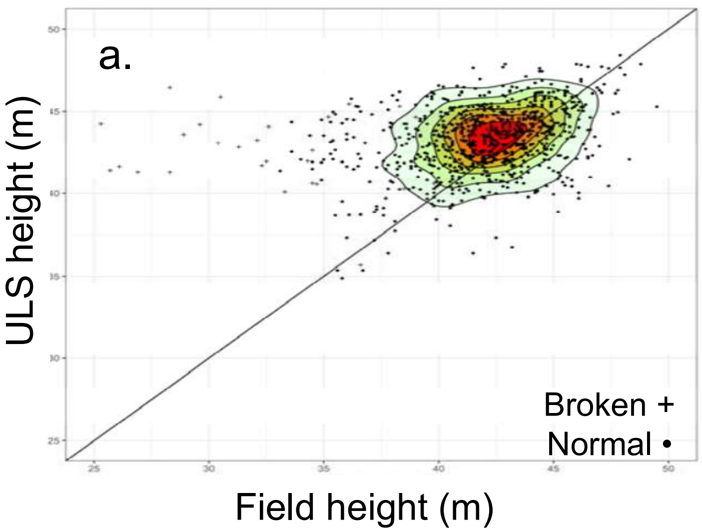
Hartley, R.J., Leonardo, E.M., Massam, P., Watt, M.S., Estarija, H.J., Wright, L., Melia, N. and Pearse, G.D., 2020. An assessment of high-density UAV point clouds for the measurement of young forestry trials. *Remote Sensing*, *12*(24), p.4039.

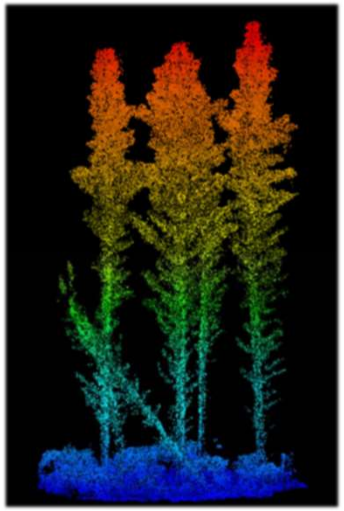
Backstory contd…

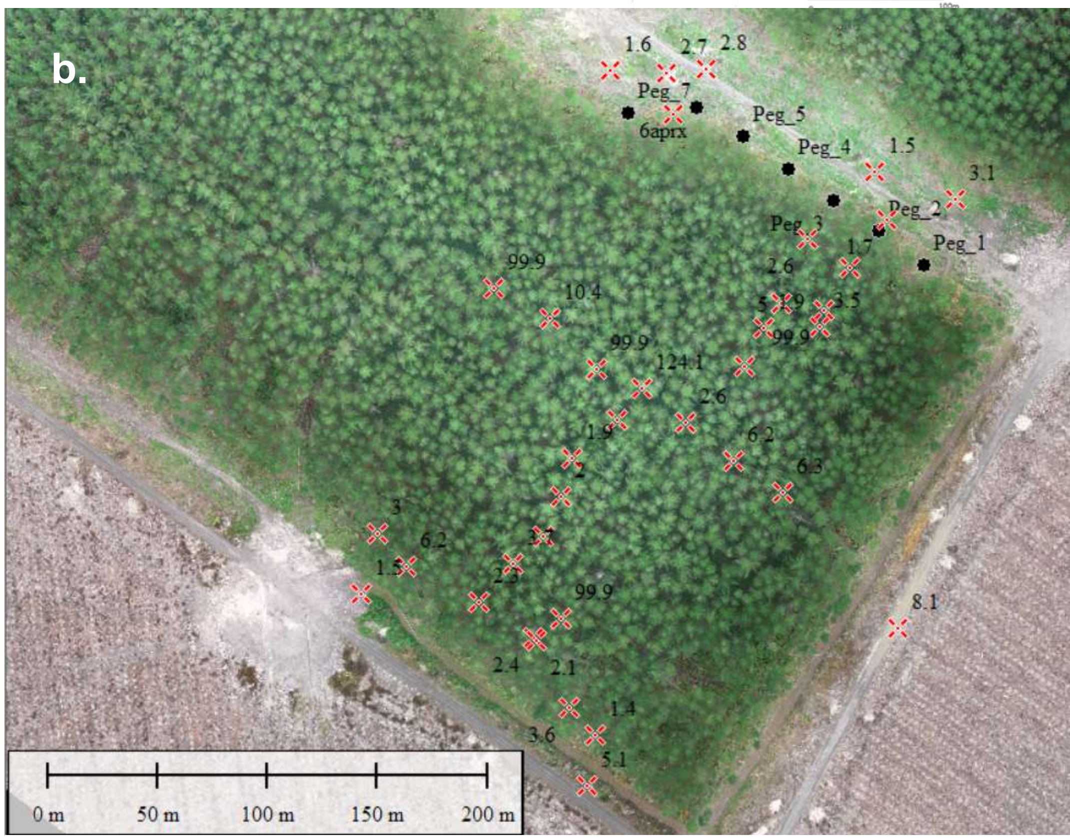
Dash, J. P., Watt, M. S. and Hartley, R. J. L. (2019) Testing UAV-borne Riegl Mini VUX-1 scanner for phenotyping a mature genetics trial. Technical Notes from the Growing Confidence in Forestry's Future Research Programme **TN-023.** https://scionforestryfuture.files.wordpress.com/2022/07/gcff-tn023.pdf



- 26 year old, pre-harvest breeding trial
- ULS from MiniVUX – 1,589 ppm²
- Heights from field and ULS didn't line up well (a)
- Lining up plots with ground truth very difficult (b)
- Started to think we needed to go sub-canopy to get a better trial map

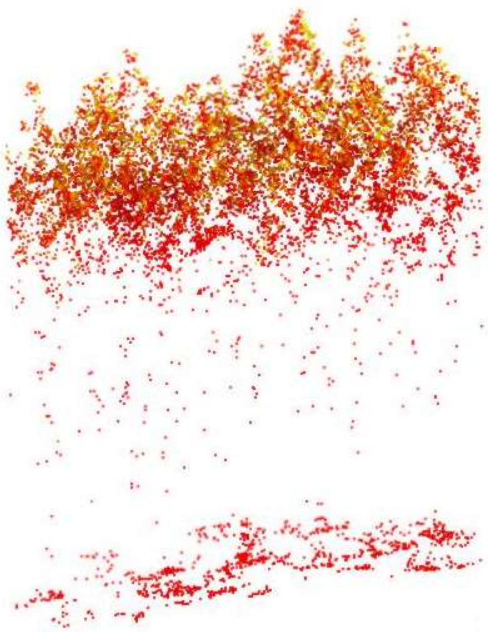




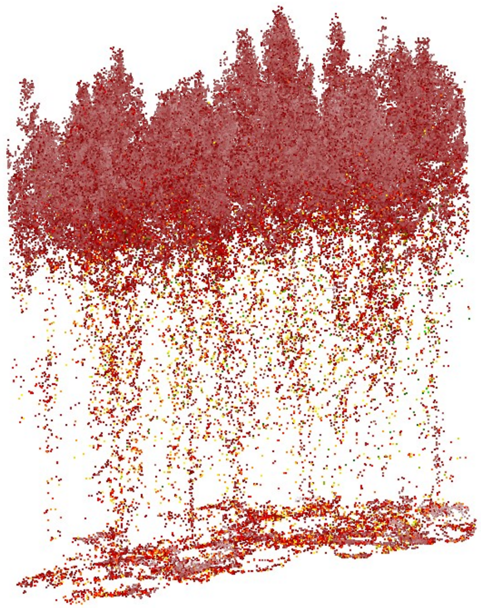


Why is sub-canopy better for single tree phenotyping?

- Scion has researched the use of airborne laser scanning (ALS) and ULS for forest characterisation and phenotyping for many years (Bombrun, et al., 2020; Hartley, et al., 2020; Pont, et al., 2020; Watt, et al., 2013, 2014).
- Scanning from above: very restricted for scanning stems due to the dense forest canopy.
- Sub-canopy scanning is the opposite effect: dense stem scans but less canopy definition.



ALS – 20 ppm²



ULS – 350 ppm²

MLS – 22,000 ppm²

Differences with scanners

GNSS/INS: relies on GPS signal to locate the scanner in the real world, and subsequently build a point cloud through post-processing

SLAM (Simultaneous Localisation and Mapping) algorithms build a virtual environment from the lidar points, which then best predicts the scanner's current location, enabling navigation whilst mapping the environment

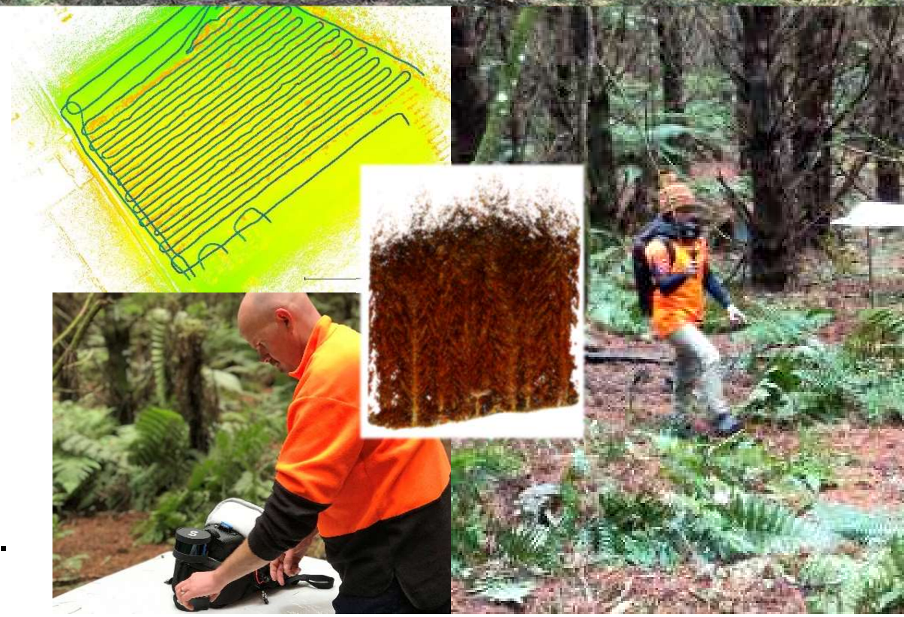
System	Weight (kg)	Autonomous flight options	Beam footprint at 100m (cm)	No. Returns	Max measurement range (m)
Riegl MiniVUX-1 UAV	2.9	Above only	1.6 x 0.5	5	150 (120m)
Emesent Hovermap	1.8	Above / Below	28.7 x 16	2	100 (50-70m)

Sub-canopy: comparison of methods

- Backpack: Point density ~22,000 ppm²
- Semi-autonomous (AL1): manually flying with industrial-grade object avoidance
- Fully Autonomous (AL2): waypoint-based flight

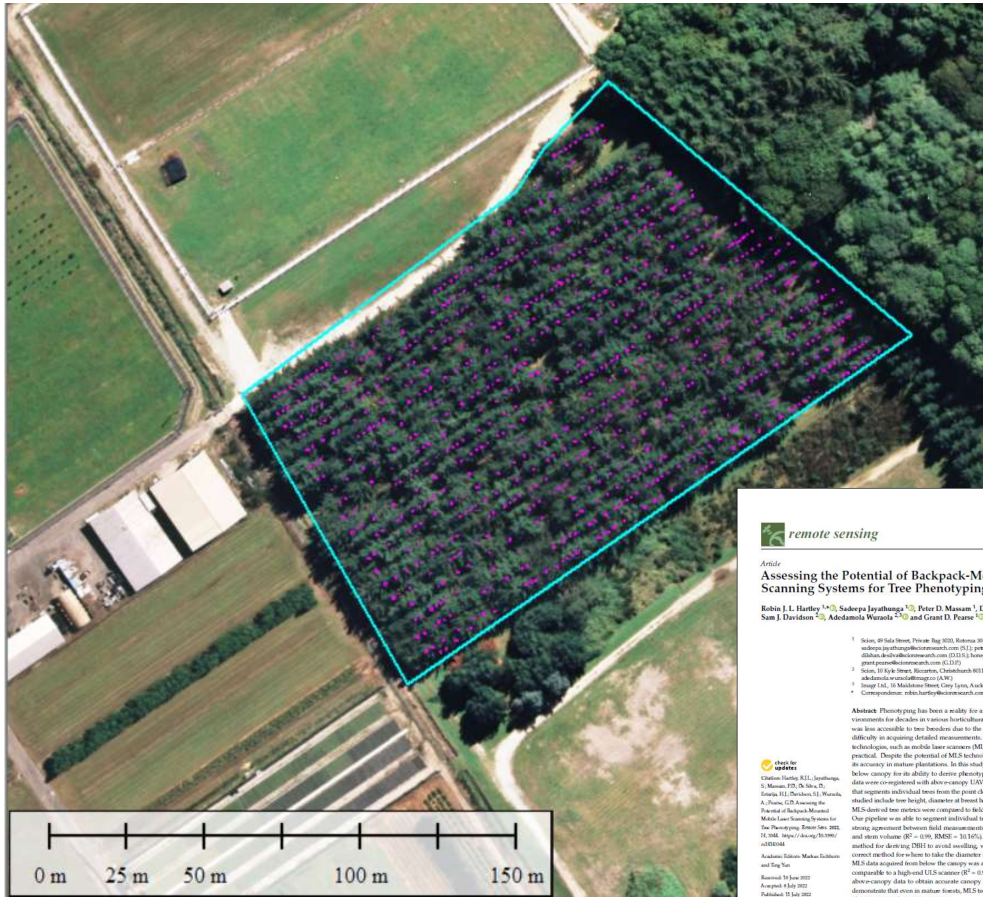
System	Time to capture (hrs:mins)	Number of scan files created	Time to process (hrs:mins)	Time to merge (hrs:mins)	Total time (hrs:mins)
Backpack	0:45	1	4:00	NA	4:45
Semi-autonomous	2:30	19	2:15	4:00	9:00
Fully autonomous	12:30	40	11:15	4:30	28:15
* Trial area of 4 rows: results multiplied x5 to estimate total area coverage lines.					

- At this stage backpack is by far the most efficient
- UAV limited by battery – more efficient crafts now available.



Study 1: Backpack scanning for Phenotyping

- Explored Hovermap in a mature genetics archive at Scion
  - 884 trees
  - Age 20-21
  - DBH: 2-67cm
  - Height 2-34 m
- Inventory (full cruise: DBH, height etc)
- Climbed and measured subset of 12 trees
  - Branching
  - Stem curve
- Published results in top tier journal



remote sensing
MDPI

Article

Assessing the Potential of Backpack-Mounted Mobile Laser Scanning Systems for Tree Phenotyping

Robin J. L. Hartley [1,*], Sadeepa Jayathunga [1], Peter D. Massam [1], Dilshan De Silva [1], Honey Jane Estarija [1], Sam J. Davidson [2], Adedamola Wuraola [2,3] and Grant D. Pearse [1]

1 Scion, 49 Sala Street, Private Bag 3020, Rotorua 3046, New Zealand; sadeepa.jayathunga@scionresearch.com (S.J.); peter.massam@scionresearch.com (P.D.M.); dilshan.desilva@scionresearch.com (D.D.S.); honeyestarija@scionresearch.com (H.J.E.); grant.pearse@scionresearch.com (G.D.P.)
2 Scion, 10 Kyle Street, Riccarton, Christchurch 8011, New Zealand; sam.davidson@scionresearch.com (S.J.D.); adedamola.wuraola@imagr.co (A.W.)
3 Imagr Ltd., 16 Maidstone Street, Grey Lynn, Auckland 1021, New Zealand
* Correspondence: robin.hartley@scionresearch.com

Abstract: Phenotyping has been a reality for aiding the selection of optimal crops for specific environments for decades in various horticultural industries. However, until recently, phenotyping was less accessible to tree breeders due to the size of the crop, the length of the rotation and the difficulty in acquiring detailed measurements. With the advent of affordable and non-destructive technologies, such as mobile laser scanners (MLS), phenotyping of mature forests is now becoming practical. Despite the potential of MLS technology, few studies included detailed assessments of its accuracy in mature plantations. In this study, we assessed a novel, high-density MLS operated below canopy for its ability to derive phenotypic measurements from mature *Pinus radiata*. MLS data were co-registered with above-canopy UAV laser scanner (ULS) data and imported to a pipeline that segments individual trees from the point cloud before extracting tree-level metrics. The metrics studied include tree height, diameter at breast height (DBH), stem volume and whorl characteristics. MLS-derived tree metrics were compared to field measurements and metrics derived from ULS alone. Our pipeline was able to segment individual trees with a success rate of 90.3%. We also observed strong agreement between field measurements and MLS-derived DBH (R^2 = 0.99, RMSE = 5.4%) and stem volume (R^2 = 0.99, RMSE = 10.16%). Additionally, we proposed a new variable height method for deriving DBH to avoid swelling, with an overall accuracy of 52% for identifying the correct method for where to take the diameter measurement. A key finding of this study was that MLS data acquired from below the canopy was able to derive canopy heights with a level of accuracy comparable to a high-end ULS scanner (R^2 = 0.94, RMSE = 3.02%), negating the need for capturing above-canopy data to obtain accurate canopy height models. Overall, the findings of this study demonstrate that even in mature forests, MLS technology holds strong potential for advancing forest phenotyping and tree measurement.

Keywords: lidar; MLS; SLAM; UAV; ULS; tree form; mensuration

check for updates

Citation: Hartley, R.J.L.; Jayathunga, S.; Massam, P.D.; De Silva, D.; Estarija, H.J.; Davidson, S.J.; Wuraola, A.; Pearse, G.D. Assessing the Potential of Backpack-Mounted Mobile Laser Scanning Systems for Tree Phenotyping. *Remote Sens.* 2022, 14, 3344. https://doi.org/10.3390/rs14143344

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1. Introduction

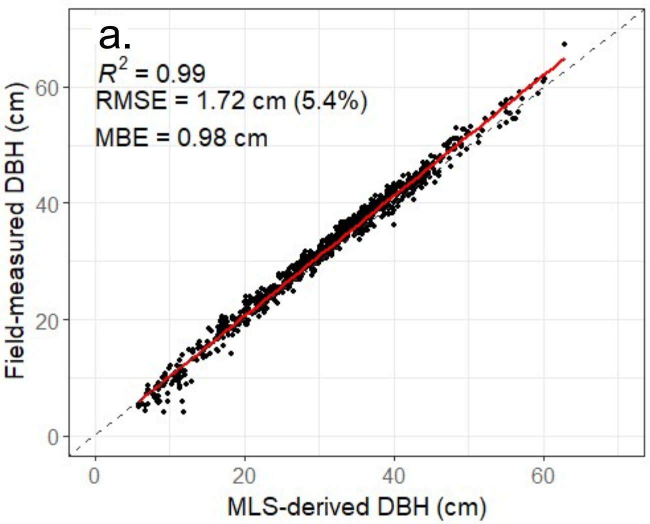
Digital phenotyping is an emerging science that uses non-invasive techniques, such as laser scanning, to assess the interaction between genetics, environmental factors and silviculture (GxExS) to guide the selection of the most productive trees for a given environment [1]. In forestry, phenotyping is emerging as a means of selecting the right tree, for the right place, for the right purpose, and to increase the efficiency of tree breeding programmes [2]. Current phenotyping methodologies require the combination of GxExS data with the physical description of tree form [3]. Traditional methods for the physical

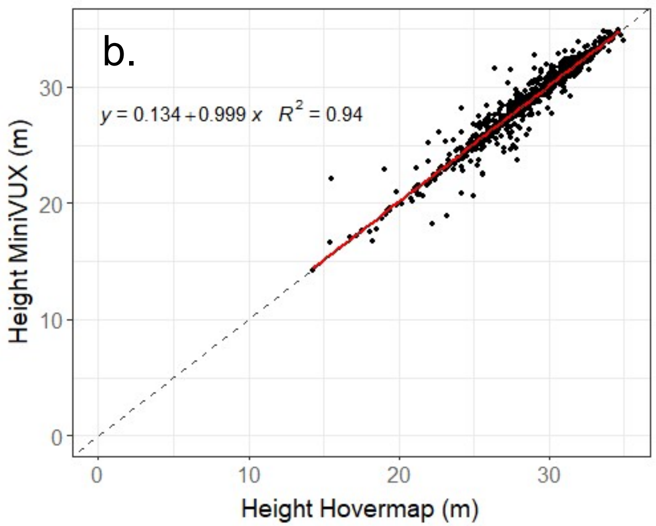
Remote Sens. 2022, 14, 3344. https://doi.org/10.3390/rs14143344 https://www.mdpi.com/journal/remotesensing

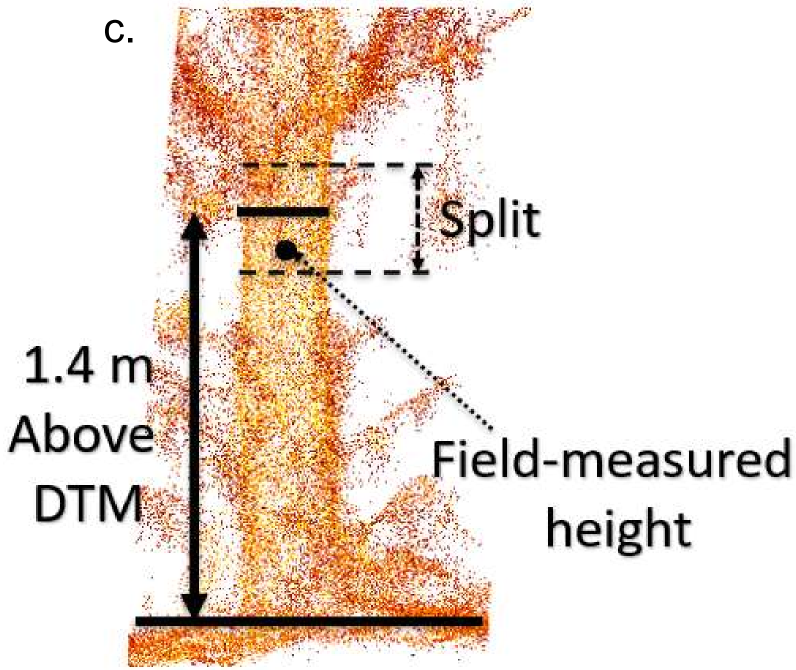
Hartley, R. J., Jayathunga, S., Massam, P. D., De Silva, D., Estarija, H. J., Davidson, S. J., Wuraola, A., & Pearse, G. D. (2022). Assessing the Potential of Backpack-Mounted Mobile Laser Scanning Systems for Tree Phenotyping. Remote Sensing, 14(14), 3344.

Findings from study 1

- DBH – can be derived with high precision and accuracy
  - – R^2 = 0.99, RMSE = 1.72 cm (5.4%)
- Introduced new method for deriving DBH
  - – Based on variable height method from PLOTSAFE
- Individual tree heights not highly accurate (suppressed trees)
- Hovermap capable of reaching canopy top:
  - – Compared to MiniVUX: R^2 = 0.94 / RMSE = 0.87 m (3%)



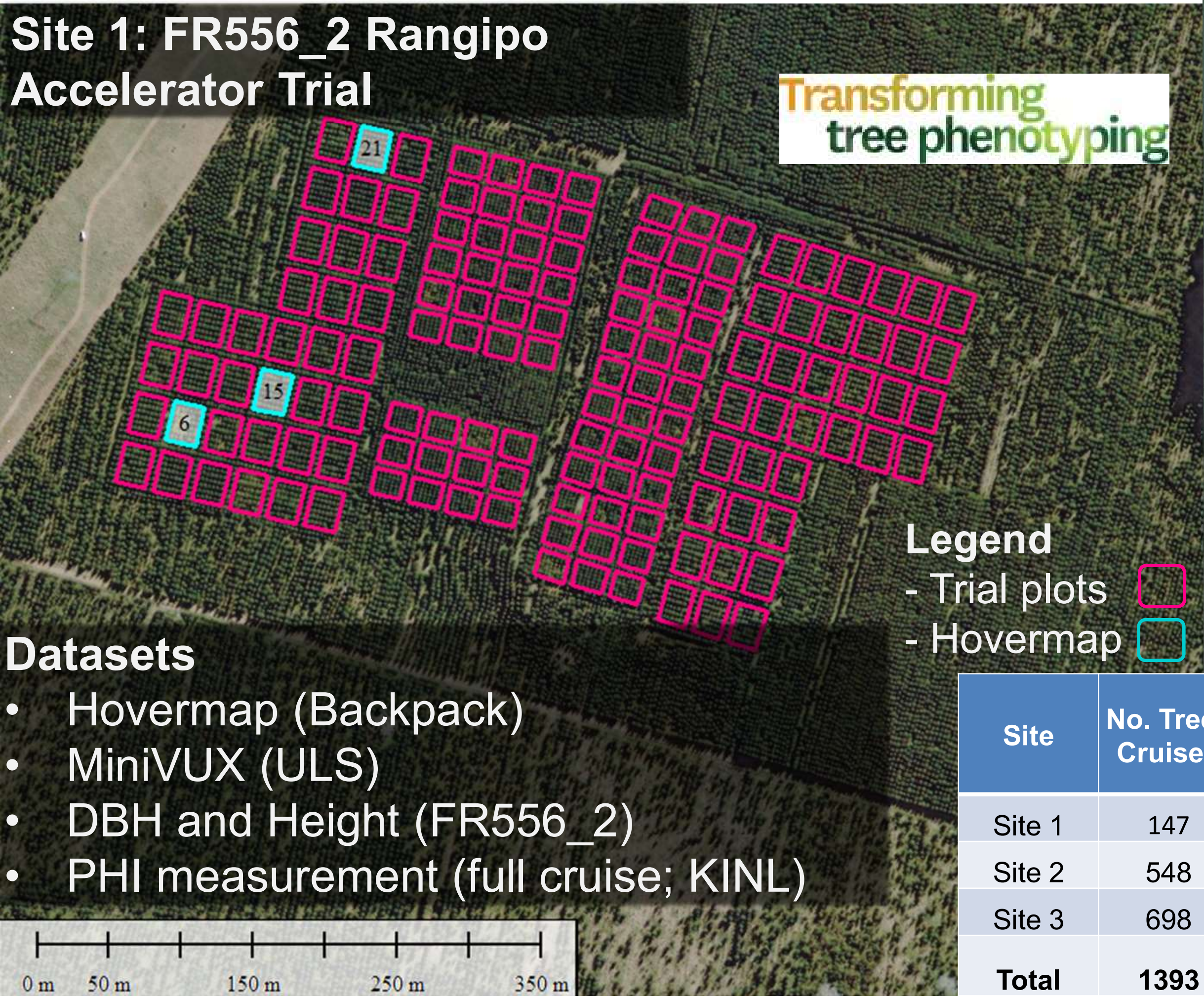


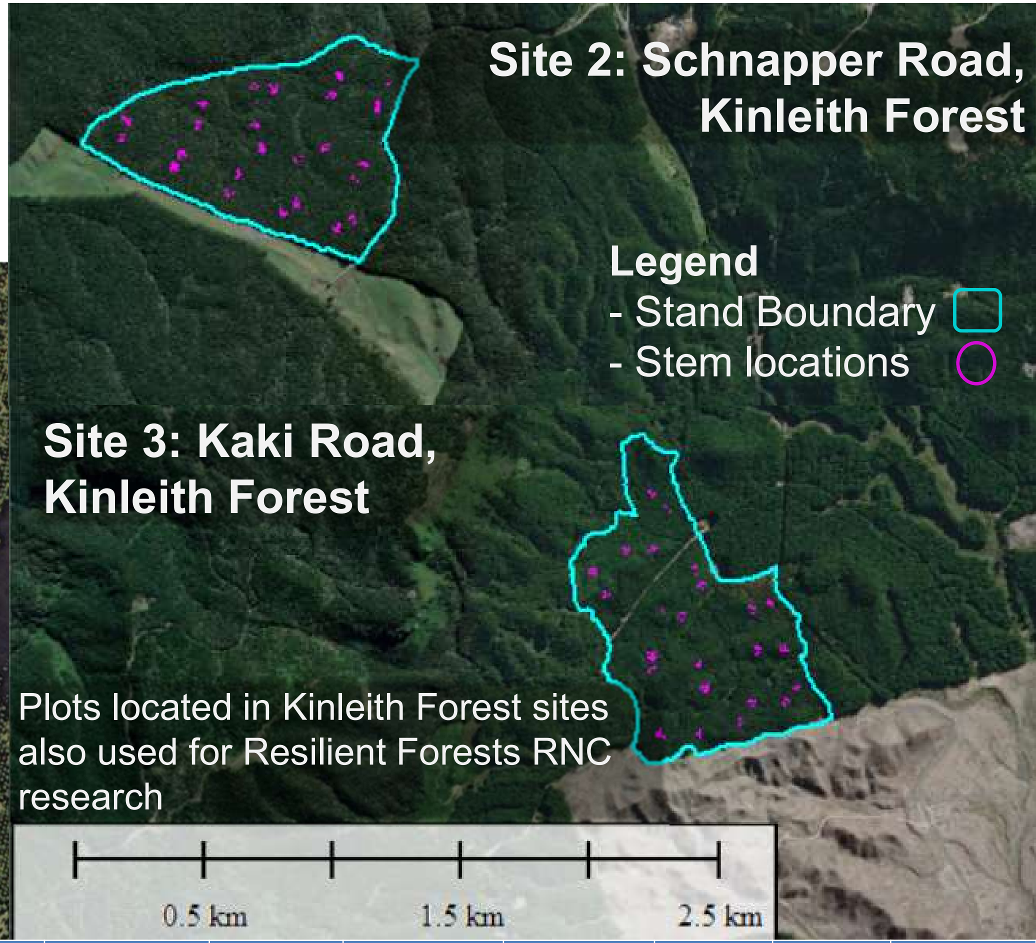


Conclusions from study 1

- Hovermap is very promising, however, needed testing in more complex environments
  - Younger/smaller trees
  - More “realistic” pre-harvest stand (slope, undergrowth, regular spacing)
- Major limitations
  - Stem volume algorithm only detects stems up to mean height of 13 m
    - Dense branching / occlusion of stem
  - Tree heights potentially accurate, but unable to detect suppressed/sub-dominant trees
    - Need a different method to find tree tops
  - Less accurate on smaller diameters (<15 cm)

Collected more data





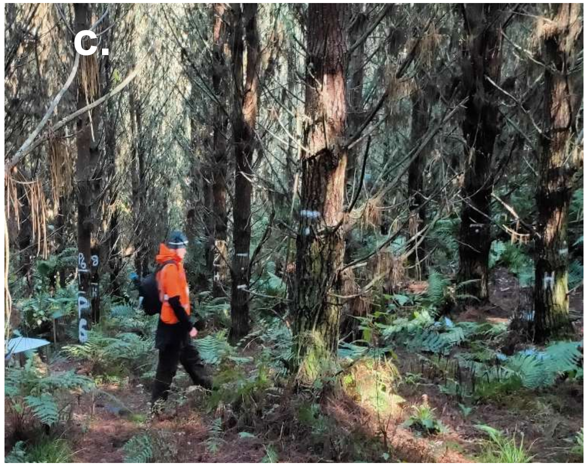
Datasets

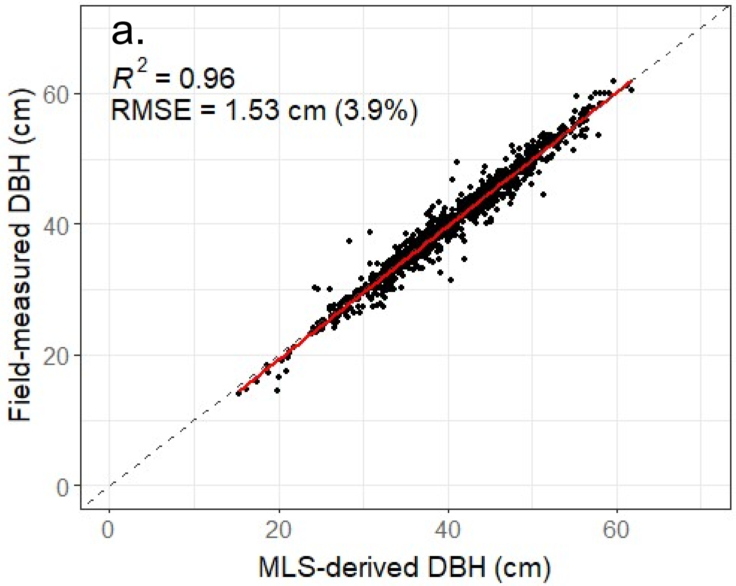
- Hovermap (Backpack)
- MiniVUX (ULS)
- DBH and Height (FR556_2)
- PHI measurement (full cruise; KINL)

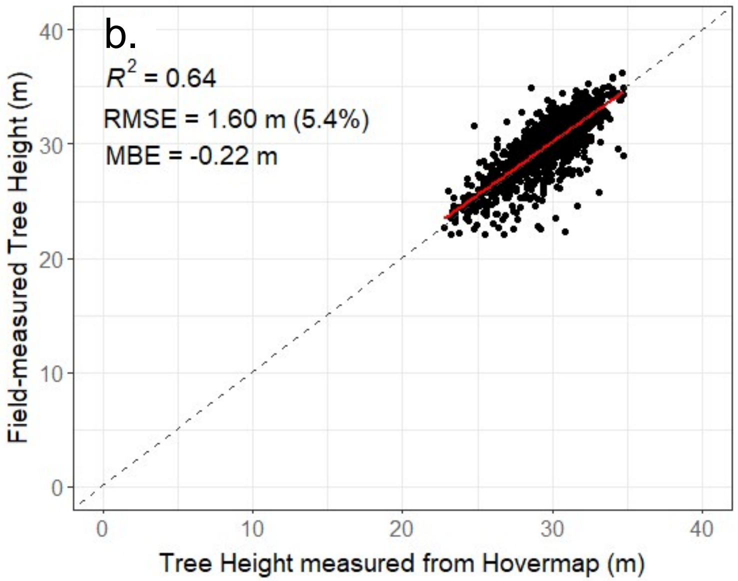
Site	No. Trees Cruised	DBH Range (cm)	Mean DBH (cm)	Tree Height Range (m)	Mean Tree Height (m)	Age (yrs)	Stand size (ha)	Plots (0.06 ha)
Site 1	147	5.1-21.9	16.3	4.3-13.4	10.1	6	20	3
Site 2	548	22.2-62.2	44.1	17-36.3	30.5	18	66	24
Site 3	698	13.3-55.7	35.5	5.5-35.3	28.3	21	66	24
Total	**1393**	**5.1-62.2**	**36.9**	**4.3-36.3**	**27.2**	**6-21**	**20-66**	**51**

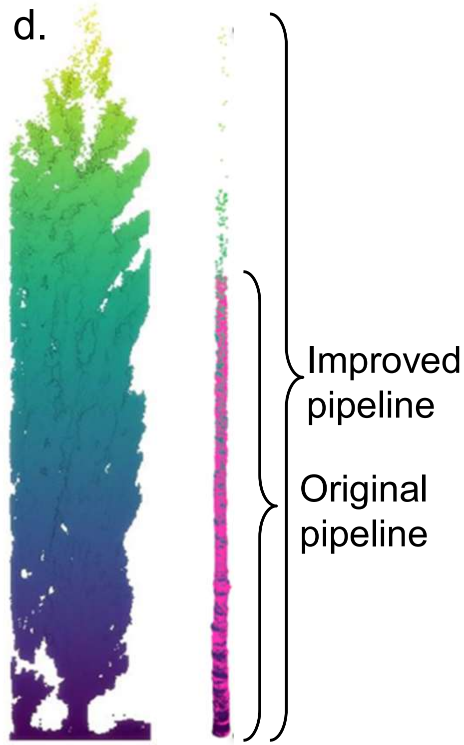
Study 2: MLS for mature plantations

- Site: Managed plantation forest with heavy understorey (c)
- Increased point coverage along the stem (d)
- Improved tree segmentation and stem delineation (d)
- Precise stem diameter predictions (RMSE = 1.5 cm, 3.9%; a)
  - Slight improvement on previous study
- Moderate-level accuracy for tree height (b)
  - Still not detecting suppressed tree peaks well



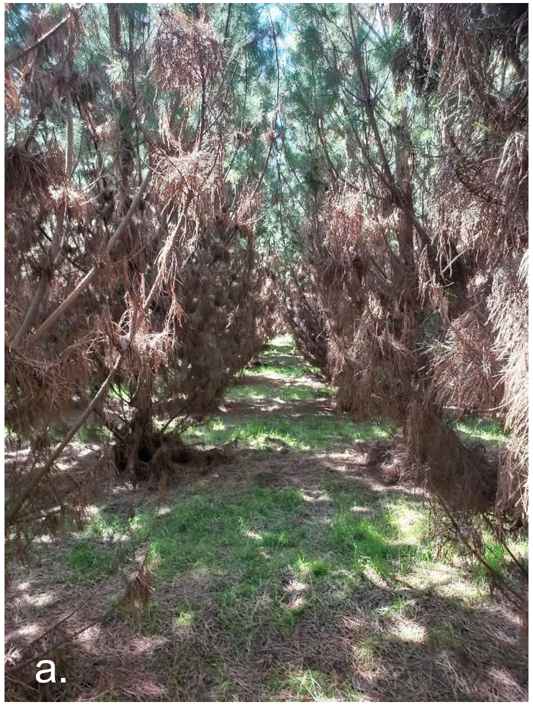


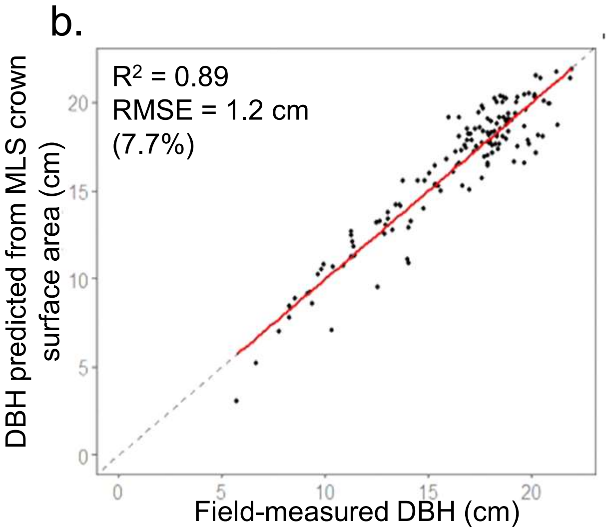


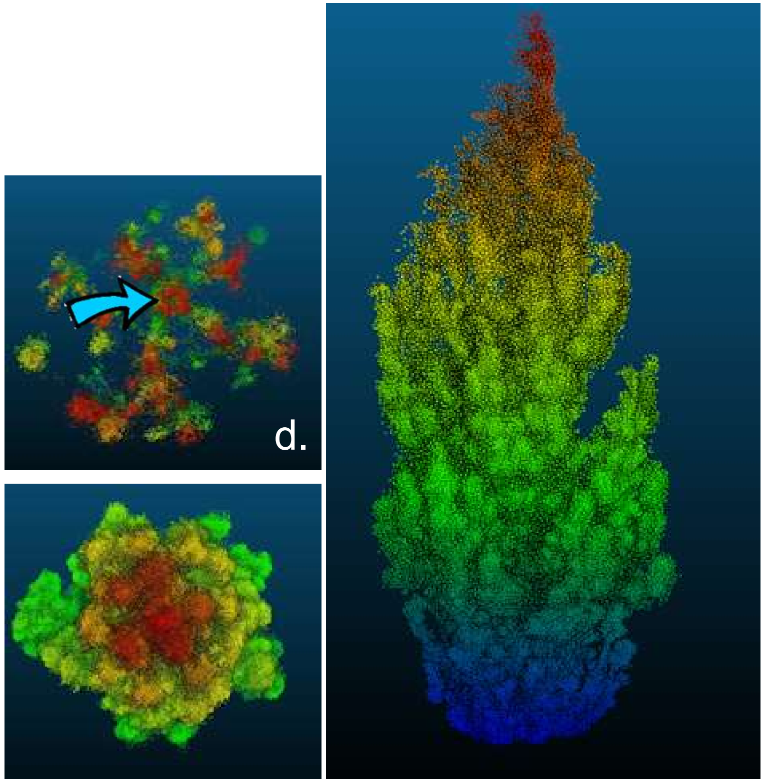


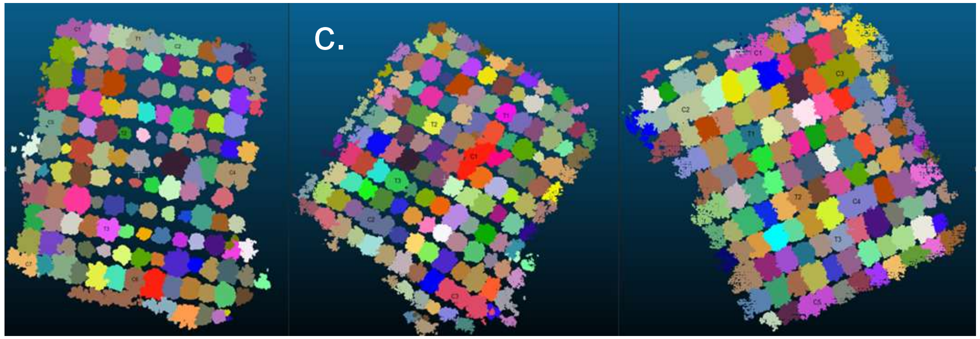
Study 3: MLS for trial selection

- Site: Young forestry trial (Rangipo accelerator trial: Age 6; a)
- Successful tree segmentation (> 97% accuracy; c)
- Inadequate laser points for stem level phenotyping (d)
- Accurate crown size estimations
- Precise modelling of diameter using crown dimensions (b)



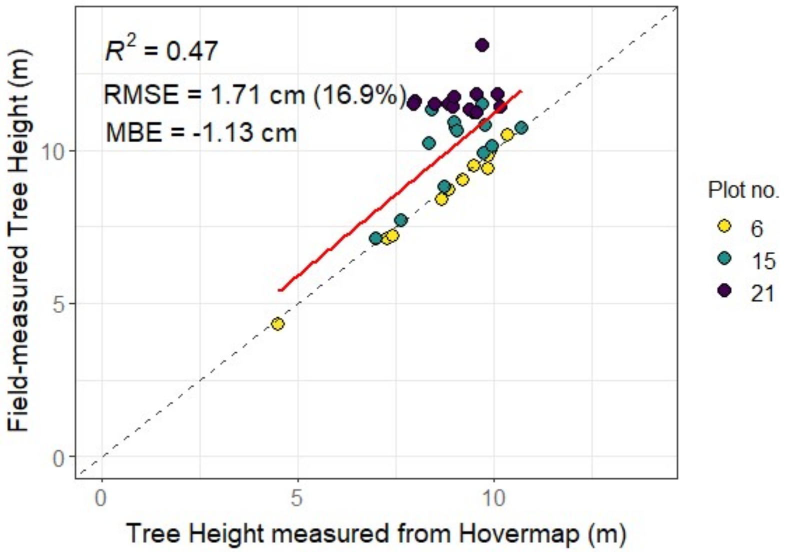


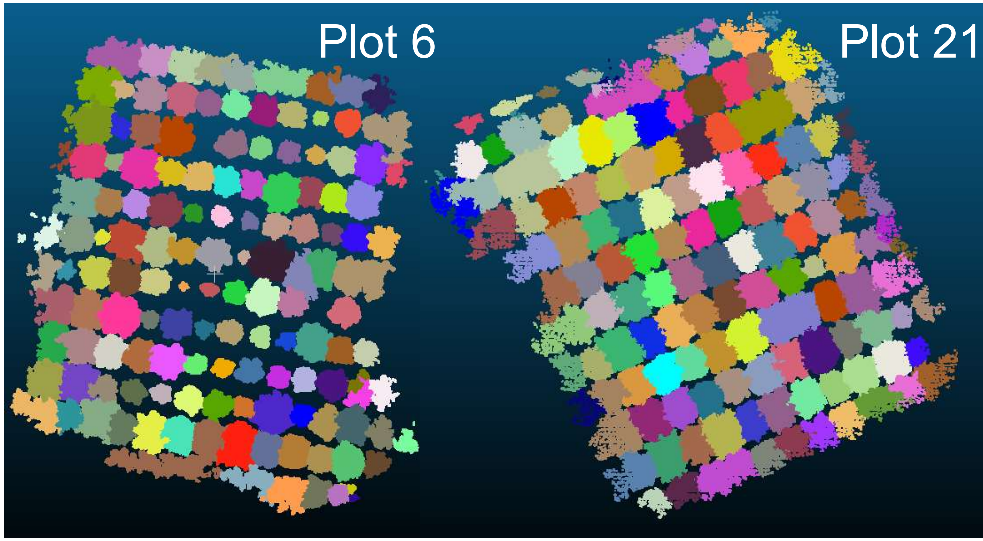




Study 3: MLS heights for trial selection

- Field measurements on 16 heights per plot
- Overall precision and accuracy are moderate:
  - R^2 = 0.47 / RMSE = 1.7 m (16.9%)
- Dependent on how open canopy is:
  - Open (Plot 6): R^2 = 0.99 / RMSE = 0.22 m (2.5%)
  - Closed (Plot 21): R^2 = 0.04 / RMSE = 2.6 m (22.1%)
- For height, previous study with the MiniVUX found
  - R^2 = 0.99, RMSE = 0.15m (5.9%) for height
- Indicates that ULS is probably better for measuring heights on small trees where canopy is closing



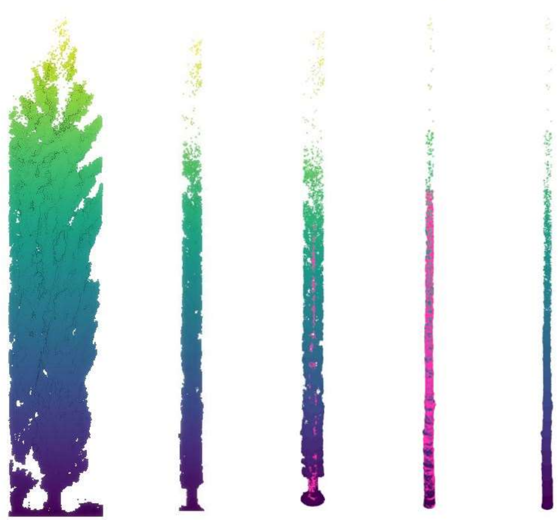


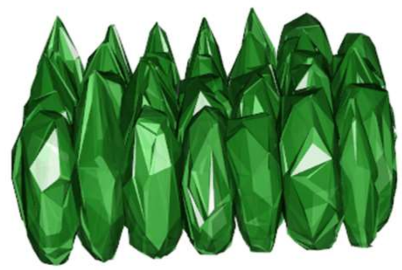
Recommendations from the study 2 & 3

- Test in more complex environments
- Improved algorithms able to characterise more of the stem
- Trial a different method for deriving tree height detection
  - Improved on previous method but more work needed

- Assess the Hovermap in more “realistic” pre-harvest stand
  - Accurate and precise DBH (R^2 = 0.96 ; 3.9% RMSE)
  - Need to assess impact of site on segmentation and height

- Assess performance in young stand
  - New method to predict DBH with high accuracy from crown (R^2 = 0.89; 7.7% RMSE)

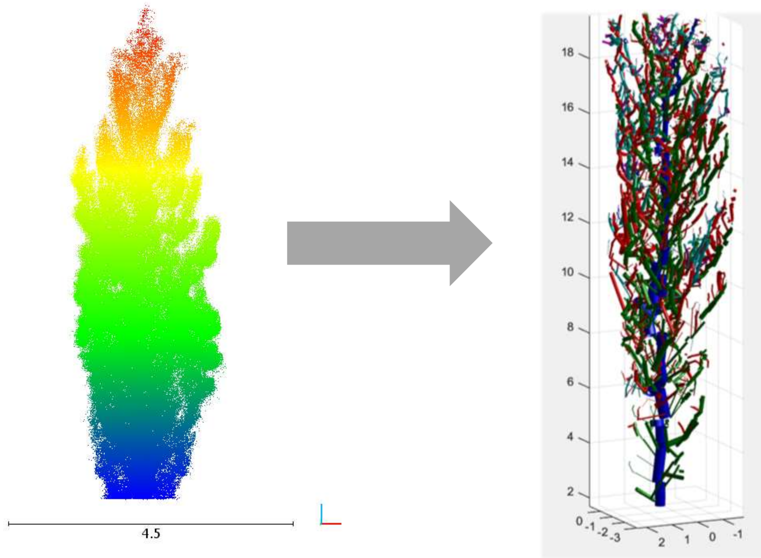




Can we use MLS to measuring branching?

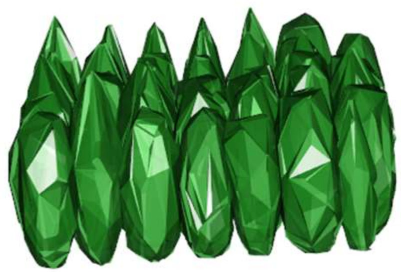
- Currently studying MForSc
  - *Assessing the efficacy of MLS as a tool for branch-level phenotyping in young breeding trials of Pinus radiata.*
- Can we resolve branch-level tree form data from Hovermap?
- 2 trial sites: Age 6 and age 9
- Climbing and crown mapping a sub-sample of the trees
  - Orientation, angle, diameter and length of each branch
- Assess the following branch phenotypes:

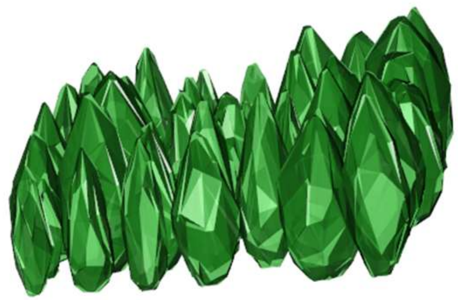
Branch Characteristic	Meaning	Unit of measurement
NB	Number of branches	*n*
NW	Number of whorls	*n*
BPW	Number of branches per whorl	*n*
NR	Number of ramicorn branches	*n*
NBM	Number of branches per tree height meter	*n*
MBD	Maximum branch diameter	cm
IL	Internode length	cm
BA	Branch insertion angle	degrees above horizontal



Future Research

- DBH
  - Manuscript: Accuracy of crown-derived DBH for trees ranging from <1m to 15m tall
    - Return to past datasets for MiniVUX and possibly SfM too
- Phenotyping
  - Return to mature genetics trial data
  - Apply new pipeline and attempt to phenotype trees
    - DBH, height, branch cluster frequency vs. genetics
- Branching
  - Continue Masters research to explore branch characterisation for young tree trials
  - Apply algorithms from MForSc branching research to genetics trial
  - Manuscript: Laser scanning for branch phenotyping: a review.
- Publish our pipeline for industry use





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  - Scion’s Tree Biometrics and Autonomous Systems teams (and Liam Wright, formerly of Scion) for the additional trial measurements and UAV/MLS data captures

Robin Hartley
Project Lead, Autonomous Systems Scientist
robin.hartley@scionresearch.com

www.scionresearch.com
www.fgr.nz

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