Vegetative Precision Propagation: Imaging Technologies Year 2 Final Report



David Siqueira, Andrea Grant, Matt Dunn, Peter Massam, Guillermo Salvatierra

Milestone Number: PSP MS 1.6

Report Number: PSP-T052

Date: June 2026

INFORMATION SHEET

Report Title	Vegetative precision propagation: Imaging technologies Year 2 Final report
Authors	David Siqueira, Andrea Grant, Matt Dunn, Peter Massam, Guillermo Salvatierra
Client	Forest Growers Research
Client Contract No:	FGR-470 (BSI CN01414599)
Approved by	Jonathan Kilgour
Date	23 July 2026
Confidentiality Requirement	
Intellectual Property	© FOREST GROWERS RESEARCH LIMITED All rights reserved. Unless permitted by contract or law, no part of this work may be reproduced, stored or copied in any form or by any means without the express permission of the FOREST GROWERS RESEARCH LIMITED.

Disclaimer

Neither Forest Growers Research, nor any of its employees, officers, contractors, agents or other persons acting on its behalf or under its control accepts any responsibility or liability in respect of any information or opinions provided in this Report.

Bioeconomy Science Institute™
Maiangi Taiao

Table of Contents

EXECUTIVE SUMMARY 4
The opportunity 4
Key results 4
Stool bed optimisation 4
Advanced imaging technologies for pine nurseries 4
Implications for the industry 5
Future work 5
INTRODUCTION 6
Background 6
Vegetative propagation: stool bed optimisation 6
Imaging technologies for pine monitoring 6
Objectives 7
METHODS AND MATERIALS 8
Nursery survey (Stool bed optimisation) 8
Pine-eye model development 8
Multi-tip detection feasibility study 8
RESULTS AND DISCUSSION 10
Nursery survey (Stool bed optimisation) 10
Perspectives around pine propagation by cuttings 10
Containerised pine production 14
Use of greenhouses and automation technologies 16
Crop monitoring and future challenges 16
Pine-eye model 19
Plant height limit *versus* tray boundaries identification 19
Saleable and unsaleable plant counts 21
Germination counts: phone app *versus* mini drone 22
Multi-tip detection feasibility study 23
CONCLUSIONS 25
FUTURE WORK AND RECOMMENDATIONS 26
ACKNOWLEDGEMENTS 26
REFERENCES 26
APPENDIX 1. Nursery survey questions 28

EXECUTIVE SUMMARY

The opportunity

Pinus radiata seedling and cutting production underpins New Zealand's forestry sector, accounting for approximately 90% of planted forest area across the country. Therefore, ensuring efficient and reliable early-stage propagation is critical for long-term forest productivity. This project focuses on improving propagation systems by targeting three key areas: optimisation of stool beds for vegetative propagation (cuttings), development and improvement of the Pine-eye imaging model and a feasibility study to investigate the technical viability of using imaging technologies to estimate cutting productivity from pine mother plants in greenhouse conditions. The Pine-eye model is a custom model built through this project that has collected images of *Pinus radiata* from germination to full growth in the nursery for AI-based monitoring in containerised systems.

Vegetative propagation enables the large-scale cloning of high-value genetic material, offering an opportunity for gains in productivity and consistency in the forest sector. However, current nursery practices face challenges, including limited environmental control in open-ground systems, which leads to unreliable cutting productivity and rooting success. These constraints shed light on future opportunities to improve efficiency and consistency in daily operations.

This workstream also explores the integration of imaging and machine learning technologies into nursery operations. Traditional germination monitoring relies on manual observation, which is labour-intensive and often subjective. Computer vision offers opportunities to generate accurate, real-time data on germination, growth, and plant stress, although its uptake in industry forestry nurseries remains limited at this stage, particularly for radiata pine.

To address these gaps, the project aims to:

1. Establish a baseline of industry practices for cutting production and identify optimisation opportunities.
2. Advance the Pine-eye model for improved germination monitoring in containerised systems.
3. Evaluate the feasibility of multi-tip detection using imaging technologies to estimate cutting productivity and support stool bed management.

Key results

Stool bed optimisation

A nursery survey sent to the main radiata pine nursery growers in New Zealand showed that the industry primarily uses seeds and cuttings for propagation, with only limited production relying on tissue culture. Respondents acknowledged that cuttings offer advantages such as higher market value, genetic uniformity, and improved growth after planting in the field. However, their wider adoption is constrained by high costs, slow and inconsistent rooting phase, large land requirements for mother plants, and the lack of standardised clone-specific protocols. As a result, cutting productivity and rooting success rates vary widely across nurseries. While containerised systems, greenhouses, and automation technologies present opportunities, their uptake remains limited mainly due to cost and market preference for lower cost bareroot plants. Overall, nurseries showed interest in innovation and imaging technologies such as the Pine-eye model but would like to see clear evidence of reliability and cost-effectiveness before adoption.

Advanced imaging technologies for pine nurseries

The Pine-eye model is able to detect pine seedlings at very early germination stages, even when the seed coat is still present. However, early-stage detection increases the chances of false positives due to uneven germination across trays. A limitation of the model is its ability to identify tray boundaries, which becomes unreliable once seedlings reach approximately 5–6 cm in height, as needles cover tray edges. This reduces the accuracy of per-tray germination counts, although there is an opportunity to explore the potential to estimate total seedling numbers across a known number of multiple trays.

The model can be deployed using a smart phone app or the mini drone system, and both are able to distinguish between saleable and unsaleable plants, supporting early stress detection and management decisions. The

smartphone app image capture showed strong correlation coefficient with manual counts of saleable plants ($R^2 = 0.88$), while the drone system performed less reliably ($R^2 = 0.57$) due to missed trays and operational limitations, when comparing both image capture methods for when seedlings were approximately 3 cm tall.

Finally, the multi-tip detection feasibility study demonstrated limited accuracy when an existing approach was adapted and a new model for tip detection in pine mother plants was developed. There was significant underestimation of cuttings per mother plants, particularly for softer, less developed tips. This indicates that further refinement is required before this approach can reliably estimate cutting productivity of pine mother plants.

Implications for the industry

The Pine-eye model has reached a satisfactory accuracy and is now ready for plant monitoring testing in industry nurseries. However, these tests would be limited to containerised nurseries and using the smart phone app which will be more deployable. Regarding the use of the mini-drone, as most nurseries are growing bare-root plants, pilot tests with industry are also limited to those nurseries with the required set up (as this mini-drone is for indoor use only). For the multi-tip detection, further discussions with partner Track32 will be needed to understand how to improve the model to achieve more reliable results.

The nursery survey results identified several challenges around the pine propagation by cuttings, use of greenhouses and other technologies. The issues highlighted by respondent nurseries were similar across the industry, particularly the lack of protocols for mother plant management and rooting phase. Opportunities to support industry to address these challenges are provided in this report.

Future work

- Test the Pine-eye model (smartphone app) in industry nurseries and validate these results with outcomes obtained by the BSI team.
- Test a new QR code recognition approach for the mini-drone system that will enable germination counting across multiple trays at one time. This should minimise the issue of pine needles covering tray boundaries, which currently reduces the accuracy of per-tray germination counts.
- Discuss with our partner (Track32) to explore the next steps for the multi tip detection and identify approaches to increase the accuracy of the model.
- As part of the integration of the imaging technologies workstream with the sensor platform, initial tests will be run using the Pine-eye phone app to monitor germination count and saleable/unsaleable plants. This can then be associated with results from sensor platform and the microenvironments in the greenhouse to understand potential effects of environmental variation on plant performance.
- Opportunity to develop a techno-economic analysis around pine propagation by cuttings with different levels of technology adopted, indicating, in the longer term, the cost/benefits of each of them.

INTRODUCTION

Background

Pinus radiata seedling and cuttings production represents a foundational step in the forest value chain in New Zealand, accounting for around 90% of the country's total planted forest area annually. Successful propagation through seeds and cuttings and reliable early growth performance are critical to long-term survival and productivity after planting. Therefore, this project aimed to address three critical aspects of the propagation stage: (1) identifying opportunities for stool bed optimisation to streamline the propagation through cuttings, (2) refinement of the Pine-eye model for germination monitoring in containerised systems, and (3) evaluate the feasibility of multi-tip detection using imaging technologies to estimate cutting productivity of mother plants in greenhouse conditions.

Vegetative propagation: stool bed optimisation

Vegetative propagation through cuttings is a key method for clonal plant production for *Pinus radiata* in New Zealand. The technique consists of successive collection of cuttings (young shoots) from mother plants produced from either seminal or asexually propagated plants and established in a nursery setting, usually sand beds or containers. This technique has been successfully used at forestry scale for Eucalyptus sp. over decades [1] and has been proven effective for several other trees species, e.g., "red cedar" *Toona ciliata* [2], "African mahogany" *Khaya ivorensis* [3] and "radiata pine*" Pinus radiata* [4].

Vegetative propagation offers significant advantages as it allows full control over the genetics of the mother plants to be propagated, enabling the cloning of high-value plants at scale. However, several challenges are involved in developing robust and reliable propagation protocols from mother plant establishment to adventitious rooting success. More specifically, nurseries in New Zealand often have their mother plants established in open ground conditions with little control over soil and climatic conditions. Additionally, nurseries predominantly grow cuttings in bare root systems, which challenges the rooting process due to the lack of environmental control required for cell reprogramming and new root formation before the cuttings dry out [5].

These challenges faced by industry around the pine vegetative propagation in New Zealand led to a strong interest in optimising this important method of plant production. However, we understand that more information from nurseries about their current processes and protocols, as well as their overall perspectives on cutting production, is crucial to identify gaps where research projects could support industry and ultimately streamline clonal radiata pine propagation.

Imaging technologies for pine monitoring

Traditionally, monitoring seedling germination and development has relied on manual observation and periodic measurements, which are labour-intensive, subjective, and limited in temporal resolution. Accurate and precise assessment of seedlings in their production environment is essential to improve propagation efficiency and uniformity. Computer vision techniques have evolved significantly in recent years, and recent developments include the integration of imaging technologies and artificial intelligence (AI) in crop phenotyping. Machine learning algorithms can predict germination counts, growth patterns, detect stress symptoms, and identify high-yield genotypes. For example, AI-driven image analysis has been applied to monitor canopy development, root architecture, disease progression and abiotic stress in various crops [6]. However, the benefits have been mostly seen in the horticulture sector [7], with little demonstrated evidence of their advantages for forestry nurseries.

By evaluating and developing technological capabilities, this research aims to provide a pathway for integrating advanced imaging technologies into containerised radiata pine seedling production workflows, ultimately supporting more efficient, data-driven, and resilient tree seedling production. For example, early detection of germination failures and other common issues nurseries frequently face in the germination stages can support timely decision making to re-sow or handle the plants appropriately. This can ensure a uniform crop that will be evenly managed in the nursery, e.g., irrigation, fertilisation and hardening off. This consistency helps ensure that seedlings are ready for dispatch, resulting in a quicker turnaround, a cost-effective nursery throughput, and better performance after planting. Similarly, this project aims to explore the feasibility of using advanced imaging technologies to estimate the productivity of cuttings from radiata pine mother plants. This would support the stool bed optimisation and help manage and forecast cutting productivity more accurately.

Objectives

Considering the challenges and opportunities for improvement and automation in nurseries producing radiata pine seedlings and cutting New Zealand, this project aims to:

- Outline the baseline case for stool bed bare root and containerised systems using industry data - survey results on industry perceptions and key opportunities for optimisation.
  Output: Outline the baseline case for stool bed bare root and containerised systems using industry data
- Further development of the Pine-eye model within the germination zone for containerised seedlings with plant height limits confirmed and all training images secured.
  Output: Robust Pine-eye model which will reliably count seedlings from germination to 10-15 cm height (height limit to be established) in containerised greenhouse by June 2026.
  Output: RBG images of seedlings of different sizes in trays over 12-month collection period.
- Establishment of mother plants in sand beds for use in multi tip detection feasibility study.

METHODS AND MATERIALS

Nursery survey (Stool bed optimisation)

Discussions were held between our Bioeconomy Science Institute (BSI) and Forest Growers Research (FGR) teams to define the survey questions which aimed to understand the current knowledge and perspectives around the radiata pine propagation in the main forestry nurseries in New Zealand. The questions focused on the main challenges and advantages around propagation by cuttings, as well as industry perceptions of the current research projects developed within the wider Precision Propagation program. Please see Appendix 1 for all survey questions.

The survey was sent out to members of the New Zealand Forest Nursery Growers Association (NZFNGA), representing the main radiata pine nursery growers in New Zealand. In total, the survey was sent out via the NZFNGA to approximately 30 respondents. The survey remained open for responses for three weeks (from 20 March to 3 April 2026), during which nine completed responses were received. As some questions were specifically related to propagation by cuttings, use of greenhouses or containerised system for plant production, the number of responses to those questions varied depending on the facilities currently available within nurseries and propagation methods used. Once the survey was closed, results were compiled and graphs were plotted as appropriate.

Pine-eye model development

As part of the Pine-eye model development, a new batch of 40 TS48 propagation trays of radiata pine was sown in February 2026. Once the first germinants were visible, photos were taken both using the smart phone app and via mini drone flights at least once a week and at various times throughout the day to cover variations in lighting such as bright morning and midday sun, overcast and rainy weather or late afternoon light. Images were uploaded directly to the cloud-based system that analyses germination and delivers reports on plant numbers per tray.

After the germination reports were delivered, each photo was reviewed for any missing plants or false detections. The “feedback” function was used to continue model learning by selecting thumbs up and thumbs-down icons in the software interface, as described in previous reports (Pont et al., 2025). A comparison between the germination counting (saleable plants; differentiation based on colours associated with healthy or unhealthy plants) by human eyes and the results delivered by the Pine-eye model was also carried out when seedlings were around 3 cm tall.

To better understand the plant size limits at which the Pine-eye model loses accuracy due to the limited tray boundary detection and would no longer provide reliable per-tray plant counts, plant height was monitored over time alongside images captured and compared with results obtained from both the smartphone app and the mini drone reports.

Multi-tip detection feasibility study

Four- and eight-month-old radiata pine seedlings were transferred to the sandbeds to form the mother plants in a greenhouse at the Rotorua campus of the BSI. Seedlings of different ages were chosen to increase variability regarding the mother plant shape and productivity of cuttings for the multi-tip detection feasibility study. The sandbeds were filled with pumice and receive daily fertigation (combined irrigation and fertiliser). The seedlings were topped at 15 cm height to encourage lateral branching. In total, 40 seedlings of each age were established in the sandbeds (Figure 1 A & B).

The multi-tip feasibility study began in collaboration with Track32 in March 2026, with regular top-down view photos taken of individual mother plants. Additional photos were also taken containing groups of mother plants framed within the same photo (Figure 1 C).

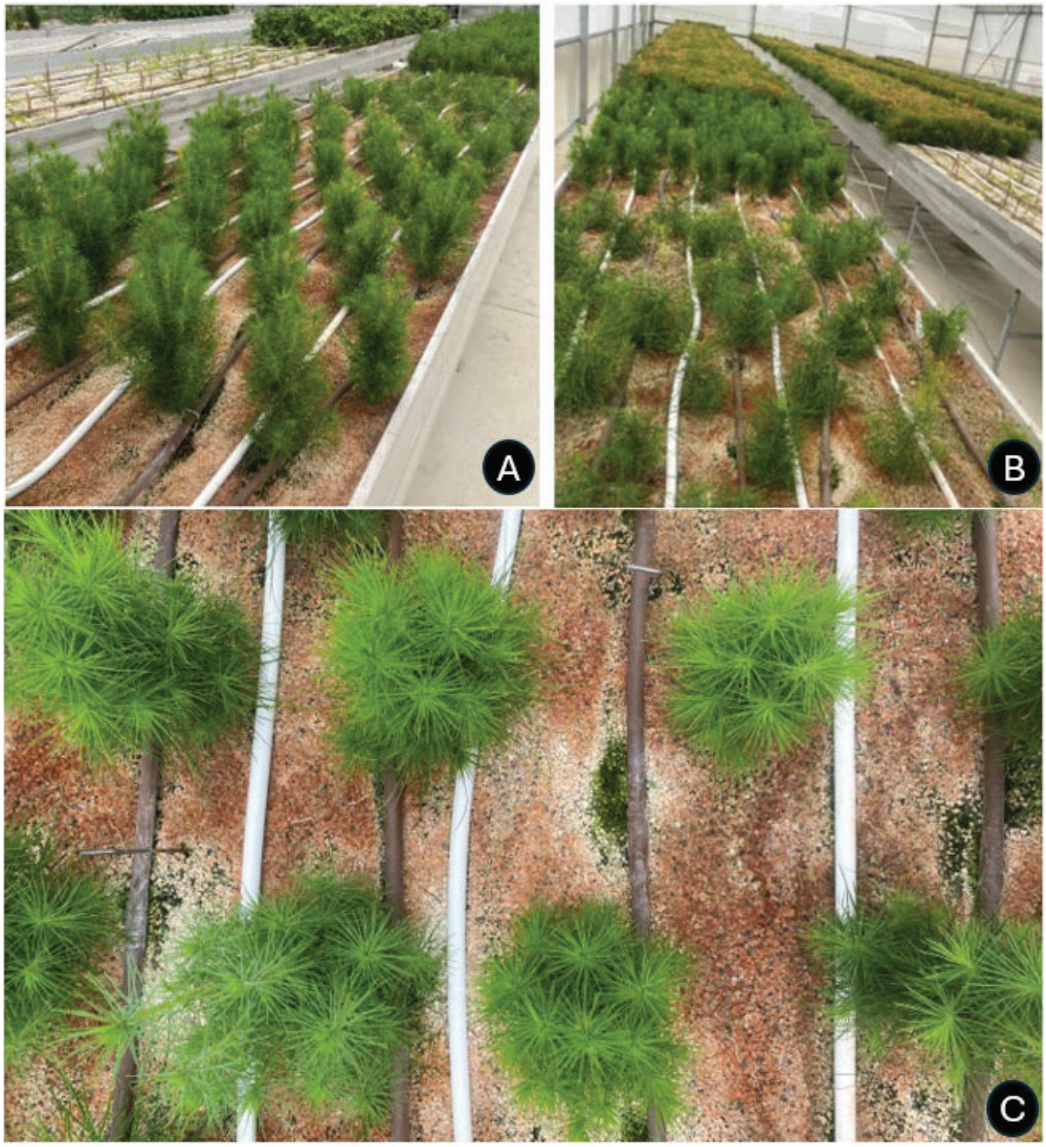


Figure 1. A: Eight-month-old plants branching out after being topped; B: four-month-old plants after being topped, and C: top-down view of eight-month-old plants being established as mother plants showing lateral branching and multiple cutting tips.

To investigate the possibility of accurately predicting the productivity of cuttings (multi tips) per pine mother plant, each mother plant was labelled, and its tips were counted when captured in a given photo. The multi tips were also manually marked in the photos so that the Track32 team could identify which tips belonged to each mother plant and their position within the photo (Figure 2).



Figure 2. Example of a pine mother plant with tips (cuttings) manually counted and marked in the image for the multi tip detection feasibility study.

To evaluate the technical feasibility of automated multi-tip detection, a computer vision pipeline was developed and executed across four steps:

1. Data Annotation and Partitioning: A dataset of 24 images was created. Centre-point coordinates were manually mapped to the midpoint of each pine tip. This dataset was then partitioned into 22 images for model training and four images for validation.
2. Image processing: To optimise computational efficiency and enhance the detection of smaller, clustered objects, the images were pre-processed and divided into 864x864 pixel grid patches.
3. Model training: The patched grid data was used to train a YOLO26s-pose architecture, a framework for point estimation rather than traditional object bounding boxes.
4. Independent evaluation: The finalised model was evaluated against independent, unseen test dataset. This final step demonstrated the model's current accuracy and provided key insights on how to optimise it for practical, industry usage. For this evaluation, the human eye multi tip counts were compared with the number of automated detections generated by the model.

For this final independent evaluation of the multi tip detection model trained, four pine mother plants were used to test the accuracy of the model.

RESULTS AND DISCUSSION

Nursery survey (Stool bed optimisation)

Perspectives around pine propagation by cuttings

All respondent nurseries currently use or have used both seed and cuttings as main pine propagation methods, and only one nursery propagates pine through tissue culture. When asked to rank the main challenges associated with the production by cutting, where 1 is 'most challenging' and 5 is 'least challenging', the responses varied widely. However, costs, the time-consuming processes, and low rooting success were top ranked by most nurseries (Figure 3).

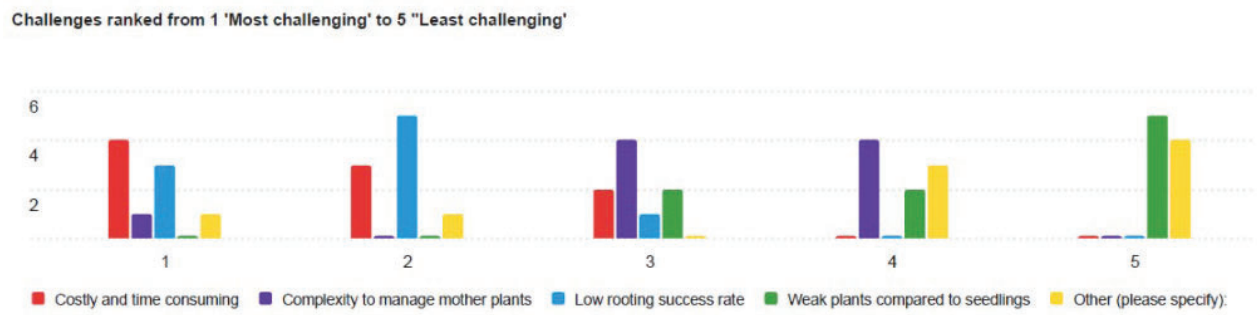


Figure 3. Ranking of challenges associated with radiata pine cutting production.

Other challenges specified by the nurseries through an open-ended question included: "*cuttings are more difficult to grade*", "*large area is required for cutting production and mother plants*" and "*2/3 of nursery area is reduced due to stool beds*". This highlights that land use to establish and maintain stool bed mother plants is also a crucial challenge for nurseries growing by cuttings.

Regarding the advantages of producing pine by cuttings, most nurseries acknowledged their higher market value followed by their genetic uniformity as key benefits of growing cuttings (Figure 4). Respondents also highlighted that "*survival rates are better for cuttings in frost prone or drought areas"* and that "*less topping is required*". This indicates that growing cuttings may potentially require less maintenance in the nursery while still resulting in a higher establishment performance after planting, particularly under harsher conditions.

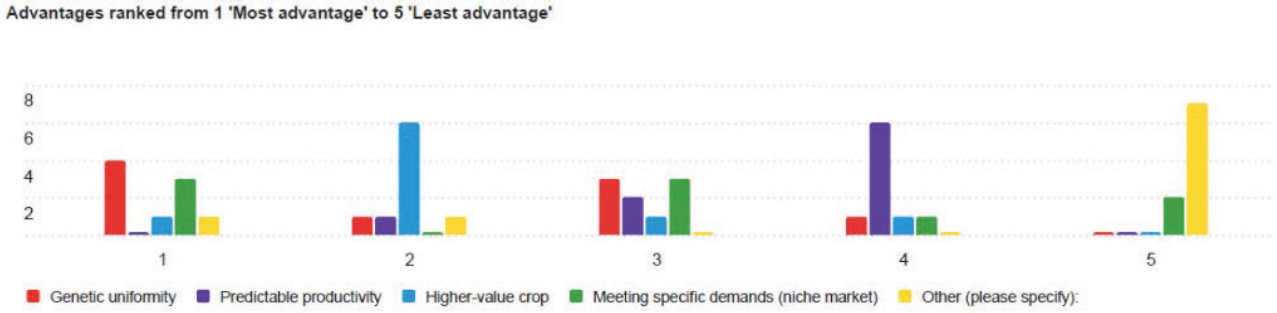


Figure 4. Ranking of advantages associated with radiata pine cutting production.

The challenges appear to outweigh the benefits leading to little interest in increasing cutting production in an outdoor bareroot environment in the coming years (Figure 5), with only one nursery possibly interested in doing so. This was despite nurseries acknowledging several important benefits of producing pine from cuttings.

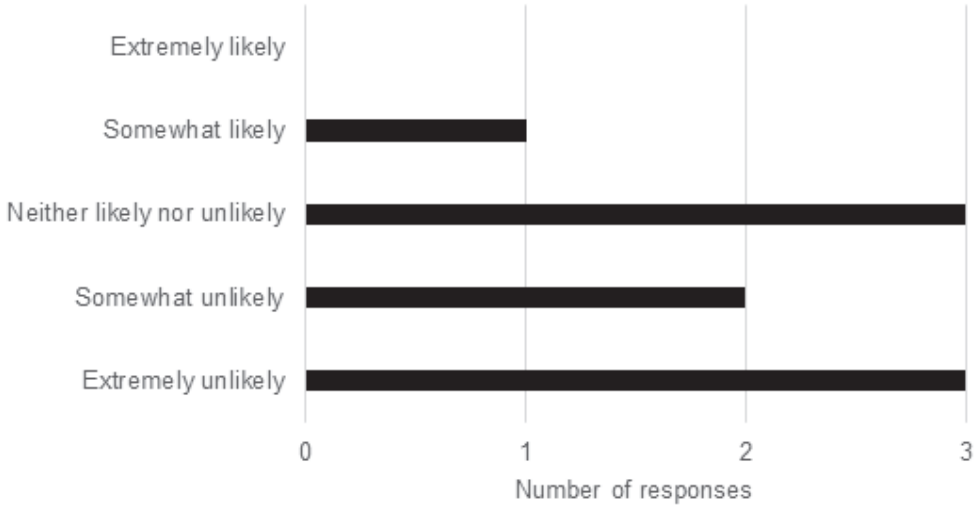


Figure 5. Likelihood of increasing pine cutting propagation in the coming years.

The lifetime of pine mother plants ranged from 2-3 and 3-4 years for most nurseries, with one respondent being unsure (Figure 6). One nursery stated that they "*no longer grow cuttings*" and another one "*uses seedlings tops*" as cuttings as opposed to keeping and maintaining mother plants. The reason for the latter is unclear, but this could possibly be related to land availability, time and costs associated with the cuttings. Using the tops reduce several steps in the usual stool bed establishment for cutting production. However, the genetic value of the cuttings produced using seedling tops is likely to be significantly lower.

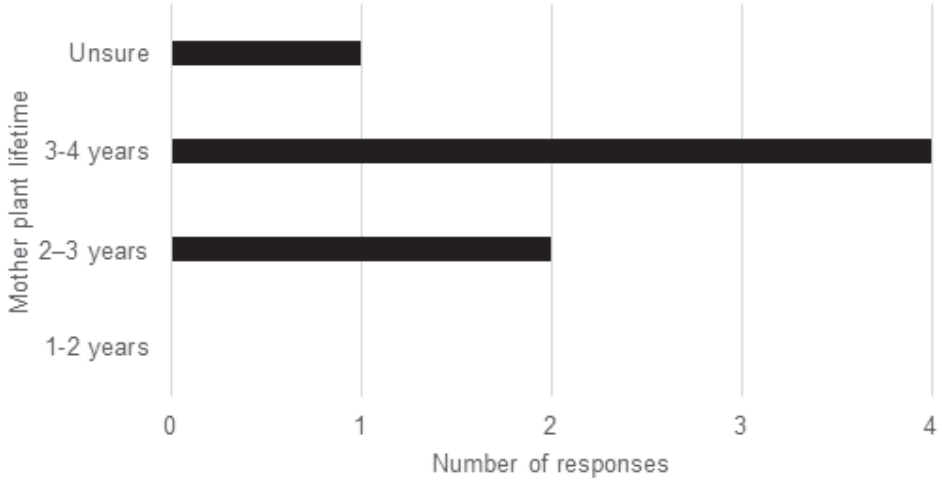


Figure 6. Lifetime of pine mother plants in years.

Regarding the productivity of cuttings harvested per mother plant annually, the results showed a wide variation across nurseries, ranging from 8 to 60 cuttings per mother plant per year (Table 1). Additionally, two nurseries also highlighted mother plant aging as a factor affecting productivity, with their productivity peaking between Year 2 and Year 3 at around 12-15 cuttings per mother plant annually. This wide variation in productivity could possibly be associated with the lack of protocols for mother plant and cutting management, as also noted by nurseries (Figure 8).

Table 1. Number of cuttings harvested per mother plant annually.

Nursery	Number of cuttings per year
Nursery A	More than 30
Nursery B	60
Nursery C	Year1 (4), Year 2 (12), Year 3 (12), Year 4 (10)
Nursery D	Year 1(3-5), Year 2 (10-12), Year 3 (15-20)
Nursery E	-
Nursery F	12
Nursery G	10-12
Nursery H	-
Nursery I	8

Moreover, most nurseries reported that the root formation process takes more than 8 weeks, and one nursery described that their rooting process takes between 6-8 weeks, while another one was unsure of the duration (Figure 7). This fact could be explained by most nurseries relying on open ground weather conditions for cutting production, which can be uncertain and unpredictable, resulting in a longer and uncertain rooting phase.

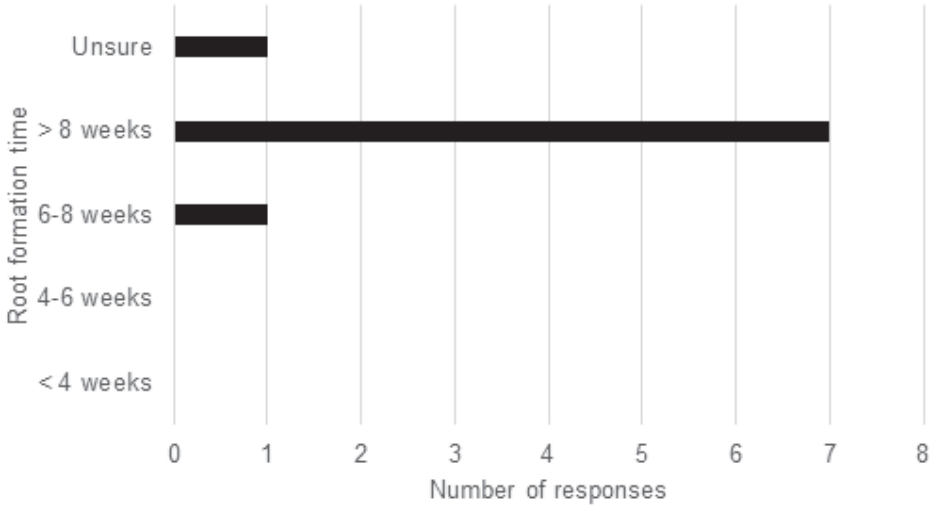


Figure 7. Period of adventitious root formation in pine cuttings.

When asked if nurseries currently have or have had clones that are difficult to root, 77% of the respondents said yes (7 nurseries). In addition to that, most nurseries reported they don't have clone-specific protocols for mother plant nutrition and management, use of hormones and rooting environment. This highlights an important research gap regarding mother plant management, cutting processing and adventitious root formation throughout the cutting production process (Figure 8).

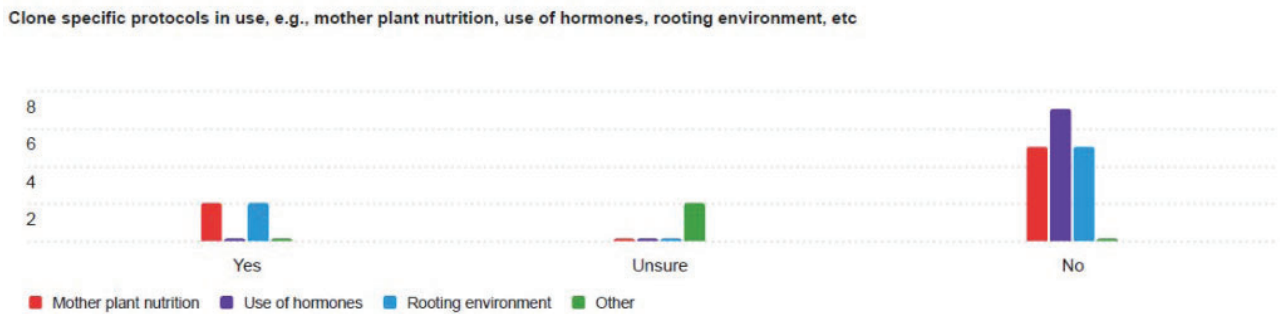


Figure 8. Existence of clone-specific protocols for pine mother plants, cuttings and rooting process.

Nurseries stated they are generally satisfied with the current cutting production systems in place. However, when this is compared with other responses provided by nurseries about the cutting process, it is clear that there is room for improvement and optimisation of the cutting process (Figure 9).

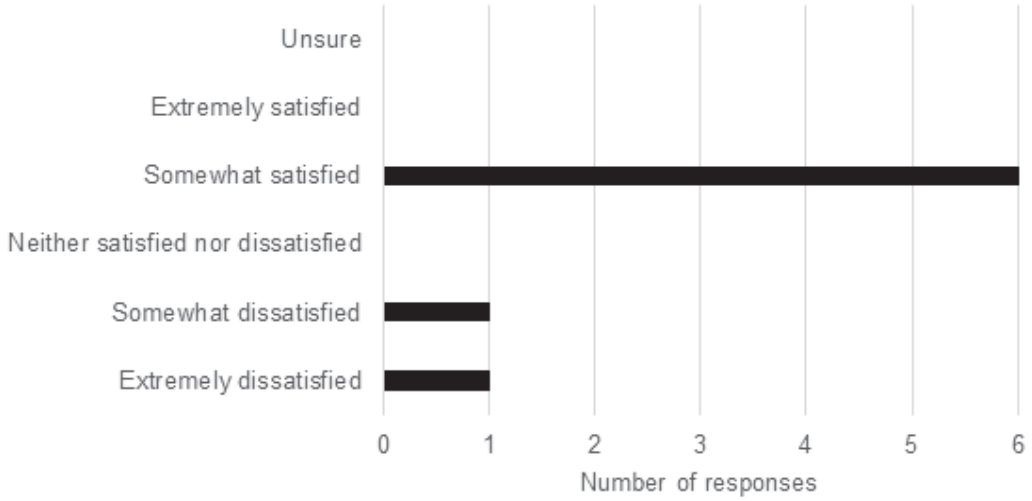


Figure 9. Satisfaction of nurseries with existing pine cutting production system.

Lastly, an open-ended question asked nurseries to provide any comments regarding pine propagation by cutting. Responses included: "*improvement on the development of the root formation in full 3 or 4 quadrants is necessary*" and "*outdoor propagation required the spring season to be warm. If cold and wet, very slow rooting*" and "*lots of money to automate*". This confirms the challenges observed throughout the survey responses around root formation, particularly for bare root open ground systems. Further, these findings support the case for indoor environments for mother plants growing under more controllable conditions.

Containerised pine production

Of the 9 completed responses, only four nurseries reported having containerised production, while five nurseries mentioned they do not have containers. Therefore, responses to most of the following questions are based on 4 respondents only. Out of the four nurseries that have containerised production, two have more than 75% of the production in containers while other two nurseries have up to 25% of their production in containers (Figure 10). This is evidence of a wide variation across the industry with most nurseries still relying on bare root systems for most of the production, while some nurseries already transitioned most of their production to containers.

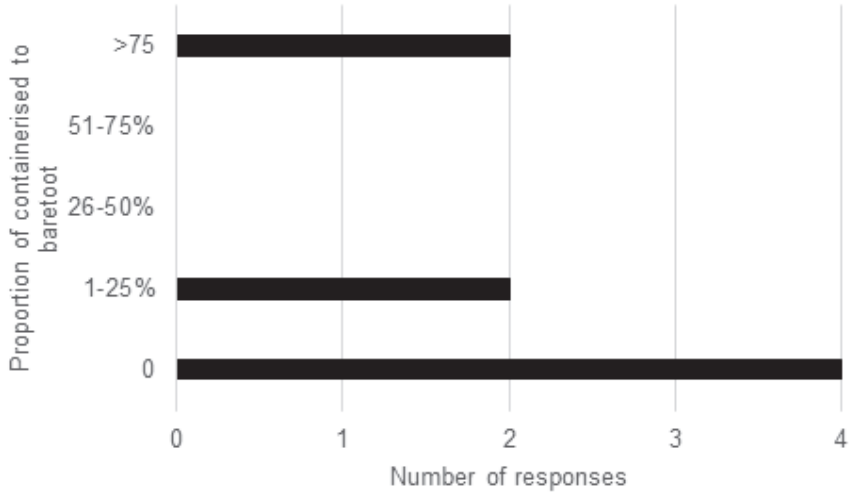


Figure 10. Proportion of containerised pine plant production in relation to bareroot production.

Similarly to the pine production by cuttings, it seems unlikely that nurseries will increase their containerised production in the coming years, with only one nursery reporting that it is somewhat likely their containerised production will increase (Figure 11).

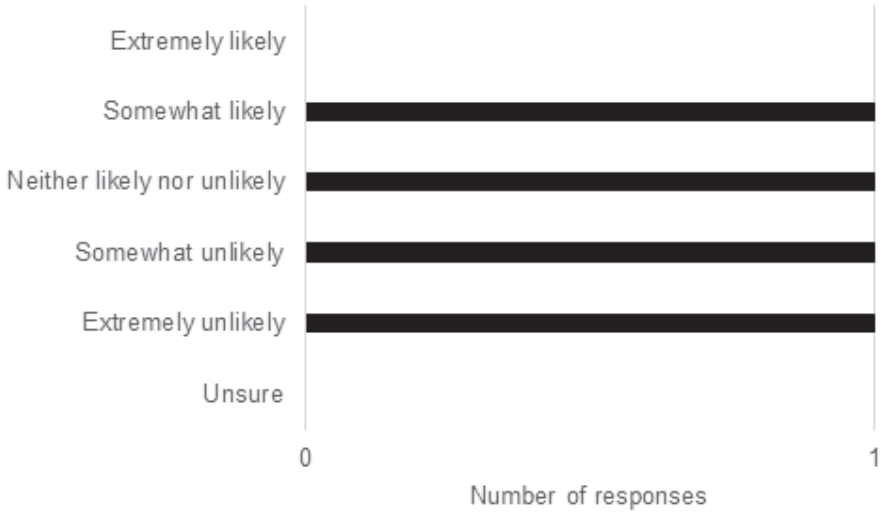


Figure 11. Likelihood of increasing containerised pine production in the next years.

Lastly, an open-ended question asked nurseries to provide any comments regarding containerised pine propagation. Responses included: "*The future* :)", "*hard to sell into a dominated bareroot market*", and "*we can easily expand; however, forest companies are reluctant to pay more for plugs in tight economic conditions. Bareroot has only been used for tough sites for survival mainly*".

Overall, there seems to be optimism about containerised production, but the lower sales prices of bareroot plants seems to make it harder to sell containerised plants, which tend to be more expensive, unless there are specific requirements such as planting under harsh conditions where containerised plants may potentially perform better than bareroot plants.

Use of greenhouses and automation technologies

Only two nurseries responded that they have greenhouses available to grow plants. Therefore, the following answers are based on two industry nurseries only. Regarding the main reasons to use greenhouses for pine production, environmental control and disease management were ranked highest for them (Figure 12).

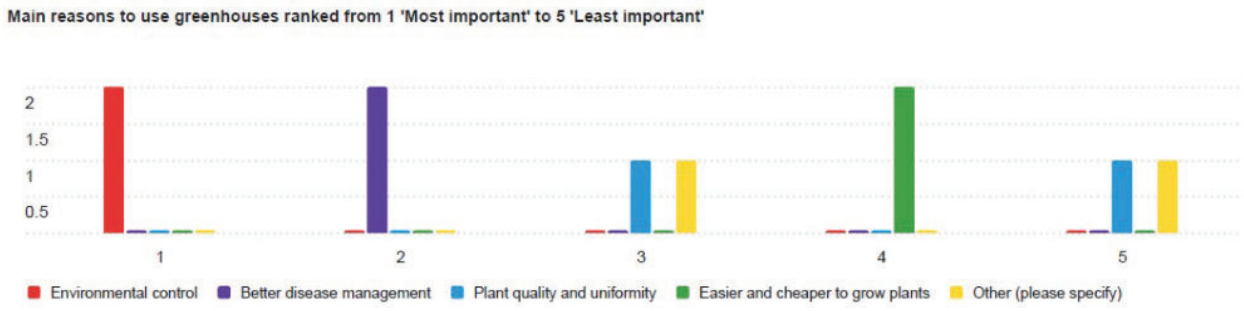


Figure 12. Ranking of the main reasons for using greenhouses to with radiata pine plants.

Regarding technology available to control the environment conditions, industry nurseries with greenhouses available are equipped with cooling, irrigation and ventilation system. More sophisticated environmental controls such as growing light and heating are also available for one of the nurseries (Figure 13).

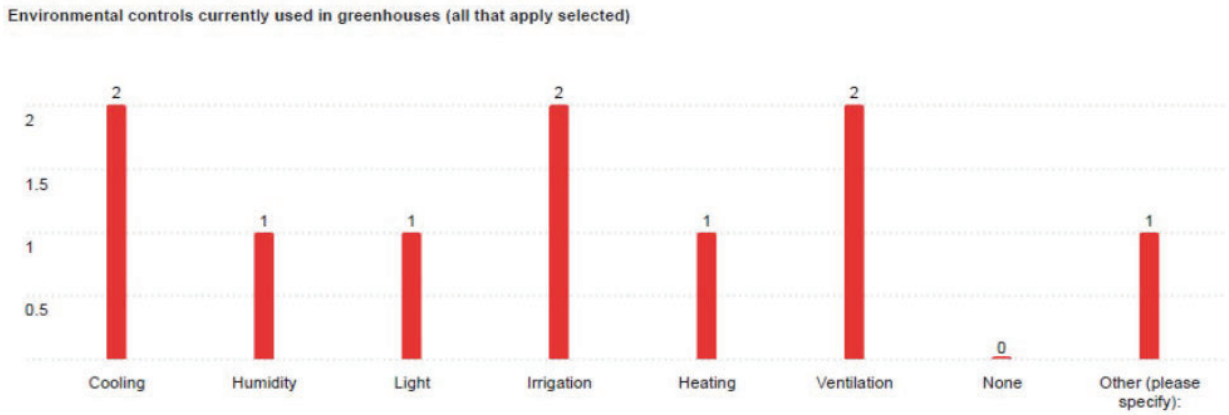


Figure 13. Environmental controls available for nurseries that have greenhouses.

An open-ended question asked nurseries to provide any comments regarding pine propagation using greenhouses. Responses included: "*Ergonomic for staff to work at table height. Ease of oversight*", "*We only use the greenhouse briefly for early sowing to get early plants up and away before going outside to harden off*".

In some nurseries, greenhouses are only being used for early germination stages, being moved to outdoor conditions for growing and hardening off. Therefore, current approaches are more about supporting the work environment and environmental conditions or variability that comes from outdoor production approaches, but greater value could be realised through more controlled indoor environmental settings not currently widely employed.

Crop monitoring and future challenges

When asked how often someone cast their eyes over the pine crop in the nursery, four respondents reported that oversight happens several times per day, while three nurseries do so once every second day and two nurseries do less frequently than that (Figure 14).

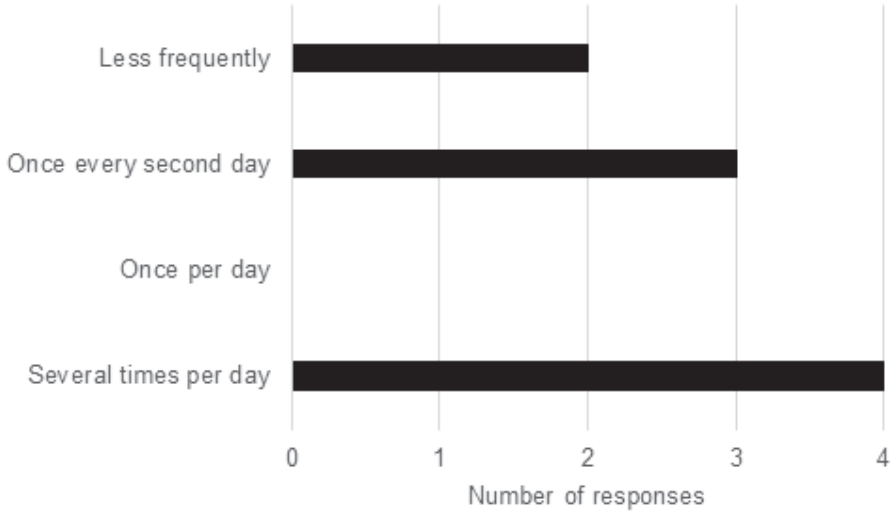


Figure 14. Frequency someone cast their eyes over pine crop in nurseries.

Additionally, most nurseries consider automation very important or moderately important for crop monitoring, particularly for disease and pest detection and plant stresses. Plant count was ranked as slightly important or moderately important by most respondents (Figure 15).

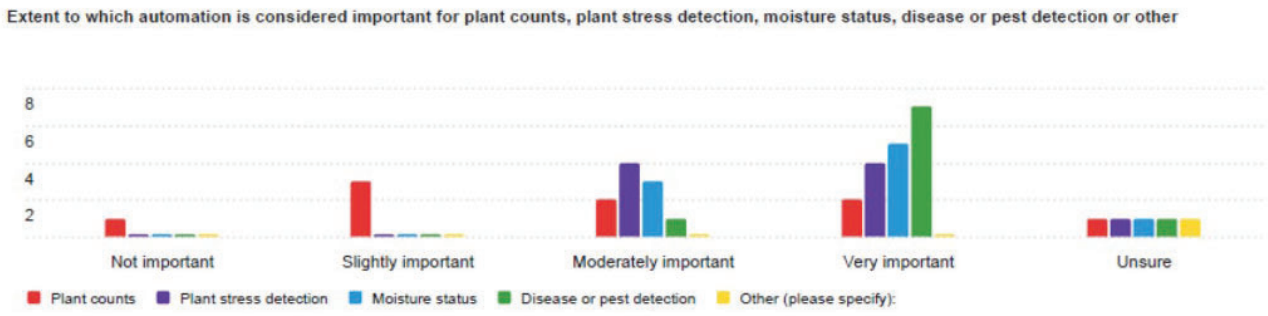


Figure 15. Ranking of the most and least important factors automation could help plant production in the nursery.

Most of the nurseries believe that future outdoor conditions, e.g. extreme weather events, will not impact nursery operations to the point that production would transition towards indoor growing (Figure 16). Two nurseries believe that this shift might happen, but only partially, and one nursery perceives that future outdoor conditions might require moving to indoor growing.

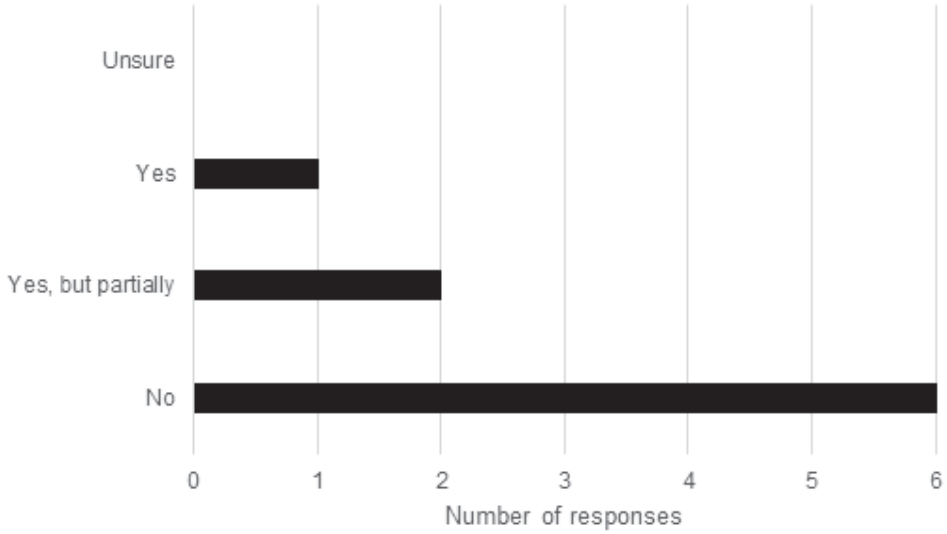


Figure 16. Perception of the nurseries around future outdoor conditions (e.g., extreme weather events) required pine production to move towards indoor growing.

Most nurseries are interested in participating in pilot testing of new imaging technologies and monitoring system as they become available. Respondents also mention: "*further information would help*", "*the ability to see some actual results from other sectors that may have applications here*", "*robotic in-shed grading would be a first step*" and "*results and access to it once developed*". There was also interest in learning from the information collected "*As long as info collected was shared so we can learn from it"*.

This indicates they would be open to new crop monitoring technologies such as the Pine-eye model if there is robust evidence of their results and benefits, as well as their desire to have technologies in other daily operations such as plant grading.

Presenting results from the Imaging Technologies tasks under development such as the Pine-eye model for plant count and potentially testing the technology in industry nurseries may create greater interest and engagement among other nurseries. Although this technology would only be available to containerised nurseries, there is no requirement for greenhouses and drones as the Pine-eye model can be used through the smartphone app. Further development of the Pine-eye model may be able to address other challenges top ranked in the nursery survey such as weed control, pest and disease detection.

Apart from the survey respondents interested in being part of pilot studies, we also had a few nurseries contacting the BSI-team directly to express their interest in being involved in these projects as well as during good engagement in the forest nursery growers meeting in March 2026.

We followed up with these nurseries, and one nursery visit was organised in April 2026. Part of the BSI team involved in this project had the opportunity to walk through their facilities and learn more about their operations and challenges. We also had the opportunity to have a more in-depth discussion following the survey results. During the visit, the BSI team was shown a greenhouse with growing lights available, however these have been used for other forest crops other than radiata pine. Additionally, most of their pine production was bare root stock, with containers being used to grow pine only upon specific client request.

The survey results revealed several challenges and inconsistencies around the pine cutting propagation in New Zealand. Although clonal propagation (using cuttings) is acknowledged by nurseries as having clear advantages, this method is still constrained by the high costs, being time consuming and technical difficulties, particularly for mother plant management and rooting success. The lack of standardised protocols and the adoption of open ground systems by most nurseries seem to be the main reasons for the

wide variation in mother plant productivity and rooting success. This is evidence that further studies are needed to develop pipelines and protocols nurseries can adopt to streamline pine production by cuttings.

The use of greenhouses for growing pine is very limited across nurseries. Nurseries are reluctant to invest in greenhouse facilities as the price of seedlings and cuttings will not be competitive in a bare root dominated market. In addition, nurseries have strong interest in adopting new technologies as they become available, particularly for plant health monitoring and stress detection. However, adoption depends on clear evidence of practical benefits being demonstrated.

Overall, the survey results show how several complex factors integrating financial, technical, environmental and practical aspects influence pine propagation in New Zealand, being one of a few cases in the world that still relies on open ground systems for most of the plant production. This is also challenging for research and development to support industry as most technologies developed globally are focused on containerised and greenhouse systems.

Pine-eye model

To test the limits lower of the Pine-eye model in terms of the smallest and tallest plants it can detect without losing accuracy, weekly photos were taken as soon as the first germinants were observed. Early germination counts were possible, with the model detecting young pine seedlings even when the seed coat was still present. However, due to the heterogeneity of the germination phase across individual trays, false positive detections were often recorded at this stage (Figure 17).

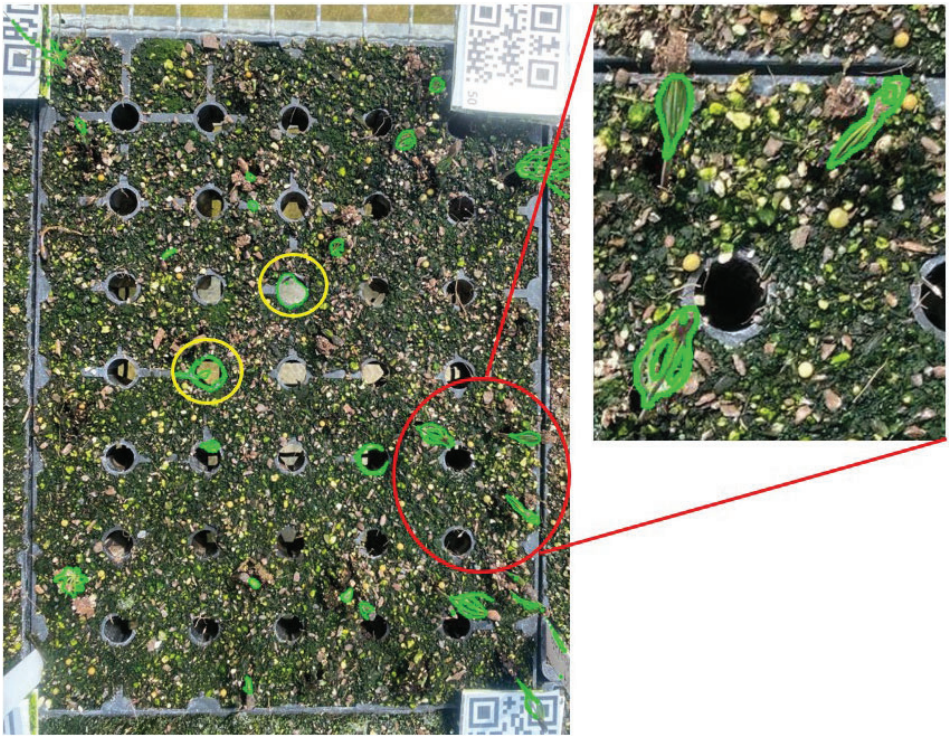


Figure 17. Early germination detection (20 days after sowing) using the Pine-eye model. Yellow circles highlight false detections.

Plant height limit *versus* tray boundaries identification

As stated in the previous reports (Pont et al., 2025; Siqueira et al., 2026), the BSI team identified that the main reason for errors made by the Pine-eye model, compared to human eye counts, was related to the identification of tray boundaries. This led to missed plants near the edge of the trays or the incorrect counting of plants from neighbouring trays. Improving tray boundary detection has therefore been the main

focus of the Pine-eye development to ensure all saleable and unsellable plants within each tray are accurately counted.

Identifying tray boundaries becomes more challenging as the seedlings grow taller, with preliminary results from the last report (Siqueira et al., 2026) indicating that around 5 cm represented the threshold for reliable plant counting within each tray. These results were confirmed by the new height measurements including a larger number of samples, along with the weekly photos, which showed that when the pine seedlings reached around 5-6 cm in height, the needles covered large areas of the trays in the background. This made it more difficult for the Pine-eye model to detect the tray boundaries (Figure 18). As a result, the accuracy of germination counts for individual trays were reduced once seedlings exceeded this height threshold.

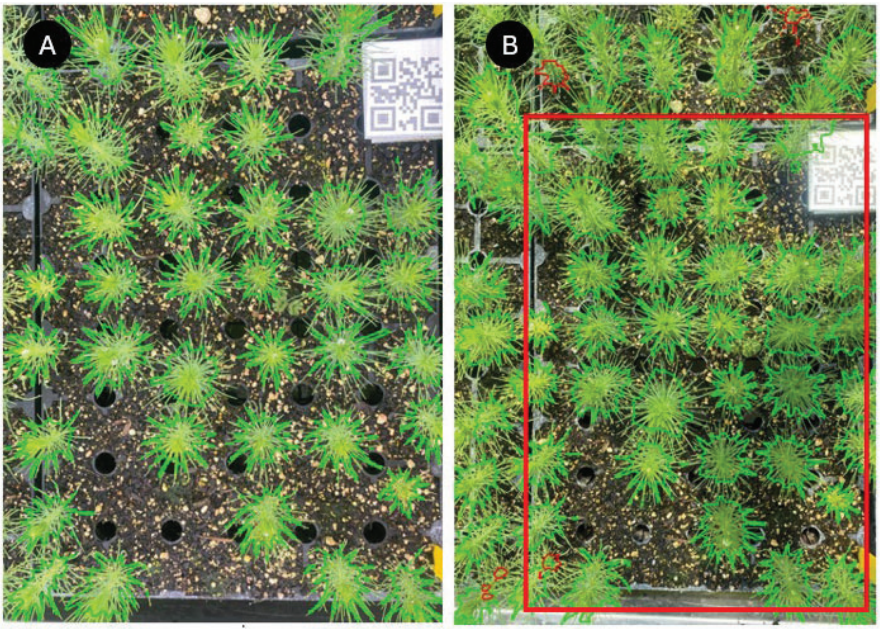


Figure 18. A: The same tray before seedlings reached the height threshold, with 100% of plant count accuracy, and B: when seedlings were around 5-6 cm tall or taller, resulting in tray boundaries no longer being detected. Red square highlights the original tray boundaries.

Despite this tray boundary identification being the main focus for the Pine-eye development, some improvements have been achieved with the model training. A sequence of photos of the same tray taken regularly overtime was used to create a time-lapse video showing changes in the Pine-eye model performance until it could no longer detect the tray boundaries.



Although accurate germination counts within trays was not feasible for seedlings over 5-6 cm, there remains an opportunity to explore alternative approaches for extrapolating the Pine-eye model from individual tray counts to whole batches of germination counts comprising a known number of sown trays. That is, it may be possible to estimate the total number of pine seedlings across many trays for seedlings taller than this height threshold, with individual tray boundary identification no longer being a limiting factor. In addition, the Pine-eye can still be used for crop monitoring, identifying saleable and unsaleable pine plants, irrespective of how tall seedlings are.

Saleable and unsaleable plant counts

The Pine-eye model is also able to identify and count saleable and unsaleable plants (Figure 19). This classification is based on the colour of the seedlings, outlining in red seedlings that developed abnormal germination or might be under stress. This can be used to enable timely re-sowing of seeds or to support decision-making if any stresses are causing damage to the seedlings.

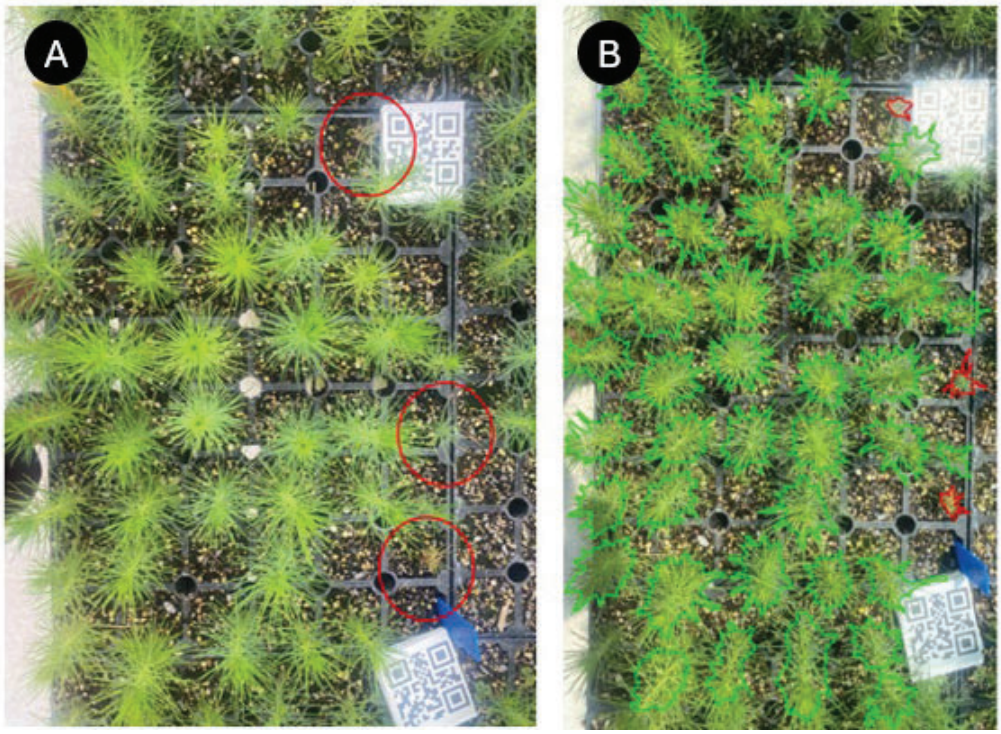


Figure 19. A: RGB photo with red circles highlighting unhealthy looking pine seedlings, and B: Pine-eye model detection outlining the same seedlings as unsaleable plants.

Germination counts: phone app *versus* mini drone

The deployment of the Pine-eye model for pine counting is possible via a smartphone app or the Corvus drone system, being more accurate when the smartphone app is deployed. Comparing both systems with the manual counts (human eye), results showed that the phone app provides higher accuracy, with a correlation coefficient of $R^2 = 0.88$, while the results from the drone correlated around $R^2 = 0.57$ (Figure 20).

Previous results (Siqueira et al., 2026) showed a correlation coefficient of $R^2 = 0.89$ between human eye counts and the smartphone app, indicating satisfactory consistency and accuracy of the Pine-eye model when compared to the human-eye count. Although the model is still under improvement, these results suggest that further gains are becoming more difficult and require considerable effort to achieve only marginal gains in accuracy. This is a common issue reported for other crops when imagining technologies are developed for complex plant phenotyping tasks [8].

The drone system sometimes misses trays during the flight, which reduces the total sample size and partially explain the lower correlation coefficient. On average, approximately 20% of the trays were not detected by the drone during flights. Further work is needed to investigate whether improvements for the QR code system used for tray identification, as well as adjustments for the flight paths, could improve detection.

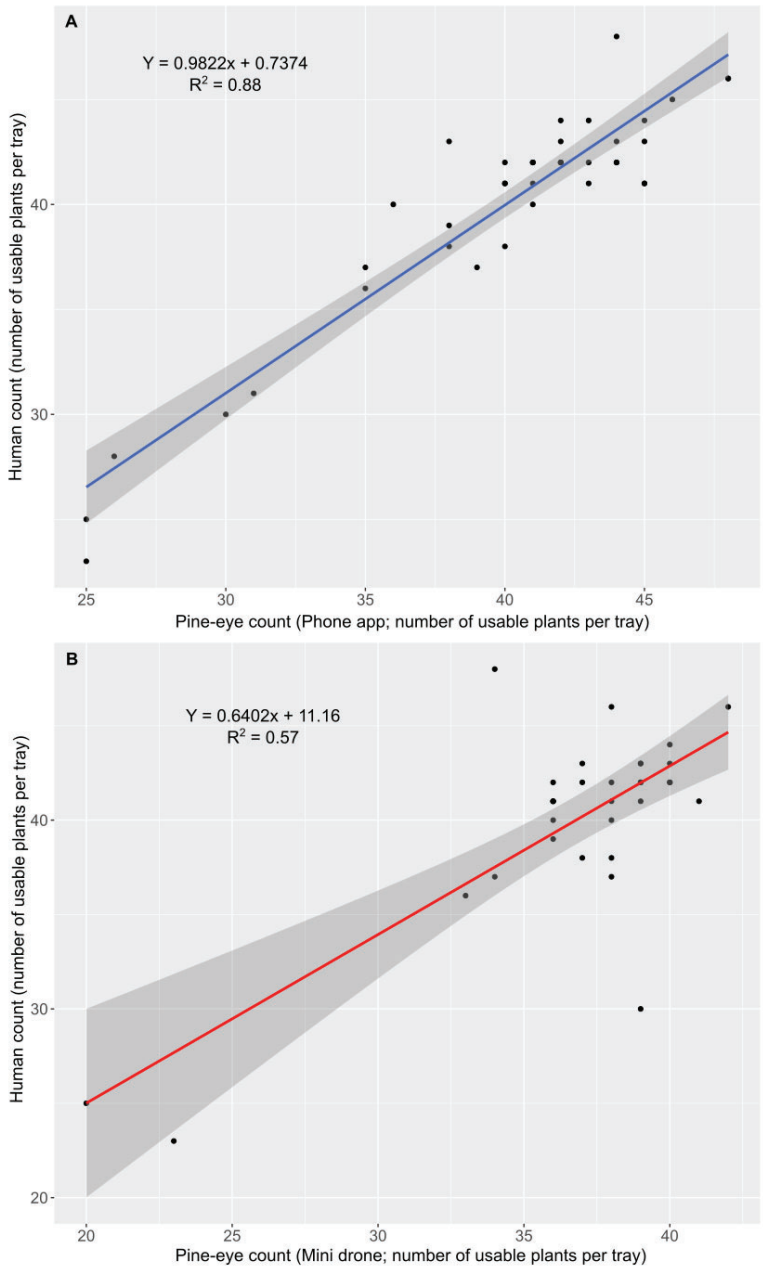


Figure 20. A: Correlation between human eye counts and smartphone app counts of useable pine seedlings, and B: Correlation between human eye counts and mini drone counts of useable pine seedlings.

Overall, the maximum variation between results from the phone app and the human-eye count was five plants (approximately ±10%), whereas the comparison between the drone system and the human-eye count showed a higher maximum variation of around ±29%. Conversely, in 22.5% of the cases, the Pine-eye model used through the smartphone app achieved perfect saleable plant detection, with no false negatives or miscounted plants within a given tray.

Multi-tip detection feasibility study

The multi tip detection model was not able to detect all tips when mother plants or conditions were different, with a correlation coefficient between the model and the manual multi tip counts of R^2=0.46 (Table 2). This study aimed to investigate the viability of estimating productivity of cuttings per pine mother plants using existing imaging technologies rather than conducting an exhaustive study.

Table 2. Comparison between human eye count and model prediction for multi tips (cuttings) from pine mother plants

ID	Human-eye count	Model prediction
Mother plant 1	20	4
Mother plant 2	12	5
Mother plant 5	15	12
Mother plant 8	8	2
Mother plant 21	11	6
Mother plant 26	13	5
Mother plant 31	22	14
Mother plant 36	18	11
Mother plant 37	24	11
Mother plant 40	17	9

Although the estimation of cuttings showed high variability, we observed that more lignified tips were often counted by the model, whereas more soft cuttings were frequently missed. Further work should explore counting cuttings while considering the quality/stage of lignification (readiness for harvest) as part of multi tip detection study (Figure 21).

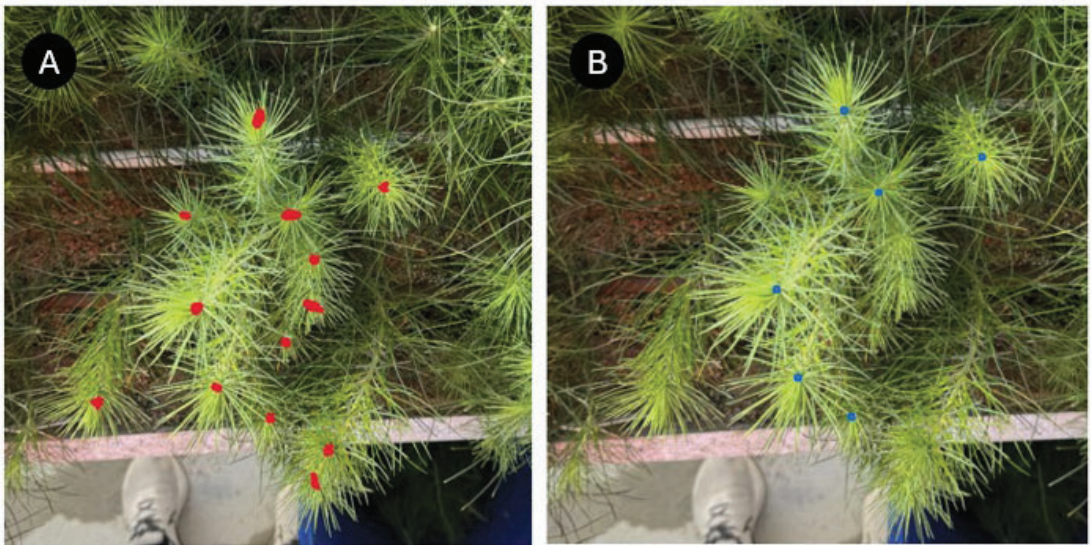




Figure 21. A: Red dots highlighting human count of tips for one pine mother plant, B: Blue dots highlighting model prediction of tips for the same pine mother plant, and C: annotated image including multiple mother plants with tips being counted by the model trained.

CONCLUSIONS

The survey results highlighted that radiata pine propagation by cuttings remains challenged by high costs, labour demands, low rooting success, and the lack of a standardised clone-specific protocols, leading to a wide variability in production outcomes and little interest in increasing cutting production in the next few years. Although nurseries acknowledge the benefits of growing pine by cuttings, such as high genetic value with higher sales price and overall uniformity, these do not seem sufficient to outweigh the challenges and drive expansion under current systems.

The adoption of containerised systems for pine production varied widely across nurseries and remains limited by cost and market preference for bareroot stock, mainly due to the lower sales price. The use of greenhouses is restricted to a few nurseries and primarily for early germination stages. Industry nurseries showed interest in automation and imaging technologies such as the Pine-eye for germination count and seedling monitoring that would facilitate daily operations, but only if practical benefits are demonstrated.

Regarding the performance of the Pine-eye model, it performed well in detecting pine seedlings and classifying them into saleable and unsaleable plants. However, accuracy is limited by plant growth, with reliable single tray counting only up to about 5–6 cm in height. This is due to loss of the tray boundary detection when needles cover most of the tray edges, which remains the main source of error for the model. Using the Pine-eye model through a smartphone app achieved a strong correlation with human-eye counts, while the drone system is less reliable.

The multi-tip detection feasibility study underestimated pine mother plant cuttings with a correlation coefficient of R^2=0.46 when compared to manual counts and showed high variability across mother plants. Further improvements should consider tip developmental stage, as more lignified tips appeared to be detected more easily, which may be aligned with cutting harvest time.

FUTURE WORK AND RECOMMENDATIONS

Considering the industry interest in participating in pilot automation studies for crop oversight, we recommend the Pine-eye model to be tested in industry nurseries in the next phase of this project. This would be limited to containerised nurseries and used though the smartphone app at this stage, but once results obtained at the BSI nursery are validated elsewhere, it may create greater interest and engagement among other nurseries.

The Pine-eye smartphone app will also be tested with pine seedlings growing in the greenhouse with the sensor platform. This is part of the integration of this workstream with the sensor platform and will enable the assessment of germination and saleable/unsaleable plant monitoring in relation to environmental variations (microclimate) in greenhouse conditions. This will enable a better understanding of the effect of the greenhouse microenvironment on early pine performance.

The survey results shed light on several challenges regarding the vegetative propagation for radiata pine in open ground systems, from mother plant management to rooting success. A critical issue for these open ground systems is the reliance on weather patterns, which can be highly variable throughout the year. Although greenhouses offer more controlled conditions for temperature, humidity, fertilisation, irrigation or misting and photoperiod, for both mother plants and cuttings during the rooting phase, there is currently limited use of these facilities for radiata pine cutting production.

There is an opportunity to develop a technoeconomic project task focused on vegetative propagation protocols for selected elite material while comparing open ground and containerised systems. This should include comparison of mother plant establishment, productivity of cuttings over time and adventitious rooting speed and overall success, with the possibility of undertaking a comprehensive financial comparison between both systems. This may be a great opportunity to demonstrate to industry the cost-benefit of greenhouse facilities and controlled environment for mother plant management and cutting production. This techno-economic analysis can also include other scenario testing to reflect the reality of different nurseries, and it should be considered as a new task and not an extension of the current imaging technologies task.

ACKNOWLEDGEMENTS

The project team would like to acknowledge the high level of professionalism and support provided by Corvus and Track32. We would also like to acknowledge the invaluable and extensive support of Elizabeth Dunningham in project management and liaison with FGR, and of Matt Dunn, Anita Wylie and Nursery staff in several essential aspects of setting up and running the parts of the project involving the nursery.

REFERENCES

1. Titon, M., A. Xavier, and W. Otoni, *Clonal propagation of Eucalyptus grandis using the mini-cutting and micro-cutting techniques.* Scientia forestalis, 2006. **71**.
2. Araujo, J., et al., *Vegetative propagation of Toona ciliata M. Roemer by the minicutting technique.* Arvore, 2009. **33**(2).
3. Barroso, D.G., et al., *Mini-stump productivity and rooting of Khaya ivorensis A. Chev mini-cuttings treated with IBA.* Cerne, 2018. **24**(2).
4. Libby, W., A. Brown, and J. Fielding, *Efects of hedging radiata pine on production, rooting and early growth of cuttings.* New Zealand Journal of Forest Science, 1971. **2**(2).
5. Diaz-Sala, C., *Direct reprogramming of adult somatic cells toward adventitious root formation in forest tree species: the effect of the juvenile-adult transition.* Frontier in Plant Science, 2014. **5**: p. 310.

6. Maraveas, C., *Image Analysis Artificial Intelligence Technologies for Plant Phenotyping: Current State of the Art.* AgriEngineering, 2024. **6**(3): p. 3375–3407.
7. Fuentes-Peñailillo, F., et al., *Automating seedling counts in horticulture using computer vision and AI.* Horticulturae. **9**.
8. Pont, D., Siqueira, D., Salvatierra, G., Palmer, M., Massam, P. Vegetative Precision Propagation - 2.1 Imaging technologies. Client report FGR.
9. Siqueira, D., Dunn, M., Massam, P., Salvatierra, G., Grant, A. Vegetative Precision Propagation - Progress report. Client report FGR
10. Ubbens, J. and I. Stavness, *Deep plant phenomics: A deep learning platform for complex plant phenotyping tasks.* Frontier in Plant Science, 2017. **8**.

APPENDIX 1. Nursery survey questions

Preamble:

We are from the Bioeconomy Science Institute Maiangi Taiao (formerly Scion) and are interested in knowing more about the introduction of new technologies in forestry nurseries.

The main goal is to identify the risks, challenges and opportunities where research and new technologies may help streamline plant production. Our objective is to understand the perspectives of industry nurseries regarding radiata pine propagation of seed produced, tissue culture and through cuttings.

Your participation is confidential and your responses will be stored securely. All responses will be anonymised and summarised together with the rest of the survey data. Once information is compiled, results of the survey will be shared. These results will highlight perceptions of the key challenges forestry nurseries face in plant propagation and their views on new automation technologies. The aim is to help align research, technology development and adoption with industry practices so that efforts are targeted and relevant.

This survey will take approximately 10 minutes to complete. Please submit your answers by 3 April 2026. All completed surveys will be entered into a draw for a $150 gift card.

Please contact: david.siqueira@scionresearch.com or 0224323046 if there are any questions or issues with completing this survey.
Thank you for participating in our survey!

Questions:

1	Have you ever used any of the following methods to propagate Pinus radiata? (Select all that apply)	☐ Seed ☐ Cuttings ☐ Tissue culture
2	Please rank the following challenges associated with propagation by cuttings in order of challenge, where 1 is 'most challenging' and 5 is 'least challenging')	☐ Costly and time consuming ☐ Complexity to manage mother plants ☐ Low rooting success rate ☐ Weak plants compared to seedlings ☐ Other (please specify): _____
3	Please rank the following advantages associated with propagation by cuttings in order of advantage, where 1 is 'most advantage' and 5 is 'least advantage'	☐ Genetic uniformity ☐ Predictable productivity ☐ Higher-value crop ☐ Meeting specific demands (niche market) ☐ Other (please specify): _____
4	How likely is your cutting production to increase in the next few years?	☐ Very likely ☐ Likely ☐ Neutral

		☐ Unlikely ☐ Very unlikely. ☐ Unsure
5	How long is the total life cycle of your pine mother plants (e.g., until productivity declines to the point where replacement is required)?	☐ 1–2 years ☐ 2–3 years ☐ 3-4 years ☐> 4 years ☐ Unsure ☐ Other_____
6	Approximately, how many cuttings would you hope to collect per mother plant per year?	*Open ended* ☐ Unsure
7	On average, how long does it take for your cuttings to form new roots?	☐ < 4 weeks ☐ 4–6 weeks ☐ 6–8 weeks ☐ > 8 weeks ☐ Unsure
8	Do you currently have or have had clones that are difficult to root?	☐ Yes ☐ No ☐ Unsure
9	Do you have clone-specific protocols e.g., mother plant nutrition, use of hormones, rooting environment, etc?	☐ Yes ☐ No ☐ Unsure
10	Overall, how satisfied are you with your current cutting production system?	☐ Very dissatisfied ☐ Dissatisfied ☐ Neutral ☐ Satisfied ☐ Very satisfied ☐ Unsure
11	Do you have containerised plant production in your nursery?	☐ Yes ☐ No
12	What proportion of your total production is containerised compared to bare roots?	☐ 0% ☐ 1- 25% ☐ 26–50% ☐ 51–75% ☐ > 75%
13	How likely is your containerised production to increase in the next few years?	☐ Very likely ☐ Likely ☐ Neutral ☐ Unlikely ☐ Very unlikely. ☐ Unsure
14	Do you have greenhouses to grow Pinus radiata in your nursery?	☐ Yes ☐ No
15	Please rank your main reasons to use greenhouses in order of priority from 1 most important to 5 least important?	☐ Environmental control ☐ Better disease management

		☐ Plant quality and uniformity ☐ Easier and cheaper to grow plants ☐ Other (please specify):_____
16	What environmental controls do you currently use in your greenhouse? (Select all that apply)	☐ Cooling ☐ Humidity ☐ Light ☐ Irrigation ☐ Heating ☐ Ventilation ☐ None ☐ Other (please specify):_____
17	What environmental parameters do you measure in your greenhouse? (Select all that apply)	☐ Temperature ☐ Humidity ☐ Light levels ☐ Soil moisture ☐ Other (please specify):_____
18	How frequently does someone cast their eyes over your crop (oversight)?	☐ Several times per day ☐ Once per day ☐ Once every second day ☐ Less frequently ☐ Other (please specify):_____
19	To what extent do you consider automation important for crop oversight in your daily nursery operations (e.g. plant counts, plant stress detection, moisture status, disease or pest detection)?	☐ Not important ☐ Slightly important ☐ Moderately important ☐ Very important ☐ Unsure
20	Do you believe that future outdoor conditions (e.g. extreme weather) might make it necessary to move the production of radiata pine plants towards indoor growing?	☐ Yes ☐ Yes, but only parts of the production ☐ No ☐ Unsure
21	Would you be interested in participating in any pilot testing of new imaging technologies and monitoring systems for nursery propagation as they become available?	☐ Yes ☐ No ☐ Possibly
22	What incentives or further information would encourage your participation such pilot testing?	*Open ended*