



Container size and site quality affect survival and early growth performance of New Zealand native tree species

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Abstract As part of the global effort to mitigate climate change effects, New Zealand's Climate Change Commission has recommended the establishment of 300,000 ha of native trees across the country by 2035. To achieve this goal, significant improvement in seedling production and field establishment is needed. Across New Zealand, there is a trade-off between seedling size and early seedling establishment success; plants grown in large pots are more resistant to weeds, pests and frost; however, they are more expensive and take longer to grow. We tested this trade-off between cost and establishment success by raising seedlings of twelve key native species in three container grade sizes: small, large, and revegetation grade, and tracking their success across five sites around Rotorua, in the Central North Island of New Zealand. After two-year post-planting, we found that high-quality sites and larger container systems tended to promote higher survival and faster early growth (plant height and root collar diameter). Some species, such as *Kunzea ericoides* and *Leptospermum scoparium*, survived and grew well (> 75%) even when raised in small container sizes. Other species such as *Sophora microphylla* had very low survival

(< 25%) even when raised in revegetation container grade sizes. If the quality of the planting site is high, the container size seems to be less important for most species. Other species such as *Aristotelia serrata*, *Cordyline australis*, *Plagianthus regius* and *Podocarpus totara* appear to depend more on site quality. In conclusion, nursery container systems for raising New Zealand native plants should be chosen based on the biology of the species, nursery management practices, quality of the planting site, and a balance between cost and benefit for each situation.

Keywords Seedling production · Containerised seedlings · Afforestation · Degraded areas · Site quality

Introduction

The global effort to slow the rate of climate change, increase forested areas and restore native forests will have a positive and multi-generational impact on biodiversity, soil conservation and watershed quality, as well as numerous socio-political, cultural, and economic advantages. As a contribution to this global endeavor, New Zealand's Government plans to plant 300,000 ha of native trees by 2035 (New Zealand's Climate Change Commission 2021). The rate at which native trees can be planted depends on the capacity of nurseries to produce plants at scale with the best chance of survival in the field. Hitherto, nursery systems for commercial plantation of exotic species are well developed, in contrast there is limited research available on best practice guidelines for native plants. To achieve the ambitious national native tree plantation goal, it is therefore essential to investigate how to achieve rapid production of good quality seedlings of native tree species that will perform well in the field.

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The type and grade of nursery container affect seedling quality and production costs (Walter et al. 2022), and is crucial for producing strong seedlings that can survive and grow, especially in the harsh conditions of the field (Cabreira et al. 2019; Tian et al. 2017). In some cases, the container system is more important than the growth media used to raise seedlings (Tian et al. 2017). For many years, nurseries have used large volume polybags to achieve successful establishment of native species, an approach that demands high labor input at planting and limits the rate of establishment. With the growing global concern over single use plastics (Haase et al. 2021), the need for non-petrochemical alternatives in seedling production is even more pressing.

There is substantial evidence that plants raised in larger volume pots such as 1.2-L polybags have higher biomass compared with those in smaller pots (Thomas et al. 2016; Tian et al. 2017; Vieira et al. 2019). However, the link between container size and type and post-planting seedling survival and growth performance is not as well understood (Davis & Pinto 2021). While it is often assumed that seedlings with higher biomass will also have a greater chance of survival and faster post-planting growth, it is also possible that larger seedlings may suffer greater transplantation shock, possibly due to being conditioning to high availability of water and nutrients in bigger containers compared with smaller grades (Close et al. 2010), which hinders the post-planting survival and growth performance of plants raised in larger containers. Additionally, the costs of transportation and field planting of seedlings raised in larger containers are markedly higher.

For instance, pine seedlings of assorted sizes were tested under dry soil conditions and smaller seedlings appeared to be the best option for planting in the field. Larger seedlings with larger shoots suffered water stress even though they had longer root system, suggesting an imbalance between above and below ground biomass (Oliet et al. 2019). Large seedlings may also be more palatable to wildlife, leading to less success in the field (Close et al. 2010). Alternatively, frost tolerance might increase with the size of the seedling as the ability to secure themselves increases (Goulet 1995).

In this context, the differences in establishment and growth performance of seedlings raised in a range of container sizes in the nursery might not be noticed some time after planting in the field. Smaller seedlings may out-perform the larger seedlings once protocols in the nursery are tailored to container volume. In those cases, genetic factors, climate and site conditions will be more important limitations to performance than container type or size (Aghai et al. 2014; Harayama et al. 2023; Pinto et al. 2011). These variable responses to container highlight that biological factors of each species and the edaphoclimatic conditions of the site must be considered when recommending best practices guidelines for the nursery. The Target Plant Concept has

been proposed to support the integration of those factors and stresses the importance of considering planting site quality for nursery practice (Landis 1990; Davis and Pinto 2021). The drive to maximise seedling production capacity with high quality plant-stock and the recent uptake of containerisation for native plant-stock in New Zealand (Bayne 2021) has heightened the need for comprehensive research on species, container and site quality interactions (Buckley et al. 2023).

While some information on propagation techniques and container types for cuttings has been published, and detailed guides are available for some species (e.g., *Leptospermum scoparium* and *Kunzea ericoides* (Saunders 2017)), there remains a need for a systematic study of the container size and type for a wider range of container grades and native species, including long-term survival and growth impacts of each growing system under different conditions of planting sites. This study therefore aims to investigate the impact of container grade size on the survival and initial field performance of twelve key New Zealand's native seedlings for rehabilitation of sites with varying levels of disturbances.

Materials and methods

Site description

Initially, five sites were established for this trial within a 15 km radius of Rotorua, in the Central North Island of New Zealand. Sites were arranged by Tipu Wai Trust, who also assisted with site preparation and planting. Sites were of varying soil quality and previous anthropic disturbance levels (Table 1). Based on site quality, three groups were defined as follows: High quality (Sites D and E), Average quality (Sites A and B), and Poor quality (Site C). The climate in Rotorua is considered mild with the average temperature ranging between 21 and 29 °C in summer and 9–16 °C degrees in winter and an average annual rainfall of 1400 mm.

Native tree species and trial establishment

Twelve species have been selected to meet New Zealand's 2035 reforestation targets (Table 2). Beyond the ecological and cultural value these species provide, several species (e.g., *Podocarpus totara*, *Leptospermum scoparium*, and *Kunzea ericoides*), also have potential to produce timber and non-timber products. The seed for all species, were collected from the Whirinaki forest by staff from Minginui Nursery; exceptions to this were *M. ramiflorus* and *K. ericoides* which were purchased from Treeline Native Tree nursery.

Container volumes were grouped into three grades studied: standard forestry grade (90–125 cm³), large forestry grade (150–310 cm³) and revegetation grade

Table 1 Description of each planting site

Site	Description	Latitude	Longitude	Altitude (m a.s.l.)
A (Average)	Roadside native tree rehabilitation of exotic block. Good soil, frost pocket, and gully	38°10'08" S	176°20'44" E	355
B (Average)	Native forest rehabilitation on nature reserve. Good soil, frosty, lakeside	38°09'42" S	176°20'58" E	347
C (Poor)	Riverine rehabilitation. Good soil, gully, heavy browsing	38°10'02" S	176°14'50" E	302
D (High)	Former dairy pasture, dryer, exposed hilltop	38°01'22" S	176°13'16" E	425
E (High)	Former dairy pasture, moist soil	38°01'28" S	176°12'59" E	358

Table 2 Twelve targeted tree species raised in the nursery using different container grades

Scientific name	Common name	Māori name
<i>Aristotelia serrata</i>	Wineberry	Makomako
<i>Coprosma grandifolia</i>	Kanono	Raurēkau
<i>Coprosma robusta</i>	karamū	karamū
<i>Cordyline australis</i>	Cabbage tree	tī kōuka
<i>Dodonaea viscosa</i>	Hopbush	ake ake
<i>Hoheria angustifolia</i>	Narrow-leaved lacebark	houhere
<i>Kunzea ericoides</i>	Kānuka	kānuka
<i>Leptospermum scoparium</i>	Mānuka	mānuka
<i>Melicetyus ramiflorus</i>	Whiteywood	māhoe
<i>Plagianthus regius</i>	Ribbonwood	mānatu
<i>Podocarpus totara</i>	Tōtara	tōtara
<i>Sophora microphylla</i>	Small-leaved kōwhai	kōwhai

(500–1200 cm³). For the standard forestry grade, we used 3.5 and 4.0 cm diameter Ellepot paper pots or TS45 and TS48 propagation trays, 90 and 125 cm³ respectively. For the large forestry grade, we used V150 (150 cm³) or V310 (310 cm³) forestry trays, and for the revegetation grade, we used T28 (500 cm³) propagation trays, Polybag PB2 (1200 cm³) or Ellepot paper pots of 8 or 10 cm diameter, 700 and 900 cm³, respectively. Seeds of all species were sown into germination trays and once they reached a height of approximately 2 cm, germinants were pricked out into the different grade containers. The seedlings were raised in the nursery for 10–13 months.

Planting was carried out from June 2020 to September 2020 for all sites, and seedlings were planted at 1.5 m × 1.5 m spacing. One year after planting, the poor-quality site received one herbicidal application between the summer and winter measurements to combat weeds. The good quality sites were mechanically weeded with a string trimmer while high quality sites have had no maintenance since planting. We did not follow a typical forestry post-planting silviculture weed and pest control program across all sites, which could positively bias for any specific container type. However, the management practices were

applied to each site for all species, isolating this variance in each individual site. The seedlings in this trial were analysed for survival, height and root collar diameter two years after planting.

Trial design and statistics

The trials were designed to represent, as much as possible, a natural forest, where single tree plots were represented multiple times and completely randomised on each site. In total, 8190 seedlings representing the combinations of tree species × container size were planted across sites of varying qualities. For analysis, we compared the effects of site quality and container size used to raise the seedlings within each tree species' level, assuming each species has variations in survival and growth rates. We performed a two-way analysis of variance (ANOVA) considering the site quality as Factor A and container sizes as Factor B. When the interaction between factors was statistically significant, the significant double interaction was unfolded, and means were compared using the pairwise post hoc Tukey's test at alpha = 0.05. When the interaction was not significant, the simple effects of each Factor were tested and means were also compared by Tukey's test at alpha = 0.05, in R environment (R Core team 2023).

Results

Species' survival and performance across a site quality gradient

We observed a higher survival rate for species planted in high quality sites, regardless of container size while the poorest quality site had the lowest survival rate (Fig. 1).

Height and root collar diameter did not differ statistically between the three quality levels of the site (Fig. 2a and b). However, there was a marginal tendency (represented by median bar in each boxplot) for taller seedlings when planted in high quality sites.

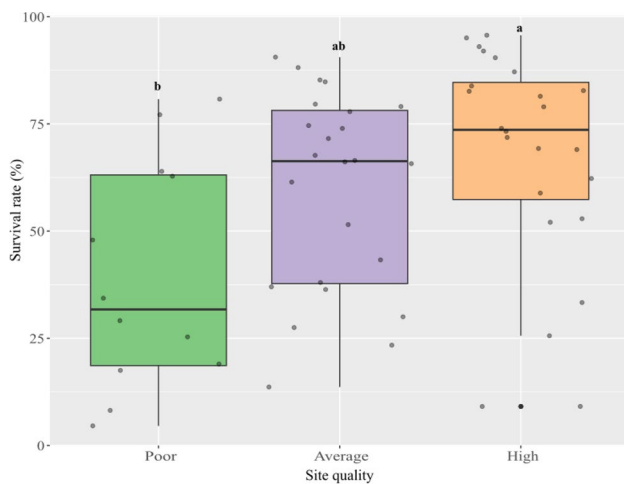


Fig. 1 Survival (%) of native tree species raised using different container grades across sites of varying qualities, at two years after planting (N=60). Different lower-case letter differ means by Tukey test ($P < 0.05$)

Overall, poor quality sites resulted in lower survival for most of the native tree species regardless of container grade. However, some species, such as *D. viscosa* and *L. scoparium*, showed relatively uniform survival across all sites (Fig. 3). Conversely, *C. grandifolia* and *S. microphylla* had low survival even when planted in high quality sites, irrespective of container grade size.

Some species such as *A. serrata* and *P. regius* seemed to be very responsive to site quality where higher seedling survival was observed when planted in higher quality sites, irrespective of container sizes. The highest variation when comparing high- and poor-quality sites was observed for *A. serrata* and *C. australis*. For *K. ericoides*, *C. australis*,

and *P. totara*, only poor-quality sites caused considerable decreases in survival percentage, at two years after planting.

The effect of container grades on survival and initial field growth

When we considered the effect of container size on seedling survival at age 2 years, we observed overall lower survival for the seedlings raised in smaller forestry grade containers than for those raised in revegetation grade containers, irrespective of site quality and species (Fig. 4).

Neither height nor root collar diameter were significantly affected by the grade of container, but revegetation forest-grade containers tended to promote faster early growth, regardless of species (Fig. 5a and b).

Looking at the species level, revegetation grade containers promoted higher survival for a few of the native tree species (Fig. 6). However, for some species such as *A. serrata*, *K. ericoides*, *P. regius*, and *P. totara*, the effect of the container grades was less pronounced. These species showed similar survival rate even when raised using standard forestry grade containers.

S. microphylla and *coprosma grandifolia* showed the lowest survival rates across all container sizes, regardless of the quality of planting site.

Combined effect of container sizes and site quality on field establishment

For some species such as *C. robusta*, *H. angustifolia* and *M. ramiflorus*, there was a significant interaction between the container size used to raise the seedlings and the quality of the site where they were planted. That is, survival rates were dependent on both factors simultaneously and

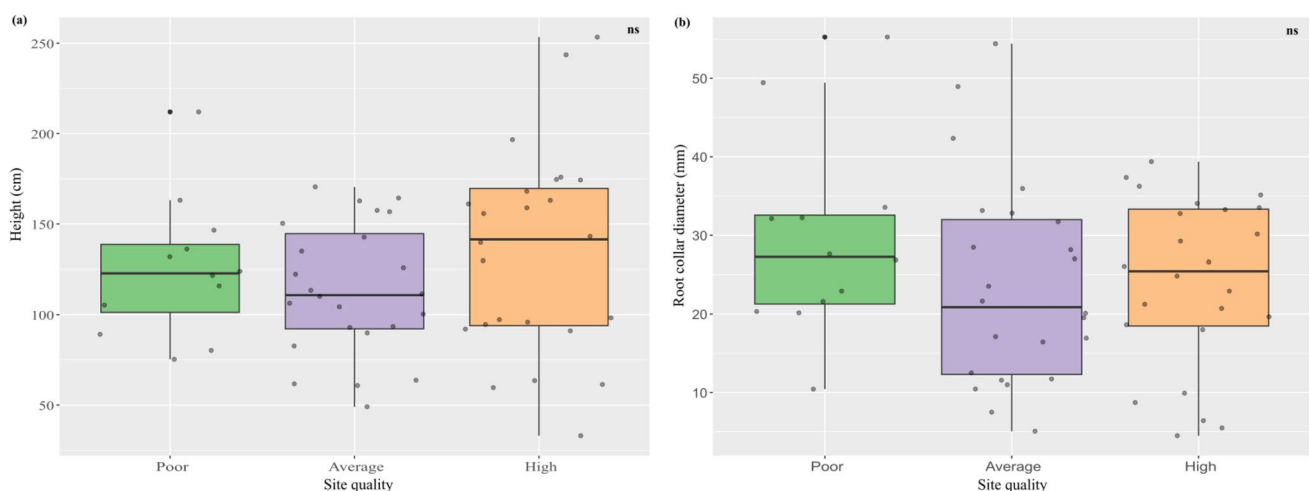


Fig. 2 Height (cm) and root collar diameter (mm) of native tree species raised using different container grades across sites of varying qualities, at two years after planting (N=60). *ns: not statistically significant

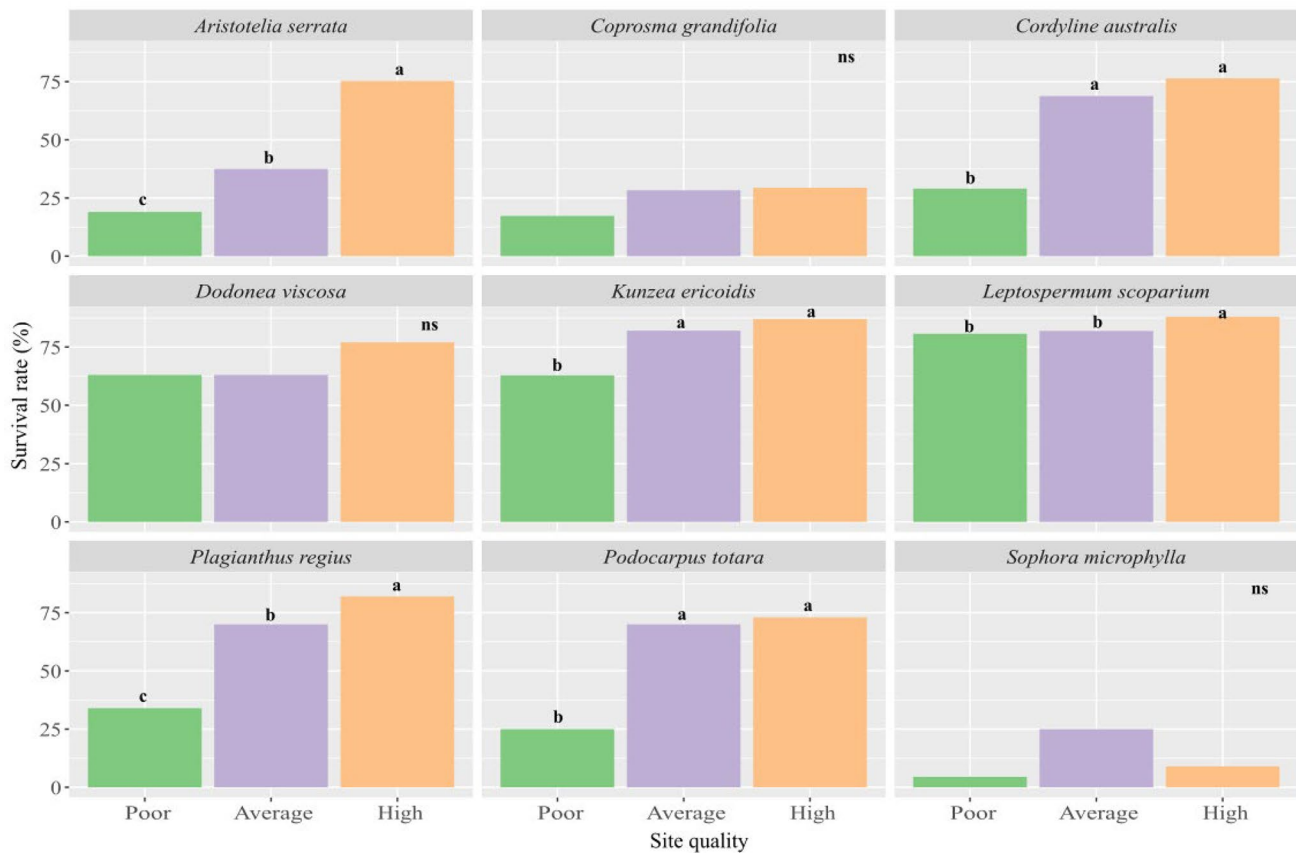


Fig. 3 Survival (%) of native tree species raised using different container grades across five different sites of varying qualities, two years after planting. Different lower-case letter differ means by Tukey test

($P < 0.05$). Error bars represent the standard deviation. *ns: not statistically significant

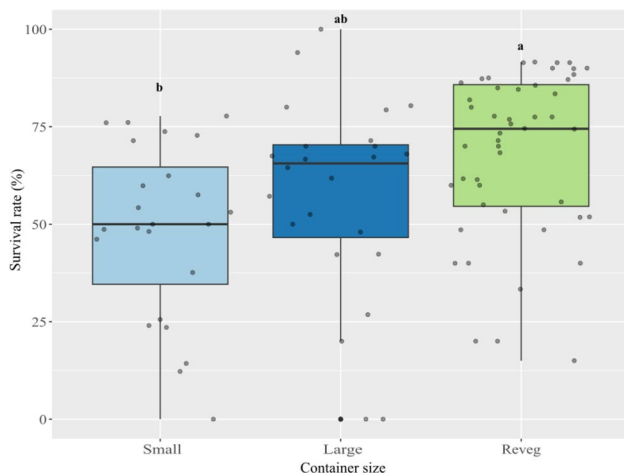


Fig. 4 Seedling survival (%) of various native tree species raised in different container groups and planted across five sites of varying qualities, at two years after planting (N=96). Different lower-case letters differ means by Tukey test ($P < 0.05$)

varied accordingly—for *M. ramiflorus* and *H. angustifolia*, bigger containers were beneficial even when seedlings were planted in high-quality sites, 44% and 33% higher survival, respectively (Fig. 7).

On the other hand, *C. robusta* had no clear advantages for being raised in larger container grades, unless when planted in poor or average site qualities. In this case, only *C. robusta* seedlings raised in small containers had lower survival rates when compared to large and revegetation grades.

Discussion

The effect of site quality on species' performance

In general, high quality sites promoted higher survival and performance in the first two years after planting for most of the native species, irrespective of the container size used to raise the seedlings. This suggests that if the seedlings are well planted under favorable growth conditions, the choice of container is less important for survival. Similar results were reported by Pinto et al. (2011), where container

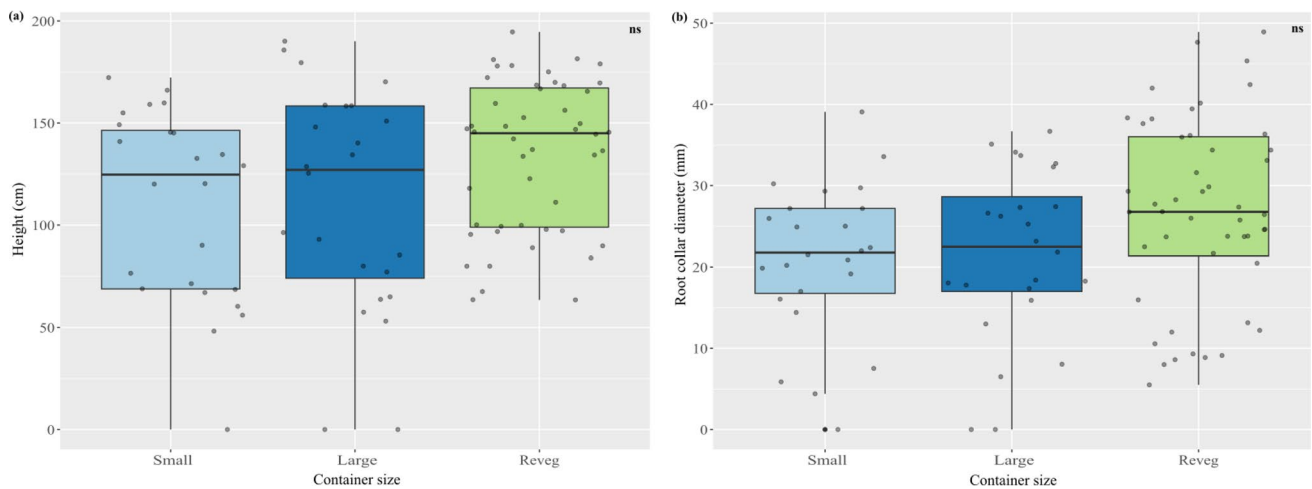


Fig. 5 Seedling height (cm) and root collar diameter (mm) of various native tree species raised in different container groups and planted across five sites of varying qualities, at two years after planting (N=96). *ns: not statistically significant

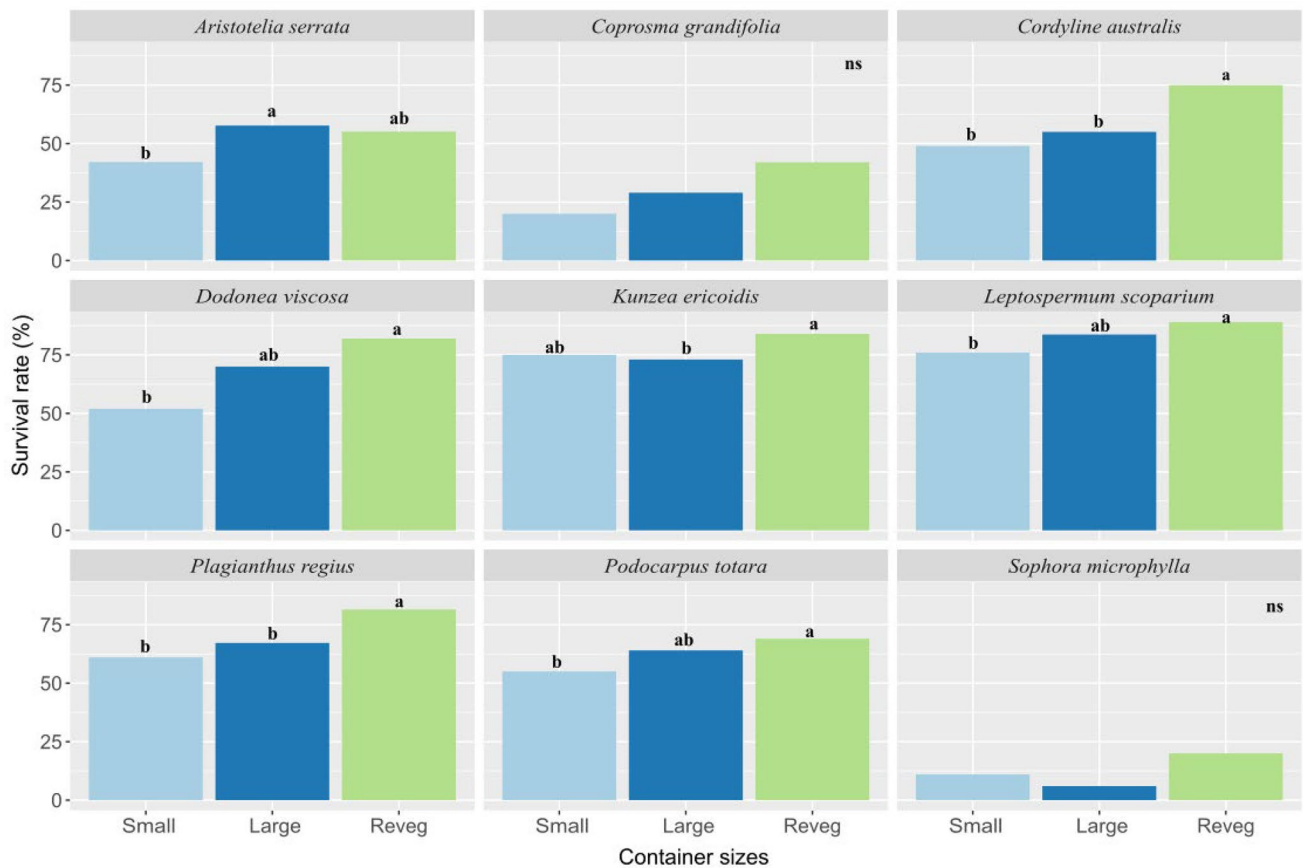


Fig. 6 Survival (%) of native tree species raised using different container grades across sites of varying qualities, at two years after planting. Different lower-case letter differ means by Tukey test ($P < 0.05$). Error bars represent the standard deviation. *ns: not statistically significant

selection also became of less importance when pine seedlings were planted at the correct time and under favorable growth conditions.

The effect of site quality on growth and survival varied amongst the species tested. For some species, such as *D. viscosa* and *L. scoparium*, we observed a relatively high

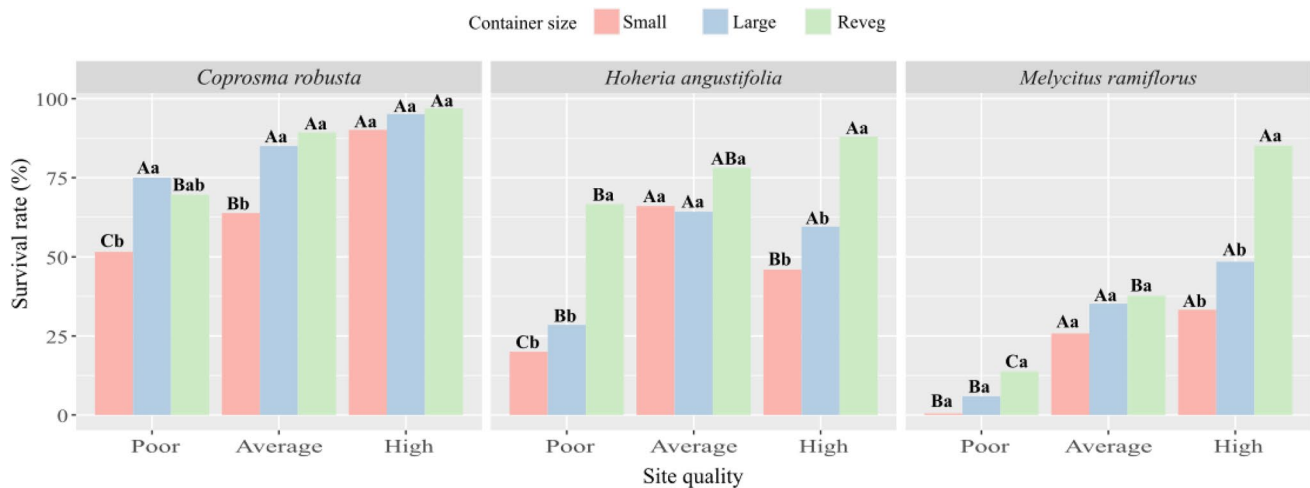


Fig. 7 Survival rate (%) of native tree species raised using different container grades across sites of varying qualities, at two years after planting. Different upper-case letters indicate significant differences

across sites and lower-case letters indicate differences between container sizes by Tukey's test ($P < 0.05$) and error bars represent the standard deviation

survival rate across all container classes, even at the poor-quality site. This suggests that these species are better suited to reclamation of heavily degraded areas than other species like *A. serrata*, *C. australis*, and *M. ramiflorus* whose survival was more dependent on site quality.

In contrast to *D. viscosa* and *L. scoparium*, *C. grandifolia* had low survival even when planted on high quality sites. These results suggest that *C. grandifolia* might have specific requirements in the nursery that were not met by any of the treatments in this study. We also observed very low survival for *S. microphylla* plants across all sites. This is explained by heavy browsing of the species which seems to be more palatable for herbivorous mammals. If the planting site is known to have problems with animal damage, *S. microphylla* is not recommended even when raised in revegetation container grades, unless an additional site preparation such as fencing is also considered.

Podocarpus totara was found to be light demanding but tolerant to dry exposed sites when compared with other native conifer tree species (Bergin 2003). This may explain the relatively high survival of the species when planted on sites of average and high qualities. *P. totara* could also be a viable alternative for economic plantation or revegetation of areas with similar characteristics; however, attention must be paid if the site quality is poor.

We observed that former pasture sites, considered of high quality due to intense previous fertilization, had a dense growth of summer grasses over many of the seedlings. Although this might have caused some light constraints and other competitive effects, the remaining dead, but still standing grass might have helped protect some seedlings from frost events through early winter. In contrast, the poor-quality sites were overrun with convolvulus and bracken. This,

together with poor overall soil conditions likely contributed to the overall lower survival and growth performance for most of the native species in this site. Regarding weed-trees competition, larger seedlings are expected to perform better than smaller seedlings (Thomas et al. 2016; Tian et al. 2017). In areas where weed competition is critical, particularly in poor quality site, revegetation forestry grade containers should be recommended to improve the success of the planting as well as higher maintenance for weed control post planting.

The effect of container grade size on species' performance

Overall, larger container sizes had a significant positive effect on the survival two years after planting and this was true for high, average and poor quality sites. Not surprisingly, seedlings raised in different container types had variable sizes at the time of planting with the small containers producing smaller seedlings. Our results showed there was a marginal tendency for increased plant size two years after planting, but the lack of significant difference is evidence that the smaller plants are catching up the bigger ones.

Looking at the species level, some of them such as *A. serrata*, *K. ericoides* and *C. grandifolia* did not show greater survival after planting when raised in larger, revegetation grade containers. These species can be raised in smaller container grades without major negative effects on seedling survival. The survival of those species seemed to be more influenced by edaphoclimatic factors other than container grade.

For *D. viscosa*, *L. scoparium*, and *P. totara*, survival was lower when seedlings were raised in the smallest

(90–125 cm³) standard grade containers when compared to revegetation grades. It seems that both large and revegetation grades containers are suitable for seedling production, regardless of planting site quality. Similarly, radiata pine seedlings raised using eleven different container sizes resulted in generally lower survival for the seedlings raised in the smallest containers (Puertolas et al. 2012). These authors recommended medium size containers to minimize cost per living seedling after planting in the field.

It is noteworthy that, even though the standard forestry grade containers resulted in lower survival for *P. regius* and *L. scoparium*, they could be considered the most cost-effective alternatives as the survival rate for both species was fairly high, at two years after planting.

Along with the quality of planting site, the root architecture and growth rate of each species are key factors to be considered when choosing containers, because tree seedlings with deep root architectures require larger container to avoid root deformation (de la Fuente et al. 2018). For species with deeper root architecture, smaller containers might restrict root growth and increase the risk of the seedlings becoming root bound, which will likely result in poor nutrient and water uptake after establishment (Chu et al. 2020). This could explain the lower survival after planting when the standard container grade was chosen for the seedling production of *D. viscosa* and *C. australis* and *H. angustifolia*, known for their rapid growth, which justifies their lower performance when raised using standard forestry grade containers.

For those species, large grade containers could be recommended as a minimum requirement irrespective of the quality of the planting site. Larger containers should produce high quality seedlings while preventing problems with nutrient and root-bound plants. However, there remains the opportunity to raise those species using the same small forestry grade containers but with variations in the growing time in the nursery. This could potentially produce good quality seedlings and reduce costs without affecting survival and establishment after planting in the field.

We observed a marginal increase in plant height up to two years after planting, when plants were raised in revegetation container grades, although this effect was not statistically significant. Initial seedling characteristics that are induced by container size lose predictive value with time after planting (Pinto et al. 2011; Rocha et al. 2022), explanation of the similar height and diameter of the root collar at all locations two years after planting. Similar findings were reported by Aghai et al. (2014), where differences in growth performance could not be seen after planting in the field. This reiterates that smaller seedlings at the moment of nursery dispatch are catching up the bigger ones two years after planting in the field. The container size used to raise the seedlings mainly affect the establishment success,

but once the seedlings are well established, differences in growth rates won't be noticeable in the long-term.

Our results revealed that the tree species $\times$ container size $\times$ quality of the planting site interactions can be broad and highly dependent on each other, particularly for *C. robusta*, *H. angustifolia* and *M. ramiflorus*. Recommendations on nursery practice guidelines on container grades need to consider those factors alongside a cost-effective analysis for each scenario before nursery production begins (Davis and Pinto 2021). This study presented findings that are a step further in recommending container grades for the seedling production of New Zealand native species that will be more suitable for planting in specific sites of varying levels of disturbances. However, further studies are needed to improve the understanding of some species that did not perform well in any condition. Also, there remains the opportunity for new studies testing growing time $\times$ tree species $\times$ container size and the field performance of those seedlings. In fact, seedling production requires specialized knowledge and attention to many key factors to be able to deliver adequate quantities of high-quality plants that might endure highly variable and harsh field conditions (Haase and Davis 2017).

Conclusion

Our study demonstrated that the Target Plant Concept also applies to New Zealand's native species where some species might require larger container sizes when planted in low quality sites such as *P. totara*, *C. robusta*, and *H. angustifolia*. However, in most cases, a large container grade (150–310 cm³) will be sufficient for a desirable cost–benefit outcome or even a small container size (90–125 cm³) can be adequate if the quality of the planting site is favorable. In contrast, no clear added advantage to survival and initial growth performance was gained when larger container sizes were used for other species such as *A. serrata*, *C. grandifolia*, and *S. microphylla*, irrespective of the quality of the planting site, indicating the need for further studies to improve post-planting performance for these species.

This study indicates it is possible to replace revegetation containers with smaller containers to raise several New Zealand native species depending on site quality, resulting in a quicker nursery throughput, more cost-effective nursery and field management without the use of traditional plastic bags.

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