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RESEARCH

Growth and survival of transplanted black beech (*Fuscospora solandri*) seedlings on Motuareronui (Adele Island)

Simon Moore[1]*, Ron Moorhouse[2], Graeme Elliott[1] and Helen Lindsay[2]

[1]Department of Conservation, Private Bag 5, Nelson, New Zealand 7010
[2]Project Janszoon, PO Box 3437, Richmond, New Zealand 7050
*Corresponding author (Email: shmoore@doc.govt.nz)

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Abstract: Black beech (*Fuscospora solandri*) seedlings were planted in randomly located plots on Motuareronui (Adele Island) to assess whether survival was sufficient for applied nucleation to be used as a restoration method on parts of the adjacent mainland. The long-term goal of this project is to re-establish black beech as a keystone canopy species on ridges and headlands that lost their primary forest cover as a result of fires by the middle of last century. One hundred and sixty-four of 199 beech seedlings (82%) planted in 2014 survived to 2019. Survival was higher in plots that had a low to moderate canopy density, or when plots had either low or moderate canopy density, when seedlings had higher levels of ambient light. There was weak evidence of a negative relationship between seedling growth and the amount of ambient light, attributable to apical dieback in some seedlings.

Keywords: applied nucleation, fire, *Fuscospora*, restoration planting, survivorship

Introduction

Aotearoa New Zealand's forest flora is poorly adapted to fire compared to that in other parts of the world, and beech forest is particularly susceptible (Wiser et al. 1997). Prior to human settlement, the frequency of fire in New Zealand was low except for in some wetlands (Perry et al. 2014). The impact of fire on indigenous ecosystems following human arrival has been profound but remains relatively under-studied (Smale et al. 2011).

Applied nucleation, planting small patches of tree seedlings as nuclei for subsequent regeneration, has been promoted as a cost-effective forest restoration strategy (Chazdon 2008; Corbin & Hull 2011). In contrast to blanket planting, this approach utilises natural successional processes that take place over decades. Direct seeding is another low-cost method of forest restoration but may be limited in its effectiveness (Douglas et al. 2007). Uncertain germination rates and a lack of knowledge around optimal sowing times, sowing rates and competition from other flora can contribute to this.

Motuareronui (Adele Island) (87 ha, 40°58′50″ S, 173°3′33″ E) lies off the coast of Abel Tasman National Park in Tasman District, Nelson Province, New Zealand. Extensive parts of the coastal and lowland zones of Abel Tasman National Park were heavily modified by fire in the 19th and 20th centuries when attempts were made to clear native vegetation for farming. Uncontrolled fires also affected areas that were not intended for farming or horticulture, including Motuareronui and the hills on the adjacent mainland, inland of Anchorage (Smith 1997) where black beech (*Fuscospora solandri*) dominated the forests on ridges and headlands. Low fertility granitic soils underlie these areas. The inability of black beech to disperse and recolonise after disturbance (Wardle 1991) has meant that re-establishment after fires has been either extremely patchy and slow, or absent. On Motuareronui, mature indigenous forest is now largely confined to the coastal fringes and gullies whereas the drier, burned ridges and upper slopes are now dominated by kānuka (*Kunzea ericoides*) and willow-leaved hakea (*Hakea salicifolia*), an invasive Australian woody weed. Open bare ground occurs throughout the burned areas where vegetation has yet to re-establish.

This study presents results from a trial designed to test the survival of transplanted black beech seedlings on Motuareronui. If sufficiently successful, the ultimate goal of this work is to then undertake an applied nucleation planting regime at strategically located sites on the adjacent mainland. We anticipate that black beech will disperse over time from the planted nuclei to once again become a dominant compositional feature of the vegetation.

Methods

While there is some evidence that hand sowing mountain beech (*Fuscospora cliffortioides*) seed immediately after fire can be an effective way of restoring this species (Ledgard & Davis 2004), we decided to plant nursery raised seedlings inoculated with mycorrhizae sourced from beneath adult black beech remnants on Motuareronui. This approach was favoured because we thought it offered the best chance of survival in low fertility soils prone to summer drought.

Black beech seeds were obtained from existing remnant

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stands in Abel Tasman National Park and propagated for two years before being transported to Motuareronui for planting in 2014. Seedlings were transported in PVC planting bags and were, on average, 99 cm tall (± 19.2 cm) at time of planting. Duff from under remnant black beech stands on Motuareronui was collected and added to the seed raising and potting mix to introduce ectomycorrhizal fungi beneficial to seedling growth. Ectomycorrhizae have a symbiotic relationship with the root systems of indigenous beech species which help with the uptake of nutrients and water (Wardle 1984). We acknowledge that the species of ectomycorrhizae required for seedling growth may differ from those associated with adult trees but felt that this inoculation still offered a potential advantage.

Seedlings were planted in twenty 9 m^2 plots, with ten seedlings per plot in two rows 1.5 m apart i.e. plots were 6 × 1.5 m. One plot contained nine seedlings because of the loss of one during transfer to the island. The survival and growth of seedlings were monitored yearly. Success was defined as > 50% survival after five years. Growth was measured from ground level at the base of the stem to the height of tallest living foliage. The following variables were thought to be the most likely to drive changes in survivorship of growth while also being relatively easy to measure for each plot at the time of establishment: slope, aspect, mean vegetation height, canopy density, dominant canopy species, dominant understory species, percentage cover of bare ground, percentage cover of moss-lichen, and percentage cover of litter/duff. Dominant canopy and understory species were based on composition, while canopy density was a subjectively assigned score moderated over the whole plot (low, low–medium, medium, medium–high, high). Seedling heights were measured to include living foliage but excluded tops of the seedlings that had died back. Plot parameters were measured only once during the establishment phase. In addition, measures of ambient light were recorded using light meters (Capital TK79 and Sekonic Auto-Lumi, calibrated to the same readings) for individual seedlings. These were undertaken three years into the project as it became clear that there was considerable variation of ambient light within plots.

Statistical analyses were performed in R version 4.1.0 (R Development Core Team 2021). We used a binomial generalised linear model to model seedling survival, and a generalised linear model to model growth, as a function of the plot variables; as ambient light values (lux) were taken for individual seedlings rather than for each plot, we used the mean ambient light values for seedlings in each plot in these analyses.

Two different subsets of data were used to analyse seedling survival and growth. The dataset used to analyse survival included all seedlings whereas that used to analyse growth only included those that survived to 2019. As the number of potential explanatory variables was large for the amount of data, we used the comparatively restrictive variance inflation factor threshold of 1.5 advocated by Booth et al. (1994) to screen variables for collinearity (Appendices S1 & S2 in Supplementary Materials). This approach left seven putative explanatory variables (ambient light, dominant vegetation cover, aspect, canopy density, dominant understorey species, percent of moss-lichen cover, and percent of duff litter) for the analysis of seedling survival and four (ambient light, dominant vegetation cover, aspect, and dominant understorey species) for the analysis of seedling growth. This still left too many variables for the amount of data; models were singular if all variables were included. We therefore decided to omit dominant understorey species and aspect from the survival model and dominant understorey species from the growth model. We excluded these variables because dominant understorey species often varied within plots and because many plots were situated on flat or low-gradient sites meaning that the effect of aspect was limited for most.

Removing these variables left five putative explanatory variables (ambient light, dominant vegetation cover, canopy density, percent moss lichen, and percent duff litter) for the analysis of seedling survival and three (ambient light, dominant vegetation cover, and aspect) for the analysis of seedling growth. We modelled change in natural log mean growth from 2014 to 2019 divided by the number of years to correct for bias in relative growth (Hoffmann & Poorter 2002). We had no a priori reason for preferring particular models over others, therefore we used the function *dredge* in the package MuMIn (Barton 2019) to compare all possible models; further, we used AICc (Anderson 2007) as model selection criteria.

Results

Seedling survival

One hundred and sixty-four of the 199 seedlings planted in 2014 survived to 2019 (82%; 95% CL=76.5–87.1%). Survival decreased over time (Fig. 1). Dead seedlings occurred in most

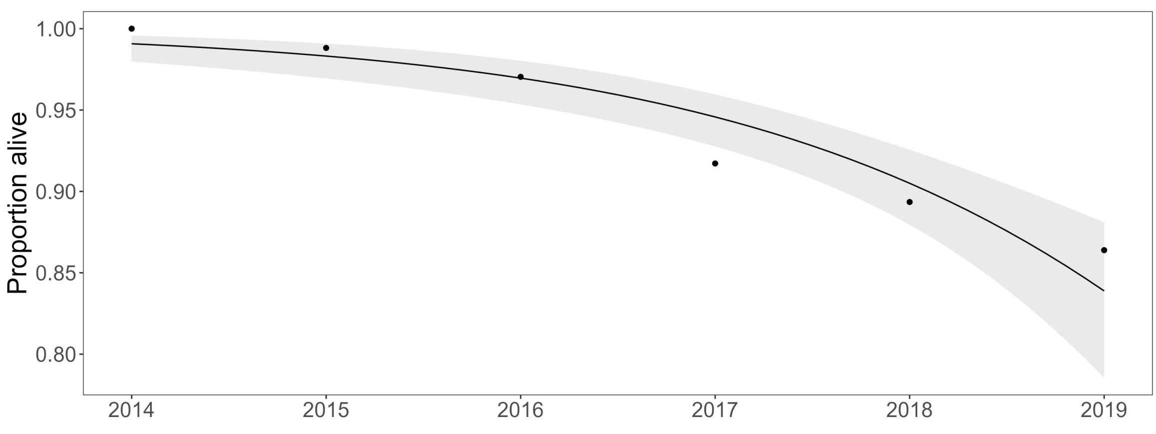

Figure 1. Survival curve for black beech (*Fuscospora solandri*) seedlings planted on Motuareronui from 2014 to 2019. Shaded area is 95% confidence limits.

Table 1. The three best models from model selection of factors affecting the survival of black beech (*Fuscospora solandri*) seedlings on Motuareronui. A total of 32 models were examined. MAL = Mean ambient light (lux), CD = Canopy density, % ML = % Moss litter cover.

Model	NP*	AICc	Delta	Weight
Survival ~ MAL + CD	4	53.4	0.00	0.387
Survival ~ CD	3	54.7	1.29	0.203
Survival ~ MAL + CD + % ML	5	57.0	3.55	0.066

*Number of parameters.

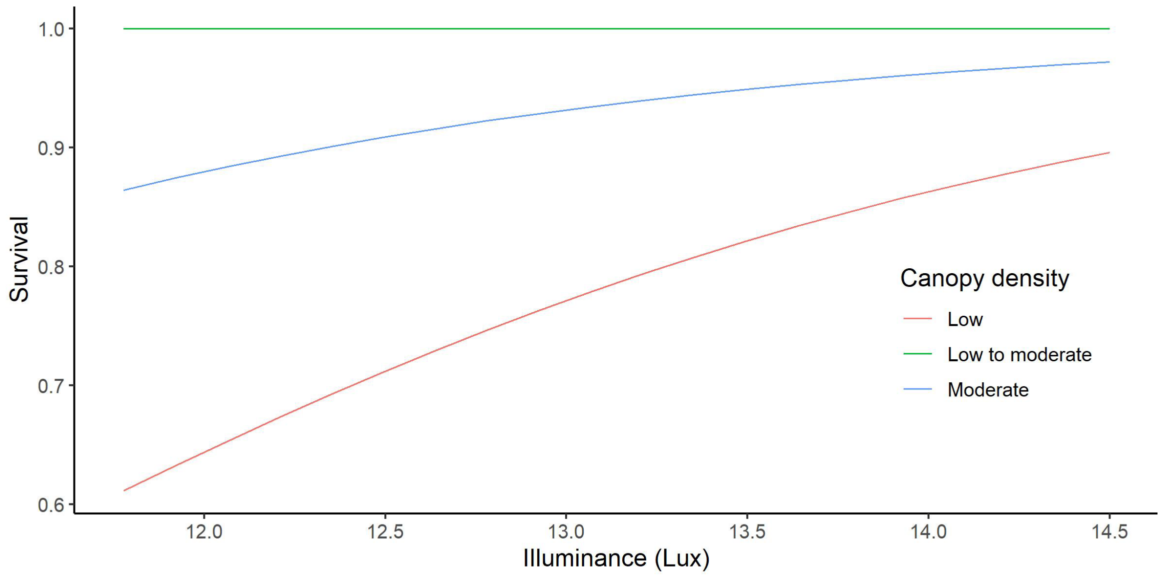

Figure 2. Survival of black beech (*Fuscospora solandri*) seedlings on Motuareronui as a function of illuminance (ambient light measured with a light meter) and canopy density (L = low, L–M = low–moderate, M = moderate).

plots and there was no visual evidence that seedlings died from disease. The apparent decrease in survival between 2016 and 2017 was significant (Chi-squared test, $P = 0.01312$). However, despite a one in a hundred-year drought in the Nelson region in the summer of 2018–2019, the decrease in seedling survival between these years is no greater than that between other years (Fig. 1). A binomial generalised linear model of seedling survival as a function of the mean ambient light (lux) and canopy density per plot was the best supported based on AICc (Table 1). Plotting seedling survival as a function of ambient light and canopy density suggests that survival was both high and unaffected by the amount of ambient light in plots with low to moderate canopy density but was positively affected by the amount of ambient light in plots with either low, or moderate, canopy density (Fig. 2).

Seedling growth

There was a marked decrease in growth in 2016, then no statistically significant change (Fig. 3). Growth increased between 2018 and 2019 despite a one-in-one-hundred-year drought that summer. A model with a single explanatory variable, mean ambient light (lux) per plot, was ranked the best predictor of seedling growth (Table 2). However, the AICc of the null model was only slightly higher and the null model had one less parameter (Table 2). Moreover, the predicted relationship between seedling growth and ambient light is negative, which is counter-intuitive (Fig. 4).

Discussion

Modelling black beech seedling survival and growth against a range of environmental variables indicated that survival was best explained by the amount of ambient light and canopy density per plot. Seedling survival was highest in plots with low to moderate canopy density irrespective of the amount of ambient light but was positively affected by ambient light in plots with either low, or moderate canopy density. Observations during annual seedling measurements suggest that while relatively open microsites were favourable to survival, mortality was spread over a range of environmental conditions and occurred in most plots. For red beech (*Fuscospora fusca*) and mountain beech seedlings, 35% of full sunlight is thought to be optimal for survival (Smale et al. 2021). In this trial at least some mortality was observed among seedlings planted in direct sunlight where there was no litter or duff, and no surrounding foliage. This suggests that there is a relatively high optimal light requirement, along with a preference for at least some vegetation and litter or duff. Seedlings in comparatively open, sunny sites may also be less subject to direct competition for nutrients and water, which could affect survival. However, there was substantial within-plot variation in canopy cover, litter and duff cover. The relatively high frequency of unexplained seedling mortality suggests that seedling survival may also have been affected by variables that were not measured in this study.

Some aspects of plant mortality are context-dependent and species-specific, making relative comparisons between planting projects difficult (Holzwarth et al. 2013). However, some generalisations are apparent. Early attempts by the New Zealand Forest Service to plant beech often had low success because of smothering by grass, browsing of seedlings by rabbits and hares, drought in the first summer, frost and winter desiccation (Smale et al. 2012). There are no rabbits or hares on Motuareronui, limited exotic grass swards and the location of the plots on ridges and shoulder slopes made them less susceptible to frost. Although soil moisture levels were below average in the Tasman Region in the early summer of 2015/16 and during the one-in-100-year regional drought in 2018/19 (NIWA 2020), seedling mortality was not significantly higher in these years. It is possible that the locally sourced seedlings planted on Motuareronui were predisposed to drought resistance.

Typically, beech seedlings under a natural beech-dominated closed canopy are suppressed until a disturbance event promotes a light well which stimulates vigorous growth (Wardle 1984; Wyse et al. 2018). Seedling growth was best explained by the amount of ambient light in each plot, but since the AICc of the null model was similar, and had one less parameter, it may have been unaffected by any of the variables

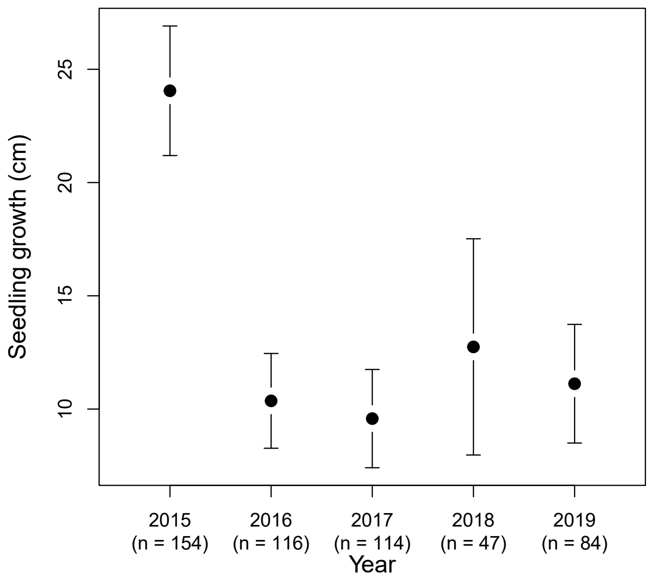

Figure 3. Average annual growth of black beech (*Fuscospora solandri*) seedlings on Motuareronui. Error bars are 95% confidence limits.

Table 2. Results of model selection for factors affecting the growth of black beech (*Fuscospora solandri*) seedlings on Motuareronui. MAL = Mean ambient light (lux).

Model	NP*	AICc	Delta	Weight
Growth ~ MAL	3	12.01	0.00	0.62
Growth ~ Null	2	11.04	0.97	0.38
Growth ~ MAL + Aspect	9	11.93	23.94	0.00

*Number of parameters.

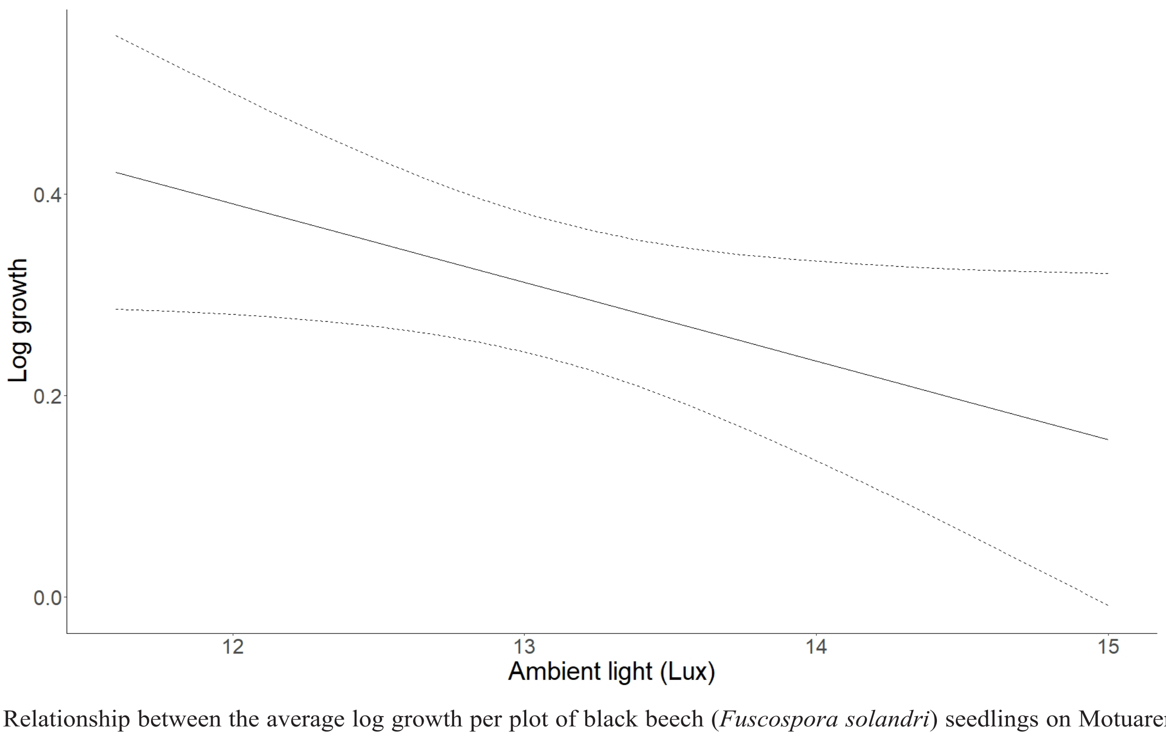

Figure 4. Relationship between the average log growth per plot of black beech (*Fuscospora solandri*) seedlings on Motuareronui and ambient light (lux) predicted by a generalised linear model. Dotted lines indicate 95% confidence limits.

measured. The apparent negative relationship between growth and ambient light is likely an artifact of apical dieback, i.e. the tops of seedlings dying but the remainder of foliage remaining healthy. Weak apical dominance is known to occur in red beech seedlings planted in open sunlight (Smale et al. 2012). Height may therefore not be the best measure of the health or vigour of black beech seedlings. The marked decrease in growth in 2016 is probably due to seedlings having to obtain nutrients from the island's low-fertility granitic soils after exhausting those contained in the nursery potting mix. Both survival and growth may have been influenced by other, unmeasured variables, including those that may have affected seedlings before they were planted on Motuareronui, such as the relative success of mycorrhizal inoculation in the nursery. Local variations in soil characteristics (e.g. soil chemistry, soil moisture) may also have impacted survival and/or growth.

Although beneficial ectomycorrhizae associated with kānuka have been found to be an alternative host of *Fuscospora*-compatible mycorrhizal inoculum (Dickie et al. 2012), there was no evidence to suggest that growth or survival of seedlings was enhanced in kānuka-dominated plots. This could be because seedlings had already been inoculated with mycorrhizae in the nursery, which may have confounded the effect of naturally occurring kānuka in plots. It is also possible that fire has altered the composition of the ectomycorrhizal fungal community of Motuareronui. A positive association between beech growth and kānuka may become apparent over time.

The relatively high survival rate of planted black beech seedlings on Motuareronui suggests that a similar planting programme could succeed on the adjacent mainland where the vegetation, soils, climate, and disturbance history are similar. Protection from browsing may be required at mainland sites. However, some browsers such as goats and possums are intensively managed as part of Project Janszoon. Browsers also tend to be observed in greater densities in higher fertility parts of the park, such as alluvial flats and limestone karst areas, than on the dry, infertile ridges where planting would take place.

Strategic reintroduction of black beech using applied nucleation could be a cost-effective method of restoring a keystone forest species to parts of Abel Tasman National Park where it has been lost or highly depleted. Over the long-term, taller indigenous forest tree species such as black beech and broadleaved associates may help to suppress willow-leaved hakea, which is a light-demanding species. We believe that applied nucleation has considerable potential as a method of restoring lost or depleted elements of native flora in New Zealand.

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Author Contributions

SM: Conceptualisation, methodology, investigation, data curation, writing – original draft, writing – review & editing. RM: Methodology, formal analysis, writing – original draft, writing – review & editing, visualisation. GM: Methodology, software, formal analysis, visualisation. HL: Investigation, resources, supervision, project administration.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Variance inflation factors (GVIFs) of candidate variables used to model survival of beech (*Fuscospora solandri*) seedlings on Motuareronui.

Appendix S2. Variance inflation factors (GVIFs) of candidate variables used to model growth of beech (*Fuscospora solandri*) seedlings on Motuareronui.

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