Te Uru Rākau New Zealand Forest Service

Covid-19 : Extending the Planting Season –

Managing Nursery Stocks – Containerised systems.

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Covid-19 planting response:
Managing Nursery Stocks – Containerised systems.

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Report information sheet

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1 Executive summary

Key results

The aim of this report is to provide information on containerised planting stocks for various exotic and native species in New Zealand. This includes radiata pine (*Pinus radiata*), Douglas fir (*Pseudotsuga menziesii*) as well as some lesser common exotic species like Californian Redwood (*Sequoia sempervirens*), Cypress and Eucalypt species. The report contains global information and recommendations on container size, design, growing media and highlights the advantages but also most common pitfalls of containerised growing systems. In addition, species-specific recommendations are given where sufficient data were available.
Furthermore, we demonstrate early results from trials with 10 native tree and shrub species established in 10 different container types of various volumes and design and provide a primarily summary of best containerised growing-systems for native species from these trials. Results from these trials indicate a great potential to grow native species much more cost-effective than in the past which would make future planting of native species more attractive.

Implications of results for the client

Information in the report will increase the success of the 1BT planting programme by extending the planting season and survival of 1BT plantings ensuring wood products, ecosystem services, biodiversity and the development of a forest carbon sink to mitigate the effects of climate change. It helps to avoid or minimise the production of poor-quality plants that might pose a risk of poor survival.

Bare root seedlings have a short seasonal planting window in which to establish large commercial volumes of seedlings, where labour and site availability can be limiting factors. Container tree stocks can be delivered and planted over a wider seasonal timeframe, which allows for more flexibility during the busy planting season.

Further work

In view of the availability of data presented in this report, it is recommended that particularly information on lesser frequent exotic species like Redwoods and Cypress are collected. Currently no solid species-specific recommendation could be given for container size and stock type of these species. To gain a better overview of available and frequently used containers for these species in New Zealand and its suitability in the field a detailed survey of major nurseries specialised in exotic species and appropriate field trials would be necessary.

Additionally, the early, promising results for the containerised native species trials will have to be reviewed in later measurements which are essential to provide reliable and rigid recommendations for future large-scale production systems.

One billion trees programme Covid-19 planting response: Objective 2 - Managing Nursery Stocks – Container systems.

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2 Project overview

2.1.1 Broad project aims and rationale

The purpose of this One Billion Tree (1BT) funded research was to support an extended forestry planting season, helping to mitigate and minimise the impact of the delays stemming from COVID-19. The work has involved the collation of existing material and learnings from short time frame experiments, with outcomes that can be quickly operationalised in the upcoming planting season. Our means of achieving this outcome were by;

- examining industry best practices and providing recommendations for propagating plants, which need to be planted outside the normal season. This includes the management of larger plants and practices to extend the "shelf-life" of material as required.
- examining existing data sets and information available under a new lens and determine optimal sites, and timing to mitigate risk associated with out of season establishment.
- reviewing options to enhance site performance to mitigate risk associated with out of season planting, and protect sites which have undergone site prep, but have had to delay planting.

This broader project brought together key knowledge and expertise from across Scion to support the extension of the upcoming forestry planting season. The table below summarises the key objectives for this project. This specific report refers to *Objective 2: Containerised systems for native and exotic tree plant production*.

COVID19 Recovery Area	**Science Delivered**
General	Objective1: Industry Survey
Managing Nursery Stocks	**Objective2: Containerised systems for native and exotic tree plant production**.
	Objective3: Managing larger stock and holding stock for later planting
	Objective4: Summary of nursery stock and site suitability
Managing Delays in Planting	Objective5: The use of hydrogels
	Objective6: Managing delays in planting – extending dormancy
	Objective7: Understanding the physiological plasticity of tree species

2.1.2 Objective 2 - Containerised systems for native and exotic tree plant production.

The aim of the Objective 2 report is to provide a summary of the best containerised plants and growing systems to extend the existing recommended planting window. This will lead to greater survival of 1BT plantings resulting in successful establishment of the required 1BT thresholds. Long-term results will contribute to more successful planting and increased success of forest carbon sinks to mitigate climate change.

Specific aims are:

- To provide a summary of best containerised growing systems for radiata pine and other exotic species' groups to extend planting window
- Results of early measurement of native tree trials established in TUR_1BT_2020_26, and a summary of best containerised growing-systems for native species.

3 Use of containerised growing systems in forestry seedlings

The New Zealand Climate Change Commission report indicates that to offset unavoidable CO_2 emissions, 300,000 ha of new native forest, together with 380,000 ha of new exotic forest will need to be planted by 2035 in New Zealand (Climate Change Commission, 2021). The 1BT program aims to support this goal and provide information for successful afforestation. One option to increase flexibility and success around planting, in order to extend the planting window and marketability of small trees and at the same time mitigate workload peaks in the nursery and for planting operators, is a containerised growing system.

Improvements of container design have led to an increased use of container systems in many countries over the last years. Detailed summaries on plant production methods and advantages and disadvantages of bare-root and containerized production systems exist and have changed over time (Landis, Luna, & Dumroese, 2014; Mathers et al., 2007; Menzies & Arnott, 1992). The main reasons for the popularity of container systems today are:

- Much faster production of planting stock is possible (e.g., radiata pine), with greater control (growing media and conditions) and more flexibility over growing schedules.
- Higher quality plants can be produced for some species, such as some eucalypt species, western hemlock and the true firs.
- Maximize seed use for scarce seeds, since germination conditions can be closely controlled.
- Extension of planting season (planting window and window of marketability).
- Less transplanting shock with an intact root system bound with a potting mix, which leads to a higher establishment success.
- Easier to handle and transport and less prone to injury.
- Planting can be easier and faster, especially in rocky soil or debris covered sites.
- Good suitability for critical sites (e.g., dry sites, remote sites, cold sites of higher altitudes) The more adverse the conditions, the more the use of container stocks is appropriate (Wezel, 2013).
- Container systems are more adaptable for mechanization, both in the nursery and in the field.
- Better and more attractive working conditions for workers (in sheds and at propagation tables compared to crouching in the bare root beds in the weather).

One of the often-cited disadvantages of containerised forestry seedlings from a forest manager's point of view is the cost per propagule. While this can be slightly more expensive than for a bare root plant, the benefits would tend to outweigh the cost. Any cost-benefit analysis should include the total cost of restocking the area and not just the cost of the plants in the nursery (Menzies & Arnott, 1992). The opportunities for mechanisation and automation of planting through containerised tree stock can significantly reduce overall establishment costs, and has done so in many developed countries Rasanen (1981).

3.1 PLANTING TIME

In bareroot crops, the optimum time for planting is winter when the plants are most dormant and are especially successful in winter rainfall areas such as New Zealand. However, this is not always feasible (Menzies & Arnott, 1992) as it represents a very short period in which to establish large commercial volumes of seedlings, where labour and site availability can be limiting factors. There are also limitations imposed on nurseries who are required to dispatch and establish the next crop in that same short winter period.

One of the main advantages of using containerised tree stocks is the option for an extended planting season. Containerized seedlings have a broader range of planting seasons than bare-root stock but the best choice of planting season will be one that minimizes stress during and after planting (Amott, 1974). In principle, containerised plants could be planted the whole year, except for frozen soil conditions (Wezel, 2013) or in the period of intensive annual increment (Mauer, Rozmánek, & Houšková, 2018). When planting outside the optimal month, special care must be given in handling practices since plants are more sensitive when freshly sprouted or not yet fully lignified in late summer. Different tree species will vary in their susceptibilities and consequently may have a more limited planting window.

Additionally, it is very important to avoid drought conditions (e.g. in mid-summer) and consider the specific sites for tree planting to prevent losses (Klinger, Lloyd, & Ford, 2021). Moreover, it is important to keep in mind that summer planting in warm temperatures, long days and high solar angles cause high evapotranspiration rates. Planting stock while it is not dormant is known as “hot-planting” (Landis, Dumroese, & Haase, 2010). These stocks need some hardening in the nursery to withstand the stresses of harvesting, packing, shipping, and outplanting. Landis et al. (2010) described that the key to a successful hot-planting operation is careful planning and coordination between the nursery and planting project managers.

While container tree stocks can be delivered over a wider seasonal timeframe, which allows for more flexibility during the busy planting season, the particular extended time frame is dependent on species and climate conditions in the specific countries, regions, and field sites. Countries in different climatic zones and altitudes have different strategies for planting containerised stock. In most of Europe spring and autumn are main planting seasons to avoid drought conditions in summer and frosts in winter. Containerised tree stocks allow customers to plant in “shoulder” months as well, that is earlier, and later, than the typical bare-root planting window when planting is also less dependent on weather conditions (Wezel, 2013). For example, late summer planting in higher elevations of the Alps is conducted in Austria and Germany. In British Columbia, the planting season ranges from early spring in coastal areas to during the summer in the interior regions of the province (Mitchell et al., 1990).

In New Zealand, the planting season of bare-root stocks is mostly restricted to the winter months when the trees are dormant, although some species may be cool-stored successfully for early spring planting (Menzies & Arnott, 1992). For most species in New Zealand it can be assumed that the planting window with containerised stocks is both earlier, and later, than the typical bare-root plants. For some species, all year planting seems possible (Milligan, 2005; Nelson, 1996) and

recommendations for different species are given later in the report. In general, the local climate of the planting site should determine which planting season is most appropriate to minimise plant losses (e.g., areas with heavy autumn and winter frosts versus areas with summer drought on dry hill slopes) (Saunders, 2017).

3.2 HANDLING OF SEEDLINGS

Bareroot plants are more sensitive to handling practices like lifting, storage, transport and planting, as the fine roots can dry out quickly or be severely compromised when not handled properly (Grossnickle & El-Kassaby, 2016). When a seedling is planted in the field, the most critical part is usually to restore and maintain a suitable water balance. Therefore, the seedling must establish good contact between its roots and the water supply in the surrounding soil (Menzies & Arnott, 1992). During lifting and handling of bareroot stock, many fine roots (up to 30% of a plant's root area) are left in the soil, lost, or damaged (Thomas, 2014). In most instances in New Zealand, these are further trimmed as part of the nursery packaging and dispatch process.

These fine roots are generally feeder roots responsible for water and nutrient uptake. When these roots are damaged or lost, the plant is put under considerable stress. Some native species produce woody or lopsided root systems with few fine feeder roots close to the stem. In some instances, the bulk of fine feeding roots are completely lost in the nursery during preparation for planting. Whereas in container production, plants are produced, handled, and transplanted with intact root systems, thus increasing their potential for transplanting success. They arrive at the planting site with their containers and can use their intact plug as a source of water and nutrient storage until they have established root contact with the surrounding soil. This reduces planting stress and increases outplanting performance. Containerised plants therefore have better drought avoidance potential and have a higher chance of field survival (Grossnickle & El-Kassaby, 2016).

In addition to stock type selection, proper planting techniques are paramount for improved field survival. With containerised stock types water deficit problems could still occur, if there is sparse contact between the root plug and the soil after planting, or if the rooting depth is too shallow after planting. An excellent publicly accessible guide on planting techniques can be found in the container tree nursery manual by Landis et al. (2010).

3.3 CONTAINER DEVELOPMENT AND CHARACTERISTICS

Early commercial scale container types were developed and tested around the 1960s, but often resulted in problems and failures of plantings. Not enough care was given around root development in the containers, which resulted in negative plant or root effects like root spiralling or poor growth (Wezel, 2013). Since then, a lot of development and testing has been done which resulted in many improvements of container systems, forms, materials, growing media and thus root growth (Jacobs, Landis, & Luna, 2009; Luna, Landis, & Dumroese, 2009; Mathers et al., 2007). Today, there are many different types of containers available and there is a constant development of various systems. Some examples of improvements to containers were the introduction of the tapered shape, a drainage hole(s) at the base, vertical ribbing to prevent root spiralling and eventually the introduction

of side slits to promote natural air pruning of roots. The containers are raised off the ground to allow air pruning of any roots growing through the drainage hole (Menzies & Arnott, 1992). In general, container type and dimensions affect root development, amount of water and mineral nutrients available for plant growth. The best design and size of containers are species specific and depend on root system morphology, target plant criteria (size of plant required for local conditions), planting logistics (weight and transport costs) and economics (Luna et al., 2009). Hence, there are appropriate containers with different volume, height, diameter and shape for specific plants to ensure a balanced root and shoot development.

Plant density and root quality are key factors in the nursery. One of the major problems in the past was root spiralling/circling in containers. It has been determined to cause long term damage to tree roots and trunks well after trees have been planted out (Harris, Clark, & Matheny, 2004). These trees will establish slowly and may continue root circling for many years after planting. This can lead to mechanical instability, poor anchorage or even girdling (strangling) of the trunk with eventual mortality or wind throw (Mathers et al., 2007). Spiralling is caused when nursery stock has spent excessive time in (too small) containers, e.g., when stock is held over to the next planting season without repotting (Lloyd & Klinger, 2021). Other causes of root spiralling can be container designs or watering practices that do not induce roots to grow downward into the centre of the container or smooth sidewalls of plastic containers and substrate compaction (Zahreddine, Struve, & Quigley, 2004). Polybags or solid wall containers like the T28 trays can cause serious issue with root development. Polybags have smooth surfaces which leads the roots to spiral around and tend to concentrate in the bottom of the bag, when they reach the walls (Haase et al., 2021). This deformed root growth pattern results in low volume and overall fibrosity (Haase et al., 2021).

In contrast, containers with vertical ribs and air slits prevented root spiralling through lateral air pruning and result in a root structure characterized by a high number of vertically oriented roots (Luna et al. (2009), Rune (2003), Ortega et al. (2006)), which reduce the risk of early instability and poor growth.

Very detailed information on further container characteristics like geometry, dimensions, colour and composition of container material are described in Luna et al. (2009) and Mathers et al. (2007).

Types of containers

The first type is made of biodegradable material and is root permeable. The materials used decompose shortly after planting. Different materials are used with different properties e.g., paper pots or jute. Plugs are stored in plastic trays with one plant per ‘cell’.

The second kind of container is much more widespread and is removed before outplanting (plug seedlings). The tree seedling roots bind the growing medium together to a firm mass, or plug (Luna et al., 2009). The plants with the root and growing medium get extracted from the container prior to shipment to the field. Many different variations and trademarks exist. An excellent listing of the many designs currently used throughout North America is found in Luna et al. (2009).

Container types range from single-cell containers (like polybags, RootMaker® Containers, Individual Natural Fiber Containers, Treepots™, Round Pots) over 'Exchangeable cell containers held in a tray or rack' (Ray Leach Cone-tainers™, Deepots, Jiffy® Pellets™, Zipset™ Plant Bands), 'Book or sleeve containers' (e.g., Rootrainers™), or 'Block containers made up of many cavities or cells' (Styroblock™ and Copperblock™, Hardwall Plastic Blocks like Ropak® Multi-Pots, IPL® Rigi-Pots™, Hiko™ Tray System ,"Groove Tube" Growing System™) or Miniplugs to start young seedlings that are transplanted later.

One trend that could be observed over the past decades was the change to larger volumes of containers (Landis et al., 2010). These authors showed that in the 1970s, Oregon nurseries typically produced container stock of 33 to 66 cm^3, whereas, by year 2000 they were growing all their seedlings in 246 to 328 cm^3 containers. The demand for larger stock types has even led to the practice of container transplanting, where seedlings are started in small "miniplugs" in greenhouses and then transplanted to larger containers grown in outdoor compounds (Landis et al., 2010).

Since there is an enormous capital cost in setting up suitable facilities for container system production, it is paramount to consider the right container system for the right trees. After a container is selected, it can be expensive and time consuming to change to another type as that affects nursery layout, bench size, production scheduling and plant transportation method (Luna et al., 2009). Therefore, containers for each species should be tried on a small scale before buying large quantities.

Growing media/substrate

The selection of a growing medium is a very important decision in the containers' culture. In nurseries growing media are commonly 'artificial soils' which provide the essential services for plant growth such as physical support, aeration, water supply and supply of mineral nutrients. More detailed descriptions on important aspects of growing media such as cation exchange capacity, water-holding capacity, porosity, pH or bulk density can be found in Jacobs et al. (2009) and Mathers et al. (2007).

To provide best results for chemical and physical properties the growing media usually consists of two or more components. Therefore, mixtures of organic (e.g., peat moss, bark, compost, rice hulls, coconut coir, and sawdust) and inorganic (vermiculite, perlite, gravel, sand, pumice, and polystyrene beads) components are most popular because these materials have opposite, yet complementary, properties (Jacobs et al., 2009). Actual potting mixes depend on local sources of suitable material. A variety of commercial mixes are available, but components are also purchased separately since distinct mixes are needed to meet propagation requirements of different species.

Examples of different mixes vary widely. Throughout North America a proportion of peat moss to vermiculite varies by volume from 1:1 to 3:1 (Jacobs et al., 2009) but bark/sand (8:1) substrates are the industry standard in the south-eastern United States for container-grown ornamental plants (Mathers et al., 2007). Composted pine bark with particle size varying from 0.5 to 10 mm in diameter is used in Chile (Escobar, Sánchez, & Pereira, 2002) where it is frequently a major component of the

mix (Mead, 2013). Positive experience with composted urban waste as a substrate for the containerized production of *Austrocedrus chilensis* in Argentina is described in Basil et al. (2009).

Generally, the finer the media, the more fibrous the root development. Therefore, to assist species such as radiata pine that do not naturally develop large diameter anchoring roots coarse media can be used (Trewin, 2001). The deeper the container the more room for good sinker root development. Slow-release fertilizers are often added to the growing medium when filling the containers, but additional fertilizers are usually required during the growing season and are applied in liquid form (Escobar et al., 2002; Mead, 2013). Hardening is usually done by reducing nutrients and/or irrigation (Mead, 2013).

3.4 A GLOBAL OVERVIEW OF CONTAINERISED PLANTING STOCK FOR PLANTATION FORESTS

Chile's plantation forestry is in some ways similar to New Zealand. In Chile, radiata pine dominates at about 75 % of forestry, followed by 20 % of *Eucalyptus* species (principally *E. globulus* and *E. nitens*) and a small amount of Douglas fir and other species (Escobar et al., 2002). Whereas most of the radiata seedlings are produced bare-root, around 90 % of the seedling production of *Eucalyptus* species is in containers. Argentina also grows a significant proportion of radiata pine. Around 10 years ago the Patagonia region changed from bare root production to containerised systems due to the much faster production of seedlings (Schinelli, 2021 personal communication).

Approximately 10-15 % (between 180,000 – 200,000 ha) of South Africa's commercially forested area falls within the Western Cape 'winter rainfall' region, at latitudes between 33°51'S and 34°04'S. These areas are predominantly softwoods (~85%) and eucalyptus species (12%). Up to the 2016/2017 growing season, the softwood area was predominantly *P. radiata* while the eucalyptus was mostly *E. grandis*. The increasing impact of pitch cancer fungus on *P. radiata* and *Leptocybe invasa* on *E. grandis* has resulted in a move away from these species, and thereby also seedling deployment, towards alternative hybrid species like *P. patula* x *P. tecunumanii*, *P. elliotii* x *P. caribaea* and *E. grandis* x *E. nitens* deployment as rooted cuttings. Since the early to mid- 1990's, no bare root stock has been produced in South Africa for forest establishment. Pine and eucalyptus seedlings are predominantly raised as plugs of 80-90 cm^3, in either plastic or polystyrene trays, with 100% composted pine bark growing media. Pine cuttings are mostly produced in 90 cm^3 Unigro 98 trays (with loose insert plugs) using 100% composted pine bark growing media, while most eucalyptus cuttings are produced in a 60 cm^3 Unigro 128 tray. Media mixes for eucalypt cuttings are somewhat variable but usually include pine bark:perlite:vermiculite or coir:perlite.

In Australia, Eucalypts (account for 93% of hardwood species) and radiata pine (accounts for 75% of softwood species) are the most common plantation species (Downham, 2020). In Western Australia, the Forest Products Commission has been producing containerised seedlings for the last 10 years and hasn't produced any bare root trees since. Seedlings are grown in 81 cell Lannen trays (85 cm^3) before being decanted into cardboard boxes for dispatch and delivery. They consider the main benefits particularly in relation to transport and storage of seedlings (Guille, 2021 personal communication).

Since 2016 radiata pine has also been completely produced via containers using TS 45 trays (93 cm^3) in the Australian Capital Territory (Flood, 2021 personal communication). The transition from bare root stocks was due to the improvements in container technology, reduction in bare rooted suppliers and lastly reduction in planters with bareroot planting skills (Flood, 2021 personal communication). Experience from Victoria, Australia, is also pointing towards a growing use of container seedlings. While currently still around half of the seedlings in one of the biggest nurseries are grown bare root, this is expected to change within the next two years towards 100% containerised systems in TS 45 trays (Torney, 2021 personal communication).

In summary, nowadays bare-rooted plant production of radiata pine predominates in New Zealand and Chile, whereas container grown stock is more common in Australia (Flood, 2021, Guille, 2021 and Torney, 2021 all personal communication), South Africa, Spain (Mead, 2013) and Argentina (Schinelli, 2021 personal communication).

4 Containerised plants and growing systems for exotic species in New Zealand

Bare-root technology has been very successful for seedlings and cuttings in New Zealand, therefore there has been little early research on container-growing of crops (Menzies & Arnott, 1992). Moreover, even though New Zealand research indicated the potential benefits of containerised stock, especially for harsh sites, container-induced deformities which resulted in poor root form inhibited further work (Baker, 1982). With improved container tree quality and prevention of root cages (root spiralling) by lateral air root pruning more potential was seen for containerised stocks (Nelson, 1996). Stock types and size specifications for exotic New Zealand plantation species were first published by Nelson (1996). The trend towards containerisation as a common nursery practice was also encouraged by the increased numbers of vegetative propagules, particularly cuttings (Menzies, Holden, & Klomp, 2001). These propagules are usually more expensive than seedlings, thus containerised stocks are often used because they can be grown indoors until rooted and with minimal root disturbance at lifting. In addition, transplanting stress is usually lower and survival rates higher compared to bare-root trees (Mead, 2013).

4.1 RADIATA PINE *(PINUS RADIATA)*

Radiata pine is by far the most important economic tree species in New Zealand. In 2019, 84 million out of 88.8 million tree stocks sold in NZ were radiata pine (Ministry for Primary Industries, 2020). This accounts for 95% of tree stocks sold and results in an estimated planted area of 82,000 ha in 2019. As well as in recent years radiata pine tree stocks have always accounted for more than 90% of tree stocks sold. According to a recent survey from Bayne (2020) around 90 % of radiata stock have historically been produced bare-root and only 10% as containerised stock, although in the 2020/2021 production season containerised production was closer to 18% of radiata stock produced.

Most of the planting stock in New Zealand is raised as bare-root as described in Menzies, Dibley, and Low (2010), but they observed an increasing use of containers. The general worldwide increase

of containerised radiata pine is mainly due to the option of planting outside the winter season (extended planting season) and the increased use of cuttings or clonal material (Mead, 2013). In New Zealand, labour availability is another huge driver towards containerised growing systems both in the nursery as well as in the forests and consequently mechanisation increases in both fields. In addition, environmental issues around nutrient and water use and a lack of chemicals for weed and disease control in the nurseries growing bare root stocks are other drivers for container production. Other cited advantages concerned with containerised radiata pine are that they allow quicker production of planting stock and the setting of smaller vegetative propagules (1–5 cm long). The option for faster production was the decisive reason in Patagonia, Argentina, that led to the change from bareroot to container production more than 10 years ago. While bareroot production took around two years to reach a satisfactory height the adoption of containerised production reduced that time to 9 months (Schinelli, 2021 personal communication). Moreover, difficulties in obtaining and maintaining sites for bare-rooted nurseries have been overcome and containerised plants are compact in nature and can easily be mechanized (Mead, 2013).

In general, the methods used to grow containerised radiata pines are like those for many other tree species (Mead, 2013). To prevent root spiralling, cells should be tapered, ribbed or have vertical slots. Drainage holes are needed in the bottom to ensure the air pruning of roots and therefore trays are put on benches. Ideally plants must have a diameter of at least 3 mm or more and not be too tall (15–25 cm) when outplanting. Menzies et al. (2005) recommend a collar diameter of 4.5 - 5mm. The target plant size in the Australian Capital Territory is a range of 22-30 cm (Minimum 20 cm; Maximum 35 cm) and a root collar diameter of 4+ mm (Minimum 3.5 mm) (Flood, 2021 personal communication). Target plant size for containerised radiata pine in a major nursery in Victoria, Australia, is 24 cm for cuttings and seedlings equally (Torney, 2021 personal communication).

Plant size can be managed since there is a good relationship between container size and size of planting stock as well as between spacing within the nursery bed and seedling diameters (Mead, 2013; Menzies et al., 2005; Menzies et al., 2010). It is recommended that the minimal container depth should be at least 8.5-10 cm. For vegetatively propagated seedlings (cuttings), the size of the containers must be deeper. In Chile, a depth of 16 cm is used since the cuttings are 8 to 10 cm long. Generally, container size varies between different countries, starting from 80 cm^3 in Chile (Escobar et al., 2002) to 93 cm^3in Australia up to 270 cm^3 in Spain (Ortega et al., 2006).

Ortega et al. (2006) have studied field performance of radiata pine produced in a nursery with different types of containers in Spain. They found significant differences in morphological responses among the seedlings to the various container characteristics at the end of the production period. On the one hand, root deformations were more frequent and severe in plants produced in closed-wall containers, which led to more stability problems in the field (e.g., toppling). This is likely to cause a reduction in lumber recovery and value in the future. On the other hand, seedlings grown in containers permitting lateral air pruning, presented less growth and lower biomass production but resulted in plants with a balanced root and stem development. Container size had a significant effect on height. Generally, bigger containers (AR260 and PT270) showed higher seedling height values compared to the smaller containers (FP200 and PF200). That is consistent with other studies (e.g., Menzies et al. (2005); Menzies et al. (2010)).

Furthermore, Ortega et al (2006) concluded that it is also important to consider the planting site, because the planting environment has a major effect on seedling growth. A more fertile soil increases the growth but also the chances for toppling, especially when having trees with a large crown and small root system. The importance of site conditions and different stock types is also pointed out in Nelson (1996). Furthermore, current information is also presented in the report on site suitability (objective 4) from this report series in Klinger et al. (2021).

In a study in New Zealand, Menzies et al. (2010) raised radiata pine seedlings and cuttings in 15 different types of commercially-available containers, ranging in size from 85 to 220 cm^3, with different shapes and surface areas and evaluated the size and quality of planting stock produced. They recommend a container cell size for seedlings and cuttings of at least 120 cm^3 and a growing density for seedlings of 330/m^2 or less when a yield of at least 80% out the gate is desired. All cuttings grown in containers with a volume of 100 cm^3 or less gave a yield of less than 70% out the gate. However, there is no single optimal container type, but dependent on the desired plant height and quality which in turn, is dependent on site specifications (e.g., warm/cold, weed or animal problems). It is important to note, that a minimum plant specification for container-grown seedlings or cuttings couldn't be defined without comparing the performance of different-sized plants in the field.

Lieco, the European market and technology leader in containerised forest trees, uses L15 red Lieco-containers with a volume of 311 cm^3 and a diameter of 7 cm for pine, larch and Douglas fir (LIECO, 2020). Argentina uses containers for radiata pine with a volume of 160 cm^3 and a depth of 15 cm (Schinelli, 2021, personal communication). In Australia, TS 45 trays (93 cm^3) or 81 cell Lannen trays (85 cm^3) are common (Flood, 2021, Torney, 2021, Guille, 2021 personal communication).
To sum up, the most commonly used sizes of containers range from 85 cm^3 up to 311 cm^3 for pines depending on target plant size.

Potting mixes consists of a combination of two or more of peat, composted bark, pumice and perlite (Menzies et al., 2005). The mix must have good water-holding capacity, yet allow free draining. A slow-release fertiliser (6-9 month) is often added to the mix. Since radiata pine does not naturally develop large diameter anchoring roots coarse media should be used (Trewin, 2001).

Planting period

Being a temperate species that prefers wet winters and dry summers, radiata pine is planted between late autumn and early spring. Only under special circumstances should summer planting be practised (Mead, 2013).

Recommendations on the planting period with different container systems can be found in (Nelson, 1996). These include planting options from late spring to autumn for Plantek and Ecopot container systems (Plantek 81F, Plantek 63F, Plantek 64F or Ecopot PS508c and PS610c). However, it must be considered that the best planting time for a tree species is generally when the plants are most dormant (in winter) or if not feasible, a time that minimizes stress during and after planting (Menzies & Arnott, 1992). However, an extension of the planting season beyond the traditional winter period for bare-root plants is also indicated in Menzies et al. (2001).

In 2020 current forestry planting period with containerised radiata pine stocks in New Zealand lasted from May to October (Bayne, 2020). However, earlier planting was prevented by COVID lockdown restriction in 2020. Depending on climate (avoidance of drought conditions) and site conditions (the less critical the more options), this period could be further extended as recommended by Nelson (1996) and based on international experiences.

4.2 DOUGLAS FIR (*PSEUDOTSUGA MENZIESII*)

Douglas fir is the second most important plantation tree species in NZ with around 2 million tree stock sales on average in the recent five years. This accounts for 2-4% of tree stock sales in NZ per year over the last years ((Ministry for Primary Industries, 2020).

Douglas fir is one of the more sensitive tree species to establish and less hardier than radiata pine. Douglas fir seedlings are particularly delicate to desiccation (Rothkegel et al., 2013) and are highly vulnerable to frost after flushing. The plants must be kept cool and moist and need to be delivered and planted into the soil quickly. After more than 4-minutes exposure of unprotected roots survival rate declines drastically (Hermann, 1962). This sensitivity could make the use of containers to establish Douglas fir a sound option. Different experiences on optimal container size exist. Rose and Haase (2005) demonstrated that large container seedlings (15.2 cm deep, volume of 336 cm^3) established and grew more quickly than bareroot transplant seedlings during the first spring after outplanting.

A study from the Western United States examined the effects of container volume (80, 130, 200, and 250 cm^3) and vegetative competition on seedling survival and physiological and morphological responses for two years, post-outplanting (Pinto et al., 2018). They found that the growth rates of the smallest 80 m^3 was significantly smaller compared to the bigger container dimensions. However, all other stock types were statistically similar. In conclusion, the benefits to post-planting seedling physiology and growth in relation to container size plateau beyond 130 cm^3 among the investigated stock types in the analysed situation.

Wightman, Gonzalez-Benecke, and Dinger (2018) described a long-term growth comparison experiment with different container types (130 cm^3, 250 cm^3, 1000 cm^3) in Oregon during the initial 8 years of establishment. The study was designed to quantify the effect of containerized stock types on Douglas-fir seedling survival and growth at two sites in the Central Coastal Range. The results of this study suggest that seedling stock type does not have a long-term effect on Douglas-fir tree size, when a minimum container size of 130 cm^3 is used. The smaller stock types had faster early growth, and initial size differences disappeared after 3 to 5 years. After this the growth of all stock types was similar, and no differences in tree size were present after 8 years. In addition, the largest stock type tested (1,000 cm^3) had the lowest survival at both study sites. Wightman et al. (2018) relate this to the larger leaf area of the larger seedlings (twice the shoot volume of the other stock types), and thus, increased evaporative demand during stand establishment. Therefore, on top of the larger

logistical effort due to the large space required to store and transport the seedlings performance didn't account for the additional effort.

In New Zealand, a container size cell volumes of 90 - 150 cm^3 is commonly used for 2/0 stock and the same growing media as for radiata pine (Menzies & Brown, 2005). In Europe, the L15 red Lieco-containers with a volume of 311 cm^3 and a diameter of 7 cm are frequently and successfully used for Douglas fir (LIECO, 2020). A container size of 160 cm^3 with a depth of 15 cm is used in Argentina (Schinelli, 2021 personal communication). Most dominant container stock types recommended for planting in British Columbia, Canada, are 105 cm^3 and 170 cm^3 (seedling containers 415B and 415D) depending on growing conditions (B.C. Ministry of Forests, 1998). The use of bigger stock types (220 cm^3, 250 cm^3, 340 cm^3 (PSB 512A/ 515A 1+0 or PSB 615 1+0) are only recommend for severe brush competition or sites with substantial animal browsing.
In summary, a container volume size around 130 cm^3 seems most appropriate for average New Zealand conditions.

Planting period

Douglas fir can grow in colder parts and higher altitudes in New Zealand (Maclaren, 2009). Therefore, winter planting might not always be feasible because ground is frozen or snow-covered. Maclaren (2009) suggested that planting of bare-root stocks should be planned for the month of June if possible, which is when the species is most dormant. Menzies and Brown (2005) recommended planting bare-rooted stock in winter, whereas containerised stock can be planted from autumn to spring.

Douglas fir's root growth precedes shoot growth in spring (Rothkegel et al., 2013). Therefore, when planting in spring it should be done as early as possible (best before bud-burst), so that plants can regenerate roots and root into the soil quickly to be adapted for a drier season. Planting in autumn is also a good option since root growth continues after shoot growth until the winter month (Rothkegel et al., 2013). Experience from the Rocky Mountains suggest that planting of containerised Douglas fir early in the autumn season is advisable if soil moisture conditions permits it (Adams et al., 1991). Nelson (1996) suggested timeframes from early summer to late spring for planting containerised Douglas fir in New Zealand depending on site conditions and stock type.

In conclusion, containerised stock extends the planting season of Douglas fir to the time from autumn to spring. However, planting in drought conditions should be avoided as with any bare-root or containerised stocks species but especially with Douglas fir (Mauer et al., 2018).

4.3 CALIFORNIAN REDWOOD (*SEQUOIA SEMPERVIRENS*)

Redwoods annual tree stocks sales in New Zealand are summarised under 'other exotic softwoods', which altogether account for around 1.4 million tree stock sales in 2019. However, 'other softwoods' stock sales and planting show an increasing trend over the last 5 years (Ministry for Primary Industries, 2020). Redwood is considered the third most important solid wood crop in New Zealand

and has further potential as a high-yielding and low-risk (high wind-firmness and resistance to fire) carbon crop or for erosion-prone sites where slope stabilisation and high water quality are key (Rapley, 2018). However, seeds are regarded as being very difficult to store successfully and germination rates are often low (Wilson et al., 2016). Therefore, it is current industry practice to plant clones of parents that have desirable characteristics in growth and form (Meason et al., 2012).

An alternative propagation method is used by NZRC (2021). They produce tissue culture and propagate it in a strictly controlled laboratory setting. A specialist nursery produces robust clones from the plantlets from the lab. In this way desired clonal varieties can be selected for growth, form, fine branching, health and wood properties and can be produced in large numbers. Lieco, the European market and technology leader in containerised forest trees, uses L15 black Lieco-containers with a volume of 311 cm^3 and a diameter of 7 cm for redwoods successfully for temperate European growing conditions (LIECO, 2020).

Altogether, there is limited up to date information available in New Zealand on container size and design of the less frequent species like Redwoods and Cypress. Historically, New Zealand have used a number of different tray types for redwood seedling and cutting production, these include but are not limited to Transplant systems TS48 (125 cm^3, slotted walls), Hiko V90 (90 cm^3, solid wall), Lannen 'Plantek' (85-128 cm^3, slotted walls) and IPL 'Rigi-pots' (110 cm^3, solid wall). In most cases growth and vigour are suitable but extraction at dispatch is problematic as the roots tend to adhere to the container walls and plugs are therefore difficult to remove, often resulting in significant damage to root plug integrity at extraction. This is especially problematic in the solid walled containers. Recent work at Scion nursery has focussed on the opportunity of using the improved air-pruning capability of the Ellepot paper-pot system and trays to manage this issue and improve extraction time and success. Early results show this may have some promise but does rely on close management and timely dispatch. It is recommended particularly, that more information on these less frequent exotic species is collected. Moreover, plant specifications for container-grown and bare-rooted plants depending on site conditions, would need to be defined in appropriate field trials.

Optimum growing media of *S. sempervirens* is described in Meng et al. (2019). They studied the effects of different substrate ratios on growth and physiology of 1.5-year-old *S. sempervirens* container seedlings. The optimal substrate ratio consists of peat: GWC (green waste compost): soil: perlite of 4: 1.5: 1: 2. This best substrate composition increased plant height and ground diameter growing in the substrate by 28% and 39% compared to their respective initial values.

Planting time for redwoods is usually in winter to minimise grass competition (NZFFA, 2007a). There is little information in the literature on the planting season of containerised redwoods used for forestry purposes.

4.4 CYPRESS (*CUPRESSUS MACROCARPA – 'MACROCARPA', CUPRESSUS LUSITANICA – 'LUSITANICA'*)

The total area of cypresses in New Zealand is estimated at around 10,000 hectares. Annual tree stocks sales of cypress are summarised under 'other exotic softwoods' as described for redwoods above. The most commonly grown cypress species are *C. macrocarpa* and *C. lusitanica*.

Propagation of cypress is commonly achieved by vegetative propagation, mostly cuttings, because seed sources are in short supply (Nicholas, 2007). Therefore, clones play an important role in cypress forestry in New Zealand and specific advantages but also risks exist around genetic diversity, as outlined in Fraser et al. (2020) and Nicholas (2007). A new cost and time-efficient method of macropropagation is described in Pericleous and Eliades (2020) with *C. sempervirens,* but could be applied for other *Cupressus* genus as well.

Cypress seedlings can be grown either as open ground (bare-rooted) or containerised planting stock, and both can be very successful (Nicholas, 2007). *C. macrocarpa* and C. *lusitanica* are either grown as 1/0 bare-rooted seedlings, 1/1 stock or as 9-month-old root-trainer-grown stock (Miller & Knowles, 1996). Cypress seedlings can be greatly stressed by conditions which would not be at all damaging to pine seedlings (Miller & Knowles, 1996), so great care is necessary in handling stock between lifting and planting out. Moreover, large seedlings are considerably more vulnerable than smaller ones. Therefore, they prefer smaller stock of C. *macrocarpa* or C. *lusitanica,* around 25-35 cm tall with a 5-6 mm root collar, over larger, older stock. Rooted cuttings should have a minimum diameter of 5 mm and a minimum height of 35 cm (Nicholas, 2007).

There is sparse information in the literature on best container size or growing system for cypresses despite a certain sensitivity in handling as described above. Nelson (1995) suggested a RCD of >3 mm on well prepared sites and a stem height of 15-30 cm sufficient for container-grown *C. macrocarpa* (Plantek 64F or Ecopot PS610c). In a Scion experiment on the use of herbicides to control weeds in container-grown cypress hybrid cuttings, RIGI-POTS with a volume of 110 cm^3 and a depth of 12.7 cm were used (Roberts, Dibley, & Low, 2016). However, information around outplanting success of other Cypress species is available: Loveall, Maiers, and Harrington (2002) compared outplanting success of *C. arizonica* of different plant and container sizes in New Mexico in the southwestern United States in a semi-arid environment. The results showed that the middle sized 262 cm^3 container showed best survival after 72 months and consistently had the greatest height growth from the 15-month measurement period through the 72-month measurement period over other container sizes (115 cm^3, 164 cm^3 and 656 cm^3). This container size also had the greatest depth of containers used in the study.

Kolevska et al. (2015) conducted a nursery trial on *C. arizonica* in Macedonia. They received good values (height, root collar diameter, high number and length of roots) for smaller container sizes (75 cm^3) in a nursery but found lower values at quality indexes and ratios (e.g. dry root weight/ dry shoot weight ratio). Furthermore, performance of survival and growth rate after planting are not covered in this study. It is recommended that more information on containerised growing systems are collected on cypresses.

Planting period

Planting cypresses should be from late autumn to late winter but can be extended into spring with container grown material (NZFFA, 2007b). Nicholas (2007) recommends to plant at the beginning of the growing season which is around August/September in cooler parts of the South Island and around July/August on the warmer North Island, but no differentiation is made for container and bare-root stocks.

4.5 EUCALYPTS (*EUCALYPTUS NITENS*, *EUCALYPTUS FASTIGATA* AND *EUCALYPTUS REGNANS*)

Tree stock sales of *Eucalyptus spp.* is summarized under 'all hardwoods', which altogether accounts for around 1.5 million trees per year in New Zealand which represents around 1-2 % of yearly tree stocks sales (Ministry for Primary Industries, 2020).

In general, containerised stock is recommended for eucalypts, although good quality bare-rooted planting stock of hardy species planted in good conditions may establish successfully (NZFFA, 2016). When planting bare-rooted stock, special care is needed and mostly 1/0 stock is used (Miller, Hay, & Ecroyd, 2000). The advantages of container stocks are predominantly the more efficient use of specific seed origins or the growing of nursery stock for a particular planting time. In addition, many eucalypts perform much better when container grown (NZFFA, 2005). Therefore, the use of container-grown seedlings, root trainers, or peat pots is increasing (Miller et al., 2000).

Early research on containerised Eucalypts in New Zealand is described in Faulds and Van Dorsser (1979). Successful techniques for different containers were developed for *E. delegatensis*, *E. nitens*, *E. regnans* and *E. saligna* and some 70,000 seedlings raised. In addition, they experimented with conditioning of seedlings for outplanting in drier month and site conditions as well as in cooler situations and give advice on correct planting technique. Despite several advantages of containerised trees, they conclude that for large scale plantings it is more economical to use bare-root stocks and establish these during the colder months of the growing season.

In Chile, around 90% of the seedling production of *Eucalyptus* species is in containers (Escobar et al., 2002). Many nurseries use 60 x 40 cm styrofoam blocks with 84 cavities, 16 cm deep, with a volume of 130 cm^3. Growing media consists of either 100% composted radiata pine bark, a mix of bark with 15% peat or 50% composted pine bark and 50% perlite.

Mullan and White (2002) have summarized experience on container design and size used in Western Australia. Examples of volumes vary between 49 and 85 cm^3, but they state that research has shown large volume cells bigger than 90 cm^3 are beneficial to plant growth. Close et al. (2006) studied effects of seedling size and container type on early after-planting performance of *E. globulus* in Australia. The different containers used were Colmax 72 (45 cm^3, 50 mm deep), Premium Plastic 104 (85 cm^3, 73 mm deep) and Lannen 63 (115 cm^3, 90 mm deep). They found that container size had strong and persistent effects on after-planting performance in some regions; Seedlings raised in Lannen 63 and Premium Plastic 104 containers outperformed those raised in the smallest

Colmax 72 containers, whereby the medium container showed the best growth. In addition, the effect of container type was greater in soils of higher clay content.

Close et al. (2010) confirmed the before mentioned findings of greater height growth by seedlings raised in higher volumes of *E. globulus* in Tasmania's Southern Forests. The Forestry Tube (12 cm deep, 115 cm^3 volume) containers with the biggest volume showed the best height growth compared to smaller container Lannen 121 (7,3 cm deep, 50 cm^3 volume), Lannen 81 (7,3 cm deep, 85 cm^3 volume).

The Forest Products Commission in Western Australia produces *E. diversicolor* seedlings in 81 cell Lannen trays (85 cm^3). They are then decanted into cardboard boxes for dispatch and delivery (Guille, 2021 personal communication).

In conclusion, many different sizes of containers exist for various *Eucalyptus* species. Most research indicates a positive effect of container size on plant development and thus a container size of 85-130 cm^3 seems most appropriate depending on target plant size.

Planting period

In New Zealand, bare rooted stock can be planted from May to September (Taranaki Regional Council), however young Eucalypt seedlings are susceptible to frost damage. Therefore, Nicholas (2008) as well as NZFFA (2016) recommend to plant Eucalypts in spring (September-October) as the best time, when the winter frosts have passed.

Container grown stock can also be planted out of season if necessary to avoid frost problems. Nelson (1996) even proposed all year planting for exposed, shallow, droughty, weedy and other difficult sites for planting containerised *E. nitens* in New Zealand. However, planting Eucalypts in drought conditions should be avoided with any bare-root or containerised stocks like with any other species.

5 Containerised plants and growing systems for native species in New Zealand

Early detailed practices with native trees grown in containers are available from 1980 (Beveridge & Dorsser, 1980). However, these early experiences were abandoned because of higher costs and because container trees proved more difficult to condition in and plant out from the nursery back then. In contrast, bare-root stock showed high survival and was therefore preferred for large-scale planting.

Research on containerised systems, mostly with planter bags, for Kauri (*Agathis australis*) but also for other native species such as Titoki (*Alectryon excelsus*), Pukatea (*Laurelia novae-zelandiae*), Mangeao (*Litsea calicaris*), Wharangi (*Melicope ternata*), Pohutukawa (*Metrosideros excelsa*), Ngaio

(*Myoporum laetum*), Pate (*Schefflera digitata*) and Puriri (*Vitex lucens*) from grey literature dates back to 1990's.

In 2003, most nurseries raised totara seedlings in containers (Bergin, 2003) and the vast majority of native trees and shrubs have been raised in containers over the last few decades (Cole, van Dorsser, & Bergin, 2014). With increasing interest in native forestry and native species during recent years, systematic research on containerised native species is growing. Current information on propagation techniques and container types for cuttings (Harris et al., 2017) as well as a plantation guide with current knowledge and experiences on establishing Manuka and Kanuka (Saunders, 2017) have been published.

Performance of native pioneer shrub hardwood species after planting is dependent on growing system (open-ground, pot, root trainer) and species (Cole, Bergin, & Kimberley, 2014). While some species show better growth and survival rates in pots (e.g., Kohuhu, Manuka, Ti kouka), others grow better bare-root (Karamu) and some show comparable performance (Harakeke, Toetoe, Koromiko). Trees in the smallest container types (root trainer) showed the worst performance in survival and height due to spindly plants being overtopped by grass competition (Cole et al., 2014).

The merits of container-grown and open-ground plant production systems and the most common container systems in different sizes (Planter bags, semi-rigid pots and root-trainers - with respective costs per plant) used for native species are compared in Cole et al. (2014). There is rationale for both types of growing systems and different native species have different demands and properties. Therefore, choice of respective container or bare-root system will depend on species grown and the age and size of plants required. A recent nursery survey showed that native species are predominantly produced as containerised stocks in more than 95 % of the cases in 2020 (Bayne, 2020).

Information on costs (bare-root vs container) on some native species can be found in Smith (2010), Ledgard and Dungey (2010) and Saunders (2017). However, it is important to note that a complete cost-benefit analysis must cover total cost of restocking the area and not only the cost of the plants in the nursery. Although biological factors should be the primary consideration, the choice of container stock type is also defined by price and preference (Landis et al., 2010a). Therefore, it is important to consider the cost per surviving plant when deciding on stock type and other target seedling factors. The price of container stock is largely dependent on nursery production space, so the prices of the various container sizes increase as their cell densities decrease (Landis et al., 2010a). Therefore, cost efficiency is also an important aspect in producing native nursery stock to achieve higher numbers of nursery stock and to reduce costs per plant.

Steward and Dibley (2015) compared nursery performance of four native tree species including Kauri and Totara raised bare-root and in six different containers (PB3 (1,700 cm^3), Large Queensland Native tube (810 cm^3), Small Queensland Native tube (260 cm^3), Tinus Root trainer (350 cm^3), Hiko V150 and Hiko V90 (150 and 90 cm^3 respectively). In accordance with most studies, plants grown in pots with the largest volumes and distance between plants, were taller and had larger root collar diameters than those in smaller pots. However, the Large Queensland Native tube requires less than

50 % of the potting medium and less space and at the same time has good seedling development. That makes them a good choice as a cost-effective option.

Planting time

Like with the exotic species planting time is to a great extent, dependent on climate region and site. Throughout the different regions of New Zealand most practitioners prefer late autumn to early spring (May/June to September/October (November)) depending on respective conditions with frost, inland or coastal sites (Ledgard & Dungey, 2010). In the West Coast, planting is conducted in any month except for January and February.

6 Native tree establishment trials 2020 – Background and early survival results

Objectives

1. To optimize growth and survival of native trees in the field, thereby establishing more native trees.
2. To generate recommendations on species nursery container requirements for successful and cost-effective establishment.

Aims

Testing field establishment success and growth of native tree species raised in Forestry trays and alternative systems. The aims of the trials outlined below, were to increase knowledge on suitability of various container types for several native species and in addition, to find economic solutions, i.e. to find a good compromise between seedling development and production costs, to enable the production of large amounts of native plants for afforestation projects.

6.1.1 Materials and methods

Treatments

1. Species

Originally 18 species were included in the trial; this early report includes 10 species (Table 1). All species, other than *Melicytus ramiflorus* and *Kunzea ericoides*, were collected from the Whirinaki forest by our project partners, Minginui Nursery (Ngati Whare). The other two species were commercially bought and supplied by our other nursery partner, Treeline Native Tree nursery.

Table 1*: Ten selected species for the container system trial early results measurement.*

Common name	Scientific name	Maori name
Wineberry	*Aristotelia serrata*	makomako
Karamu	*Coprosma robusta*	karamu
Cabbage tree	*Cordyline australis*	tī kōuka
Hopbush	*Dodonaea viscosa*	ake ake
Narrow-leaved lacebark	*Hoheria angustifolia*	houhere
Kānuka	*Kunzea ericoides*	kānuka
Mānuka	*Leptospermum scoparium*	Mānuka
Whiteywood	*Melicytus ramiflorus*	mahoe
Ribbonwood	*Plagianthus regius*	Manatu
Tōtara	*Podocarpus totara*	tōtara

2. Container type

11 container types were originally included in the test series, 10 containers are included in this early report (Table 2).

Table 2: 10 different growing systems included in early results measurement.

Grade	Volume (cm^3)	Description	Container type
Retail/revegetation grade	1200	PB2	PB2 plastic propagation bags
	900	P10	10.0 cm diameter Ellepot paper pots
	700	P8.0	8.0 cm diameter Ellepot paper pots
	500	T28	T28 Propagation trays
Large forestry grade	310	V310	Hiko V310 forestry tray
	150	V150	Hiko V150 forestry tray
Standard forestry grade	125	P4.0	4.0 cm diameter Ellepot paper pots
	125	TS48	Transplant systems TS48 forestry tray
	90	P3.5	3.5 cm diameter Ellepot paper pots
	90	TS45	Transplant systems TS45 forestry tray

Trial design

Randomised complete blocks (single tree). Total possible treatments – 341 (Species by container type). Replications – 6 (Each replication comprises 1774 trees as randomised single tree plots, some treatments are represented multiple times, in order to establish a 'natural looking' stand at the trials' conclusion). Sites – 6 (each with 1 replication).

Methodology

1. Seedlings were used to establish this field trial series between June and September 2020.
2. Individual trees were tagged with a unique identifier and trial establishment details have been mapped.
3. All tagged trees had height and root collar diameter measured in the nursery before dispatch.
4. Scion staff transported plants to each establishment site and oversaw the trial establishment.
5. Tipu Wai Trust, or other partnering landowners, arranged site preparation and planting crews. They also arranged release weeding as and when appropriate.

6. The Scion nursery team returned to assess 'six-month' survival and growth during February and March 2021.

6.1.2 Field trial sites

Six sites were established for this trial all are within a 15 km radius of Rotorua (Table 3). Sites were arranged by Tipu Wai Trust and trees were planted at 1.5 m X 1.5 m spacing. For the early measurement required for this report sites C, D and E2 were selected for measuring based on accessibility and budget.

Table 3: Site details of the six sites used for field planting.

Site ref.	Site name	Description	Latitude	Longitude	Altitude (m)	Planting date
A	"Okareka Loop Rd – Lake Okareka"	Roadside native tree rehabilitation of exotic block	38°10'08"S	176°20'44"E	355	26/06/2020
B	"Miller Road – Lake Okareka"	Native forest rehabilitation on nature reserve	38°09'42"S	176°20'58"E	347	24/07/2020
C	**"Hemo Gorge"**	**Riverine rehabilitation**	**38°10'02"S**	**176°14'50"E**	**302**	**14/08/2020**
D	**"Horohoro - roadside"**	**Pasture revegetation on farm block**	**38°13'52"S**	**176°10'59"**	**368**	**27/08/2020**
E1	"Kaharoa" - Top	Pasture revegetation on farm block	176°13'17"E	176°13'17"E	425	22/09/2020
E2	**"Kaharoa" - Bottom**	**Pasture revegetation on farm block**	**38°01'28"S**	**176°12'59"E**	**358**	**22/09/2020**

* Highlighted sites (C, D and E2) were measured for this report.

6.1.3

6.1.4 Results and recommendations

Species performance across all container types

In this trial series, average species survival (for the 10 species included in this analysis) ranged from 69% to 96%. Irrespective of container type or size some species survived consistently well and were not significantly different to each other (Figure 1), these include *Coprosma robusta* (93%), *Cordyline australis* (89%), *Dodonaea viscosa* (96%), *Kunzea ericoides* (88%), *Leptospermum scoparium* (94%), *Plagianthus regius* (89%) and *Podocarpus totara* (91%). *Hoheria angustifolia* (84%) showed good overall survival too, although not as good as the top three other species. The two worst surviving species were *Melicytus ramiflorus* (70%) and *Aristotelia serrata* (69%). This suggests that these two species are generally poorer performers or may not have been well suited to certain container types.

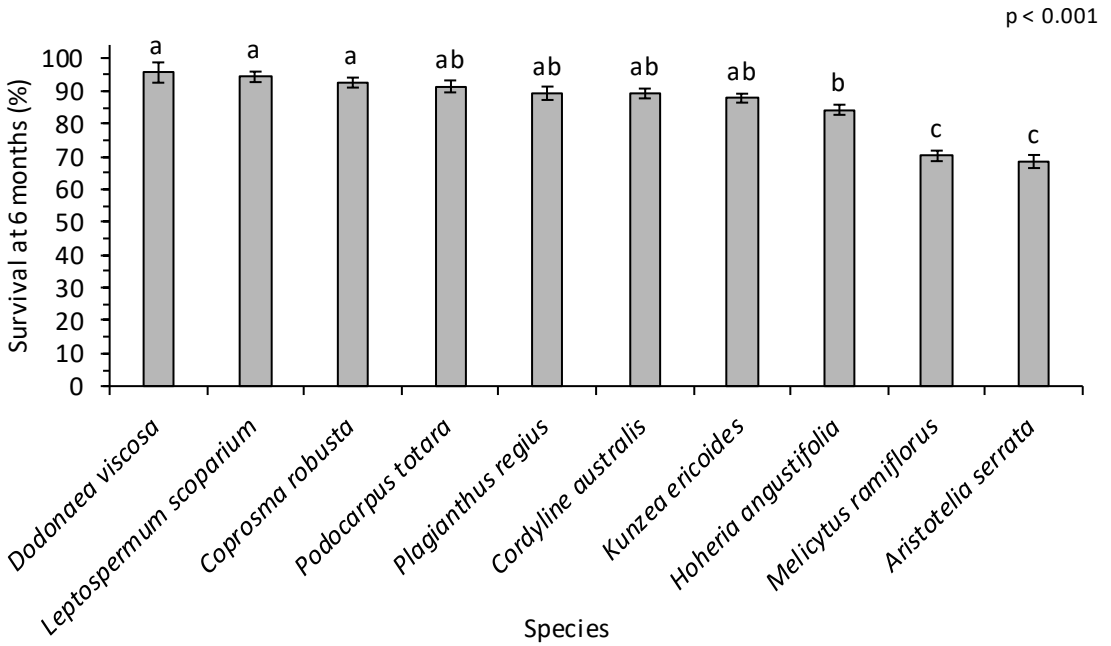

Figure 1: Survival of species, across all tray types, included in this trial.

Container performance across all species

In this trial series, average container type survival (for the 10 containers included in this analysis) ranged from 79% to 94%. At 93%, 92% and 94% respectively, the PB2 plastic propagation bags, 10.0 cm diameter Ellepot paper pots and 8.0 cm diameter Ellepot paper pots ranked highest in survival, although these were not statistically better than the smaller T28 Propagation trays (87%), Hiko V310 forestry tray (87%) or Hiko V150 forestry tray (85%). These results suggest that any of the above containers are generally suitable for native tree establishment, but, due to the significant advantages for nursery and field planting efficiency, smaller containers would be preferable. At almost half the plug volume, the 8.0 cm diameter Ellepot paper pots would be more preferable to the PB2 plastic propagation bags if a large plant was required, but a volume of approximately 150 cm^3 would actually suffice generally.

In the smaller grade containers (90-125 cm^3), there were no significant differences between the four container types, that is, 4.0 cm diameter Ellepot paper pots (83%), Transplant systems TS48 forestry tray (79%), 3.5 cm diameter Ellepot paper pots (79%) and Transplant systems TS45 forestry tray (81%). Having less growing media on the plug, may make establishment on harsh sites more difficult than for larger containers, our sites C (86%) and E1 (97%) were not very challenging and this wasn't considered to be a large factor there, although Site D (80%) with shallow, dry and compact soil was slightly more challenging and could have been impacted. Site C experienced heavy browsing initially, presumably by wallaby and possum, which may have reduced survival compared to site E1 which did not. Site E1 also had a professional planting crew where sites C and D did not.

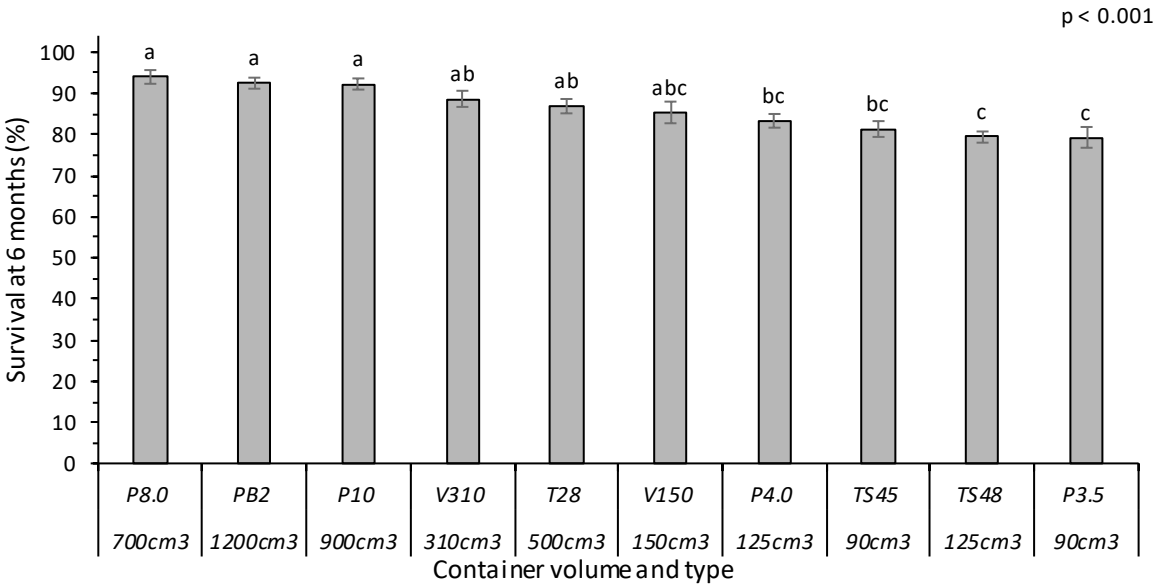

Figure 2: Survival of container types, across all species, included in this trial.

With all seedlings having been grown for the same amount of time it is possible that the smaller plugs could have become root bound, which in turn could have impacted survival. Table 4 shows that there was certainly an increase in the average root bound index across species as the container size decreases and this appears to be reasonably well correlated with survival. Figure 3 shows the relationship between root bound index and survival, and it seems that generally an index of 0.02 or less is optimal.

Table 4: Summary of plant* quality parameters measured at planting and six-month heights and survival across all species and container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT avg (cm)	RCD avg (mm)	Sturdiness ratio**	Root bound index***	Height at six months (cm)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	669	88.0	9.9	103.5	0.008	108.1	92.2
	900	P10	678	79.0	9.1	100.3	0.010	100.4	92.6
	700	P8.0	486	93.1	9.6	107.0	0.014	115.3	94.2
	500	T28	312	87.8	8.0	119.5	0.016	101.8	86.8
Large forestry grade	310	V310	249	74.0	6.7	118.2	0.022	89.8	88.7
	150	V150	184	56.7	5.9	108.8	0.039	73.8	81.0
Standard forestry grade	125	P4.0	414	52.3	4.2	131.5	0.034	65.7	87.0
	125	TS48	507	56.2	4.8	128.0	0.038	70.8	77.7
	90	P3.5	237	52.6	4.5	124.3	0.050	69.4	76.4
	90	TS45	257	59.0	4.7	141.9	0.052	73.0	82.1
			3993	73.0	7.3	115.5	0.024	91.8	87.4

***This table excludes the Cabbage tree (because it's a monocot and growth form is quite different – a species specific summary for it appears later).**
**** Sturdiness ratio is a measure of how long and thin a plant is, calculated as height / root collar diameter. Generally 120 or below is good and below 100 being preferable, but is species dependant.**
***** Root bound index in this instance is a measure of the relative size of the plant compared to its container size, calculated as Root collar diameter (mm) / Container volume (cm^3)).**

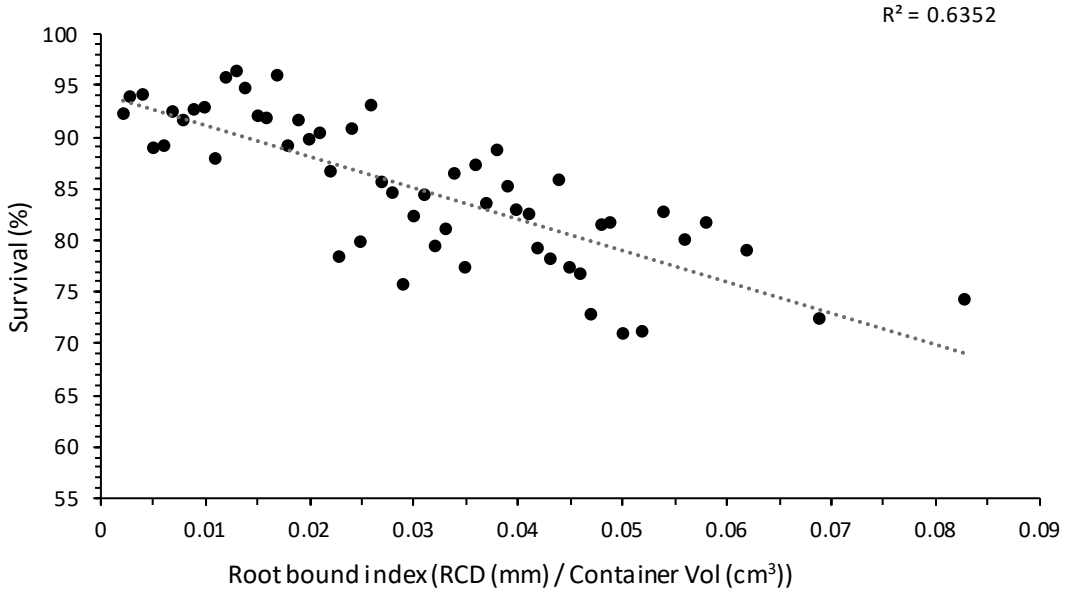

Figure 3: Relationship of root bound index and field survival at six months after planting, across all species and containers in this trial (excluding Cabbage tree).

As shown in Table 4 the 8.0 cm diameter Ellepot paper pots (700 cm^3) showed, by rank, the largest seedling heights, second highest root collar diameters, highly favourable sturdiness and root bound indexes, as well as the highest field heights and survival. The recommendation from these trial results would be that Ellepot paper pots are the most preferred container type for field establishment of these native tree species tested. Although, with potentially acceptable trade-offs between survival, raising and establishment efficiencies and costs, some of the smaller forestry grade containers (125 – 150 cm^3) show great promise and may be best for some species.

6.1.5 Species group 1 – good survival in forestry grades in this trial

Forestry grade containers (~90-125 cm^3) are by far the most economic and ergonomic choice for large scale revegetation projects. As well as being the cheapest, lightest and most easy to handle, we saw no significant compromise in survival (as compared to larger volume containers) in shrub species such as Kanuka, Manuka and Ake Ake, as well as larger tree species like Totara, Cabbage tree and Ribbonwood, despite being planted at a smaller height. All these species are summarised under species group 1. We will discuss the species with compromised survival (species group 2) in the next section.

The larger growth rate seen in some species can likely be attributed to a larger root biomass upon planting (often proportional to shoot height) along with increased nutrient availability in the extra 35-1110 cm^3 of media. These preliminary results highlight how appropriate forestry grade containers can be for native revegetation and these trials could be the groundwork for future experimentation involving all indigenous species.

Shifting towards forestry grade containers for compatible indigenous species production could be hugely beneficial to the 1BT project. For example, the indigenous plant output of a nursery producing 90 cm^3 containerised stock will be significantly higher (per unit area) than one producing the same

species and numbers in PB2's, resulting in more plant stock with roughly the same chance of survival in the field. Furthermore, as nutrient management is easier when dealing with smaller plugs containing less media, plants can be starved off and held within the nursery for longer, following any disruption to the planting season. In addition, when plants are introduced to a field site, those that have undergone hardening prior, are less susceptible to abiotic damage such as frosts and drought, as well as biotic damage, such as herbivory by predators. Thus, there could be huge advantages to growing a selection of indigenous species in forestry grade trays, with little apparent effect on field survival and establishment.

With decreasing container size, the risk of trees becoming root bound increases for all species from this species group. These negative effects, which can lead to spiralling and thus severe long-term damage and instability, must be monitored closely to prevent mistakes of the early container development in many countries as outlined in section 'container development and characteristics'. However, for Totara and followed (with some limitations) by Ake Ake, Manuka and Kanuka, root bound index values indicate an acceptable range even with the smaller forestry grade containers. In contrast, for Cabbage tree, Karamu and Ribbonwood the root bound index ratio becomes critical for smaller container sizes.
Browsing seems to be a problem for Totara and Cabbage tree at the outplanting sites and can lead to reduced growth and survival. Therefore, appropriate protection of young trees at the outplanting site must be assured.

Podocarpus totara (Totara)

Survival of Totara seedlings across the three sites and nine container types was very good at 92%. Container specific survival ranged from 74% to 97% (Table 15 – Appendix 1). At 88% and 74% respectively, the Transplant Systems TS48 and TS45 trays ranked lowest. These differences were not, however, statistically different. The recommendation is that all of the container sizes were suitable for establishing Totara, but for the 90 and 125 cm^3 containers it would probably be preferable to use a paper pot, which holds the growing media better and thereby retains root plug integrity. Based on measured data for all containers used, a guide to plant quality measures for each container tested for Totara is supplied in Table 5.

Table 5: Summary of plant quality parameter guidelines for *Podocarpus totara* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	35-55	2.8 - 4.0	< 105	0.018 - 0.022	14-18
	900	P10	30-50	2.6 - 4.0			12-16
	700	P8.0					
	500	T28					
Large forestry grade	310	V310	28 - 48	2.6 - 3.7			12-14
	150	V150	25 - 40	2.5 - 3.5			11-13
Standard forestry grade	125	P4.0		2.4 - 3.2			
	125	TS48					
	90	P3.5	20 - 35	2.2 - 2.6			10-12
	90	TS45					

Dodonaea viscosa (Ake Ake)

Survival of Ake Ake seedlings across the three sites and nine container types was very good at 94%. Container specific survival ranged from 85% to 100% (Table 16 – Appendix 1). At 85% survival the T28 Propagation trays ranked lowest. Survival differences were not, however, statistically different. The recommendation is thus that all of the container sizes and types were suitable for establishing Ake Ake. Based on measured data for all containers used, a guide to plant quality measures for each container tested for Ake Ake is supplied in Table 6.

Table 6: Summary of plant quality parameter guidelines for *Dodonaea viscosa* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	90-125	7.0 - 12.0	< 120	0.010 - 0.030	11-14
	900	P10	80-120	6.0 - 10.0			10-13
	700	P8.0					
	500	T28					
Large forestry grade	310	V310	70-90	4.0 - 8.0			9-12
	150	V150	30-55	3.2 - 7.0			8-11
Standard forestry grade	125	P4.0	30-50				
	125	TS48					
	90	P3.5	25-45	2.6 - 4.8			7-10
	90	TS45					

Cordyline australis (Cabbage Tree)

Survival of Cabbage tree seedlings across the three sites and nine container types was very good at 89%. Container specific survival ranged from 81% to 94% (Table 17 – Appendix 1). At 83%, 83% and 81% respectively, the Transplant Systems TS48, Ellepot P4.0 and Ellepot P3.5 trays ranked lowest. Again, however, survival differences were not statistically different. The recommendation is thus that all of the container sizes and types were suitable for establishing Cabbage trees. Based on measured data for all containers used, a guide to plant quality measures for each container tested for Cabbage trees is supplied in Table 7.

Table 7: Summary of plant quality parameter guidelines for *Cordyline australis* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	42-75	18-40	< 30	0.030 - 0.075	11-14
	900	P10	38-70	16-32			10-13
	700	P8.0					
	500	T28		14-30			
Large forestry grade	310	V310	30-55	12-26			9-12
	150	V150	28-50	10-20			8-11
Standard forestry grade	125	P4.0	25-45	9-18			7-10
	125	TS48					
	90	P3.5	20-40	8-15			6-9
	90	TS45					

Kunzea ericoides (Kanuka)

Survival of kanuka seedlings across the three sites and nine container types was good at 88%. Container specific survival ranged from 76% to 100% (Table 18 – Appendix 1). At 76% the T28 trays ranked lowest for survival and the Hiko V310 forestry tray ranked first, but survival differences were not statistically different. The recommendation is thus that all of the container sizes and types were suitable for establishing kanuka. Based on measured data for all containers used, a guide to plant quality measures for each container tested for kanuka trees is supplied in Table 8.

Table 8: Summary of plant quality parameter guidelines for *Kunzea ericoides* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	60-125	4.2 - 12.0	< 140	0.010 - 0.040	12 - 14
	900	P10	52-125	4.0 - 10.0			11 - 13
	700	P8.0					10-12
	500	T28		3.6 - 7.6			
Large forestry grade	310	V310		3.4 - 7.2			
	150	V150	40-90	3.0 - 6.0			
Standard forestry grade	125	P4.0		2.8 - 5.4			9 - 11
	125	TS48					
	90	P3.5	35-60	2.6 - 4.8			8 - 10
	90	TS45					

Coprosma robusta (Karamu)

Survival of karamu seedlings across the three sites and nine container types was excellent at 93%. Container specific survival ranged from 87% to 100% (Table 19 – Appendix 1). At 87% survival the Transplant systems TS48, Hiko V150 and Ellepot 4cm trays ranked lowest for survival but these were not statistically different to the top ranked treatments. The recommendation is thus that all of the container sizes and types were suitable for establishing karamu. Based on measured data for all containers used, a guide to plant quality measures for each container tested for karamu trees is supplied in Table 9.

Table 9: Summary of plant quality parameter guidelines for *Coprosma robusta* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	60-120	8.0 - 18.0	< 100	0.010 - 0.030	12-14
	900	P10		7.0 - 16.0			11-13
	700	P8.0	60-100				10-12
	500	T28					
Large forestry grade	310	V310	40-80	6.2 - 10.0			9-11
	150	V150	30-60	4.8 - 7.8			
Standard forestry grade	125	P4.0		4.2 - 7.4			8-10
	125	TS48					
	90	P3.5	25-50	4.0 - 6.8			7-9
	90	TS45					

Leptospermum scoparium (Manuka)

Survival of manuka seedlings across the three sites and nine container types was excellent at 94%. Container specific survival ranged from 89% to 100% (Table 20 – Appendix 1). At 89% survival the T28 and Ellepot 3.5cm trays ranked lowest for survival but these were not statistically different to the top ranked treatments. The recommendation is thus that all of the container sizes and types were suitable for establishing manuka. Based on measured data for all containers used, a guide to plant quality measures for each container tested for manuka trees is supplied in Table 10.

Table 10: Summary of plant quality parameter guidelines for *Leptospermum scoparium* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	60-120	4.2 - 12.0	< 150	0.010 - 0.040	12 - 14
	900	P10		4.0 - 10.0			11 - 13
	700	P8.0					10-12
	500	T28		3.8 - 7.6			
Large forestry grade	310	V310		3.6 - 7.2			
	150	V150	50-100	3.2 - 5.8			9-11
Standard forestry grade	125	P4.0	40-80	3.0 - 5.2			8 - 10
	125	TS48					
	90	P3.5	35-70	2.8 - 4.6			7 - 9
	90	TS45					

Plagianthus regius (Ribbonwood)

Survival of Ribbonwood seedlings across the three sites and nine container types was good at 89%. Container specific survival ranged from 83% to 94% (Table 21 – Appendix 1). At 84%, 85% and 85% survival the Ellepot 3.5cm, Hiko V150 and Transplant systems TS48 trays, respectively, ranked lowest for survival but these were not statistically different to the top ranked treatments. The recommendation is thus that all of the container sizes and types were suitable for establishing Ribbonwood. Based on measured data for all containers used, a guide to plant quality measures for each container tested for Ribbonwood trees is supplied in Table 11.

Table 11: Summary of plant quality parameter guidelines for *Plagianthus regius* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	80-120	7.2-12.0	< 120	0.010 – 0.040	12-14
	900	P10	80-110	7.0-12.0			11-14
	700	P8.0		7.0-11.0			11-13
	500	T28					10-13
Large forestry grade	310	V310	75-100	6.0-8.0			10-12
	150	V150	70-90				
Standard forestry grade	125	P4.0	50-80	4.2-7.0			9-11
	125	TS48	50-80				
	90	P3.5	45-70	4.0-6.8			8-10
	90	TS45	45-70				

6.1.6

6.1.7 Species group 2 – compromised survival in forestry grades in this trial

Hoheria, Mahoe and Wineberry show a significantly reduced survival in smaller containers compared to the beforementioned species of species group 1. The bigger the container volume, the better the survival for these species. There is an almost linear decrease in survival after six months with decreasing container size. This trend is particularly evident for Hoheria and Wineberry.

Sturdiness ratio of all three species can be described as very good for all container types, but root bound index becomes a critical issue for plants growing in smaller containers, especially in the standard forestry grade containers. As described before, ensuring a proper root development is critical in the nursery and will have long-term effects for the plants.

Hoheria angustifolia (Hoheria)

Survival of Hoheria seedlings across the three sites and nine container types was reasonably good at 84%. Container specific survival was wide and ranged from 67% to 98% (Table 22 – Appendix 1), suggesting there may have been a significant tray type effect. At 67%, 73% and 77% survival the Ellepot 3.5cm, Ellepot 4.0cm and Transplant systems TS45 trays, respectively, ranked lowest for survival but were not statistically different to the top ranked treatments. With the highest root bound indexes of 0.058, 0.043 and 0.048, respectively, this ranking is as expected. The recommendation is thus that all of the container sizes and types are likely to be suitable for establishing Hoheria, but close attention should be paid to raising period and root binding for smaller plug sizes. For Hoheria a raising period of 7-9 months for 90 cm^3 plugs is likely to be more successful. Based on measured

data for all containers used, a guide to plant quality measures for each container tested for Hoheria trees is supplied in Table 12.

Table 12: Summary of plant quality parameter guidelines for *Hoheria angustifolia* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	70-150	8.0-16.0	< 130	0.010 - 0.018	11-14
	900	P10	65-140	7.5-14.0			10-13
	700	P8.0	65-120	7.0-12.0			
	500	T28	65-100	6.5-10.0			9-12
Large forestry grade	310	V310	60-90	5.2-8.0			9-11
	150	V150	55-75	4.6-7.2			8-10
Standard forestry grade	125	P4.0	35-60	4.2-6.6			
	125	TS48					
	90	P3.5	30-50	3.8-6.0			7-9
	90	TS45					

Melicytus ramiflorus (Mahoe)

Average survival of Mahoe seedlings across the three sites and nine container types was not very good at 70%. Container specific survival was wide and ranged from 48% to 88% (Table 23 – Appendix 1), suggesting there was a significant tray type effect. At 48%, 54%, 63% and 63% survival the Transplant systems TS48, Hiko V150, Ellepot 4cm and Transplant Systems TS45 trays, respectively, ranked lowest for survival. With the highest root bound indexes of 0.056, 0.060, 0.057 and 0.073, respectively, this ranking is as expected. The recommendation is thus that most of the container sizes and types are likely to be suitable for establishing Mahoe, but close attention should be paid to raising period and root binding for smaller plug sizes. For Mahoe a raising period of 7-9 months for 90 cm^3 plugs is likely to be more successful but further work is required to support this recommendation. Based on measured data for all containers used, a guide to plant quality measures for each container tested for Mahoe trees is supplied in Table 13.

Table 13: Summary of plant quality parameter guidelines for *Melicytus ramiflorus* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	45-75	10.0-20.0	< 55	0.012 - 0.022	12-14
	900	P10	45-70	9.5-18.0			11-13
	700	P8.0		9.0-15.0			10-12
	500	T28	40-65	8.0-13.0			
Large forestry grade	310	V310	35-50	7.0-12.0			9-11
	150	V150	30-40	6.0-11.0			
Standard forestry grade	125	P4.0	25-35	5.0-9.0			8-10
	125	TS48					
	90	P3.5	20-30	4.4-8.0			7-9
	90	TS45					

Aristotelia serrata (Wineberry)

Average survival of wineberry seedlings across the three sites and nine container types was relatively poor at 69%. Container specific survival was extremely wide and ranged from 33% to 92% (Table 24 – Appendix 1), suggesting there was a significant tray type effect. At 33%, 42% and 52% survival the Ellepot 3.5cm, Transplant Systems TS45 and Transplant systems TS48 trays, respectively, ranked lowest for survival. With the highest root bound indexes of 0.050, 0.048 and 0.040, respectively, this ranking is as expected. Figure 4 shows the relationship between root-bound index and survival. The recommendation is thus that most of the container sizes and types are likely to be suitable for establishing wineberry, but close attention should be paid to raising period and root binding for smaller plug sizes.

For wineberry a raising period of 7-9 months for 90 cm^3 plugs and 8-10 months for 125 cm^3 is likely to be more successful but further work is required to support this recommendation. Based on measured data for all containers used, a guide to plant quality measures for each container tested for wineberry trees is supplied in Table 14.

Table 14: Summary of plant quality parameter guidelines for *Aristotelia serrata* based on these trial results.

Grade	Volume (cm^3)	Container type	Planting HT (cm)	RCD (mm)	Sturdiness ratio	Root bound index	Nursery growing period estimate (months)
Retail/ revegetation grade	1200	PB2	90-120	9.0-14.0	< 120	0.010 - 0.022	11-13
	900	P10	80-110				10-13
	700	P8.0	75-100				10-12
	500	T28		8.0-12.0			
Large forestry grade	310	V310	70-90	7.0-10			9-12
	150	V150	60-80	5.5-8.0			9-11
Standard forestry grade	125	P4.0	45-65	4.0-6.0			8-10
	125	TS48					
	90	P3.5	40-60	3.6-5.0			7-9
	90	TS45					

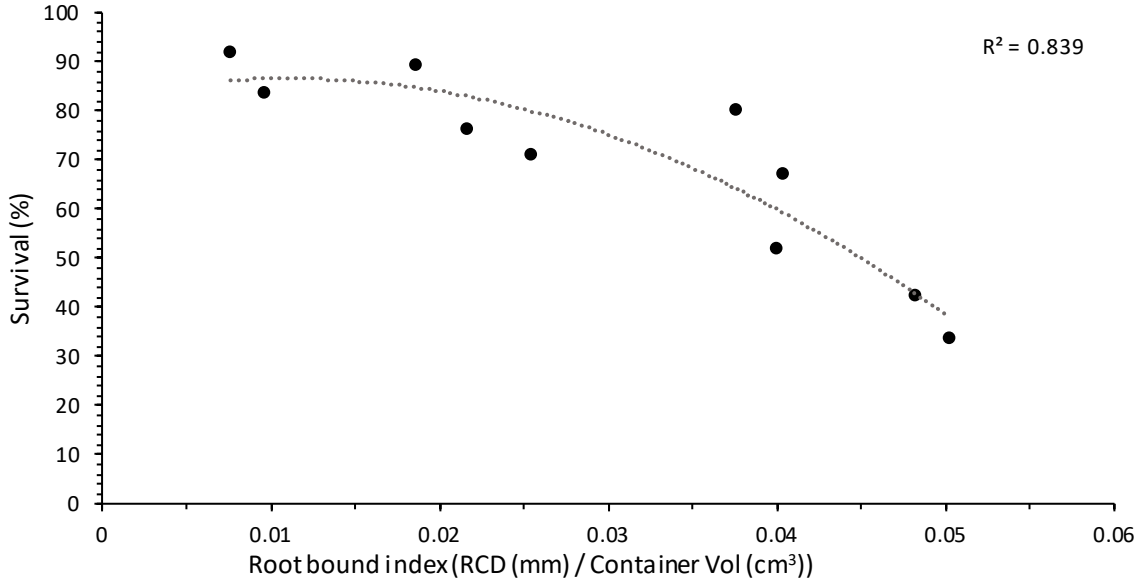

Figure 4: Relationship of root bound index and field survival at six months after planting for Wineberry in this trial.

7 Recommendations and conclusions

Containerised plants and growing systems for exotic species

We summarised best containerised plants and growing systems for Radiata pine, Douglas fir and other exotic species' groups. Containerised growing systems can help to extend planting season and ensure better survival of 1BT plantings especially on critical sites. Container seedlings are easier to handle and transport and less prone to injury. Less transplanting shock and an intact root system bound with a potting mix can lead to a higher establishment success.

Practical experience on containerised exotic trees is limited compared to bare root establishment. However, good information and experience exist for radiata pine, Douglas fir and Eucalypts, thus recommendations on container size, dimensions or planting time could be given. However, for the lesser frequently used exotic species redwood and cypress very limited information could be obtained. Therefore, it is recommended that more species-specific information on these less frequent exotic species are collected. Plant specifications for container-grown plants depending on site conditions would need to be defined in appropriate field trials. This includes different climatic or edaphic conditions as well as sites strongly influenced by competing vegetation or animals.

Early results from trials with containerised growing systems for native species

Early results from the native tree establishment trials indicated that survival is usually best in big containers. However, our research showed that difference in survival and other indicators like root bound index or growth between plants in bigger sized containers and smaller ones are sometimes comparably small and are also species specific. Irrespective of container type or size some species survived consistently well during the first 6 months. These results suggest that most of the tested containers are suitable for several native trees, but, due to the significant economic advantages for nursery and field planting efficiency, smaller containers would be preferable. These species are summarised under species group 1, good survival in forestry grade. However, these early results have to be confirmed in measurements after several years to make solid recommendations.

Species group 1 includes Totara, Ake Ake, Manuka, Kanuka, Cabbage tree, Karamu and Ribbonwood. However, the latter three species show an increased risk of becoming root bound in small forestry grade containers with potentially long-term negative effects. Large forestry grade containers seem to offer a good compromise between plant development and survival on the one hand - which is still on a high level - and economic considerations on the other hand using smaller containers to produce planting stock in high numbers cost-effectively.

Conversely, species group 2 (Hoheria, Mahoe and Wineberry) shows a significantly reduced survival in smaller containers and increased risk of trees getting root bound.

8 Acknowledgements

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10 Appendix A

10.1 FULL SPECIES X CONTAINER SUMMARIES FOR THIS TRIAL SERIES

Podocarpus totara (Totara)

Table 15: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Podocarpus totara* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	72	29.1	2.89	101.8	0.002	48.5	168.7	8.3	93.1
	900	P10	72	24.8	2.73	92.2	0.003	41.7	170.2	18.1	94.4
	700	P8.0	33	33.1	3.87	90.5	0.006	50.2	154.2	18.2	97.0
	500	T28	36	40.7	3.93	106.5	0.008	54.4	132.9	5.6	94.4
Large forestry grade	310	V310	30	32.2	3.15	103.6	0.010	45.4	138.1	10.0	93.3
	150	V150	13	23.9	2.83	85.6	0.019	38.3	169.5	7.7	92.3
Standard forestry grade	125	P4.0	111	25.7	2.38	110.9	0.019	36.8	144.9	13.5	93.7
	125	TS48	60	25.1	2.48	106.6	0.020	34.7	137.1	8.3	88.3
	90	P3.5	15	27.8	2.56	109.4	0.028	39.5	142.9	6.7	93.3
	90	TS45	19	20.6	1.93	108.0	0.021	30.8	150.2	21.1	73.7

Dodonaea viscosa (Ake Ake)

Table 16: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Dodonaea viscosa* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	24	106.8	11.11	103.7	0.009	145.1	137.2	0.0	100.0
	900	P10	21	80.2	8.82	94.2	0.010	117.5	149.7	0.0	100.0
	700	P8.0	18	104.2	8.76	122.2	0.013	138.0	132.8	0.0	100.0
	500	T28	21	116.6	7.36	159.7	0.015	142.3	122.5	0.0	85.7
Large forestry grade	310	V310	12	86.3	5.91	150.3	0.019	107.9	125.6	0.0	91.7
	150	V150	4	35.5	5.25	67.7	0.035	65.0	185.1	0.0	100.0
Standard forestry grade	125	P4.0	54	50.4	4.19	128.1	0.034	72.9	152.7	5.6	88.9
	125	T48	24	47.8	4.13	117.8	0.033	74.5	160.8	0.0	95.8
	90	P3.5	3	39.3	3.17	127.2	0.035	73.2	200.9	0.0	100.0
	90	T45	16	48.6	3.62	135.7	0.040	71.7	147.6	0.0	93.8

Cordyline australis **(Cabbage Tree)**

Table 17: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Cordyline australis* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	96	57.2	30.97	18.7	0.026	70	123.3	13.5	92.7
	900	P10	96	47.5	25.85	18.8	0.029	68.1	143.8	8.3	89.6
	700	P8.0	78	60.2	29.09	21.2	0.042	69.2	117	17.9	91
	500	T28	42	52.2	21.19	24.8	0.042	61	116.2	14.3	90.5
Large forestry grade	310	V310	30	43.1	18.84	23.1	0.061	56.3	130.9	10	93.3
	150	V150	32	32.5	12.42	27.7	0.083	46.1	144.8	18.8	93.8
Standard forestry grade	125	P4.0	30	38.9	14.42	28	0.115	44.1	113.4	20	83.3
	125	T48	66	33.1	12.07	27.8	0.097	42.9	131.8	24.2	83.3
	90	P3.5	36	33.6	13.06	26.2	0.145	42.2	128.7	22.2	80.6
	90	T45	33	32.2	11.53	28.4	0.128	43.2	134.5	15.2	93.9

Kunzea ericoides **Kanuka**

Table 18: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Kunzea ericoides* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	117	98.5	8.15	130.8	0.007	120.9	123.4	1.7	91.5
	900	P10	117	90.4	6.83	135.4	0.008	114.8	127.1	0.0	92.3
	700	P8.0	132	99.7	7.84	129.8	0.011	122.6	121.4	0.8	91.7
	500	T28	42	94.1	6.66	146.9	0.013	110.6	113.4	0.0	76.2
Large forestry grade	310	V310	33	95.2	6.35	152.3	0.020	108.6	114.4	0.0	100.0
	150	V150	38	75.1	4.79	159.6	0.032	91.3	122.2	2.6	81.6
Standard forestry grade	125	P4.0	66	67.3	4.03	171.0	0.032	85.7	142.7	0.0	87.9
	125	T48	66	73.3	3.95	189.3	0.032	88.6	120.6	1.5	80.3
	90	P3.5	36	56.7	3.78	162.1	0.042	75.3	133.9	0.0	88.9
	90	T45	40	67.8	5.34	166.6	0.059	80.6	119.6	0.0	87.5

Coprosma robusta Karamu

Table 19: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for Coprosma robusta across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	96	86.3	12.41	75.7	0.010	106.9	124.3	2.1	92.7
	900	P10	96	79.6	12.57	65.5	0.014	104.0	130.9	4.2	94.8
	700	P8.0	63	85.1	14.28	61.5	0.020	109.5	128.6	3.2	95.2
	500	T28	42	88.5	10.30	88.0	0.021	103.5	117.0	2.4	100.0
Large forestry grade	310	V310	30	68.1	8.55	81.3	0.028	88.7	133.0	0.0	100.0
	150	V150	31	32.7	7.31	45.4	0.049	57.4	178.2	3.2	87.1
Standard forestry grade	125	P4.0	30	53.5	5.82	93.3	0.047	65.3	128.1	3.3	86.7
	125	T48	63	45.4	5.94	77.9	0.048	63.1	139.4	4.8	87.3
	90	P3.5	33	47.9	5.58	89.3	0.062	62.3	130.8	3.0	87.9
	90	T45	31	65.9	5.38	131.3	0.060	75.5	114.6	12.9	93.5

Leptospermum scoparium **Manuka**

Table 20: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Leptospermum scoparium* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	108	105.1	8.05	141.8	0.007	127.1	121.6	1.9	95.4
	900	P10	114	99.4	7.37	141.9	0.008	123.0	131.0	0.0	97.4
	700	P8.0	108	103.5	8.28	130.8	0.012	125.4	121.3	0.0	97.2
	500	T28	45	96.4	5.96	167.1	0.012	111.8	117.3	2.2	88.9
Large forestry grade	310	V310	36	98.1	6.06	168.2	0.020	111.7	114.8	2.8	91.7
	150	V150	11	98	4.79	209.2	0.032	105.1	107.0	9.1	100.0
Standard forestry grade	125	P4.0	39	77.1	4.00	197.6	0.032	84.9	110.2	2.6	94.9
	125	T48	60	82.7	4.30	198.7	0.034	93.4	113.7	3.3	93.3
	90	P3.5	36	68.2	3.76	186.0	0.042	92.2	133.6	0.0	88.9
	90	T45	41	76.4	3.92	201.0	0.044	91.9	121.8	4.9	95.1

Plagianthus regius **Ribbonwood**

Table 21: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Plagianthus regius* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	24	100.8	9.73	104.6	0.008	129.6	129.4	0.0	87.5
	900	P10	24	88.3	8.42	107.1	0.009	117.1	132.6	4.2	91.7
	700	P8.0	18	96.8	10.06	97.0	0.014	139.2	145.0	0.0	94.4
	500	T28	21	98.3	8.57	115.4	0.017	125.3	126.8	0.0	90.5
Large forestry grade	310	V310	24	91.1	7.32	125.9	0.024	120.8	134.9	0.0	87.5
	150	V150	13	82.2	6.52	126.6	0.043	108.8	135.2	7.7	84.6
Standard forestry grade	125	P4.0	36	75.5	5.36	141.6	0.043	96.6	130.7	2.8	94.4
	125	T48	54	72.7	5.23	141.5	0.042	91.4	124.6	1.9	85.2
	90	P3.5	24	66.9	5.60	120.7	0.062	102.3	152.6	0.0	83.3
	90	T45	31	66.6	5.31	127.4	0.059	90.5	135.7	3.2	93.5

Hoheria angustifolia **Hoheria**

Table 22: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Hoheria angustifolia* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	96	120.3	11.47	113.3	0.010	139.0	115.6	2.1	97.9
	900	P10	96	109.9	10.02	114.2	0.011	129.4	116.6	1.0	95.8
	700	P8.0	54	111.3	9.71	117.1	0.014	132.5	119.9	1.9	96.3
	500	T28	42	101.5	7.87	132.8	0.016	117.6	113.7	2.4	87.8
Large forestry grade	310	V310	33	84.1	6.28	138.0	0.020	92.1	109.2	0.0	87.9
	150	V150	30	67.5	5.17	131.9	0.034	76.3	108.8	6.7	80.0
Standard forestry grade	125	P4.0	30	68.1	5.41	133.2	0.043	75.5	113.6	0.0	73.3
	125	T48	60	63.1	4.65	137.8	0.037	73.6	114.3	8.3	80.0
	90	P3.5	30	58.8	5.18	118.5	0.058	67.3	114.0	3.3	66.7
	90	T45	30	62.4	4.30	150.3	0.048	67.7	107.2	6.7	76.7

Melicytus ramiflorus **Mahoe**

Table 23: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Melicytus ramiflorus* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	96	53.8	15.33	39.3	0.013	58.5	109.8	24.0	82.3
	900	P10	102	43.0	14.60	34.6	0.016	49.4	118.6	24.5	83.3
	700	P8.0	42	65.7	14.59	47.7	0.021	75.5	112.9	9.5	88.1
	500	T28	42	62.0	11.62	55.4	0.023	63.4	106.8	9.5	78.6
Large forestry grade	310	V310	27	36.4	9.49	42.0	0.031	38.7	107.3	22.2	70.4
	150	V150	24	23.2	8.95	32.0	0.060	32.3	138.4	12.5	54.2
Standard forestry grade	125	P4.0	30	25.8	7.17	44.7	0.057	31.4	112.1	13.3	63.3
	125	T48	60	30.3	6.98	49.9	0.056	33.2	112.4	10.0	48.3
	90	P3.5	30	25.1	4.93	53.9	0.055	27.3	106.1	20.0	70.0
	90	T45	30	29.0	6.56	55.8	0.073	28.8	106.2	16.7	63.3

Aristotelia serrata **Wineberry**

Table 24: Summary of plant quality parameters measured at planting, six-month heights, browsing and survival for *Aristotelia serrata* across container types.

Grade	Volume (cm^3)	Container type	Trees measured (n)	Planting HT average (cm)	RCD average (mm)	Sturdiness ratio	Root bound index	Height at six months (cm)	Height growth at six months (%)	Browsing at six months (%)	Survival at six months (%)
Retail/ revegetation grade	1200	PB2	36	108.9	9.13	121.7	0.008	120.5	114.5	2.8	91.7
	900	P10	36	96.6	8.68	112.2	0.010	117.9	118.4	0.0	83.3
	700	P8.0	18	113.7	13.05	89.1	0.019	132.3	118.3	0.0	88.9
	500	T28	21	120.1	10.84	113.9	0.022	124.8	103.8	0.0	76.2
Large forestry grade	310	V310	24	73.4	7.88	95.9	0.025	91.7	123.6	0.0	70.8
	150	V150	20	69.1	5.63	124.5	0.038	80.9	120.8	0.0	80.0
Standard forestry grade	125	P4.0	18	81.8	5.05	165.1	0.040	81.1	96.8	11.1	66.7
	125	T48	60	61.1	5.00	124.5	0.040	72.0	125.2	5.0	51.7
	90	P3.5	30	57.5	4.52	129.9	0.050	66.4	120.9	3.3	33.3
	90	T45	19	67.6	4.33	165.4	0.048	71.4	103.6	10.5	42.1