Precision Silviculture Programme

Review of Planting Stock Quality and Performance

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Context

There are questions about the future demand for container grown radiata-pine (*Pinus radiata*) planting stock in New Zealand as the forestry industry explores options to mechanise planting operations to overcome potential labour shortages. Most mechanised planting systems have been developed in Scandinavia or Brazil and are designed to work with container grown plants. However, mostly bare-root stock is deployed in New Zealand, which raises the issue of how easy the adoption of such mechanised systems would be. One of the advantages of using container-grown rather than bare-root stock in mechanised planting systems is the extended period over which container stock can be planted, allowing the machines to operate over extended planting periods thereby increasing their economic performance. Container-grown stock constitutes only a small proportion of the radiata pine material currently planted in New Zealand so there is limited understanding of the specifications for containerised stock and/or factors that may affect their performance in field.

This project

In response to the issues highlighted above, the Precision Silviculture Programme undertook to review the current status of knowledge of container-grown radiata pine stock with respect to its quality and performance in the field in relation to bare-root stock. Specifically, the objectives of this report were to:

1. Review publications comparing field performance of containerised and bare-root planting stock;
2. Evaluate through a survey of nursery growers and forest companies planting radiata pine the current perceptions of stock quality (nursery growers) and relative field performance of container versus bare-root planting stock (forest companies);
3. Identify key knowledge gaps or barriers in New Zealand with respect to benchmarking stock quality and performance of container-grown plants in-field (for potential future use in mechanised planting systems).

Outcomes

Overseas studies with a wide range of forestry species have shown that stock-type performance during the establishment phase is strongly predicted by root quality at planting as well as the diameter and sturdiness of the plant. A range of research trials internationally with a wide variety of species showed that container-grown seedlings typically had a greater survival on harsher, drought-prone sites than bare-rooted stock. However, survival rates between stock types were generally comparable on sites where there was minimal stress after planting.

The New Zealand industry surveys indicated that container-grown stock is more expensive to produce and plant than bare-rooted material but provides greater flexibility in planting due to a longer planting season and better stock survival if not planted immediately. A perception of mixed performance in containerised planting stock still persists with some New Zealand forestry growers due to historical issues with toppling. The advantages and disadvantages of all available stock types must be recognised in order for informed decisions to be made on what the most suitable stock for the conditions at a particular planting site are**.** Information on field performance of different stock types is currently limited and needs to be obtained from the establishment of well-designed field trials over a variety of sites and multiple years.

Current definitions of the ideal plant specifications (particularly height and diameter) for containerised radiata-pine seedlings and cuttings are poor and more data is urgently required. Defining the ideal container is also important. Many different container types are currently used although there is strong interest in the Norwegian paper Ellepot type among both nursery practitioners and forestry planters.

Availability of labour is a major constraint in both nursery and planting operations; therefore, efforts to increase mechanisation across the entire supply chain are warranted. One of the most significant knowledge gaps is the link between the specifications for quality container stock and the requirements for integration with mechanised planting machinery. This needs to be addressed. Systems supporting mechanised planting of bare-root stock also need to be a priority.

Review of Planting Stock Quality and Performance

BACKGROUND

Millions of new plants are required each year to re-stock harvested areas of radiata pine or to create new planted forests. Currently, most of this stock is grown in commercial nurseries and sold to forest owners as bare-rooted plants, either as seedlings (derived from seed orchard seed or stand select seedlots) or cuttings (either of control pollinated stock or clonal stock). In recent years, labour shortages have caused problems in nurseries for lifting bare-root planting stock, and in forest-planting operations. The seasonal nature of this manual work has made it difficult for employers to source competent staff and these issues were exacerbated during the COVID-19 pandemic.

Bare-root nursery propagation systems, as opposed to containerised propagation systems, predominate for radiata pine in New Zealand (Mead 2013; Bayne 2021). There is very little published data on the numbers of different types of radiata-pine planting stock (containerised versus bare-root) currently being deployed in New Zealand but survey results from Bayne (2021) indicated that approximately 89% of New Zealand's radiata-pine planting stock produced in 2020 was bare-rooted and about 11% was containerised stock.

There is interest in whether the demand for container-grown stock in New Zealand will increase as the forestry industry explores options to mechanise planting operations to overcome potential labour shortages. Most mechanised planting systems have been developed in Scandinavia or Brazil and are designed to work with container-grown plants. However, mostly bare-root stock is deployed in New Zealand, which raises the issue of how easy the adoption of such mechanised systems would be. One of the advantages of using container-grown rather than bare-root stock in mechanised planting systems is the extended period over which container stock can be planted, allowing the machines to operate over extended periods, thereby increasing their economic performance. Container-grown stock constitutes only a small proportion of the radiata pine material currently planted in New Zealand so there is limited understanding of the specifications for containerised stock and/or factors that may affect their performance in field.

There has been a wealth of research over many decades on bare-root nursery practices in New Zealand, designed to create the ideal root system and physical dimensions for optimising field performance (van Dorsser & Rook 1972; Menzies *et al.* 2001; Menzies *et al.* 2005; Mead 2013). These nursery practices include optimising the spacing of seedlings, root-culturing treatments such as undercutting and wrenching, and judiciously topping seedlings to control top growth and ensure a balanced shoot/root ratio and ensure a sturdy plant is produced.

In contrast, there has been limited research on development of containerised planting stock in New Zealand, particularly in regard to field performance (Nelson 1996; Menzies *et al.* 2001; Mead 2013; Klinger *et al.* 2022; Nanayakkara *et al.* 2022), raising questions around the field performance of container-grown stock compared with bare-root material.

In response to the issues highlighted above, the Precision Silviculture Programme undertook to review the current status of knowledge with respect to defining the quality of container -grown radiata pine (*Pinus radiata*) stock and its performance in the field in relation to bare-root stock. Specifically, the objectives of this report were to:

1. Review publications comparing field performance of containerised and bare root planting stock;
2. Evaluate through a survey of nursery growers and forest companies planting radiata pine the current perceptions of stock quality (nursery growers) and relative field performance of container versus bare-root planting stock (forest companies);
3. Identify key knowledge gaps or barriers in New Zealand with respect to benchmarking stock quality and performance of container -grown plants in-field (for potential future use in mechanised planting systems).

A description of the methods used for the literature review and surveys, as well as a full outline of the survey questions and extended results are provided in Appendices 1-4.

SUMMARY OF RESULTS

Review of publications comparing field performance of *radiata* pine containerised and bare-root stock to identify emerging trends for containerised plants

To read the full literature review please see Appendix 1. The following text is a summary of the full review.

History

Considerable research has been undertaken over many decades on bare-root nursery practices in New Zealand, designed to create the ideal radiata-pine bare-root planting stock. Bare-root planting stock has subsequently become the norm, and plant specifications have been well defined. However, interest increased in containerised stock in the early 1990s, largely driven by increased demand for rooted cuttings. Subsequently, bare-root systems were developed for cuttings propagation, but interest in containerised stock remained, particularly for clonal deployment.

In 2001, it was recognised by industry that research was needed to determine plant quality standards for radiata-pine containerised stock to ensure successful establishment. It was understood that bare-root and containerised stock were fundamentally different and that optimal specifications were not universal across stock types. This view was subsequently supported by overseas studies. Early research on the potential benefits of containerised stock in New Zealand indicated some advantages, particularly for harsh sites, but container-induced root deformities had a negative impact on field performance.

The relatively slow uptake of containerised stock by the radiata-pine industry over the last 25 years is due in part to the limited research on containerised systems in New Zealand. In particular, there are a very limited number of scientifically designed field trials to objectively test the field performance of containerised stock alongside standard bare-root planting stock.

Establishment of well-designed field trials over a variety of sites and years is essential for the successful development of new propagation technologies but, **to date, there has been very limited field testing of containerised stock in New Zealand.** However, information is available on overseas studies for a wide range of forestry species.

Overseas studies

Plant quality is best assessed using physiological traits but these traits cannot be practically assessed on a large scale. Instead, morphological traits (e.g. plant height and root collar diameter) are often used as indicators of plant quality as they are much easier to measure than physiological traits. Also, container size, shape and design, and growing regimes are critically important for plant quality. Other important factors for subsequent field performance are: (a) container types that improve root morphology by influencing the direction and depth of root development; (b) air pruning of the roots; (c) adequate drainage of nursery benches; and (e) inoculation of symbiotic mycorrhizae. However, growing planting stock for too long within a container causes plants to become root-bound, which will have a negative impact on subsequent field performance.

Overseas studies with a wide range of species have shown that stock type performance during the establishment phase is strongly predicted by root quality at planting, and the diameter and sturdiness of the plant. Field comparisons across different international research trials with a wide range of species showed that container-grown seedlings typically had a greater survival on harsher, drought-prone sites. However, **survival rates between stock types were generally comparable on sites where there was minimal stress after planting**. Bare-root stock was found to be more sensitive to handling practices during lifting, storage, transport and planting, which can negatively affect field performance.

New Zealand

There is a lack of consistency in the limited number of publications and industry reports on size specifications recommended for radiata-pine containerised planting stock in New Zealand. It is important not to piggyback on systems developed overseas as they are not tailored to New Zealand conditions and circumstances. While the international information is useful, it does not substitute for R&D within the New Zealand context. This must include field testing. It is also important to acknowledge that there is unlikely to be 'one size fits all' in terms of types of planting stock and ideal specifications for said stock. New Zealand has a highly varied geography, with a wide range of terrains and climates.

Toppling is a major issue in New Zealand with radiata pine, particularly on heavy soils and exposed, ex-farm sites. There has been particular concern about toppling in containerised stock, although it is also identified as a problem with bare-root stock.

It is now well recognised that container-grown methods allow greater flexibility in planting programmes as there is a longer planting season and stock can be held over until conditions are ideal and planters or planting machines are available. In addition, container-grown stock is more amenable to the mechanised planting machines that are currently deployed, albeit currently at small scale in New Zealand.

However, the perception of mixed performance in containerised planting stock that persists with some forestry growers in New Zealand will likely only be countered by presentation of solid data on relative field performance, from scientifically designed trials. Many of the issues identified with container -grown stock in the late 1990s and early 2000s have since been resolved with improvement in the technology, although there has been limited formal scientific research on containerised systems in New Zealand, compared with the wealth of research and development in bare-root system.

It is important to ensure that plant specifications that have proven to result in good field performance are not compromised to suit planting machines, i.e., mechanical planting systems and plant specifications need to be optimised to ensure both high productivity of machines as well as good field performance of planted stock. Also, it is important not to compromise on media mixes that have been tested and proven to optimise plant quality, rather than adjusting media mixes to fit in better with mechanised planting systems.

It is now well recognised that container-grown methods allow greater flexibility in planting programmes as there is a longer planting season and stock can be held over until conditions are ideal and planters or planting machines are available. In addition, container-grown stock is more amenable to the mechanised planting machines that are currently deployed, albeit currently at small scale in New Zealand.

Surveys on planting stock quality and containerised systems

Two separate surveys were sent out to: (a) forest nurseries producing *radiata* pine planting stock; and (b) forest managers, planting *radiata* pine. The key points from the surveys are shown below, with a full outline of the survey results presented in **Appendix 2**.

Survey of forest nurseries growing radiata pine planting stock

Separate surveys were sent out to 28 forest nurseries producing radiata pine planting stock. The Nursery Survey captured responses from 13 respondents (46% response rate) representing most of the commercial forestry nurseries selling radiata-pine planting stock in New Zealand. Some nurseries provided a range of different types of planting stock, while others specialised in either bare-root or containerised stock.

Key findings:

- In terms of percentages, the proportion of bare-root plants produced by the survey respondents was 72.5%, and the proportion of containerised plants was 27.5%.
- The container preferred by most practitioners producing containerised stock was the Norwegian container brand, the paper Ellepot.

- The major constraints for nursery operations were hiring enough skilled labour at the right time followed by difficulty recruiting and retaining nursery staff with sufficient technical knowledge.
- Containerised stock is more expensive to produce than bare-root stock due to more infrastructure and capital costs, and the ongoing cost of potting media.
- An overall decrease in demand for radiata-pine planting stock was anticipated over the next five years, accompanied by shift in demand for a different type of radiata pine planting stock**.** Changes to the ETS and uncertainty in the carbon industry, as well as a shift to other exotic and native species, was expected to drive change over the next five years.
- The biggest anticipated changes regarding radiata pine planting stock were a decrease in the demand for bare-rooted seedlings together with an increase in the requirement for cuttings (including bare-root but particularly containerised cuttings). The proportion of container-grown seedlings produced was not anticipated to change.
- The top drivers for change were identified as: labour costs and availability; followed by new technological developments (e.g., mechanised planting systems); and legislative/political changes leading to a decrease in radiata-pine planting.
- Opinions of survey respondents were split on whether bare-root or containerised systems perform better in the field. However, it was recognised that bare-root and containerised stock are very different crops that require different management regimes to optimise their establishment success. Since many of the industry accepted practices and quality measures for container stock have been developed based on bare-root systems (often acquired though anecdotal evidence), there is no good empirical data from trials to establish specifications for container -grown plants.
- Specifications for quality container planting stock vary, with inconsistencies noted particularly in height and diameter specifications and whether the shoots should be topped or not. Most respondents think there is a difference between propagule types (seedlings, rooted cuttings, other) in the specifications that constitute a quality container-grown nursery plant.
- **Knowledge gaps are: growing regimes and specifications for containerised stock; the need for field trials comparing containerised versus bare-root stock; and issues and logistics associated with deploying containerised stock.**

Survey of forest companies planting radiata pine stock.

The Planter Survey was sent to 20 forestry companies and 10 responses were received**,** ranging from small to large forestry operations. However, this survey only captured a small proportion of the radiata-pine forestry planters in New Zealand.

Key findings were:

- **Bare-root seedlings are currently the most widely planted stock** (60% average) by the forestry companies represented in this survey followed by bare-root cuttings (32% on average). Container-grown seedlings represented 7% of planted stock and 1% were container-grown cuttings. Planters are interested in using more bare-root cuttings but have difficulty obtaining sufficient stock.
- **Most respondents preferred planting bare-root cuttings versus seedlings**. Four respondents considered rooted cuttings (particularly bare-root) were better for topple-prone sites, three considered the resilience of cuttings was greater on harsher sites, three used a strategic approach of matching different stock types to different sites (cuttings on harsher sites, seedlings elsewhere), two preferred cuttings for multiplying CP seed and genetic gain but four found seedlings were cheaper.
- Respondents planting containerised stock preferred the Norwegian container brand, the paper Ellepot.
- Obtaining enough planting stock of sufficient quality followed by finding sufficient skilled planters at the right time were the highest ranked constraints to planting operations.
- Containerised stock is more expensive than bare-root stock. Extra costs are also associated with the extra weight of the planting boxes filled with containerised stock so planters require a higher rate of pay.
- Opinions were split on whether bare-root or containerised stock performs better in the field. However, a popular option was to plant a mix of stock types depending on the site conditions and time of year for planting operations.
- **Limited empirical information exists on optimum planting windows for containerised stock resulting in a wide range of planting times used by the New Zealand industry**. However,

respondents consider that using containerised stock lessens the risk when being forced to plant outside the optimum planting time (as stock is either available and/or is perceived to perform better).

- **What they could foresee happening in the next 5 years** - most respondents thought that either there would be *'Approximately the same area planted in radiata pine'* and some thought there would be a '*A shift in types of nursery stock that we are planting'*.
- **Type of nursery stock they could foresee planting 5 years from now** - decrease in the proportion of bare-root seedlings planted, and an increase in the proportion of containerised cuttings planted.
- **The top drivers of change** were *'New technological developments (such as mechanised planting systems)'* and *'Legislative/political changes leading to a decrease in radiata-pine planting',* followed by *'Labour costs and availability'.*
- **There are stock supply issues** - Many respondents had issues with getting a full supply of stock, or getting the stock type they want, particularly bare-rooted cuttings so are forced to plant seedlings instead.
- **Regarding their specifications for a quality planting stock**, similar to the Nursery Survey, there are some clear inconsistencies for specifications. The inconsistencies were particularly in height and diameter specifications and whether the shoots should be topped or not.
- **Knowledge gaps** – The main themes were root issues, including: looking at root architecture post-planting; relative performance of bare-root and containerised stock on different sites, and in different locations nationwide (including southern and ex-farm sites); and containerised handling systems, site access restrictions and logistics, and planting methods, including use of the Pottiputki planting tool**.**

Key outcomes and knowledge gaps in New Zealand

The two industry surveys provide an indication of current industry knowledge and practitioner perceptions and experience in planting stock production through to forest establishment. This and a review of relevant New Zealand and international scientific literature, and industry and government reports, helps provide information to formulate R&D priorities regarding containerised stock, planting stock specifications and field performance.

1. Research is urgently needed, in collaboration with nurseries and forest growers, to determine optimum specifications (height and diameter) for containerised radiata-pine stock for the range of sites that are likely to be planted in the foreseeable future. Defining the ideal container is also important. However, there is strong interest in the Ellepot among both nursery practitioners and forestry planters.
2. Concurrently, research to define the optimal window for planting containerised stock is also needed on a range of sites throughout the country.
3. A database of historic and forestry company planting-stock trials is needed (where companies are willing to share data and outcomes). While these trials may not all have an ideal experimental design, measuring these trials and sharing outcomes could provide valuable information of comparative field performance.
4. If planting machines are to become an important part of the forest industry in New Zealand, there needs to be integration and optimisation across the value chain from propagation through to planting and establishment. For example, the ideal match of planting stock specifications to planting machine requirements needs to be determined. Plant specifications that have proven to result in good field performance for manual planting may not suit planting machines resulting in stock that cannot be used and machines that don't perform well.
5. Availability of labour is a major constraint in both nursery and planting operations, therefore, efforts to increase mechanisation across the entire supply chain are warranted.
6. One of the most significant knowledge gaps is the link between the specifications for quality (container or bare-root) stock and the requirements for integration with mechanised planting machinery. Bare-root nursery production will likely remain an important part of planting stock production in New Zealand (and for good reasons) therefore, it is recommended that industry determine the need or desire to procure or develop planting machines that are compatible with bare-root stock.

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APPENDIX 1 - LITERATURE REVIEW

Methods

Published information was sought on the following topics:

1. An overview of propagation and deployment systems for radiata pine in New Zealand.
2. Data on number and type of radiata-pine stock being planted in New Zealand.
3. Stock types.
4. Plant quality.
5. Constraints, emerging issues and trends regarding propagation and deployment of radiata pine in New Zealand and overseas.
6. Relative field performance of radiata-pine containerised and bare-root stock.
7. Recommended specifications for container-grown stock and bare-root stock in New Zealand.
8. Mechanised planting systems and requirements for planting stock.

Key publications and forestry industry reports were identified in the literature collection of the author, within Scion databases, and through online global literature searches. Relevant references were also identified via citations in key papers. Online search tools ResearchGate and ScienceDirect were used and searches based on key words were undertaken in two key journals - the *New Zealand Journal of Forestry Science* and the *New Zealand Journal of Forestry*. General on-line searches also included publicly available government and industry reports.

Results

An overview of propagation and deployment systems for radiata pine in New Zealand.

In recent years, radiata pine has accounted for about 90% of the forest plantation estate in New Zealand (Manley 2023; Ministry for Primary Industries 2023a). Radiata-pine forestry is also economically important in Chile and Australia, and as well as being extensively planted in parts of Spain and South Africa (Mead 2013). Profitable radiata-pine plantation forestry depends on the successful propagation and deployment of genetically improved planting stock.

Radiata pine is native to California, USA, and Baja California, Mexico. Although there are only five small natural populations, it has become the most extensively planted exotic softwood species in the world (Mead 2013). The first radiata-pine plantations were established in New Zealand in the 1870s. It proved to be a highly adaptable species, performing well over a wide range of sites throughout New Zealand. Large-scale planting started in the Great Depression during the 1930s (Mead 2013; Ministry for Primary Industries 2022).

The New Zealand 'land race' of radiata pine was highly variable, suggesting significant genetic gains could be achieved (Shelbourne *et al*. 1986; Mead 2013). The New Zealand radiata-pine breeding programme was initiated in 1953 with plus-trees in the local 'land race' initially selected primarily for growth and form (Shelbourne & Carson 2019), cited in (McLean *et al*. 2023). The first open-pollinated seed orchard was established in 1957 (Shelbourne *et al*. 1986). Breeding for disease resistance and wood-quality traits were included later in the programme.

The control-pollinated (CP) seed orchard concept was developed in the 1980s and 1990s in New Zealand. Crosses were made between the top selected male and female parents to produce CP seed (Carson 1986) and included 'family' forestry, i.e., multiplication and deployment of CP seed from elite families (Carson & Burdon 1989). This approach significantly increased the genetic gain obtained from the resulting progeny compared to open-pollinated orchards, but the labour and seed-production costs were much greater (Horgan 1993; Mead 2013).

Estimates of realised genetic gains for radiata pine using data from a wide range of field trial site types throughout New Zealand showed highly improved (GF Plus 25[a]) seedlots had 25% greater total volume at age 30 years than unimproved (GF Plus 9.9[a]) seedlots (Kimberley *et al*. 2015). More recently, genomic selection has been utilised to accelerate genetic gain through early selection (McLean *et al*. 2023).

The genetic gains from the radiata-pine breeding programme would not have been realised without good propagation and planting practices. Poor propagation and planting practices will result in poor field performance no matter how good the genetics are.

Radiata pine is relatively easy to propagate vegetatively either as cuttings from juvenile plants or via micropropagation. Development of vegetative propagation systems enabled scarce elite CP seed to be multiplied cost effectively and economic gains from the radiata-pine tree improvement programme could be quickly realised. New systems included juvenile rooted cuttings (from nursery stool-beds), micropropagation, and somatic embryogenesis (Horgan 1993; Horgan *et al*. 1997; Menzies & Aimers-Halliday 2004; Mead 2013). Also, young seedlings proved easy to vegetatively propagate, which helped bulk up supplies of scarce and expensive seed orchard seed, thus extending availability and diluting the costs of expensive CP seed (Menzies & Klomp 1988; Horgan 1993; Menzies *et al*. 2001; Aimers-Halliday *et al*. 2003; Menzies *et al*. 2005). However, vegetative propagation from donor plants becomes more difficult as they increase in age and the growth of the propagules declines with increasing donor age (Menzies & Klomp 1988; Horgan 1993; Menzies *et al*. 2001; Aimers-Halliday *et al*. 2003; Menzies *et al*. 2005).

A 'sweet spot' was found where slight maturation in nursery stool-beds could be exploited to help improve tree form without compromising the growth rate of propagules (Aimers-Halliday *et al*. 2003; Holden & Menzies 2005). Extensive field tests were established with rooted cuttings derived from donor trees with a physiological age (maturation state) of less than five years. Performance was compared with conventional seedlings on both farm and forest sites. Results from these trials showed that considerable improvement in form could be achieved without any loss of growth by planting rooted cuttings generated from juvenile donor plants compared with seedlings (Holden & Menzies 2005).

Clonal forestry[b] has been another important, but challenging, development that required considerable research (Aimers-Halliday *et al*. 1997; Aimers-Halliday & Burdon 2003; Burdon & Aimers-Halliday 2006) before it became operationally feasible and commercialised (Menzies & Aimers-Halliday 2004; Sorensson & Shelbourne 2005; Mead 2013; McLean *et al*. 2023; Reeves *et al*. 2023). Somatic embryogenesis is used in combination with cryopreservation, which allows for clonal storage during the clonal testing phase, thus circumventing the maturation barrier. However, only some genotypes within a limited number of families are amenable to propagation via somatic embryogenesis, which is a major drawback (Carson 2019; (Montalbán & Moncaleán 2019).

In summary, genetically improved radiata pine in New Zealand is deployed as:

(i) Seedlings derived from seed-orchard seed, or 'stand select' seedlots[c].

(ii) Vegetatively propagated CP seed, either from cuttings or micropropagation systems.

(iii) Clonal stock, i.e., specific, tested genotypes, clonally propagated and planted in monoclonal blocks or clonal mixtures tested clones, largely deployed via somatic embryogenesis and cryopreservation systems.

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[a] *Note: GF is a rating for growth and form used to rank the genetic improvement of radiata-pine seedlots*

[b] *Clonal forestry involves deployment of identified and tested clones, capturing even greater genetic gains, and allowing for more precise matching of genotypes to sites, forestry regimes, and specific end uses.*

[c] https://www.proseed.co.nz/catalogue/radiata-pine

Data on number and type of radiata-pine stock being planted in New Zealand.

A survey of 32 commercial forestry nurseries by the Ministry for Primary Industries (Ministry for Primary Industries 2022) showed that radiata-pine planting stock sales were steady between 2014 and 2017 (46 – 48 million) but more than doubled over the next five years to 114 million units in 2022 despite disruptions to site preparation and subsequent planting caused by the COVID-19 pandemic (Bayne 2021). Possible reasons for this increase include the Government's 'One Billion Trees' programme (Te Uru Rakau 2018) and high carbon and log prices (Ministry for Primary Industries 2022). Provisional data for 2023 indicated 113 million radiata pine were planted over an area of 111,000 ha[d].

The number of cuttings/clones in the radiata-pine planting stock sales from 2003 – 2021, varied from a low of 8.1 million in 2007 (22% of total planting stock sales for that year) to a high of 18.4 million in 2021 (20% of total planting stock sales for that year) (Ministry for Primary Industries 2022).

From 2012 to 2017, the **proportion of planting stock derived from control-pollinated seed, including seedlings, rooted cuttings, and clonal stock increased.** Recent growth in planting stock demand has put pressure on availability of planting stock derived from control-pollinated (CP) seed, which has resulted in higher reliance on alternatives, i.e., seedlings from 'Stand Select' (selected stands in Kaingaroa) and open-pollinated seedlots (Ministry for Primary Industries 2022).

A survey of afforestation and deforestation intentions in late 2022 (Manley 2023) found 28 exotic forestry respondents (out of 65 in total) referred to the limited tree stocks available from nurseries as a barrier to afforestation with a further three noting shortages of genetically improved material (shortage of stock derived from CP seed). Nine respondents highlighted the challenges in acquiring land, while eight said that labour availability (planting crew and nursery labour) was a barrier.

The substantial increase in planting in the last 5 to 6 years has put pressure on forestry nursery and planting operations. It has particularly highlighted problems with labour shortages for lifting bare-root planting stock from nursery beds and subsequent planting operations, which was further exacerbated by the COVID-19 pandemic (Klinger 2022; Klinger, Ford *et al*. 2022).

Stock types

There are three main types of radiata-pine planting stock grown in New Zealand:

(i) **Bare-root planting stock**, which is produced in nursery beds and lifted immediately prior to planting. Most of the soil is lost from the root system, along with many of the fine roots (Menzies *et al*. 2001; Menzies *et al*. 2005) prior to transport and re-planting. Root systems are trimmed after lifting (Menzies *et al*. 2005; Mead 2013).

(ii) **Containerised stock**, which is grown in potting media in various types of containers. Ideally, the potting media around the root systems is retained during transport and planting. Containerised stock can either be grown in a controlled greenhouse environment or on benches in an open nursery environment (Grossnickle & Ivetić 2022) with the latter more common in New Zealand (Menzies *et al*. 2005; Mead 2013).

(iii) **Hybrid systems**, such as mini-plugs, that are subsequently lined out in nursery beds. For example, somatic plantlets can be multiplied via juvenile cuttings systems to bulk up scarce, expensive plant material and/or improve plant quality (Menzies & Aimers-Halliday 2004). Hybrid systems are still relatively uncommon, but use is increasing use internationally (Grossnickle & Ivetić 2022) and in New Zealand (Mead 2013).

[d] *The nursery survey and the associated modelling are only intended to provide early approximations of the areas of total planting and planting by species or species groups for the year. These are subsequently revised as necessary when data are received directly from forest owners through the annual survey for the National Exotic Forest Description (NEFD).*

The **advantages and disadvantages of all available stock types** must be recognised in order for informed decisions to be made on the most suitable stock for conditions at a particular planting site (Grossnickle 2005). In addition, **information on field performance of different stock types is essential**. Such information is obtained from the establishment of well-designed field trials over a variety of sites and multiple years (Horgan 1993).

Bare-root nursery propagation systems for radiata pine predominate in New Zealand (Mead 2013; Bayne 2021), Chile, and most of Australia (Mead 2013). Containerised systems for radiata-pine planting stock are more common in Spain, South Africa, and Western Australia (Mead 2013). Internationally, there is an increasing trend towards containerised systems (Mead 2013; Klinger 2022; Klinger, Lloyd, *et al*. 2022). Development of containerised systems has mostly proceeded in Northern Hemisphere countries where field-grown (bare-root) stock can take years to get big enough to transplant. Instead, state-of-the-art glasshouse technology is used to produce seedlings big enough to plant out in under a year (Dr Rowland Burdon, pers. comm.).

Little published data exists on the amount of containerised versus bare-root radiata-pine planting stock currently being deployed in New Zealand. However, increased interest in containerised stock has been reported by various authors (Menzies *et al*. 2008; Mead 2013; Bader 2016). Survey results from Bayne (2021) indicated that approximately 89% of New Zealand's radiata-pine planting stock produced in 2020 was bare-root and with the remaining 11% being containerised stock. However, there may have been a higher proportion of containerised stock produced in 2020 due to pandemic disruptions.

Plant quality and field performance

Research to improve bare-root nursery practices in New Zealand over many years has generated appropriate root systems and physical dimensions for optimising field performance (van Dorsser & Rook 1972; Menzies *et al*. 2001; Menzies *et al*. 2005; Mead 2013). Nursery practices such as the spacing of seedlings, root-culturing treatments (e.g., undercutting and wrenching), and judicious topping seedlings to control top growth have ensured a sturdy plant is produced that has a balanced shoot/root ratio.

In contrast, there has been limited research on development of containerised planting stock in New Zealand, particularly in regard to field performance (Nelson 1996; Menzies *et al.* 2001; Mead 2013; Klinger *et al.* 2022; Nanayakkara *et al.* 2022). In a paper on trends in nursery practices in New Zealand, Menzies *et al.* (2001) recommended more research to determine what plant quality standards are required for containerised stock to ensure successful establishment.

Nelson (1996) reviewed container types and containerised stock for afforestation in New Zealand. He contended that the wealth of information and experience with containerised planting stock available internationally should give New Zealand foresters confidence to use containerised stock, particularly as local experience was gained. However, he also noted that "*There is a growing body of evidence indicating that the parameters important for containerised stock are different from those for bare-root stock*". The relatively slow uptake of containerised stock by the radiata-pine industry over the last 25 years is due, at least in part, to the very limited number of field trials scientifically designed to objectively test the field performance of containerised stock alongside standard bare-root planting stock.

Early research in New Zealand indicated the potential benefits of containerised stock, particularly for harsh sites. However, container-induced root deformities were found to have a negative impact on field performance, which reduced uptake of container-grown stock and limited further research and development in containerised systems (G.C.B. Baker 1982; Nanayakkara *et al*. 2022). Bare-root cuttings propagation systems were also being extensively researched, and subsequently became routine practice (Menzies *et al*. 1988; Menzies *et al*. 2001; Menzies *et al*. 2005; Mead 2013). Containerised propagation was developed in the 1990s for vegetative propagules in New Zealand (Nelson 1996) but was used primarily for propagation of clonal planting stock (Menzies *et al*. 2008).

Nelson (1996) also emphasised the importance of incorporating lateral root pruning within the container design, as this helps reduce the risk of root deformation, which was a problem with many earlier container designs. Fortunately, container types that allow for lateral root pruning have had a quick uptake in New Zealand (Nelson 1996; Menzies *et al*. 2001; Menzies *et al*. 2005; Lloyd & Klinger 2022). Avoiding root deformation is critical for field performance. Nelson (1996) also recommended planting stock that was well hardened and larger (thicker root-collar diameter) for more difficult sites.

While there has been very limited published research on containerised propagation systems and field performance in New Zealand (Menzies et al. 2008), there has been a wealth of overseas research comparing plant quality and subsequent field performance of bare-root and containerised nursery stock. Mead (2013) provides a good overview in regard to radiata pine, grown in New Zealand and elsewhere. Reviews by Grossnickle and El-Kassaby (2016), Grossnickle and Ivetić (2022), and Klinger et al. (2022) provide an international context covering major forestry plantation species and different stock types. These reviews include physiological aspects of plant quality as well as readily measurable morphological traits.

The physiological quality of planting stock is difficult to measure but can be assessed on a small sample of nursery stock. It should be assessed as part of research and development where changes in nursery practice and variations of current types of planting stock are being considered. Also, physiological measurements often involve destructive sampling so do not substitute for easily measured morphological grading on an operational scale. Rook and Menzies (1981) tested various assessment methods of physiological quality on radiata-pine bare-root stock in New Zealand and recommended the root-growth potential technique.

Specifications for determining plant quality are described further in Sections that follow.

Nursery practices for producing quality container-grown planting stock are well documented in the international literature, e.g., in the review by Grossnickle and Ivetić (2022). The importance of root growth potential, root/shoot ratio, and food stores (or sturdiness used as a proxy) were expounded by Grossnickle and Ivetić (2022). They contend that root growth potential and field performance are inextricably linked and review international research on nursery practices designed to produce planting stock with a fibrous root system with good root growth potential.

Container size, shape, design and growing regimes are critically important to plant quality (Grossnickle & Ivetić 2022). Container types that improve root morphology, including direction and depth of root development, are linked to better survival and growth after planting. Also, containers must have bottom openings, and nursery benches must be set up to provide an air space under the containers to allow for drainage and air pruning of the roots. This also allows for inoculation of symbiotic mycorrhizae, which is important for field performance (Mead 2013; Nanayakkara *et al*. 2022).

Root development needs to fill up the container and hold the growing medium together in a structurally sound unit, so it doesn't fall apart when removed from the container prior to planting (Grossnickle & Ivetić 2022). However, growing planting stock for too long within a container causes excessive root coiling and restriction, i.e., plants can become root-bound, which will have a negative impact on subsequent field performance. Problems with root coiling and spirally in containers have been linked to weakened anchoring of trees (Grossnickle & Ivetić 2022; Lloyd & Klinger 2022). An assessment of root morphology of container-grown and bare-root radiata-pine planting stock in New Zealand indicated some differences between stock types (Holden & Dibley 2002). Root spiralling was virtually non-existent in bare-root stock, but the roots often appeared to have been flattened into one plane at planting. There was considerable root spiralling in some container-grown stock that depended on container type. Hiko container-grown stock had approximately 20% of spiralled roots spiralling, whereas smaller containers (BCC and Lannen types) produced slightly better root systems, with a lower number of spiralling roots. Also, it is more expensive to grow stock in large containers, so there are always trade-offs between container volume, plant quality, and cost-effectiveness (Menzies *et al*. 2001; Menzies *et al*. 2008).

Various morphological traits can be used as a proxy for physiological quality. Root/shoot ratio gives an indication of the rate of water uptake by the root system, relative to the rate of transpiration (water loss) by the foliage. Height/diameter ratio (sturdiness) gives a good indication of the food reserves (carbohydrates stored in the plant) and, therefore, the ability of the plant to survive the stress of the initial establishment phase, until it can sufficiently photosynthesise and resume active growth. Carbohydrate stores are particularly relevant for bare-root stock, which lose most of their fine roots when lifted from nursery beds (Menzies 1988). The importance of root-growth potential, root/shoot ratio, and food stores (or sturdiness used as a proxy) for producing quality container-grown planting stock overseas were also expounded by Grossnickle and Ivetić (2022). They contended that **root mass is generally related to root growth potential, which is an important predictor of field performance**. However, Grossnickle and Ivetić (2022) considered that morphological attributes in isolation will not define the physiological status of planting stock.

Relative field performance of radiata-pine containerised and bare-root stock

An international review comparing bare-root and containerised stock across a range of field sites (and with a range of forestry species) showed that **container-grown stock typically had a greater survival on drought-prone sites** (in 61% of trials, n=122), but there were comparable survival rates for both stock types on sites where there was less stress after planting (Grossnickle & El-Kassaby 2016). This finding was confirmed in more recent international field trials and has been linked to containerised stock having less water stress after planting (Grossnickle & Ivetić 2022).

Containerised systems typically produce planting stock with a lower shoot-to-root ratio and a greater root growth potential compared with bare-root stock, conferring a greater tolerance of dry conditions and better field performance on harsher sites. Containerised plants tended to have a more fibrous root system, a greater number of root initiation points, and a greater total root length. Also, the container plug acts as a source of water and nutrient storage, which supports field performance once planted. However, bare-root and containerised stock generally have comparable field performance on all sites once plantings are established (Grossnickle & El-Kassaby 2016).

Research in New Zealand has indicated the potential benefits of containerised stock especially for harsh sites (G.C.B. Baker 1982; Menzies & Arnott 1992). More hardened and larger stock (particularly a larger root collar diameter) are recommended for these sites (Nelson 1996). The advantages of containerised plants are particularly evident on critical sites, i.e., dry, cold, and higher elevation sites (Klinger 2022).

Toppling can cause major problems in radiata-pine stands in New Zealand (Mason 1985; Trewin 2003; Moore *et al*. 2008). Toppled trees are not blown completely over, but instead attain a lean that exceeds 15° from vertical. Severely toppled trees have a poor chance of survival. Those with a slight to moderate lean can recover, though they develop butt sweep, which can severely reduce their value at harvest (Mason 1985; Trewin 2003). Therefore, **planting stock quality in New Zealand is important for resistance to topple** as well as survival and early growth (Rook & Menzies 1981).

Factors contributing to toppling of radiata pine in the field include inappropriate nursery growing conditions, planting stock with distorted root systems, genetic factors, and poor planting methods (Ortega *et al*. 2006; Mead 2013). Ortega *et al*.'s study (2006) found root deformations of radiata-pine planting stock were more frequent and severe in seedlings grown in closed-wall containers. Seedlings grown in containers that permitted lateral air pruning had lower biomass production but had a more balanced root and stem development. Container size had a significant effect on height. Generally, bigger containers resulted in greater seedling height compared with smaller containers. However, the faster-growing trees showed more problems of stability than plants with a balanced root and stem development. Confinement of roots in small containers can result in serious root distortion (root-bound plants). Problems were noted with roots of some containerised cuttings growing upwards towards the surface, forming a bird's nest configuration. Also, an investigation into toppling of 1-year-old container-grown stock revealed that the plug had been squashed up and the roots deformed at planting (Trewin 2003, 2005). These issues make it hard for the tree to form anchoring roots and become wind firm. Many of the problems encountered with container-grown stock in the past were due to the roots becoming deformed once they made contact with the container but improvements in design of containers and nursery regimes for raising containerised stock have dramatically reduced these problems (Moore *et al*. 2008; Lloyd & Klinger 2022).

Toppling is particularly prevalent on fertile ex-farm sites, on wet, heavy soils, and where there are strong turbulent winds (Mason 1985; Moore *et al*. 2008). Root distortion caused by propagation practices or poor planting can increase the risk of toppling but there are many confounding factors in field trials, and resistance to toppling is inherently difficult to test due to the lack of control of weather events that cause topple. Some forest managers consider that susceptibility to toppling can be influenced by the choice of planting stock but the link between stock types, root deformations, and toppling have not been definitively proved with radiata pine (Moore *et al*. 2008).

Container-grown stock from 10 field trials exhibited slightly less topple than the bare-root stock, particularly on farm sites, though this may have been related to the smaller size of the container-grown stock at planting, rather than their inherent stability (Aimers-Halliday *et al*. 1999).

A 2008 New Zealand study evaluated commercially-available containers for raising radiata-pine seedlings and cuttings. Fifteen types of commercially-available containers were looked at, ranging in size from 85 to 220 mL, with different shapes and surface areas (Menzies *et al*. 2008). At the time of study, the choice of containers being used operationally appeared to be based largely on price, with trade-offs between container volume, plant quality, and cost-effectiveness. More recently, a report by (Klinger, Ford *et al*. 2022) provided a review of containerised stock with information and recommendations on container size, design, and growing media – for exotic and native species in New Zealand. It also highlighted the advantages and common pitfalls of containerised systems.

The long-term effects of <u>bare-root</u> seedling root form on mechanical stability were reported to be minor internationally (Grossnickle & El-Kassaby 2016), but this is not in accordance with many observations of stability issues with bare-root radiata-pine stock in New Zealand (Mason 1985; Trewin 2003; Watson & Tombleson 2004; Trewin 2005; Moore *et al*. 2008; Mead 2013). Many of the problems encountered with container-grown stock in the past were due to the roots becoming deformed once they made contact with the container but improvements in design of containers and nursery regimes for raising containerised stock have dramatically reduced these problems (Moore *et al*. 2008; Lloyd & Klinger 2022). Holden and Dibley (2002) considered the 'ideal' root system to have a well-developed tap-root or sinker roots heading vertically down, and lateral roots distributed around the stem in all four quadrants to ensure the tree is well anchored and unlikely to topple. The lateral roots should come straight out from the tap-root and not spiral around through more than one quadrant. Roots spiralling around the tap-root can subsequently cause weak zones due to strangulation of the tap-root (or sinker roots) as it grows in diameter. Spiralling roots are either the result of poor planting or a flawed container design.

Constraints, emerging issues and trends regarding propagation and deployment of radiata pine in New Zealand and overseas.

The most commonly cited reasons, internationally, for changing from bare-root to containerised stock production are:

a. the reduced production period with containerised stock;
b. labour shortages in nursery lifting (of bare-root stock) and in planting operations;
c. potential to extend the planting season;
d. compatibility with mechanised planting systems; and
e. use of vegetative propagation to multiply scarce, elite genetic material

Reduced production period is less relevant in New Zealand than in other countries due to the mild climate and fertile soils. Also, the growth pattern of radiata pine in New Zealand (particularly, a lack of true dormancy) means that bare-root stock can be produced in a relatively short period of time compared with many overseas operations (Mead 2013). Historically, a low population density and good availability of arable land in New Zealand have been factors in the development and predominance of bare-root forestry nurseries, although land availability has changed as the population has grown and cities have expanded.

In terms of labour shortages and ability to extend the planting season, these are important drivers in New Zealand for switching to containerised systems (Menzies *et al.* 2008; Baker 2018; Petro 2022; Klinger *et al.* 2022; Klinger 2022). Nursery managers expect labour costs for lifting bare-root stock to increase due to higher labour demand (Klinger *et al.* 2021, 2022). An extended planting season offers greater employment certainty for nursery and planting contractors, with more continuity for the work force. The benefits of increased flexibility in dispatching and planting times were highlighted by the COVID-19 lockdowns (Klinger 2022). However, there has been increased automation within some bare-root nurseries in New Zealand, to varying degrees, which has improved efficiencies and lowered the demand for nursery labour (Nanayakkara *et al.* 2022). Murray's Nursery[e] in Tararua is an example of a highly automated bare-root nursery.

Regardless, the availability of labour for lifting in nurseries and planting has been an ongoing problem in New Zealand. The growing interest among some forestry companies in mechanised planting as a potential strategy to overcome labour shortages, has become a driver for a switch to containerised planting stock in New Zealand (Baker 2018; Klinger 2022; Petro 2022). Most modern planting machines require containerised stock. This is discussed further, below.

Part of the increasing interest in containerised systems in New Zealand has been for vegetative propagation of expensive clonal material, due to the added labelling and identity verification needed for clonal genotypes (Nelson 1996; Aimers-Halliday & Burdon 2003; Menzies *et al*. 2008; Mead 2013; Klinger 2022; Klinger, Lloyd, *et al*. 2022; Nanayakkara *et al*. 2022). However, clonal material is also being successfully propagated via bare-root systems at Arborgen (Mark Ryan, pers. com.).

Klinger (2022) noted that establishing a containerised nursery incurs high initial capital costs. Regardless, some of New Zealand's major forestry nursery operations have made the decision to grow containerised planting stock, as they see it as a profitable business case despite the high initial costs (Klinger 2022).

Supply chain logistics

Costs, logistics, and regulations are important when comparing the relative benefits of bare-root versus containerised planting stock.

The extended planting season, the benefits of increased flexibility in dispatching and planting times are big advantages for containerised stock (Klinger 2022). Also, automated, containerised propagation systems create better ergonomic working conditions, as nursery employees work at elevated propagation benches, in sheds, rather than crouching down in bare-root nursery beds (Klinger 2022).

Seasonal labour can be difficult to obtain for bare-root nursery operations that involve working in winter, outside, in often wet and cold weather, in muddy conditions. There are often erratic work-flows, so it can be hard to manage crews, particularly when planting operations are postponed, due to weather issues (Mark Ryan pers. com.). However, bare-root stock is much lighter and more compact to transport and carry (Menzies *et al*. 2008). This factor can be important if planting operations are in more remote areas, on steep terrain, and planting is done by hand. Planting contractors will often ask to be paid more money to plant heavier containerised stock as there is more weight to carry uphill (Peter Harington, pers. com.; Mark Ryan pers. com.). However, the more remote planting sites tend to have harsher conditions, and containerised stock tend to perform better on harsher sites (as discussed above). In addition, the cost of freight is higher for heavier containerised stock (Mark Ryan pers. com.). For safety reasons, the weight per box of planting stock is often limited, meaning that fewer container-grown plants are packed per box. The

[e] https://www.youtube.com/watch?v=luoVrN5lAWs

weight of the planting stock is no longer an issue once it reaches the planting site if planting is mechanised. However, mechanised planting machines are largely confined to more accessible, flat to rolling country (Petro 2022).

Another consideration is that bare-root stock is more sensitive to handling practices during lifting, storage, transport and planting, which can negatively affect field performance (Sharma *et al*. 2007; Mead 2013; Grossnickle & El-Kassaby 2016). **Once bare-root stock is lifted, any delay in planting will progressively result in declining food and water reserves** (Menzies *et al*. 2005). Containerised stock may be better for planting in remote sites, where there are longer transporting distances, or harsher conditions (Klinger, Ford *et al*. 2022) but there can be considerable mortality if there are long transportation delays between the nursery and the planting site (Peter Harington, pers. com.).

Increasing environmental regulations and social licence to practice are also becoming issues for bare-root nursery operations (Mark Ryan pers. com.). New Zealand is imposing more stringent rules on agrichemical use along with increasing restrictions and difficulties in getting resources consents for water take and use of fertiliser (Nanayakkara *et al*. 2022). This is making it increasingly difficult for bare-root nurseries to operate and creating a pressure to switch to containerised operations (Mark Ryan pers. com.)

Finally, containerised stock is generally more expensive to produce than bare-root stock (Mead 2013; Klinger *et al*. 2021). However, when considering deployment of elite genetic material, such as tested clones, this planting stock is far more expensive anyway, regardless of whether bare-root or containerised nursery propagation systems are used (Mead 2013). Another important consideration is survival. If containerised stock has higher survival on harsher sites, as indicated by research overseas (Grossnickle & El-Kassaby 2016; Grossnickle & Ivetić 2022), and in New Zealand (Baker 1982; Menzies & Arnott 1992) then the extra cost of containerised stock may well be worth it (Klinger *et al*. 2021).

Recommended specifications for container-grown stock and bare-root stock.

One size does not fit all- it is inherently difficult to come up with a set list of specifications because of the wide range of conditions at planting sites**.** The wide range of conditions present at planting sites make it difficult to produce appropriate planting stock with a high probability of survival and strong subsequent growth (Menzies & Arnott 1992; Nelson 1996; Mead 2013).

In New Zealand and internationally, planting-stock specifications have been based on morphological traits (Nelson 1996; Menzies *et al*. 2001; Menzies *et al*. 2005; Mead 2013). Commonly used traits are height, root collar diameter (RCD), sturdiness (height/diameter ratio), root/shoot ratio, and root features but no single trait is sufficient, i.e., a combination of traits is preferable (Menzies & Arnott 1992). For example, plant height by itself is a poor indicator of subsequent performance, as tall but very thin trees do not perform well. Sturdiness and RCD and are better indicators of planting stock quality (Menzies *et al*. 2001; Menzies *et al*. 2005).

Specifications for bare-root radiata-pine stock in New Zealand have been well defined (Menzies *et al*. 1988; Dibley & Clausen 1997; Menzies *et al*. 2001; Menzies *et al*. 2005)**. However, the same cannot be said for container grown plants. Specifications for container grown plants are not well defined in New Zealand**.

General specifications for <u>bare-root stock</u> are:

- Height 20 – 40 cm
- Diameter >5 mm (but > 6 mm for harsh or frosty sites)
- Sturdiness[f] <60 (all plants with a sturdiness ratio above 80 should be culled).
- Good fibrous root system

[f] *Sturdiness = height/diameter ratio, which is influenced by nursery environment and treatments*

More detailed specifications for bare-root seedlings and cuttings, and containerised cuttings (but not containerised seedlings) were provided by Menzies *et al*. (2005):

- Height: 20 to 30 cm (no separate specifications for different stock types)
- Diameter (RCD): at least 5 mm for bare-root seedlings; at least 7 to 8 mm for bare-root cuttings; and at least 4.5 to 5 mm for container-grown cuttings;
- Sturdiness: 45 for bare-root seedlings grown in high-elevation nurseries, or those with heavier soils or 60 for nurseries with light soils.
- Root system quality:
  - Bare-root seedlings should have a compact root system, with lateral roots trimmed to about 10 cm, and moist fine roots and mycorrhizae.
  - Bare-root cuttings should have roots emerging evenly from around the base of the cutting, preferably with roots in four quadrants. Cuttings with roots in only one quadrant should not be accepted, as they will be susceptible to toppling.
  - Container-grown cuttings should bind the potting mix firmly, with roots vertically trained downwards and no root spiralling.

Distribution of lateral roots can affect the stability of trees in their first few years after planting. Generally, planting stock with lateral roots in at least three of the four quadrants around the tap root (for seedlings) or the cutting base (for cuttings) are considered desirable (Dibley & Clausen 1997; Holden & Dibley 2002).

Four field trials in New Zealand trials with radiata pine fascicle cuttings[g] raised as bare-root stock found that subsequent growth after planting was positively related to initial stock size, i.e., diameter, height, sturdiness, and bulk-index (diameter squared x height) (South *et al*., 2005). The authors concluded that good field performance could be expected when RCD ranged from 8 to 10 mm, and heights ranged from 25 to 40 cm (South *et al*., 2005).

According to another New Zealand forest industry report by Holden and Dibley (2002), the 'ideal' root system has a well-developed tap-root or sinker roots heading vertically down, and lateral roots distributed around the stem in all four quadrants. This will ensure the tree is well anchored and unlikely to topple. The lateral roots should come straight out from the tap-root and not spiral around through more than one quadrant. Roots spiralling around the tap-root can subsequently cause weak zones due to strangulation of the tap-root (or sinker roots) as it grows in diameter. Spiralling roots are either the result of poor planting or a flawed container design (Holden & Dibley 2002; South *et al*. 2005).

Specifications for containerised stock are not well quantified and will be different than for bare-root stock, particularly for vegetative propagules (Nelson 1996; Menzies *et al*. 2001; Klinger, Lloyd, *et al*. 2022). Development of container designs and containerised-stock nursery protocols over the last 30 years make historical specifications (e.g., Table 1 in Nelson (1996)) less meaningful. However, a review of the information available is provided. Container-grown seedlings are usually smaller than bare-root stock (Menzies *et al.* 2001; Mead 2013) and range from around 15 to 25 cm in height and 3 to 5 mm in diameter (Nelson 1996; Mead 2013), Table 1. Other than these papers, there is very limited published information listing specifications for containerised radiata-pine planting stock grown in New Zealand. Unfortunately, there is no information on whether this smaller size, relative to bare-root seedling stock, is important for subsequent field performance.

Klinger *et al* (2021), reported that smaller containerised stock types are cheaper to produce, easier to handle, and faster to correctly plant; however, they are more vulnerable, have a higher mortality on more exposed sites and where there is strong weed competition. Conversely, larger planting stock is more expensive, and handling and planting more difficult, but it is better suited to harsher conditions and where weed competition is a problem (Klinger, Ford *et al*. 2022).

[g] *Fascicle cuttings are primarily used for establishing stool-beds for clonal and family forestry.*

Table 1: Specifications for containerised planting stock from different published sources

Parameter	Study				
	Nelson (1996)	**Nelson (1996)**	**Nelson (1996)**	**Mead (2013)**	**Mead (2013)**
Stock type	Containerised	Containerised	Containerised	Containerised	Bare root
Site type	Good, well-prepared, fertile	Poor, droughty & shallow	Very difficult, exposed, droughty & shallow	Not specified	Not specified
Stem height (cm)	10 – 20	15 – 25	30 – 50	15 – 25	20 – 40
Root collar diameter (mm)	>3	>3.5	>4.5	3 – 5	>5
Planting density	<600 plants/m^2	<500 plants/m^2	<450 plants/m^2	Not specified	Not specified

Menzies *et al*. (2008) evaluated commercially-available containers for raising radiata-pine seedlings and cuttings in New Zealand. A minimum height of 20 cm, and a minimum root collar diameter of 3 mm were often specified (at the time of publication). The authors found that container shape did not have a consistent significant effect on plant size but a container cell size of at least 120 mL was required for 80% of stock to meet minimum size nursery-gate specifications. **The authors concluded that it was not possible to define a minimum plant specification for container-grown seedlings or cuttings without comparing the performance of different-sized plants in the field.** Possible differences in the way roots grow out from the container plug would also need to be evaluated in field trials.

In conclusion, there is a lack of consistency in the limited number of publications and industry reports on size specifications recommended for radiata-pine containerised planting stock in New Zealand so the ideal size for containerised seedling stock, based on field performance tested over a range of sites and seasons is not known.

There is no information on **optimal container sizes and shapes and potting media mixes required to produce containerised stock** that meet the minimum size specifications.

It is recommended that the work of Menzies *et al*. (2008) be repeated using the current range of containers in operational use today and continued on to field trials.

Mechanised planting systems and requirements for planting stock

Mechanised planting systems are being successfully used in Scandinavia, Brazil, USA, Canada, and more recently, in New Zealand and Australia (Innovotek 2023). Internationally, labour shortages and increased labour costs have been the main drivers for development of mechanical planting systems (Nieuwenhuis & Egan 2002; M. Baker 2018; Petro 2022).

Most planting machines used internationally are designed to work with containerised planting stocks. However, the New Zealand plantation-forest industry currently uses predominantly bare-root stock and manual labour for most planting operations (Mead 2013; M. Baker 2018; Petro 2022). Most bare-root stock is planted between May through to September. Specialised planting spades are used, and planting stock carried in planting bags, which generally contain 100 bare-root plants. It is a physically demanding task, and the planter and contractor are usually paid on a piece rate (Petro 2022).

Unfortunately, there is a lack of published information in the international literature linking specifications for planting stock with requirements for mechanised planting machinery.

An important question is whether the forestry industry is interested in developing mechanised systems for planting bare-root stock, or will the companies interested in mechanised planting be prepared to switch to containerised planting stock?

It is important that forestry nurseries provide planting stock with suitable specifications to ensure the success of planting with machines (Laine & Rantala 2013). Nanayakkara *et al*. (2022) emphasised the importance of working with a standardised stock-type. Research and development has been undertaken overseas on adapting seedling supply systems for mechanised tree planting, although largely around seedling packaging and increasing the efficiency of reloading systems, which is a major barrier to productivity of machine planting (Laine & Rantala 2013).

It is important to ensure that plant specifications that have proven to result in good field performance are not compromised to suit planting machines.

Potting media mixes suitable for containerised plants destined for mechanised planting need to be determined rather than simply adjusting existing media mixes. It is important to have appropriate media mixes and growing regimes to ensure the roots fill the container and bind the media, without the plant becoming root bound yet not compromise on media mixes that have been tested and proven to optimise plant quality.

Nanayakkara *et al*. (2022) also recommended further work to help guide industry specifications for planting stock, including determining optimal container sizes, plant-quality expectations, and site-specific media mixes for New Zealand situations.

There is a lack of published information in the international literature linking specifications for planting stock with requirements for mechanised planting machinery.

It is important to ensure that plant specifications proven to result in good field performance are not compromised to suit planting machines.

APPENDIX 2 – SURVEY SUMMARIES

Methods

Two surveys were conducted: a Nursery Survey for planting stock providers and a corresponding 'Planter Survey' specific for forestry growers. The aim of the surveys was to obtain information on the current (and predicted) status of production and subsequent planting of *radiata* pine planting stock. This included information on container and bare-root systems used, and anticipated trends, particularly in relation to potential use of planting machines.

A link to the Nursery Survey (Appendix 3) was emailed to nursery growers (Forest Nursery Growers Association members). A link to the Planters Survey (Appendix 4) was sent to forestry companies in the PSP network. The surveys were designed to have corresponding questions, to allow for cross referencing on key issues. For the larger companies, a request was made to forward the questionnaire to relevant regional managers in order to obtain responses that reflect the status across the industry and throughout New Zealand.

The surveys were aimed at collecting the following information:

- The type of planting stock currently being produced and planted.
- Nursery practitioners' and forestry growers' preference for planting stock, in terms of bare-root versus containerised and seedlings versus cuttings – based on relative field performance.
- The types of containers in use.
- The current specifications for container-grown stock, and the recommended 'ideal' specifications.
- Perceived issues and challenges for growing and planting container stock in New Zealand.
- If there is any information, anecdotal or based on field trials, on correlation with field performance.
- Whether there is likely to be an increasing demand for planting container stock, cuttings and seedlings.
- The cost of container stock versus bare-root stock.
- Growers' perspectives on the future of container stock versus bare-root stock in New Zealand.
- If there is an appetite for adoption of new and emerging container systems (e.g., Ellepot systems).
- Industry field trials testing planting stock types that companies are prepared to share.
- Knowledge gaps in industry with respect to deploying and using container -grown plants.

Nursery Survey Results

Section A: Information on the respondents and their nursery organisations

In total, 28 nurseries were contacted and 13 respondents completed the nursery survey questionnaire (Appendix 3), with 12 completed on-line via Survey Monkey, and one survey completed in a face-to-face interview. For the larger companies, a request was made to forward the questionnaire to relevant regional managers in order to capture responses that reflect the status of the industry throughout New Zealand.

This was a 46% response rate from all the nurseries contacted. The majority of the respondents (11 of the 13) were nursery managers or owners. Other respondents had the role of nursery operator, nursery supervisor, nursery R&D manager, ex-nursery manager, or they were in charge of labour management. Note that some respondents ticked multiple boxes for roles within their organisation. There was a good geographic spread of nursery operations, with some nurseries providing planting stock for clients throughout New Zealand, and others primarily supplying clients within their region. Three responses were from nurseries primarily supplying planting stock to South Island clients.

Section B: Respondents' current standard nursery operations

The 13 respondents reported that the average number of radiata-pine plants produced by per year (over the last 5 years) by their nursery operations, ranged from 20,000 to 13,000,000 (Figure 1), with an average of nearly 6,164,000[#]. The sum total number of planting stock units estimated to have been produced per year, averaged over the last 5 years, was 80,120,000. There was a good spread of small, medium, and large nurseries in the survey. Some of the nurseries only produced radiata-pine planting stock, while others produced planting stock for multiple species.

The number of radiata-pine plants each nursery anticipated selling this year (2023) ranged from 60,000 to 15,500,000 (Figure 1). The sum total number of planting stock units that the nurseries anticipated selling this year (2023) was estimated at 88,260,000 plants. As stated earlier, the Ministry for Primary Industries reported survey results of commercial forestry nurseries indicated that 91.8 million units of radiata-pine planting stock were sold in 2021 in New Zealand(Ministry for Primary Industries 2022). Therefore, it is safe to say that this Nursery Survey has captured responses from the bulk of the commercial forestry nurseries selling radiata-pine planting stock in New Zealand.

According to these Nursery Survey results, the majority (80% to 100%) of the radiata-pine planting stock sold by the North Island nurseries went to commercial forestry planting operations, and only a small proportion was sold to farm forestry operations. However, there were two South Island nurseries where farm forestry markets were important. One small, South Island containerised nursery sold all its stock to farm forestry planting operations, and a moderately large South Island bare-root nursery sold about an even 50:50 to commercial and farm forestry operations. The other South Island nursery, which produces a large quantity of stock (mostly bare-root) sells its stock largely to commercial forestry operations.

#. Please note there may be some errors in figures due to overlaps in information where we had multiple respondents from one company.

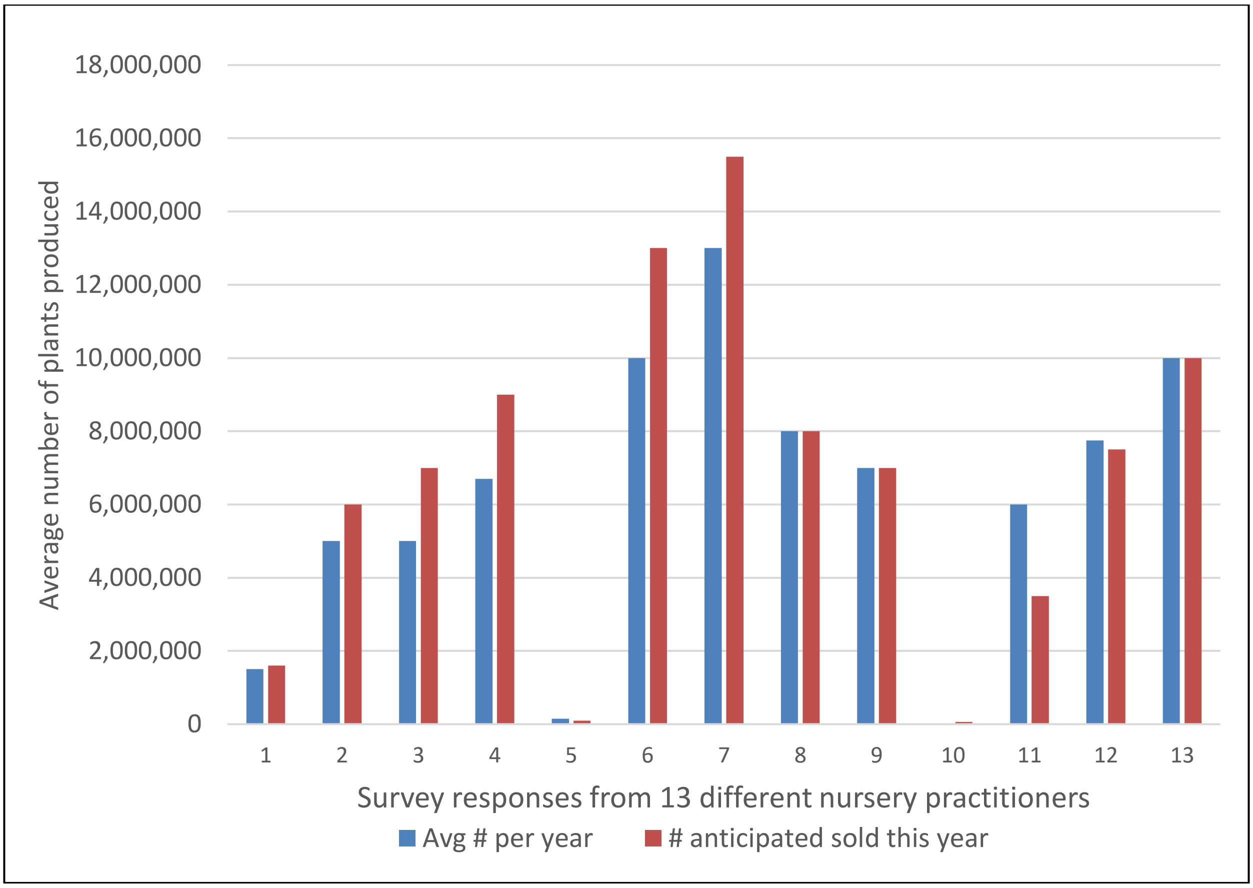


Figure 1: Average number of plants produced per year (over the last 5 years) and the number anticipated sold this year (2023). (Responses to Q.4 and Q.5).

According to the nursery survey results, the total number of bare-root planting stock (seedlings and cuttings) is just under 64 million, while the total number of containerised stock (seedlings, cuttings, and tissue-culture plantlets) is over 24 million.

Table 2: The types of planting stock the survey respondents are currently producing.

Type of planting stock	Total number across the 13 nurseries	Average Percentage
Bare-root seedlings	53,618,000	61
Bare-root cuttings	10,360,000	12
Container-grown seedlings	19,362,000	22
Container-grown cuttings	4,760,000	5
Container-grown tissue-culture plantlets	160,000	<1
Total number produced	88,260,000	

Overall, the proportion of bare-root plants is 73%, and the proportion of containerised plants is 27%.

There was considerable variation in the types of planting stock each of the nurseries in the survey are currently producing (Figure 2). Eight out of the 13 nurseries produced containerised stock. Some nurseries specialised, i.e., largely or totally producing just one type of planting stock. Two are producing only bare-root seedlings (Nurseries #3 and #7) and three are producing mostly bare-root seedlings (Nurseries #4, #6, and #13). Two nurseries are only producing container-grown seedlings (Nurseries #10 and #11). Six nurseries are producing two different types of planting stock (Nurseries #2, #4, #5, #6, #8 and #12). One nursery is producing three types of planting stock, although they are all container-grown, i.e., containerised seedlings, cuttings, and tissue culture plantlets (Nursery #1). One nursery is producing four types of planting stock, i.e., bare-root cuttings and seedlings, and container-grown cuttings and seedlings (Nurseries #9).

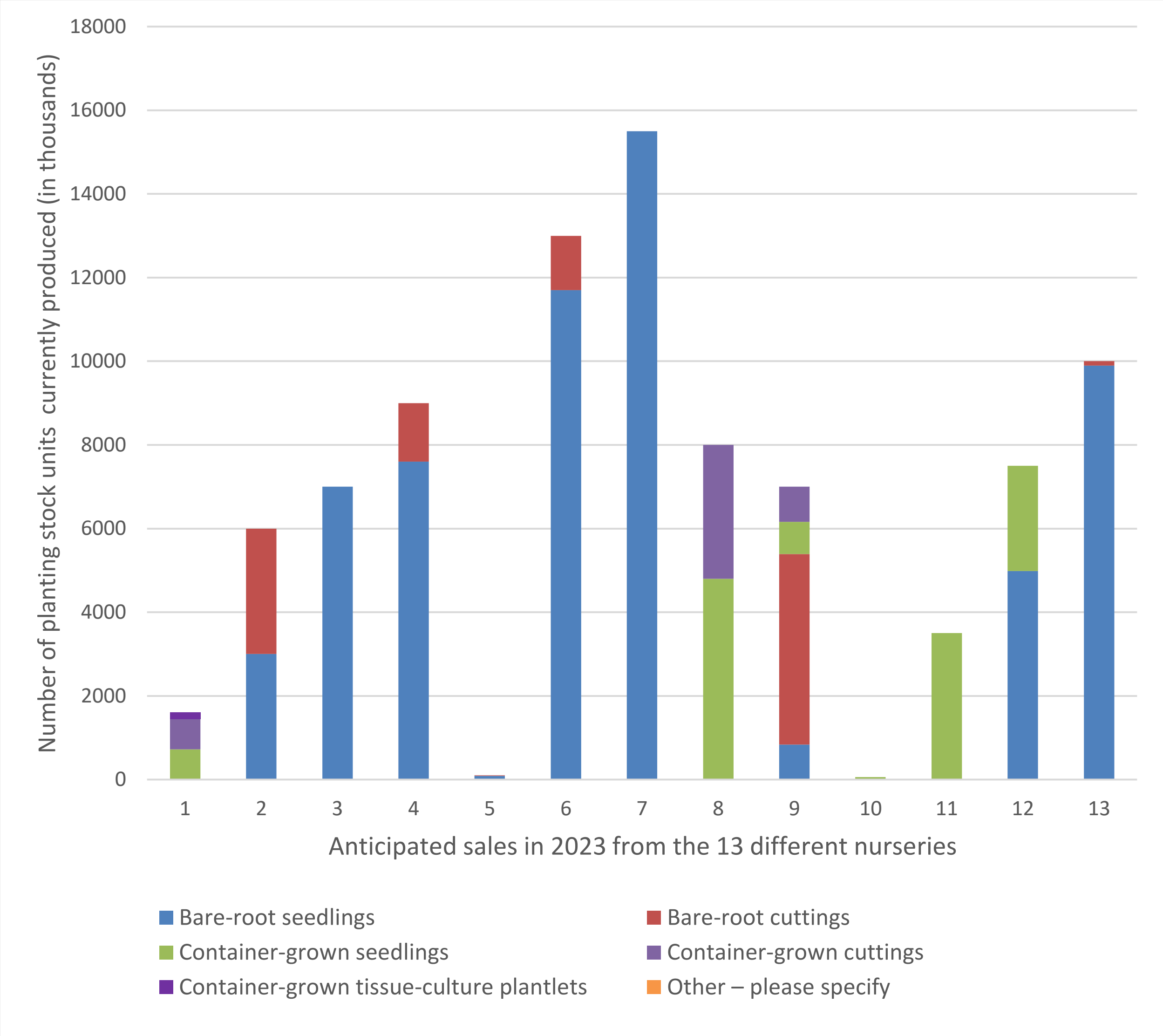


Figure 2: The type of radiata-pine planting stock the 13 nurseries are currently producing, in thousands (Response to Q.7, within total number anticipated sold from Q.5). Note that the figures are in thousands of planting stock units. We note that the information from nursery No.3 is not complete and may be incorrect.

Types of container currently used and the types of container preferred

Eight respondents provided information on the types of container currently used in their nurseries (Q.8); and the types of container they would prefer to use for radiata-pine propagation (Q.9) (Table 3). For Q.9, it was explained that their preference may differ from the type of containers actually being used in their nursery, as it may be dictated by available resources or the market. Note that the answers for Q.8 and Q.9 are aligned for each respondent in Table 3.

Table 3: The types of containers currently used (Q.8), and types of containers preferred (Q.9)

Types of container currently used	Types of container preferred
63F, 64F, TS48, Ellepots	Ellepot - ability to sort and consolidate
Ellepots and Jiffy pots	40 mm Ellepot
TS48 and 40 mm Ellepot	40 mm Ellepots because they appear to grow quicker, have better root form and hold better than TS48. We can direct sow either, but the Ellepots take longer to make than a TS48 takes to fill. Both sizes fit 100 in a forestry box.
64F	Plastic, we are in first year of containers and our set up is for Plastic

TS48, Proptec 48 cell, 40 mm Ellepot	Ellepot paper pots for cuttings, TS48 for seedlings.
Paper pot – 50 mm x 90 mm, Ellepot 100% from Nov 2022 (Production previously Lannen 63F and Hiko)	Paper pot showing rapid root development, but poor nursery holding potential (shorter sales window). Great for multi crop rotation and space conservation over the year.
Lannen 63F 80% bcc81 20%	63F volume of soil vs weight for planter to carry is a good balance
TS48, Ellepot	Ellepot, better performance of plugs, easier to lift, handles better. TS48, can get higher throughput on the machines vs current Ellepot setup.

The paper Ellepot proved to be a popular container type in this nursery growers' survey. Six out of the eight respondents who answered Q.8 are currently using the Ellepots, and there is a strong preference (six out of eight respondents) for the Ellepot (Q.9). The Ellepot is a preferred container type for multiple stated reasons, including logistical reasons and good root development (Table 3).

Constraints and limitations in nursery operations

In Q.10, the respondents were asked to rank the major constraints or limitations for their nursery operations. A list of constraints was provided and they were asked to rank them, with 1 being the most significant constraint, and 9 being the least significant constraint. The constraints listed in Q.10 were:

- Difficulties lining up enough skilled labour at the right time.
- Difficulty recruiting and retaining nursery staff with sufficient technical knowledge.
- Constraints due to limitations in nursery infrastructure, i.e., lack of space and equipment to meet current demand.
- Lack of capital to invest in new infrastructure.
- The challenges of meeting market specifications for planting stock.
- Slippage due to clients not taking stock on time.
- Lack of certainty in forestry industry regarding amount of, and/or type of planting stock required in near future.
- Nursery pathogens and the challenge of managing diseases such as terminal crook and Phytophthora.

All 13 respondents ranked each constraint and the averages of these rankings are provided in Table 4. The smallest score is for the issue that respondents ranked the most important constraint in getting their nursery operation, and the largest ranking score is for the constraint deemed the least important. The figures in blue in the Averaged Ranking column are above the mean average of 5 (i.e., the constraints ranked as having the most importance), and the figures in red are below this average (i.e., the less important constraints). The figure in black is the closest to the mean average of 5.0 for the rankings.

Table 4: Ranking of constraints or limitations in nursery operations (Q.10). The constraint listed at the top (smallest number) was the highest ranked constraint, and the constraint listed at the end (biggest number) is the lowest ranked constraint.

List of constraints ranked from greatest to least	Averaged Ranking	Range of Rankings
Difficulties lining up enough skilled labour at the right time	3.2	1 - 6
Difficulty recruiting and retaining nursery staff with sufficient technical knowledge	3.4	1 - 8
Constraints due to limitations in nursery infrastructure, i.e., lack of space and equipment to meet current demand	3.9	1 - 7
Nursery pathogens and the challenge of managing diseases such as terminal crook and *Phytophthora*	4.2	1 - 8

The challenges of meeting market specifications for planting stock	4.5	2 - 8
Lack of certainty in forestry industry regarding amount of, and/or type of planting stock required in near future	5.9	2 – 9
Lack of capital to invest in new infrastructure	6.2	2 - 9
Slippage due to clients not taking stock on time	6.2	1 - 8
Other, please specify …………………………………………	7.5	1 - 9

The highest ranked constraint was – *'Difficulties lining up enough skilled labour at the right time'*. Close behind this was – *'Difficulty recruiting and retaining nursery staff with sufficient technical knowledge'*. The constraint ranked third was – *'Constraints due to limitations in nursery infrastructure'*. There is a possibility of bias created by the way this question was set up in the survey, i.e., the respondents may have been influenced by the order of the constraints listed in the questionnaire. The first three constraints listed in the question ended up being ranked in the same order by the respondents. However, one listed constraint – *'Nursery pathogens and the challenge of managing diseases'* - was listed lowest in the list of constraints provided in the questionnaire, but was ranked fourth by the respondents at 4.2, and was above the average ranked score of 5.

Cost differences in the production of bare-root versus containerised stock

Survey participants were asked if there was a cost difference in the production of bare-root versus containerised stock (Q.11). All 13 respondents answered this question:

- Yes – seven respondents (54%)
- No – no respondents (0%)
- N/A (we don't produce both types of planting stock, so cannot make a comparison) – six respondents (46%).

The respondents who answered 'Yes', were subsequently asked to provide details, i.e., what is the more expensive stock type and where is the cost difference incurred? They were also asked (if their nursery produces different stock types), to comment on the relative cost differences in production of seedlings versus rooted cuttings, via both bare-root and containerised propagation systems.

Eight respondents provided the following comments:

- Containerised cuttings are by far more expensive, requiring higher skills set, mother plant stock management and lower plant/m² density.
- Containers are more costly by about 40 - 50%.
- Bare rooted are a lot less expensive than containerized with no special infrastructure required. Container cuttings require bottom heat and the cost of mycorrhizal inoculated plug.
- Containerised is likely more expensive but gives a longer planting season and spreads pressure on planting crews.
- Cuttings are approx. 50% more expensive due to cost of labour to sow, top and the cost of mix to go into trays.
- Cost to produce bare-root seedlings is cheaper than container, cuttings work out about the same through the two systems.
- Capital cost that you need to recoup on each seedling. Currently price does not allow for new container nurseries to be built.
- Different labour productivity between bare rooted and containerised systems, therefore the high labour input crops (clonal cuttings) being the most expensive, low input crops bare root seedlings being the cheapest to produce.

Of the eight respondents who commented, all indicated that containerised stock is more expensive, or far more expensive to produce than bare-root stock. The reasons for the cost difference were given as to the need more infrastructure and capital cost with containerisation, and potting media.

Section C: Future nursery operations

In Q.12, survey participants were asked what they could foresee happening in the next 5 years. They were given five options to tick, with the capacity to choose multiple options. All 13 survey participants answered this question (Table 5).

Table 5 – What trends do survey respondents foresee happening in the next 5 years? (Q.12)

What do respondents foresee happening in the next 5 years?	Number (percentage) selecting each option
An increase in demand for radiata-pine planting stock?	4 (31%)
Approximately the same demand for radiata-pine planting stock?	2 (15%)
A decrease in demand for radiata-pine planting stock?	6 (46%)
A shift in types of nursery stock that we are producing - please specify	6 (46%)

The options that were selected the most (by nearly half of the respondents) were *'A decrease in demand for radiata-pine planting stock'* and '*A shift in types of nursery stock that we are producing'*. However, there were some optimistic responses, with four respondents anticipating an increase in demand for radiata-pine stock, and two respondents predicting that there will be approximately the same demand for radiata-pine stock.

The comments on what they foresee happening in the next 5 years mostly fall into two themes:

- Concern over government policy, changes to the ETS, and uncertainty in the carbon industry (four respondents).
- Foreseeing a shift to other species – alternative exotic species and native species (four respondents).

In Q.13, survey participants were asked what type of nursery stock they thought their organisation would be producing 5 years from now? Respondents were asked to tick all options that applied and indicate the proportions they envisage being produced (approximate percentages). All 13 survey participants responded to this question (Table 6). In regard to the 'Other, please specify' category, there were two responses, one for 'tissue culture plugs' and the other 'redwoods in containers'. Note that the averaged percentages of types of planting stock currently produced (from Q.7, above), are also provided as a comparison to the averaged percentages anticipated in 5 years' time.

Table 6: Percentages of different types of planting stock: (i) currently produced (Q.7); and (ii) what respondents anticipate their organisations will be producing 5 years from now (Q.13)

Type of planting stock	Current averaged percentage (from Q.7)	Averaged percentage anticipated in 5 years' time (Q.13)
Bare-root seedlings	61	48
Bare-root cuttings	12	16
Container-grown seedlings	22	23
Container-grown cuttings	5	12
Container-grown tissue-culture plantlets	<1	1
Other, please specify (e.g., stock produced via 'hybrid' propagation methods, such as Plug+)	-	<1
Don't know	-	-

In comparison to the current relative proportions of different types of stock being produced (Q.7, Table 2 and Figure 2), some respondents did not foresee too much change in 5 years' time, while others anticipated slight changes. The overall percentages (averaged over the 13 responses) indicate that there will be a decrease in the proportion of bare-root seedlings produced – this is the biggest anticipated change; however, it is anticipated that there will be a small increase in the proportion of bare-root cuttings produced. Another anticipated change is an increase the proportion of container-grown cuttings produced in 5 years' time.

So, **the biggest anticipated changes are a decrease in the proportion of bare-root seedlings produced, and an increase in the proportion of cuttings produced – bare-root and particularly containerised cuttings;** while the percentage of container-grown seedlings produced is not anticipated to change in 5 years' time.

In Q.14, survey participants were asked that, if they foresee change, what do they think will drive this? They could select all the options listed that they thought were relevant (Table 7).

Table 7: Summary of what nursery survey respondents think will drive the changes in 5 years' time (Q.14)

What will drive these changes?	Number & (percentage) selecting each option
New technological developments (such as mechanised planting systems)	7 (58%)
Labour costs and availability	10 (83%)
Difficulties lining up planting stock availability (lifting in the nursery) with availability of planters	1 (8%)
Legislative/political changes leading to a decrease in radiata-pine planting	7 (58%)
Other, please specify – (see comments below)	7 (58%)

The top driver of change according to respondents is '*Labour costs and availability'* (83%), followed by three equally rated factors (at 58%), i.e., *'New technological developments (such as mechanised planting systems)', 'Legislative/political changes leading to a decrease in radiata-pine planting',* and *'Other, please specify'* (these are noted below)

Seven respondents provided the following additional drivers of change (Q.14):

- Pest & Disease pressure.
- A shift into lower genetics to cut costs.
- Climate changing leading to warmer temperatures require containerized stock as it increases the planting timeframe.
- Legislation around chemical use (H&S and Environmental), particularly impacting the bare-root system.
- A growing acceptance in the industry of containerised production systems.
- Labour shortages, extending the planting season, and the possibility of mechanised planting.

Section D: Planting stock quality

In Q.15, survey participants were asked how they thought the field performance of containerised radiata-pine stock compares with bare-root stock, based on their experience and feedback from customers. They were given five options to choose from and could choose more than one option. All 13 survey participants completed this question (Table 8 and Figure 3).

Table 8: Summary of responses on how field performance of containerised compares with bare-root radiata-pine stock (Q.15)

How does field performance of containerised stock compare with bare-root stock?	Number & (percentage) selecting each option
Not sure which performs better	2 (15%)
Containerised planting stock performs better than bare-root stock	3 (23%)
Bare-root stock performs better than containerised planting stock	4 (31%)
Similar performance if good quality stock is provided	1 (8%)
Bare-root stock performs better in some situations, and containerised stock performs better in other situations	5 (38%)

The results show that opinions are split on whether bare-root or containerised stock performs better in the field, though the bare-root stock has a slight edge with four respondents versus three respondents. Two respondents were not sure what performs better. However, the option that was selected the most (by five respondents, 38%) was that bare-root stock performs better in some situations, and containerised stock performs better in other situations.

Ten respondents provided comments on the relative field performance of both stock types (Q.15): Five respondents mention the longer planting season for containerised stock; two mention that containerised stock outperforms bare-root on hard sites; two mention the comparative logistics of planting - including increased planting timeframe for containerised stock, with one respondent also stating that there are lower planting rates for containerised. There is one comment on bare-root stock having better stiffness on windy sites. And finally, one comment sums it up by stating that they are very different crops to manage, and both nurserymen and foresters need to understand how to best manage the stock type in order to maximise establishment success.

In Q.16, survey participants were asked if they could describe what they think constitutes a good container-grown radiata-pine plant. Among other information provided, five respondents made the following comments:

- Consolidated root plug, balance of white and brown roots, Ht: rcd ratio.
- Plants need to be hardy with lignified stem but without becoming root bound or left too long in a high -density situation so the bottom needles senesce.
- Same as bare root. Good RCD. Strong root growth, but more likely to get 360 degrees in container. Not root bound, less likely in Ellepot as is air pruned. Suitable planting height.
- Good root structure, RCD within spec, Seedling hardened off before being despatched.
- To make containerised stock economical to produce, need to have quite closely grown stock, therefore, have smaller sized plants, i.e., have lower size specifications: 5 mm RCD for bare-root and 3.5 mm for containerised. The most important specifications are RCD and root/shoot ratio, and also the time spent in cool storage prior to planting.

Nine survey participants completed questions (Q.17 to Q.20) on what constitutes a good, containerised plant. In Q.17, they were asked if they thought that there is a difference between propagule types (rooted cuttings, seedlings, tissue culture plantlets, etc.) in terms of the specifications that constitute a quality container-grown nursery plant. Nine responded. Six (i.e., two-thirds) thought that there should be a difference between specifications for the different propagule types – seedlings and rooted cuttings (Table 9).

Table 9: Response to the question of whether they think there is a difference between propagule types (seedlings, rooted cuttings, other) in the specifications that constitute a quality container-grown nursery plant (Q.17).

Is there a difference between containerised propagule types in the specifications?	Number & (percentage) selecting each option
No	2 (22%)
Yes	6 (67%)

Not sure	1 (11%)

In Q.18 and 19, survey participants were asked to define the characteristics of a quality container-grown radiata-pine seedling and rooted cutting. The results are summarised below in Tables 11 and 12, for containerised seedlings and cuttings, respectively.

In comparing responses from the nine survey participants, there are **some clear consistencies for some of the specifications, but not for others.**

The consistencies include:

- Fairly consistent specifications for container volume (120±5 cc).
- A strong preference for the paper Ellepot.
- Good root system with lack of root defects, plug consolidated, holding together (without being root bound).
- A strong, straight, single leader that is stiff (not soft) and a healthy shade of green.
- The plant must be hardened.

The inconsistencies include:

- Variation in height specifications ranging from 10 to 35 cm.
- Variation in diameter specifications ranging from 3 to 6 mm.
- Whether the shoots should be topped or not.

In comparing Tables 10 and 11, some respondents provided specifications that have little or no difference for containerised seedlings versus rooted cuttings. However, others provided specifications somewhat different for the two stock types, particularly for stem diameter. Four respondents provided slighter higher diameter specifications for rooted cuttings, while four provided the same diameter specifications. In regard to Q.20, specifications for other containerised propagule types, e.g., tissue culture plantlets, there were only two responses – N/A, and ‘as above’.

Table 10: Characteristics (specifications) of a quality container-grown, radiata-pine seedling - according to nine of the Nursery Survey participants (Q.18)

	1	2	3	4	5	6	7	8	9
Container Volume	100 cc	100 – 120 cc with good taproot depth	120 ml	125 cc	64	125 ml	Greater than 100 cc	N/A	?
Container Type	Paper pot	Preferably paper Ellepot	Paper style pot	Ellepot 40 mm	Lannen 64	TS48	Not critical - root quality is key, some containers impact this	must have air pruning for roots	Paper pot
Approximate shoot height (cm)	22 cm	Seedling needs to be topped and so 22 cm – 35 cm	30 cm	25 cm	25 cm	25 cm	10 cm or more	25 cm	20-25 cm
Approximate shoot diameter (mm)	4 mm	>3 mm<5 mm	4 mm	3.5 - 4 mm	5 mm	3.6-4.0 mm	>4 mm	3 mm	3 - 6 mm
Shoot characteristics	Not topped	Must be lignified otherwise end up with wind lash & spiralling in the planting spot with bark being worn off	Stiff	Straight, even, healthy green	Single, rigid healthy green	Mid-green colour, no signs of disease	Strong central leader, preferably not topped	Green and facing up	Actively growing, good form.
Root characteristics	Balance of white and brown roots, not moribund	Not root bound and ready to regrow - meaning a paper Ellepot is best	Air pruned and not root bound	360 degrees, air-pruned	Consolidated plug	Well consolidated root plug, ectomycorrhizae, presence of white root tips	Most critical quality factor - roots visible on walls of pots, and at base. Holds soil together when removed from pot. No upwards growing roots, no root defects; e.g. hockey sticks or spiralling roots, root masses in pot corners or 'toes' from pot feet.	White roots and consolidated plug	Plug newly consolidated
Hardiness	?	Seedlings have an issue with wind and frosts if too soft	Topped to induce hardiness	Hardened off for direct planting	Hardened off and rigid	Cold and drought conditioned but good nutrient status	Must have been outdoors for at least 4 weeks, preference for all of growth cycle	Can't be flushing, e.g., deep green colour	Site dependent
Other characteristics		Seedlings must be topped to lignify them and still have buds swelling				Some people prefer seedlings to be topped (avoid frost damage to shoot tips)	Exposure to water stress to increase hardiness. free of pest and disease		

Table 11: Characteristics of a quality container-grown, radiata-pine rooted cuttings - according to nine of the Nursery Survey participants (Q.19)

	1	2	3	4	5	6	7	8	9
Container Volume	120 cc	Minimum of 120 cc with > 10cm depth	120 cc	125 cc	N/A	125 cc	Greater than 100 cc	N/A	?
Container Type	Ellepot	Ellepot	paper or jiffy	Ellepot 40 mm	N/A	Ellepot 40 mm	not critical - root quality is key, some containers impact this	must have air pruning for roots	Ellepot
Approximate shoot height (cm)	22	25 cm - 35	30 cm	25 cm	N/A	25 cm	10 cm or more	25 cm	25 cm
Approximate shoot diameter (mm)	4.5 mm	4 mm and greater	4 mm	3.5 - 4 mm	N/A	3.8-4.2 mm	4 mm or more	3 mm	4 - 7 mm
Shoot characteristics	Not topped	Topped and lignified	Straight	Straight, even, healthy green	N/A	mid-green colour, no signs of disease	strong central leader, preferably not topped	green and facing up	good form, actively growing apical bud
Root characteristics	Consolidated plug rather than quadrant checks	Roots ready to move on planting not bound up	Roots in three quadrants	360 degrees, air-pruned	N/A	well consolidated root plug, ectomycorrhizae, presence of white root tips	Must have more than 2 roots emerging from propagule to provide adequate anchorage at plant out. Most critical quality factor - roots visible on walls of pots, and at base. Holds soil together when removed from pot. No upwards growing roots, no major root defects from propagule; e.g. hockey sticks or spiralling roots; no root defects from container; no root masses in pot corners or 'toes' from pot feet.	white roots and plug just holds together	plug consolidated all round, not rootbound
Hardiness	?	Topped and buds developing	Topped	Hardened off for direct planting	N/A	Cold and drought conditioned but good nutrient status	Must have been outdoors for at least 4 weeks, preference for all of growth cycle	Can't be flushing, e.g., deep green colour	Site dependent
Other characteristics		Standard nutrition	Single stem not multi leadered		N/A		Exposure to water stress to increase hardiness. free of pest and disease		

Section E: Comments on knowledge gaps, and final comments

In Q.21, survey participants were asked if there are any **major issues/gaps in knowledge limiting an evaluation of performance of containerised stock** in New Zealand? All 13 survey participants completed this question, some of the key comments are shown below:

- Plant density in trays - checker boarding or spacing or inserts. Sell by dates for crops.
- A lot of variability out there and every year some failures more than in bare-root stock. So, room for improvements on where best to site containerised seedlings and time of the year to use them.
- Yes - when comparing bare -root cuttings with container cuttings there is no allowance in container production for the 'roots on 3 quadrants' rule. Is there a diameter standard for container production?
- Getting tissue culture to root in the lab, rather than in the nursery.
- Yes! Most field trials comparing stock types I am aware of have failed to use seedlings from good preforming field nurseries and therefore have been promotional activities.
- Changes are not easily accepted, so despite having enough information available to evaluate the performance I believe that the decision maker would be on assuring a healthy stock to be planted as the containerized can be better monitored and controlled along the production cycle.
- Plant quality field trials - quantifying the relative impact of each quality parameter on planting survival, as well as long term survival and growth.
- Toppling container vs bare root. Foresters think that containers are more likely to topple at age 2-4. Data that we have is that it is evenly balanced, and based more on site e.g., ex farmland.
- Stop trying to mimic a bare root tree, different drivers for successful establishment.
- Containerised stock is still somewhat experimental due to knowledge gaps. Some forestry corporates have been using containerised stock for about 15 years, but there are limited field trials testing bare-root versus containerised stock, and a lack of publicly available information. There was a big investment in R&D into bare-root systems in the past so it has become well established, with high survival and good field performance. Containerised systems also need R&D investment. There is one set of rules (specifications) for bare-root and another for containerised – is it justified? We need to be careful about piggybacking on European systems as they are not tailored to NZ.

There are some common threads in these comments. six comments queried growing regimes and specifications for containerised stock. four comments highlighted the need for field trials comparing containerised and bare-root stock and one on the need for R&D investment for containerised systems.

In Q.22, survey participants were asked if they have any final comments and if the survey missed anything?
Six respondents provided final comments:

- Containerised nurseries are essential to provide a production alternative to bare-root ones due to potential disease threats. Mechanised planting requires containerised plants.
- Specifications can be frustrating, for example, downgrading when there is a bend in a root system when the bend will not be in the harvested portion of the tree.
- Increased capacity of the containerised stock production system with its high capital cost and lack of performance advantage will further enhance the high margins achievable in a highly mechanised field nursery production system. However, container stock and mechanised planting systems will be limited to specific terrains and planting area size, setting higher establishment cost expectations for the broader forest industry during the fluctuations in both demand and labour resources, which are politically driven.
- High client specifications for tree stocks reduce production yields compared to other countries.
- Many of the industry accepted practices and quality measures for container stock have been based on what we do in bare root (arguably acquired though anecdotal evidence mostly) and not on good empirical data from trials.
- Planters do not want to pay more for planting containerised stock and also prefer not planting containerised stock because it is heavier. Some contractors are not prepared to take on contracts for planting containerised stock.

Planters' Survey Results

Section A: Information on the respondents and their forestry organisations

In total, 20 forestry companies were contacted and 10 respondents completed the Planters Survey questionnaire (Appendix 4). For the larger companies, a request was made to forward the questionnaire to relevant regional managers, in order to capture responses that reflect the status of the industry throughout New Zealand. Responses were received from survey participants in nine different forestry companies, with two received from one company – two regions.

This was a 50% response rate from all the forestry companies contacted. The majority of the respondents (6 out of the 10) were forestry managers, or forestry planting or establishment managers (4 out of the 10). Other respondents had the roles of R&D manager, field operations manager, nursery R&D manager, senior forester, or technical forester. There was a good geographic spread of forestry operations, including companies that operated throughout much of New Zealand, and others operating regionally. Regions where they operated included northern regions, Waikato, Bay of Plenty, Gisborne, Hawkes Bay, upper South Island, Canterbury, Otago, and Southland.

Section B: Respondents' current standard forestry operations

All 10 respondents answered Question 3, which asked for the average area their forestry company planted in radiata-pine per year, over the last 5 years. This ranged from 320 to 4000 ha (Figure 4), with an average of 1,461 ha over the different forestry companies in this survey.

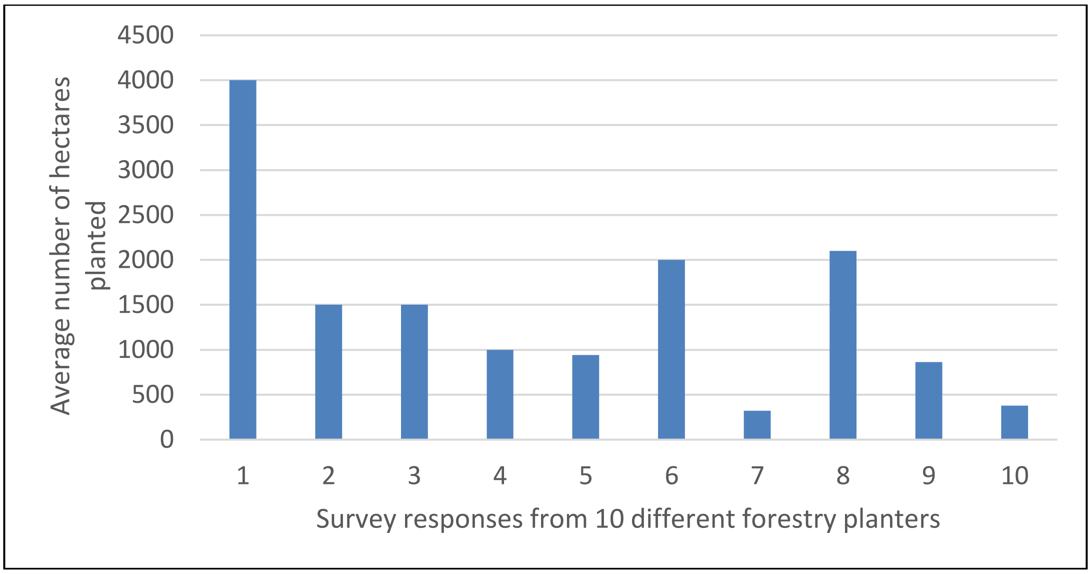


Figure 4: Average area planted in radiata-pine per year (over the last 5 years).

The total number of hectares planted per year by the forestry companies in this survey, based on the average area planted over the last 5 years, was 14,605 ha. This represents a good spread of smaller through to larger forestry operations. However, this survey only captured a small proportion of the radiata-pine forestry planters (13%) in New Zealand considering that 112,000 ha of radiata pine was planted in 2022 ((Ministry for Primary Industries 2023)).

In Q.4, survey participants were asked what type of radiata-pine planting stock they were currently planting, and the proportions of each (approximate percentages) (Table 12 and Figure 5).

Table 12: Averaged percentages of types of planting stock currently being planted (Q.4)

Type of planting stock	Averaged percentage	Range of percentages
Bare-root seedlings	60.2	14 – 100
Bare-root cuttings (unspecified)	24.2	0 – 82
Bare-root juvenile cuttings	3.7	0 – 37
Bare-root aged cuttings	3.9	0 – 39
Container-grown seedlings	7.3	0 – 20
Container-grown cuttings (unspecified)	0.4	0 – 4
Container-grown clonal cuttings	0.3	0 – 3
Container-grown tissue-culture plantlets	0.1	0 – 1
Total percentage	100.1	

Bare-root seedlings are currently the stock type proportionally (60.2%) being planted the most by the forestry companies represented in this survey. Bare-root cuttings were the next highest proportionally being planted (31.8%). Container-grown seedlings were the next highest proportionally, at 7.3%. There were only small proportions of container-grown cuttings (unspecified and clonal cuttings) and tissues culture plantlets being planted (<1%).

There was considerable variation in the types of planting stock currently being planted by each of the forestry companies (Figure 5). All are currently planting bare-root stock, particularly bare-root seedlings. Three respondents only planted bare-root stock types (#1, #5, and #6). The other seven respondents all had some type of containerised stock in their planting mix, but no more than 20% of their total stock. (Figure 5).

In the additional comments from the respondents, key points were made around an increase in use of containerised planting stock where mechanisation was being tested and also difficulty in finding nurseries to supply cuttings (due to additional labour and growing constraints).

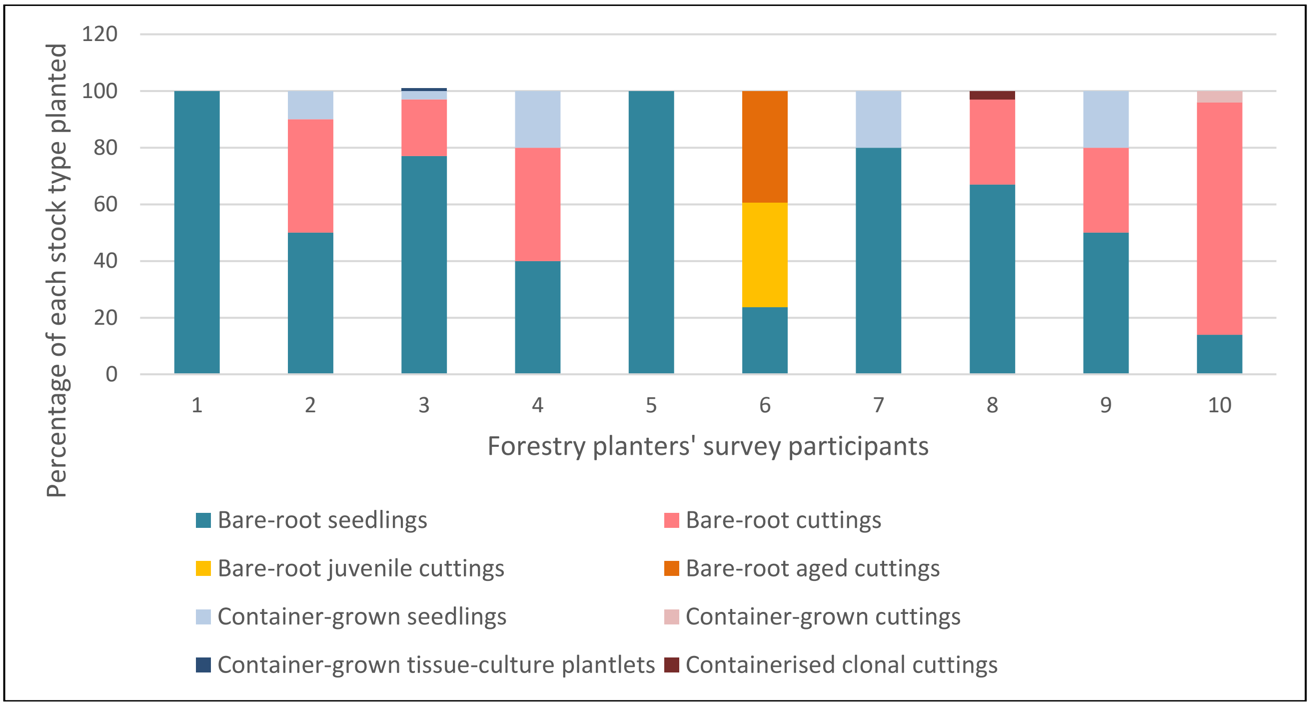


Figure 5: Percentages of types of planting stock the respondents are currently planting (Q.4).

Preference for planting cuttings versus seedlings

In Q.5, survey participants were asked if they have a preference for planting cuttings versus seedlings (container or bare-root), with eighty percent of respondents selecting Yes, they preferred planting cuttings versus seedlings?

The survey participants were then asked to explain why they answered Yes or No for Q.5, with some of the explanations (for yes) shown below:

- Prefer bare-root cuttings vs seedlings (container or bare-root). Have experienced toppling and rooting issues with containerised seedlings. Also prefer cuttings as a hardier plant, especially when planting into a harsh climate. Containerised cuttings are okay, but typically smaller plant than bare-root cuttings. Also, for our CNI operations, there is the issue of location of containerised nursery (distance) to our forest vs bare-root nursery (adjacent to forest and same climate).
- All have their place in our estate, containers allow for early start to the season and avoid having to compete with certain weeds, cuttings are better for stands exposed to wind and seedlings are used for the remaining areas as they are generally cheaper.
- Cuttings provide better uniformity and ability to multiply genetic gain.
- Proven performance for aged cuttings in region, particularly on ex-farm pasture afforestation blocks where early root development and tighter crown (less sail area) is important to prevent toppling.
- It is site specific but in general we prefer cuttings because they can allow you to grow CP genetics without needing a large amount of CP seed. Also, we prefer the benefits of hardiness (generally thicker RCD in cuttings and more resilient to animal browse) and the reduced branching habit helping in both wind -exposed sites and aids in future pruning operations.
- Cuttings are more resilient but there are issues with obtaining in sufficient quantities to meet program needs. Cost also comes into play. Cuttings are grown on the hardest / exposed sites.
- Depends on site and timing. Cuttings on some sites, other sites indifferent. Containers on some sites, bare-root on others.

There are some common threads in these comments, notably that rooted cuttings (particularly bare-root) are perceived to be better for topple-prone and harsh sites and seedlings being cheaper and better elsewhere. In addition, two commented on cuttings being good for multiplying CP seed and genetic gain.

Types of container currently used and the types of container preferred

Six respondents who have planted containerised stock provided information on the types of container they would prefer for radiata-pine planting stock (Q.6) and the types of container their planting stock has been grown in (Q.7). Results are shown in Table 13, with the answers for Q.6 and Q.7 aligned for each respondent.

Table 13 – The types of containers preferred (Q.6) and types of containers currently used (Q.7)

Types of container preferred	Types of container currently used
We haven't used Ellepot, so not preference. Prefer larger cell size (120cc or 125cc) as produces a larger plant (min 4 mm RCD). However, if planting manually then the preference from planters is 90cc (min 3.5mm RCD) as lighter box weights.	90cc Lannen 63F 120cc Lannen 64FD 125cc 48F
No preference	63F / 64F
Ellepot if the cost can be reduced.	-
Minimal containerised stock used, no preference.	N/A
Minimal containerised stock used, no preference.	-
Plastic - No Ellepots.	Lannen 63F or TS48-F
Ellepot. Recognised as having better integrity when compared to traditional "containers".	-

From the responses to Q. 6 and Q.7, it is clear there is a preference for Ellepots, if cost could be reduced.

Constraints in getting planting stock in the ground

In Q.8, the respondents were asked to rank the major constraints for getting planting stock in the ground (Table 14), with 1 being the most significant constraint and 6 the least significant (Table 14).

All 10 respondents ranked each constraint with a summary of the rankings indicating that each forestry planting operation has a different mix of factors causing the most constraints (Table 14). The mean average of ranking scores is of 3.5. The figures in blue in the Averaged Ranking Score column are above this mean average (i.e., these are for the constraints ranked as having the most importance), and the figures in red are below this mean average (i.e., less important constraints). The figure in black is the closest to the mean average.

Table 14 – Ranking of constraints in getting planting stock in the ground (Q.8). The constraint listed at the top (smallest number) was the highest ranked constraint, and the constraint listed at the end (biggest number) is the lowest ranked constraint.

List of constraints ranked from greatest to least	Averaged Ranking	Range of rankings
Difficulties obtaining enough planting stock of sufficient quality	2.6	1 - 6
Difficulties lining up enough skilled planters at the right time	2.7	1 - 5
Difficult site conditions	3.1	1 - 5
Difficulties coordinating planting stock availability (lifting in the nursery) with availability of planters	3.3	1 - 5
Cost constraints	3.4	1 - 5
Other constraint	5.9	5 - 6

Note that the five constraints listed in the question, are quite closely bunched together in order of their average ranking score, and all ranked above the mean average ranking of 3.5. The highest ranked constraint was – *'Difficulties obtaining enough planting stock of sufficient quality'*. Very close behind this was – *'Difficulties lining up enough skilled planters at the right time'.* The constraint ranked third was – *'Difficult site conditions'*, and the constraint ranked fourth was – *'Difficulties coordinating planting stock availability (lifting in the nursery) with availability of planters*.*'* This was closely followed by – *'Cost constraints'* in fifth place.

Further insight can be gained by comparing the results from this question in the Planter's Survey with the corresponding question in the Nursery Survey (Table 4). In the Nursery Survey, The highest ranked constraint was – *'Difficulties lining up enough skilled labour at the right time'.* Close behind this was – *'Difficulty recruiting and retaining nursery staff with sufficient technical knowledge'.*

So, there is the commonality across both surveys in that a major identified constraint is obtaining enough skilled labour.

Stock type preferences and cost differences in planting bare-root and containerised stock

In Q.9, survey participants were asked if there was a cost difference between planting bare-root versus container stock, considering both the cost of the planting stock and logistics (Q.9). All 10 respondents provided an answer:

- Yes – five respondents (50%)
- No – one respondent (10%)
- Not sure – four respondents (40%).

The respondents who answered 'Yes', were subsequently asked to provide details, i.e., what is the more expensive stock type and where is the cost difference incurred (transport and other logistics, or per unit purchased)? All five of these respondents stated that containerised stock is more expensive than bare-root stock. Also, three respondents commented on the extra costs associated with the extra weight of the planting boxes filled with containerised stock, and the subsequently higher rate of pay for planters.

In Q.10, survey participants were posed the question that if cost and logistics were not an issue, e.g., there was no problem with stock availability and no difference in cost between the different types of planting stock, etc, **what would they prefer to plant based solely on field performance?** They were given five options of different stock types. Nine (out of the 10) respondents answered this question (Figure 6, below). Four of the nine respondents selected the option of planting a mix of stock types depending on the site conditions and time of year for planting operations. Three respondents would plant bare-root cuttings, one would plant bare-root seedlings, and one would plant containerised cuttings. *No respondents selected the final option of planting containerised seedlings.*

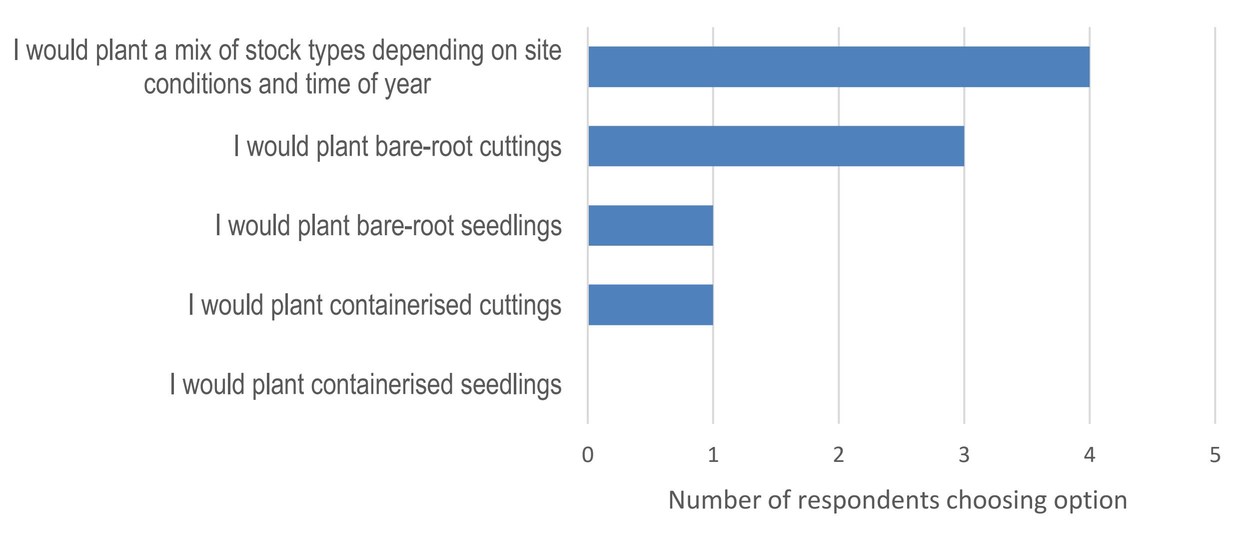


Figure 6: Graph of survey participants' preferences for different stock types, if cost and logistics were not an issue (Q.10).

Earliest, latest and optimum planting times

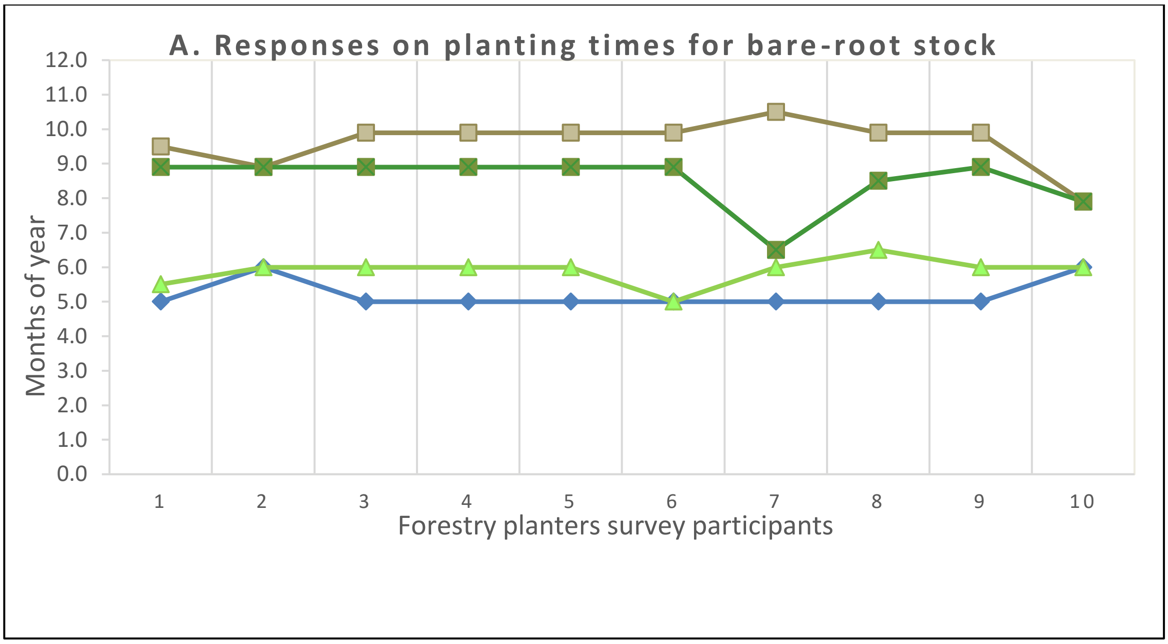
In Q.11, survey participants were asked what months are optimum for planting, and what they considered were the earliest and latest months for planting - depending on the type of planting stock. All ten respondents provided responses on planting times for bare-root stock (Figure 7a, below), and eight respondents provided responses for containerised stock (Figure 7b, below).

However, there were some caveats:

- For the earliest month they would consider planting bare-root stock, one respondent qualified his answer as "May if the weather was cold enough and the ground moisture was high enough".
- For the latest month for planting bare-root stock, one respondent qualified his answer as "August in Northland, September in CNI"; and another stated "October (if still moist and conditions are cold)".

In Figure 7a, some of the variations in earliest, latest, and optimum months for planting bare-root stock will relate to the region where they are planting – the climate and the harshness of the sites. The narrower windows specified for planting are likely from the respondents planting on sites with less soil moisture. However, other than for respondents #7 and #10 in Figure 7a, the results are fairly consistent. Most of the responses for earliest month for planting bare-root stock were May (eight respondents), while two respondents considered June to be the earliest. Most of the responses for latest month for planting were September (six respondents), with two respondents (operating in more northern areas) stating August, one respondent (from Wairarapa) stating July, and one stating October, though makes the caveat “if still moist and conditions are cold”.

However, the most striking results are the differences in the responses regarding planting times for bare-root versus containerised stock – comparing Figures 7a and 7b. (Note that the respondent numbers from Figures 7a and 7b don’t entirely match up, due their being only eight respondents in Figure 7b).



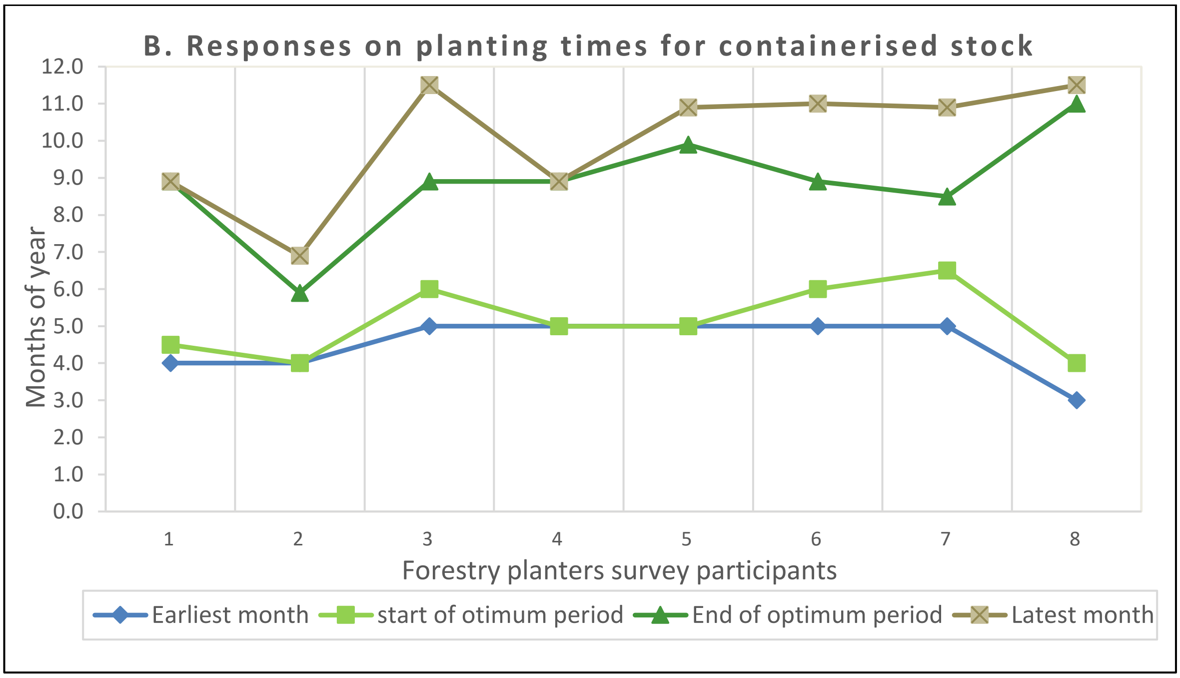


Figure 7: Graph of survey participants’ responses regarding what they think are the earliest and latest months, and the optimum period for planting: **(A)** bare-root stock (Q.11a): and **(B):** containerised stock (Q.11b).

There was considerable variation in what respondents considered were the optimum months for planting containerised stock, but a trend to use the container stock to extend the planting season window outside of the traditional window used for bare-root stock.

This indicates there is limited information on optimum planting times for containerised stock.

There are some clues to the inconsistencies in responses in the comments:

- Potential for material to become root bound if container stock left too long in the nursery. This could be managed through the timing of setting the plants if using large scale containers.
- Have provided estimates only as limits have not been well tested.
- Depends on season. Need soil moisture, stock to be ready and land prep to be ready.
- Based on being able to plant containers in Dec 2022 - which may be an anomaly as the season (2022) was unseasonably wet.

Survey participants were asked how often they are forced by circumstances to plant outside the optimum planting season for bare-root (Q.12) and containerised stock (Q.13) (Table 15). All ten respondents answered this question, though four selected N/A for Q.13 as they do not plant containerised stock. While it is clear respondents are, for the most part, rarely forced to plant outside what they consider is the optimum planting season, there are slight differences between the two sets of results. Only one respondent planting bare-root stock reported that they were frequently forced to plant outside their optimum planting time, with 80% rarely doing so (Table 15). No respondents planting containerised stock were often forced to plant outside their optimum planting time, and only 30% were rarely forced to. The survey results indicate that being forced to plant outside of the optimum planting time is generally a rare situation. However, it can have serious repercussions, as there is a greater risk of establishment problems.

These results indicate that using containerised stock lessens the risk of being forced to plant outside the optimum planting time.

Table 15 – How often are respondents forced by circumstances to plant outside their optimum planting season with: (i) bare-root stock; and (ii) containerised stock (Q.12 and Q.13).

How often are you forced to plant outside your optimum planting season?	**Number & (percentage) selecting each option**	
	Bare-root stock	**Containerised**
Often	1 (10%)	0
Rarely	8 (80%)	3 (30%)
Only during COVID-19 pandemic restrictions	1 (10%)	1 (10%)
Never	0	2 (20%)
Not applicable - we don't plant this stock type	0	4 (40%)

Comments alluded to availability of labour as sometimes extending planting season, and forestry organisations looking at container-grown stock to extend the planting season (for these reasons).

Section C: Future planting operations

In Q.14, survey participants were asked what they could foresee happening in the next 5 years. They were given five options to tick, with the capacity to choose multiple options. All 10 survey participants answered this question (Table 16).

The option that was selected the most frequently (by six of the 10 respondents) was *'Approximately the same area planted in radiata pine'.* The next most popular option was '*A shift in types of nursery stock that we are planting'* (three of the 10 respondents). Two respondents anticipated an increase, and two anticipated a decrease in area planted in radiata-pine.

Table 16 – What trends do survey respondents foresee happening in the next 5 years? (Q.14)

What do respondents foresee happening in the next 5 years?	Number selecting each option
An increase in area planted in radiata pine?	2 (20%)
Approximately the same area planted in radiata pine?	6 (60%)
A decrease in area planted in radiata pine?	2 (20%)
A shift in types of nursery stock that we are planting – please specify	3 (30%)

Six respondents provided comments, which had some common themes including government changes to the ETS negatively affecting planting rates (three respondents), optimism over planting rates of radiata pine (two respondents), different stock types being planted either due to supply issues with preferred stock or changes in preferences (two respondents), mechanised planting (two respondents), labour issues and extending planting season (two respondents).

Further insight can be gained by comparing the results from this question in the Planting Survey with the corresponding question in the Nursery Survey (see Table 5).

In the Nursery Survey, the two options that were selected the most frequently (by six of the 13 respondents) were '*A decrease in demand for radiata-pine planting stock'* and *'A shift in types of nursery stock that we are producing'*. However, there were six respondents in the Nursery Survey who either anticipated an increase in demand, or approximately the same demand for radiata-pine stock.

Overall, compared with the Planters' Survey, the Nursery Survey respondents predicted a bigger shift in the status quo regarding radiata-pine planting and types of stock being planted.

Also, there is considerable commonality in the comments associated with the corresponding question in the Nursery Survey, particularly concern over government changes to the ETS and how this will affect planting rates. However, in the Nursery Survey, four respondents could foresee a shift to other species – alternative exotics and native species. In the Planter's Survey, no comments were made about this, indicating that the forestry planters did not foresee a shift to other species.

In Q.15, survey participants were asked what **type of nursery stock they could foresee planting 5 years from now**. Respondents were asked to tick all options that applied and indicate the proportions they envisaged being planted (approximate percentages). All 10 survey participants responded to this question (Table 16 and Figure 8). Some respondents could foresee little or no change in the type of planting stock being planted in 5 years' time, while others could foresee changes (Figure 8). It is interesting to compare Figure 8 with Figure 5 (above), which shows the percentages the respondents are currently planting.

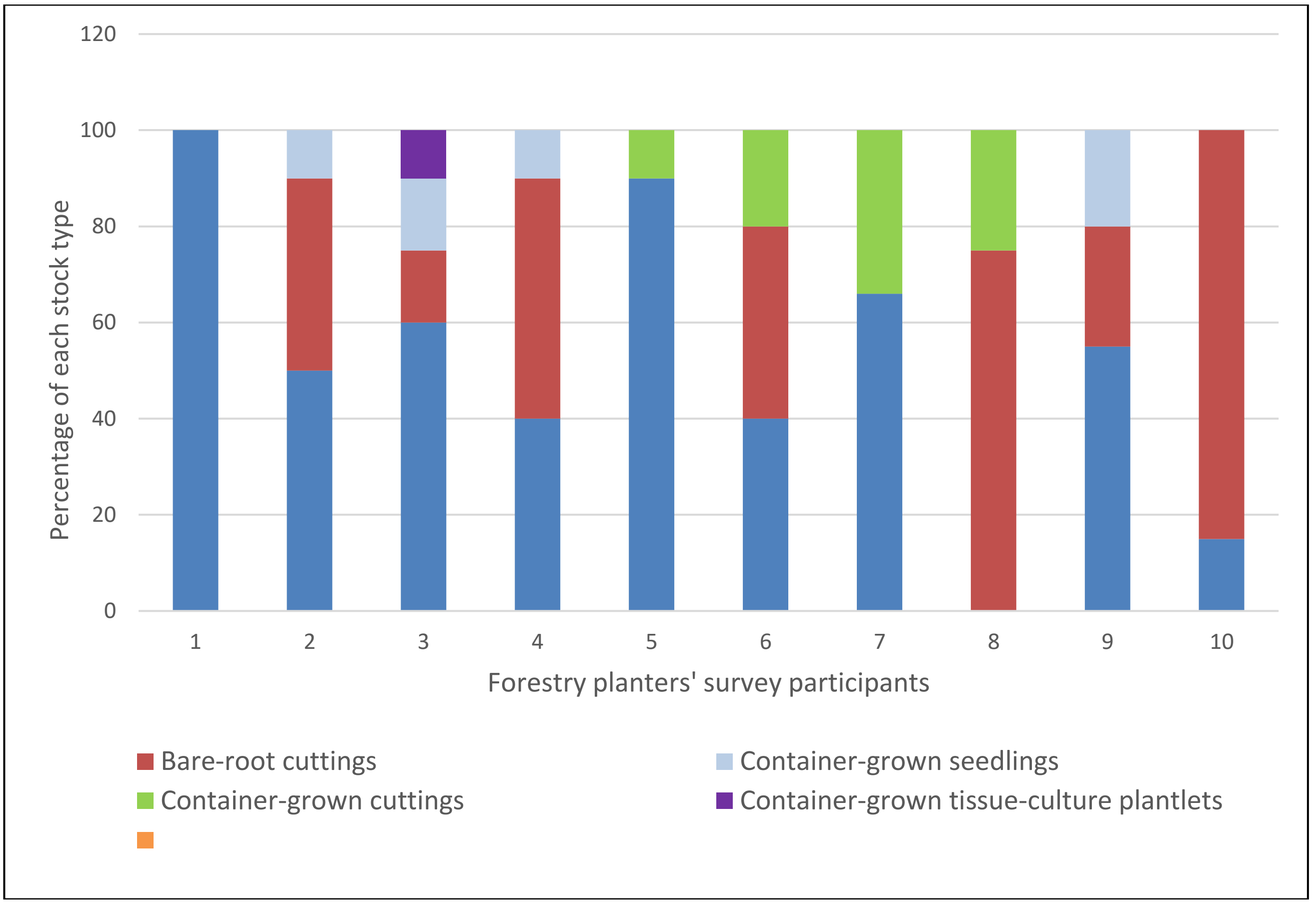


Figure 8: Percentages of different types of planting stock that the respondents could foresee being planted 5 years from now (Q.15).

In Table 17, the results for Q.15 - the averaged percentages anticipated in 5 years' time - are listed with the results reported for types of planting stock currently produced (from Q.4, Table 13, above). On average, the respondents foresee bare-root seedlings remaining the most common type of planting stock, though at a somewhat reduced level. The proportion of bare-root cuttings and container-grown seedlings remain about the same. However, there is an increase in container-grown cuttings expected proportional to the decrease in bare-root seedlings.

Table 17 – Averaged percentages of different types of planting stock: (i) currently being planted (Q.4); and (ii) what respondents foresee their organisations planting 5 years from now (Q.15).

Type of planting stock	Current averaged percentage (from Q.4)	Averaged percentage anticipated in 5 years' time (Q.15)
Bare-root seedlings	60	51
Bare-root cuttings	32	33
Container-grown seedlings	7	6
Container-grown cuttings	<1	9
Container-grown tissue-culture plantlets	<1	0
Container-grown clonal cuttings	<1	0
	100%	100%

So, **the biggest anticipated changes are a decrease in the proportion of bare-root seedlings planted, and an increase in the proportion of containerised cuttings planted**.

In Q.16, survey participants were asked that, **if they foresee change, what do they think will drive this?** They could select all the listed options that they thought relevant. Eight of the ten survey participants provided responses (Table 18). The top drivers of change according to respondents were *'New technological developments (such as mechanised planting systems)'* and *'Legislative/political changes leading to a decrease in radiata-pine planting',* followed by *'Labour costs and availability'.*

Table 18 – Summary of what respondents think will drive the changes in 5 years' time (Q.16).

What will drive these changes?	Number & (percentage) selecting each option
New technological developments (such as mechanised planting systems)	6 (75%)
Labour costs and availability	4 (50%)
Difficulties lining up planting stock availability (lifting in the nursery) with availability of planters	3 (38%)
Legislative/political changes leading to a decrease in radiata-pine planting	6 (75%)
Other, please specify – (see comments below)	2 (25%)

Interestingly, this is a somewhat similar result compared to the Nursery Survey, reported in the previous section, except that '*Labour costs and availability'* was selected as the top driver by the nursery survey respondents; and '*Difficulties lining up planting stock availability (lifting in the nursery) with availability of planters'* was less important, selected by only one nursery respondent.

Two respondents in the Planter's Survey specified additional drivers of change (Q.16):

- Reduced demand for bare rooted seedlings will encourage some nurseries to increase cuttings production again.
- Nursery supply limitations on bare root cuttings. Possibility of mechanised planting becoming a more attractive option (and requiring containerised stock).

Two other Planter's Survey respondents provided these comments:

- All the above will have an influence to varying degrees. Labour and costs are probably the biggest drivers for change in all industries not just establishment operations.
- Nurseries need to progress with automation of lifting.

Mechanised planting systems

In Q.17, survey participants were asked if they saw any potential for mechanised planting within their operations? They were asked to select the option that best represents their situation. All 10 respondents answered this question (Table 19).

None of the respondents are currently using mechanised planting systems operationally. Three are trialling (or have trialled) mechanised systems – M-Planter or PlantMax – with one respondent commenting that they had trialled the M-Planter but currently found it too expensive to continue. Five of the respondents could possibly see some potential for mechanised planting in the future for part of their estate – with three comments that they are currently watching from the sidelines, and two comments that they are uncertain if it would be suitable for their types of sites. Two can see no potential for mechanised planting systems within their planting operations due to the type of terrain. One also commented that planting was a welcome change for their silvicultural crews.

There was also the opportunity for respondents to add additional comments about **constraints, suitability, uncertainties, knowledge gaps**, etc., and four respondents contributed the following comments:

- Issues around the supply chain for mechanised planting - location of nursery, tree stock type (i.e. preference for cuttings). Also issue of suitable topography.
- Steep terrain and performance in cutover need to be determined.
- We manage our silvicultural contractors around available annual pruning/thinning/planting. If we begin mechanical planting this will have implications for the pool of work available to our

contractor workforce and could have spillover effects into thinning/pruning operations, and maintaining fire fighting resources.
- To understand how the machinery can work on differing soil types and locations, what additives can we use to get improved results or extend planting seasons, what stock type (Ellepot vs. container) is best suited?

These comments (above) are highly relevant to R&D on mechanised planting. They include issues of supply chain logistics, impact on silvicultural contractors, and the need for knowledge on how the machines work on different terrains, soil types, types of sites (cutover?), stock types, container type, etc.

Table 19 – Potential for mechanised planting within their operations, with number and percentage of respondents selecting each option, with explanatory comments (Q.17).

Options	No. & (percentage)
We are already using mechanised planting systems.	-
We are currently trialling mechanised planting systems.	3 (33%)
We see good potential in the near future for including mechanised planting systems within our operations.	1 (10%)
We possibly see some potential for mechanised planting systems in the future, for part of our forestry estate	5 (50%)
We see no potential for mechanised planting systems within our planting operations.	2 (20%)

Section D: Planting stock quality

In Q.18, survey participants were asked if they are happy with the quality of their current planting stock. They were given three options to select and the opportunity to add comments. All 10 respondents answered this question (Table 20). Four respondents have a good supplier and are happy with their planting stock, while six think it is OK, but not perfect. No respondents are unhappy with the quality of their current planting stock.

Table 20 – Summary of responses on how happy respondents are with the quality of their current planting stock (Q.18)

Quality of current planting stock	Number & (percentage) selecting each option
Yes, we have a good supplier of quality planting stock	4 (40%)
It is OK, but not perfect (please describe issues below)	6 (60%)
No, we are not happy (please describe issues below)	0

Seven respondents provided comments:

- We have been unable to buy the quantities of bare rooted cuttings that we would like and have been forced to use seedlings.
- Good quality planting stock currently being supplied, but continuing that supply going forward will likely become an issue.
- Consistent troubles with nurseries saying they will deliver X number of trees for the season and then being caught significantly short (>100,000 trees short) for 2 years in a row now. Aside from that the quality of the stock that we get is generally good (although this year trees are smaller than previous years due to high rains and lower sunlight in North Island).
- Bare-root so seeing issues in plant health, root quality and grading.
- With the containers used being put through a machine planter we find they are not maintaining container integrity throughout the process. Ellepot may alleviate this in the future. Nursery growers are reluctant to invest in this technology without forest grower commitment which does not come due to cost so we go round and round "making do" instead of improving.

Field performance of containerised versus bare-root stock

In Q.19, survey participants were asked how they thought the field performance of containerised radiata-pine stock compares with bare-root stock, based on their experience. They were given four options to choose and could choose more than one option. All 10 survey participants completed this question (Table 21)

The results show that opinions are split on whether bare-root or containerised stock performs better in the field, though the bare-root stock has a slight edge with three respondents versus two respondents. Two respondents are not sure what performs better. However, the option that was selected the most (by five respondents, 50%) was that they have a similar performance if good quality stock is provided.

Table 21: Summary of responses on how field performance of containerised compares with bare-root radiata-pine stock (Q.19)

How does field performance of containerised stock compare with bare-root stock?	Number & (percentage) selecting each option
Not sure which performs better	2 (20%)
Containerised planting stock performs better than bare-root stock	2 (20%)
Bare-root stock performs better than containerised planting stock	3 (30%)
Similar performance if good quality stock is provided	5 (50%)

Eight respondents selected just one option, but two respondents selected two options, explaining in their comments that bare-root stock performs better in some situations and containerised performs better in other situations (Table 21). This opinion was also strongly evident in the Nursery Survey (see Figure 3).

It is pertinent to compare these results for Q.19 with results for Q.10 (see Figure 6, above), where survey participants were posed the question that if cost and logistics were not an issue, what would they prefer to plant based solely on field performance? The most popular option chosen was planting a mix of stock types depending on the site conditions and time of year for planting operations.

Seven respondents provided comments on the relative field performance of both stock types (Q.19):

- Have had rooting issues with bare-root seedlings (not cuttings) and also toppling. Also, general hardiness of bare-root seedlings - not suitable when coming from a benign environment into a harsher climate. i.e. need to be locally grown.
- Containers grow better at the front end of the planting season, up North they don't perform well when planted at the end of the season.
- Containerised stock has better survivability in dry conditions, but can be prone to toppling at age 6 or 7 when the effect of root binding in the container becomes apparent.
- Minor amounts of plugs used 5+ years ago, possibly similar performance to bare-root but requires proper testing to confirm this on our sites / in our southern environment.
- As mentioned previously, containerised have issues with 'root-bounding' meaning they are more susceptible to windblow in future years. Also, they are generally smaller trees and less hardy and resilient to animal browse and take longer to get above the weeds in weed heavy areas (due to being smaller to start with).
- We have examples both ways for first 3 years growth.
- We planted stock that was a bit past it's ideal and pushed the envelope as far as timing goes. The stock was also very slender and tall. It has performed ok in several stands but that may have come down to the season we had post planting.

Concern about toppling in bare-root and containerised stock, based on past experience, is evident in three comments. Also, three respondents express concern about issues with hardiness in both bare-root and containerised stock, based on previous experience. Two respondents mention the extended planting season for containerised. There were two comments on relative performance of both stock types being similar. Finally, one respondent commented on better survival of containerised stock in dry conditions.

Interestingly, these comments align well with the comments made in the Nursery Survey, for the corresponding question, as reported in the previous section.

In Q.20, survey participants were asked if they could **describe what they think constitutes a good container-grown radiata-pine plant, suitable for their planting sites**. Survey participants were subsequently instructed to either complete Q.21, or skip to the final questions in the questionnaire. Two respondents skipped this question as they only plant bare-root stock. Eight survey participants completed Q.21, although four identified that they were not sure what constitutes a good container-grown radiata-pine plant (Table 22) (*Note that in the Nursery Survey, responses were requested on specifications for containerised seedlings and cuttings, while in the Planters' Survey, there was just one question on specifications for a containerised radiata-pine plant without a division between seedlings and cuttings. Also, there were fewer questions on specifications for the Planters' Survey*).

Some respondents have provided detailed and well-informed specifications, while others have provided limited information. In general, however, there is less detail provided compared with the corresponding question in the Nursery Survey (Tables 11 and 12, above). The forest planters gave some clear specifications for some characteristics, but not for others. Interestingly, these consistencies and inconsistencies are similar to what was identified in the Nursery Survey.

The consistencies include:

- Good root system with lack of root defects, plug holding together without being root bound.
- Dominant single leader that is vigorous.
- The plant must be hardened.

The inconsistencies include:

- Some variation in height specifications though most have a minimum (where stated) of 20, 22, or 25 cm and a maximum of 30 or 35 cm.
- Considerable variation in diameter specifications ranging from a minimum (where stated) of 3.5 through to 5 mm, and a target of 5 to 10 mm.

Table 22 – Characteristics of a quality container-grown, radiata-pine plant - according to eight of the Planters' Survey participants (Q.21)

	1	2	3	4	5	6	7	8
Approximate shoot height (cm)	22 – 35 cm	20 cm	30 cm	-	20 cm	Minimum 25 cm	min 20 cm, target 25 cm, max 30 cm	25 – 30 cm
Approximate shoot diameter (mm)	Min 3.5 mm RCD for 90 mL pot and min 4.5 mm for 120 mL+	Minimum 3.5 mm	5 mm	-	10 mm	5 mm	min 5 mm, target 6-7 mm, no max.	5 - 6 mm
Shoot characteristics	Single leader. No significant sweep (30 mm deviation)	-	-	-	Single leader, vigorous	Single leader (topped)	Single leader, no fluffy tops, 100% healthy green foliage	Dominate single leader
Root characteristics	Well established roots. Not twisted or root bound.	Not root bound	Not root bound	Not twisted	Good amount of fine roots, and not root bound	Enough to hold plug together but not too much that the roots are growing around outside of plug which would increase root-bound issues post-planting	Container holds together- cannot compress, no wrapping or climbing roots, roots even from stem if media washed off, healthy mycorrhiza	Even distribution within the container, high density/proportion of fibrous roots
Hardiness	Stiff stem, no new soft shoots longer than 3 cm. Appropriate timing of topping.	-	Should be frost hardened	-	Hardy	Need to be topped and something needs to be done to increase hardiness	Sturdy	Has to be "hard / sturdy" not "soft and floppy"
Other characteristics	Foliage cover min 60% of total plant height (90 mL pot); 70% for 120, 125 mL	-	-	-	Has had prior hardening	-	no needle disease, optimum foliar nutrition, no weeds in medium stock must fit in boxes. Ht/Diameter ratio less than 1:50	Healthy and displaying good vigour

In Q.22, survey participants were asked if they were aware of any recently planted field trials comparing container-grown stock versus bare-root stock that would increase understanding on field performance of different stock types. And if they answered 'Yes' – would they be willing to share this data or outcomes of the trial with the Precision Silviculture Programme?

Eight respondents answered this question, with three indicating that they **may have relevant field trial data that they are prepared to share**, and four who were not sure and would need to check. Four respondents provided comments:

- Trial set up as genetic gain trial. Had containerised seedlings and cuttings, and bare-root cuttings. Noticeable difference in toppling and rooting issues between containerised seedlings and other stock types.
- We do have many compromised stands where containerised stock has been used, either as the main planted crop or as blanking plants. Subsequent root binding issues have meant that silvicultural options are more limited (don't want to invest in pruning these stands), and thinning is delayed to allow vulnerable trees more time to topple. There is also a hidden productivity loss, in that trees that appear ok but have substandard root systems will be restricted in their growth below the potential of the site.
- Currently in the process of establishing 3x demonstration trial areas comprised of bare root seedlings / bare-root cuttings (juvenile) / plugs on ex-farm pasture sites to aid future planting stock decisions. No data yet, but there will be in coming years.
- Last year we planted OP Containerised, SS Bare-root Seedlings, and CP Bare-root Cuttings on a greenfields site in the Waikato (this is because the nursery was short on cuttings). This is not a setup trial in the true sense but we have been able to observe quite different growth characteristics between the three stock types already (12 months old). Seedlings have already been susceptible to socketing as they were the fastest to grow post planting and have heavier (more) branching/foliage. Containerised is the slowest growing of them all. And cuttings took a bit longer to get going but have showed the best growth characteristics so far with minimal socketing.

Section E: Comments on knowledge gaps, and final comments

In Q.23, survey participants were asked if there are any **major issues/gaps in knowledge limiting an evaluation of performance of containerised stock** in New Zealand? Eight of the ten survey participants completed this question, providing the following comments:

- Yes - sorting out rooting issues.
- Variability in Nursery manager experience.
- Yes - almost impossible to quantify the productivity gap resulting from poor root structures.
- Performance in southern locations, and on ex-farm afforestation sites.
- To be honest, we have not researched the performance so am not sure what is available in regards to reports on the subject.
- I think so. If there was any way to make them hardier and sturdier without getting the root bounding issues then I would be inclined to use them more.
- Containerised handling systems, site access restrictions, planting method (Pottiputki use), root architecture comparison post planting
- Would need to understand the scale / ratio of bare root to containerized stock nationwide to appreciate how widespread the different stock types are. Is there a region that is using more containers vs bare root and would need forest managers to explain why they have a specific selection of one vs another.

There are some common threads in these comments. Four comments are about root issues, including looking at root architecture post planting, and two comments are about relative performance of bare-root and containerised on different sites, and in different locations nation-wide, including southern and ex-farm sites. There was also a mention of containerised handling systems, site access restrictions and logistics, and planting methods, including Pottiputki use.

In Q.24, survey participants were asked if they have any final comments and if the survey missed anything?
Two respondents provided final comments:

- Nursery practice has probably improved significantly from when we were using containerised stocks.
- Toppling in containerized if they grow too quickly, socketing containers same issue, supplying containers to planters in poor access, issues in mechanised planters (straight, depth, firming in), mechanised planters for steep slopes.

SURVEY CONCLUSIONS and RECOMMENDATIONS

The two industry surveys provide an indication of current industry knowledge and practitioner perceptions and experience in planting stock production through to forest establishment. This, along with a dive into relevant New Zealand and international scientific literature, and industry and government reports, helps provide information to formulate R&D priorities regarding containerised stock, planting stock specifications and field performance.

One comment from the Nursery Survey sums it up - "*They are very different crops to manage, and both nurserymen and foresters need to understand how to best manage the stock type in order to maximise establishment success*". However, they need the evidence-based information to help make informed decisions.

Bare-root planting stock is likely to remain important in New Zealand, due to the wealth of investment in R&D and proven performance, and low cost. Also, New Zealand has the ideal climate and availability of land for bare-root nurseries. So, it is no surprise that there is a preference among the forest planters for bare-root stock, though in good part this is due to the lower cost. However, it is well recognised that container-grown stock allow greater flexibility in planting programmes as there is a longer planting season and stock can be held over until conditions are ideal and planters (manual or mechanised) are available.

There is concern about the field performance of both containerised and bare-root planting stock, particularly in regard to toppling, which needs to be addressed. There is also the belief that containerised stock do better on harsher sites, which is well documented overseas, but only to a very limited extent in New Zealand. There is also interest in rooted cuttings (bare root and containerised) for harsher sites, and for topple-prone sites, though there are currently supply issues. Interest in cuttings (containerised and bare-root) is anticipated to increase – according to both nurserymen and forestry planters.

There is a lack of good data defining the ideal plant specifications for a containerised radiata-pine seedlings and cuttings – particularly height and diameter specifications. This urgently needs to be addressed. Defining the ideal container is also important. However, there is strong interest in the Ellepot among both nursery practitioners and forestry planters.

Availability of labour is a major constraint in both nursery and planting operations, therefore, efforts to increase mechanisation across the entire supply chain are warranted. One of the most significant knowledge gaps is the link between the specifications for quality container stock and the requirements for integration with mechanised planting machinery. This needs to be addressed. Systems supporting mechanised planting of bare-root stock also need to be a priority.

Recommendations

1. Research is urgently needed, in collaboration with nurseries and forest growers, to determine optimum specifications for containerised radiata-pine stock for the range of sites that are likely to be planted in the foreseeable future. Relevant information on plant quality measurement, experimental design, field trial design are provided in (Dibley & Clausen 1997; Aimers-Halliday *et al*. 1999; Ortega *et al*. 2006; Menzies *et al*. 2008). It would be good to repeat this work using the current range of containers in operational use today and following through to operational field trials.

2. Concurrently, research to define the optimal window for planting containerised stock is also needed – on a range of sites throughout the country.
3. Contact forestry companies who have run their own field trials, and who are prepared to share data. While these trials may not have an ideal experimental design, measuring these trials could provide valuable information of comparative field performance.
4. If planting machines are to become an important part of the forestry industry in New Zealand, there needs to be integration and optimisation across the propagation value chain through to planting and establishment. For example, the ideal match of planting stock specifications to planting machine requirements needs to be determined. However, plant specifications that have proven to result in good field performance must not be compromised to suit planting machines, i.e., mechanised planting systems need to be optimised, together with planting stock specifications to ensure both good productivity and field performance of stock.
5. If possible, work with these same companies to evaluate the potential operational and cost effectiveness compared with manual planting. Deduce the point where manual labour becomes uneconomical and mechanisation is cost-competitive.
6. Examine the supply-chain logistics and efficiency issues throughout the entire mechanised planting operation to see where there are issues that could be resolved to improve outcomes (survival and performance) and reduce cost.
7. Bare-root nursery production will likely remain an important part of planting stock production in New Zealand (and for good reasons), therefore, it is recommended that FGR engage with industry to determine if there is a need or desire to procure or develop planting machines that are compatible with bare-root stock.
8. Examine options to improve planting operations on steep slopes. This may not necessarily include planting machines as such but could include back-pack type hydraulic systems that aid planting on sites where the current planting machines cannot easily access. There is currently interest in the Pottiputki planting tool, which would be a good starting point.
9. Work with industry to see how early field performance of trees planted by machines, compares with those planted manually. However, there would need to be comparable plantings of both manual and mechanised systems to give weight to any comparisons made, due to the likelihood of confounding factors compromising any comparisons; i.e., scientifically designed field trials are needed to test mechanised planting operations with manual planting.
10. These field trials would need to include an appropriate selection of types of planting stock and container types, as per industry preferences and recommendations from the appropriate Technical Steering Committees. The trial design should include sacrificial plots where trees can be excavated for inspection of root distribution for each treatment combination. It is advised that field measurements are taken for at least the first 6 years.
11. These field trials would also need to be carefully designed to avoid confounding factors, e.g., planting stock sourced from at least two different nurseries, and the same or similar genetic material is used for each stock type, preferably across all nurseries, but at least within each nursery. Also, field trials should be on a variety of sites, including sites with characteristics linked to a high risk of topple.

APPENDIX 3 – QUESTIONNAIRE FOR NURSERY SURVEY

Planting Stock Quality and Containerised Systems

Background

This survey is being undertaken because of increased interest in container-grown radiata-pine nursery stock, due at least in part to development of mechanised planting systems. There are also questions about how the field performance of containerised stock compares with bare-root stock. Currently, most of radiata-pine planting stock in NZ is bare-root, although some forestry companies are deploying increasing amounts of containerised stock.

In recent years, labour shortages have hampered nursery operations (particularly lifting bare-root planting stock) and also planting operations. These problems were exacerbated by the COVID pandemic, but it is also due in part to the seasonal nature of nursery and planting operations and issues sourcing seasonal labour. This has been a driving factor in increasing interest in use of mechanised planters and deployment of containerised stock.

The big questions are:

- **how do we define a quality container-grown radiata-pine plant (i.e., are current specifications fit-for-purpose), and**
- **how does field performance of containerised radiata-pine stock compare with bare-root stock?**

In order to answer these questions, we are sending this survey to nurseries producing containerised and/or bare-root stock. The survey will take about 10 to 30 minutes to complete. Survey responses will help inform research and development within the SFFF Precision Silviculture Programme, ultimately for the benefit of forestry nursery growers and the forestry industry.

Forest Growers Research (FGR) is part of the Forest Owners Association (FOA). FGR co-ordinates industry input and funding of research programmes relevant to the forest growing sector. This includes research programmes funded by the Forest Growers Levy Trust, and other government and industry-funded programmes including the Precision Silviculture Programme (PSP).

We appreciate your time filling out this questionnaire and providing comments. If you would like to speak with a member of the research team, or would prefer to provide feedback by email or phone, feel free to contact us:

- Dr Jacqui Aimers (Contractor) Ph 021 1507883 jacqui.aimers@xtra.co.nz
- Dr Carol Rolando (Planting Theme Workstream Lead, PSP) Ph 027 7065248 Carol.Rolando@scionresearch.com

Confidentiality statement

We are aware that some nurseries may be reluctant to share commercially sensitive information. We will be respecting confidentiality.

FGR will not share individual responses with any individual or any other party. All responses will be grouped with others and analysed to provide summaries of data and any comments or suggestions will be kept anonymous. All data collected in the survey will be kept in secure facilities. Responses provided are confidential and will only be used to inform our research programme.

Section A: Please tell us about yourself and your organisation

1. Tell us about yourself:

- Your name ……………………………………………………………………………….
- Your organisation ……………………………………………………………………….
- Email address ……………………………………………………………………………
- Phone number ………………………………………………………………………….
- Are you open to being contacted in follow-up to this survey (Yes or No)………….

2. Your role in your organisation

- ☐ Nursery manager or owner
- ☐ Nursery operator
- ☐ Nursery supervisor
- ☐ Nursery R&D manager
- ☐ Other, *please specify*…………………………………………………………….

……………………………………………………………………………………………………..

3. Region(s) of NZ where your nursery supplies planting stock -

……………………………………………………………………………………………………..
……………………………………………………………………………………………………..
……………………………………………………………………………………………………..

Section B: Your current standard nursery operations

4. How many radiata-pine plants on average has your nursery produced per year, over the last 5 years? ……………..

5. How many radiata-pine plants do you anticipate selling this year? ……………………..

6. What proportion of your radiata-pine planting stock is sold to commercial forestry planting operations (as compared with farm forestry planting, or other)?

- ☐ Stock destined for commercial forestry planting operations …………. %
- ☐ Stock destined for farm forestry planting …………. %
- ☐ Don't know
- ☐ Other, *please specify* ……………………………………………………..%

7. What type of radiata-pine planting stock is your nursery **currently** producing? Please tick all that apply and indicate proportions (approximate percentages).

- ☐ Bare-root seedlings ………. %
- ☐ Bare-root cuttings ………. %
- ☐ Container-grown seedlings ………. %
- ☐ Container-grown cuttings ………. %
- ☐ Container-grown tissue-culture plantlets ………. %
- ☐ Other (e.g., stock produced via 'hybrid' propagation methods, such as Plug+) - *please specify* - ……………………………………………………………%

8. If you are growing radiata-pine containerised stock, what type of container(s) is your nursery using, e.g., Lannen 63F, 64F, 64FD, 81F; BCC S/S 81, V120 S/S; Panth S120-2; TS48-F trays; Paper pot (e.g., Ellepot), or other container type? **(If only growing bare-root stock, please skip Q.9 and go onto Q.10).**

…………………………………………………………………………………………………….

9. Please specify what type of container <u>you</u> prefer for radiata-pine propagation, e.g., a preference for plastic versus paper Ellepot, and a particular shape or volume of container? Please explain why. (Please note that your preference may differ from the type of containers actually being used in your nursery, which may be dictated by available resources or the market, rather than your preference). Please specify what <u>you</u> think is the best option.

……………………………………………………………………………………………………..

10. What are the major constraints or limitations in your nursery operations? Please indicate which apply and rank them with **1** being the most significant constraint.

- ☐ Difficulties lining up enough skilled labour at the right time
- ☐ Difficulty recruiting and retaining nursery staff with sufficient technical knowledge
- ☐ Constraints due to limitations in nursery infrastructure, i.e., lack of space and equipment to meet current demand
- ☐ Lack of capital to invest in new infrastructure
- ☐ The challenges of meeting market specifications for planting stock
- ☐ Slippage due to clients not taking stock on time
- ☐ Lack of certainty in forestry industry regarding amount of, and/or type of planting stock required in near future
- ☐ Nursery pathogens and the challenge of managing diseases such as terminal crook and phytophthora
- ☐ Other, *please specify* ……………………………………………………………

…………………………………………………………………………………………….

Comments –
…………………………………………………………………………………………………….

11. Is there a cost difference in the production of bare-root versus containerised stock?

- ☐ Yes
- ☐ No
- ☐ N/A – we don't produce both types of planting stock, so cannot make a comparison

If you answered **Yes**, please provide details, e.g., what is the more expensive stock type and where is the cost difference incurred? Also, if your nursery produces seedlings and rooted cuttings, and bare-rooted and containerised stock, please comment on the relative cost differences in production of seedlings versus rooted cuttings via both propagation systems.
…………………………………………………………………………………………………….

Section C: Future nursery operations

12. In the next 5 years, do you foresee:

- ☐ An increase in demand for radiata-pine planting stock?
- ☐ Approximately the same demand for radiata-pine planting stock?
- ☐ A decrease in demand for radiata-pine planting stock?
- ☐ A shift in types of nursery stock that we are producing - *Please specify* - ………………………………………………………………………………………...

Comments –
…………………………………………………………………………………………………….

13. What type of nursery stock do you foresee your organisation producing **5 years from now**? Please tick all that apply and indicate the proportions you envisage producing (approximate percentages).

- ☐ Bare-root seedlings …….. %
- ☐ Bare-root cuttings …….. %
- ☐ Container-grown seedlings …….. %
- ☐ Container-grown cuttings …….. %
- ☐ Container-grown tissue-culture plantlets …….. %
- ☐ Other, *please specify* (e.g., stock produced via 'hybrid' propagation methods, such as Plug+) …………………………………………………….%
- ☐ Don't know

14. If you foresee a change, what do you think will drive this? Please tick all that apply.

- ☐ New technological developments, such as mechanised planting systems.
- ☐ Labour costs and availability.
- ☐ Difficulties lining up planting stock availability (lifting in the nursery) with availability of planters.
- ☐ Legislative/political changes leading to a decrease in radiata-pine planting.
- ☐ Other, *please specify* - …………………………………………………………

Comments –
……………………………………………………………………………………………………

Section D: Planting stock quality

15. Based on your experience and feedback from customers, how do you think the field performance of containerised radiata-pine stock compares with bare-root stock?

- ☐ Not sure which performs better
- ☐ Containerised planting stock performs better than bare-root stock
- ☐ Bare-root stock performs better than containerised planting stock
- ☐ Similar performance if good quality stock is provided

☐ Bare-root stock performs better in some situations, and containerised stock performs better in other situations - *Please specify below*

Additional comments, e.g., on relative performance of different planting stock types. Also, if you have concerns about performance of a particular stock type, please explain what these concerns are and what improvements are needed – …………………………………………………………………………………………………..

There has been considerable research on bare-rooted planting stock, allowing for good definitions of ideal planting stock criteria. However, there is less research defining what constitutes a good quality containerised nursery plant. Please describe below what you think constitutes a good container-grown radiata-pine plant.

16. Can you define what constitutes a quality container-grown, radiata-pine plant?

- ☐ No, we only produce bare-root planting stock – *Please skip Q.17 and Q.18, and go to Q.19*
- ☐ Not sure - *Please attempt to answer Q.17 and Q.18, or provide comment*
- ☐ Yes - *Please answer Q.17 and Q.18 below*

17. Do you think that there is a difference between propagule types (rooted cuttings, seedlings, tissue culture plantlets, etc.) in terms of the specifications that constitute a quality container-grown nursery plant?

- ☐ No
- ☐ Yes
- ☐ Not sure

18. **18– 20.** Can you define what you think constitutes (in terms of characteristics) a quality container-grown radiata-pine nursery plant? If unsure, include a question mark. If your nursery does not produce one of the propagule types listed, then put N/A for that stock type or leave blank.

	Seedling	Rooted Cutting	Other Propagule *Please define below* ……………………
Container Volume			
Container Type			
Approximate shoot height (cm)			
Approximate shoot diameter (mm)			
Shoot characteristics			
Root characteristics			
Hardiness			
Other characteristics			

Comments – …………………………………………………………………………………………………..

21. Are there any major issues/gaps in knowledge limiting an evaluation of the performance of containerised stock in New Zealand? *Please comment* –

…………………………………………………………………………………………………..

22. **Do you have any final comments? Have we missed anything?**

…………………………………………………………………………………………………..

Thank you for your participation in this survey. We appreciate your time and input!

APPENDIX 4 – QUESTIONNAIRE FOR PLANTERS' SURVEY

Planting Stock Quality and Containerised Systems

Background

This survey is being undertaken because of increased interest in container-grown radiata-pine nursery stock, due at least in part to development of mechanised planting systems. There are also questions about how the field performance of containerised stock compares with bare-root stock. Currently, most of radiata-pine planting stock in NZ is bare-root, although some forestry companies are deploying increasing amounts of containerised stock.

In recent years, labour shortages have hampered nursery operations (particularly lifting bare-root planting stock) and also planting operations. These problems were exacerbated by the COVID pandemic, but it is also due in part to the seasonal nature of nursery and planting operations and issues sourcing seasonal labour. This has been a driving factor in increasing interest in use of mechanised planters and deployment of containerised stock.

The big questions are:

- **how do we define a quality container-grown radiata-pine plant, and**
- **how does field performance of containerised radiata-pine stock compare with bare-root stock?**

The survey will take about 30 minutes to complete. Survey responses will help inform research and development within the recently funded SFFF Precision Silviculture Programme, ultimately for the benefit of forestry nursery growers and the forestry industry.
Forest Growers Research (FGR) is part of the Forest Owners Association (FOA). FGR co-ordinates industry input and funding of research programmes relevant to the forest growing sector. This includes research programmes funded by the Forest Growers Levy Trust, and other government and industry-funded programmes including the Precision Silviculture Programme (PSP).

We appreciate your time filling out this questionnaire and providing comments. If you would like to speak with a member of the research team, or would prefer to provide feedback by email or phone, feel free to contact us:

- Dr Jacqui Aimers (Contractor) Ph 021 1507883 jacqui.aimers@xtra.co.nz
- Dr Carol Rolando (Planting Theme Workstream Lead, PSP) Ph 027 7065248 Carol.Rolando@scionresearch.com

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FGR will not share individual responses with any individual or any other party. All responses will be grouped with others and analysed to provide summaries of data and any comments or suggestions will be kept anonymous. All data collected in the survey will be kept in secure facilities. Responses provided are confidential and will only be used to inform our research programme.

Section A: Please tell us about yourself and your organisation

1. Tell us about yourself:

- Your name ……………………………………………………………………………….
- Your organisation ……………………………………………………………………….
- Email address ……………………………………………………………………………
- Phone number …………………………………………………………………………..
- Regions where your organisation operates …………………………………………..
- Are you open to being contacted in follow-up to this survey? ……………………..

2. Your role in your organisation

- ☐ Forestry manager
- ☐ Field operations manager
- ☐ Forest planting or establishment manager
- ☐ Contracting company or consultant
- ☐ R&D Manager
- ☐ Other, *please specify*……………………………………………………………

Section B: Your current standard planting operations

3. On average, what area do you plant in radiata pine per year (ha)? ……………………

4. What type of nursery stock are you **currently** planting? Please tick all that apply and indicate proportions planted (approximate percentages).

- ☐ Bare-root seedlings …….. %
- ☐ Bare-root cuttings …….. %
- ☐ Container-grown seedlings …….. %
- ☐ Container-grown cuttings …….. %
- ☐ Container-grown tissue-culture plantlets …….. %
- ☐ Other, *please specify* ……………………………………………….%

5. Do you have a preference for planting cuttings versus seedlings (container or bare-root)?

- ☐ Yes
- ☐ No
- ☐ Not sure

Please explain why you answered Yes or No

……………………………………………………………………………………………..

6. If you are using containerised planting stock, do you prefer any particular container type, e.g., a preference for plastic versus paper Ellepot, and a particular shape or volume of container?

……………………………………………………………………………………………..

7. If you know the type of container(s) that your planting stock has been grown in, then please indicate what it is, e.g., Lannen 63F, 64F, 64FD, 81F; BCC S/S 81, V120 S/S; Panth S120-2; TS48-F trays; Ellepot H111, or other container type.

……………………………………………………………………………………………..

8. What are your major constraints in getting planting stock in the ground? Please indicate which apply and, if possible, rank them from **1** to **5**, with **1** being the most significant constraint.

- ☐ Difficulties obtaining enough planting stock of sufficient quality.
- ☐ Difficulties lining up enough skilled planters at the right time.
- ☐ Difficulties coordinating planting stock availability (lifting in the nursery) with availability of planters.
- ☐ Cost constraints.
- ☐ Difficult site conditions, *please specify* ………………………………………….
- ☐ Other, *please specify* ……………………………………………………………

  ………………………………………………………………………………………….

Comments –

……………………………………………………………………………………………..

9. Is there a cost difference between planting bare-root versus container stock, considering both the cost of planting stock and logistics?

- ☐ Yes
- ☐ No
- ☐ Not sure

If you answered **Yes**, please provide details, e.g., what is the more expensive stock type and where is the cost difference incurred (transport and other logistics, or per unit purchased)?

…………………………………………………………………………………………………..

10. If cost and logistics were not an issue, e.g., there was no problem with stock availability and no difference in cost between the different types of planting stock, etc, what would you prefer to plant based solely on field performance?

- ☐ I would plant containerised seedlings
- ☐ I would plant containerised cuttings
- ☐ I would plant bare-root seedlings
- ☐ I would plant bare-root cuttings
- ☐ I would plant a mix of stock types depending on site conditions and time of year for planting operations. *Please specify* -

…………………………………………………………………………………………………..

11. What months are optimum for planting in your operation? Please fill in what applies, depending on what type of nursery stock you plant.

Bare-root planting stock

a. The earliest month I would consider planting is …………………………………
b. The optimum months of planting are (start - finish):……………………………..
c. The latest month I would consider planting is ……………………………………

Containerised planting stock

d. The earliest month I would consider planting is …………………………………
e. The optimum months of planting are (start - finish):……………………………..
f. The latest month I would consider planting is ……………………………………

Comments –

…………………………………………………………………………………………………..

12. How often are you forced by circumstances to plant outside your optimum planting season?

With bare planting stock

- ☐ Often
- ☐ Rarely
- ☐ Only during COVID-19 pandemic restrictions
- ☐ Never
- ☐ Not applicable – we don't plant bare-root stock

13. How often are you forced by circumstances to plant outside your optimum planting season?

With containerised planting stock

- ☐ Often
- ☐ Rarely
- ☐ Only during COVID pandemic restrictions
- ☐ Never
- ☐ Not applicable – we don't plant containerised stock

Comments –

…………………………………………………………………………………………………..

Section C: Future planting operations

14. In the next 5 years, do you foresee:

- ☐ An increase in area planted in radiata pine?
- ☐ Approximately the same area planted in radiata pine?
- ☐ A decrease in area planted in radiata pine?
- ☐ A shift in types of nursery stock that we are planting - please specify

Comments –

…………………………………………………………………………………………………..

15. What type of nursery stock do you foresee planting **5 years from now**? Please tick all that apply and indicate proportions planted (approximate percentages).

- ☐ Bare-root seedlings …….. %
- ☐ Bare-root cuttings …….. %
- ☐ Container-grown seedlings …….. %
- ☐ Container-grown cuttings …….. %

- ☐ Container-grown tissue-culture plantlets …….. %
- ☐ Other, please specify …………………………………………………..%

16. If you foresee a change, what do you think will drive this? Please tick all that apply.

- ☐ New technological developments in mechanised planting systems.
- ☐ Labour costs and availability
- ☐ Difficulties lining up planting stock availability (lifting in the nursery) with availability of planters.
- ☐ Other, please specify …………………………………………………………..

Comments –
……………………………………………………………………………………………………

17. Do you see any potential for mechanised planting within your operations? Please tick the option that best represents your situation:

- ☐ We are already using mechanised planting systems. *Please specify type of system* – ………………………………………………………………………………………..
- ☐ We are currently trialling mechanised planting systems. *Please specify type of system* - ………………………………………………………………………………………..
- ☐ We see good potential in the near future for including mechanised planting systems within our operations. *Please specify type of system* - ………………………………………………………………………………………..
- ☐ We possibly see some potential for mechanised planting systems in the future, for part of our forestry estate.
- ☐ We see no potential for mechanised planting systems within our planting operations.

Please feel free to add comments, e.g., constraints, suitability, uncertainties, knowledge gaps, etc.
……………………………………………………………………………………………………..

Section D: Planting stock quality

18. Are you happy with the quality of your current planting stock?

- ☐ Yes, we have a good supplier of quality planting stock
- ☐ It is OK, but not perfect *(please describe issues below)*
- ☐ No, we are not happy *(please describe issues below)*

If there have been issues, please specify what they are -
……………………………………………………………………………………………………..

19. Based on your experience, how do you think the field performance of containerised radiata-pine stock compares with bare-root stock?

- ☐ Not sure which performs better
- ☐ Containerised planting stock performs better than bare-root stock
- ☐ Bare-root stock performs better than containerised planting stock
- ☐ Similar performance if good quality stock is provided

If you have concerns about the field performance of a particular type of planting stock, please explain what they are –
……………………………………………………………………………………………………..
……………………………………………………………………………………………………..

There has been considerable research on bare-rooted planting systems, allowing for good definitions of ideal planting stock criteria. However, there is less research defining what constitutes a good quality containerised nursery plant. Please describe below what you think constitutes a good container-grown radiata-pine plant.

20. Can you define what constitutes a quality container-grown radiata-pine nursery plant, suitable for your planting sites?

- ☐ No, we only use bare-root planting stock – skip Q.19 and go to Q.20
- ☐ Yes - please answer Q.19 below
- ☐ Not sure - please attempt to answer Q.19, or comment below

21. Can you define what you think constitutes (in terms of characteristics) a quality container-grown radiata-pine nursery plant, suitable for your planting sites?

g. Approximate shoot height (cm) ……………………………………………………
h. Approximate shoot diameter (mm) …………………………………………………..
i. Shoot characteristics ………………………………………………………………..
j. Root characteristics …………………………………………………………………
k. Hardiness……………………………………………………………………………
l. Other characteristics ………………………………………………………………..

Comments -
……………………………………………………………………………………………………..

22. Do you have any recently planted field trials comparing container-grown stock versus bare-root stock that would add value to our understanding on field performance of different stock types? If yes – would you be willing to share this data or outcomes of the trial with the Precision Silviculture Programme?

- ☐ No, we don't have any field trial data that we can share
- ☐ Yes, we may have relevant field trial data that we are prepared to share
- ☐ Not sure – would need to check

Comments –
……………………………………………………………………………………………….

23. Are there any major issues/gaps in knowledge limiting an evaluation of the performance of containerised stock in New Zealand? *Please comment* –
………………………………………………………………………………………………..

24. **Do you have any final comments? Have we missed anything?** Please feel free to add comments -
………………………………………………………………………………………………..

Thank you for your participation in this survey. We appreciate your time and input!

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