Research Report
Urban Plantings

people+cities+nature

restoring indigenous nature in urban environments

Planting a Lasting Urban Forest

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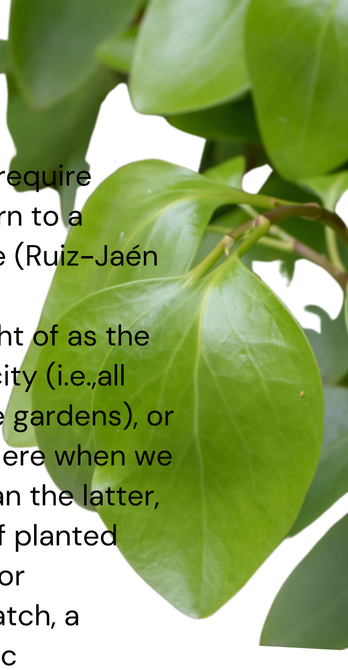
Background

About 86% of Aotearoa New Zealand citizens live in cities (The World Bank 2014), where their opportunity to connect with nature regularly is often in a small, local forested park. However, despite the manifold benefits we now know forests and nature provide for people, most Aotearoa New Zealand urban centres have very little of their native ecosystem cover remaining (cover ranges from approximately 2% - 10% depending on the city; Clarkson et al. 2007). Forests and other native ecosystems are now mostly left on upland rural areas, and even there, restoration work is often needed (Norton et al. 2018). Therefore, now more than ever, we need to plant new urban forests for the benefit of both people and wildlife.

Urban forests are different from rural forests both ecologically (e.g., greater fragmentation and non-native weed species pressure) and environmentally (e.g., urban heat island, higher pollution levels). They are also more dynamic than rural forests (Groffman et al. 2016; Doroski et al. 2017), with frequent changes in tree population sizes and ages due to human activity.

Unique challenges to urban forest restoration worldwide include the urban heat island effect (Samuel et al. 2016), fragmented city landscapes (Drinnan 2005), and constant non-native species invasion (Trammell et al. 2012; La Sorte et al. 2014). Planted urban forests are therefore faced with additional pressures and require intensive management to return to a functional, mature, native state (Ruiz-Jaén and Aide 2006).



Urban forests can be thought of as the collective trees throughout a city (i.e.,all park trees, street trees, private gardens), or as discrete patches of trees. Here when we speak of urban forests we mean the latter, discrete patches or pockets of planted forests, and give suggestions for establishing an urban forest patch, a process that requires a specific management approach, different from other types of trees in the collective urban forest.

The People, Cities & Nature Plantings team have found that the underpinnings of urban forest patch planting and restoration should be scientifically proven to ensure success, because little is known about this process of reconstruction of forest from scratch (i.e., plantings in former pasture or parkland, Clarkson and Kirby (2016)). Urban forest restoration by trial and error is costly, and can often result in failures that are both discouraging to stakeholders, practitioners, and condemning of future funding approval. Instead, we propose taking an evidence-based approach developed with on-the-ground partners and practitioners, informed by ecological science, and applied through practice-oriented principles. This completes the full cycle of discovery through to implementation, allowing restoration efforts to be successful.

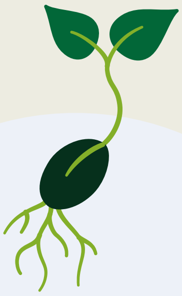
Planting an urban forest is a very worthwhile endeavour, but requires special management to get it right in the long term. People, purpose, plants, and patience are all required. This synthesis of our results aims to support using scientific research to inform those undertaking urban forest management and restoration.

Research Aims

The People, Cities & Nature research programme aimed to broaden understanding about how to optimise urban forest restoration plantings in order to maximise efficient use of resources (e.g., funding, employee hours) and promote long-term ecological success. We had two main questions:

- Research Question 1 - What factors limit successful spontaneous native plant regeneration in urban forest restoration?
- Research Question 2 - What factors limit successful enrichment planting in urban forest restoration?

The following sections describe the background, methods and results of our investigations to answer each question.



1

Regeneration

- What factors limit successful spontaneous native plant regeneration in urban forest restoration?

Background

Forest restoration plantings have been initiated in urban centres throughout Aotearoa New Zealand over approximately the past six decades. While establishment of the initial canopy has been relatively successful in most cases, long-term success of forest restoration plantings depends on the sustainability of these plantings to reproduce themselves. Our question centres not just on how the planting looks in one moment in time, but the long term vision and journey for that forest's future. This is especially in regards to whether that forest can self-perpetuate growing the next generation of trees under its canopy.

Forests in more natural rural settings can often naturally go through a process called ecological succession. Ecological succession is the process of ecosystem development following a disturbance, typically beginning as the presence of early-successional (i.e., pioneer) plant species that facilitate changes in their immediate environment to make way for mid and late-successional species (Connell & Slatyer, 1977; Bazzaz, 1979; Fig. 1).

Because there is so much disturbance in altered city environments, we must actively engage in the act of ecological restoration to re-create ecosystems we want there by mimicking this successional process. In succession, the regeneration of native tree, shrub and epiphyte species beneath the canopy of the initial restoration planting is a key process in forest succession, and is therefore a great indicator of restoration success. However, we have known little about the precise factors that constrain or promote successful native plant regeneration under planted urban forest canopies until our research occurred. This has made it difficult to manage these planted forests in a way that encourages growth of the next generation of forest within them.

Our work is based on previous research in Hamilton and New Plymouth showing that native plant regeneration under planted canopies appears to be mostly constrained by the age of the initial forest planting, competition from herbaceous weeds, and the microclimate (temperature/humidity) of the understory of the forest (Wallace et al.

Figure 1. Forest ecological succession through time, from early, through mid, to a late-successional forest. The pioneer plant species present during early-succession ameliorate conditions to be suitable for the mid-successional plant species to establish and grow, and then eventually the plant species which are long-lived late-successional plant species. Achieving the late-successional stage is vital to promote forest stability and provide maximum biodiversity support and ecosystem services. (Figure from our research output: Hall 2020)

2017). However, the work we discuss here came about because we wanted to discover whether canopy formation is similarly crucial for the next generation of forest seedling germination in all Aotearoa New Zealand cities (not just Hamilton and New Plymouth). Moreover, we wanted to ask questions like: how long does it take for canopy closure to occur and those herbaceous non-native weeds to diminish and when does microclimate become suitable for late-successional native seedling regeneration? And when regeneration does occur, what species are popping up under our planted urban forest canopies? Finally, does it matter how big a forest patch is, or can seedlings pop up anywhere? By answering these questions, our results have shaped a more informed approach to urban forest restoration and how to encourage a mere planting to become a fully-developed forest ecosystem (Fig 2).

Methods

The People, Cities & Nature Plantings team established 79 permanent forest vegetation plots in 9 cities across Aotearoa New Zealand. In each city 200 m2 data collection plots were established spanning variation in forest age in nine different restored forests (except only 8 were established in Dunedin and Invercargill). These 79 urban restoration sites were selected for this study to form a plot chronosequence spanning 4 years to 58 years since initial planting.

Chronosequences use space as a substitute for time in order to study the temporal dynamics of systems and uncover potential causal links between response and predictor variables (Dornelas et al., 2013). The area of the forest patches that the plots occurred within ranged between 0.1 ha to 77.3 ha, with a mean size of 8.01 ha.

In each plot, we measured forest structure and composition, generally following methods in Wallace et al. (2017) and the New Zealand National Vegetation Survey protocol. These vegetation metrics included adult tree species and their basal area (e.g., a measure of tree size), any regenerating plant species (of trees, shrubs and epiphytes), and non-native herbaceous weed cover (without species identification) and other ground covers such as leaf litter and moss. In each plot we also measured forest environmental conditions, including soil temperature (using iButton dataloggers), air temperature and humidity (using HOBO dataloggers), and light transmittance through the canopy to the forest floor(using a densiometer). Finally, we

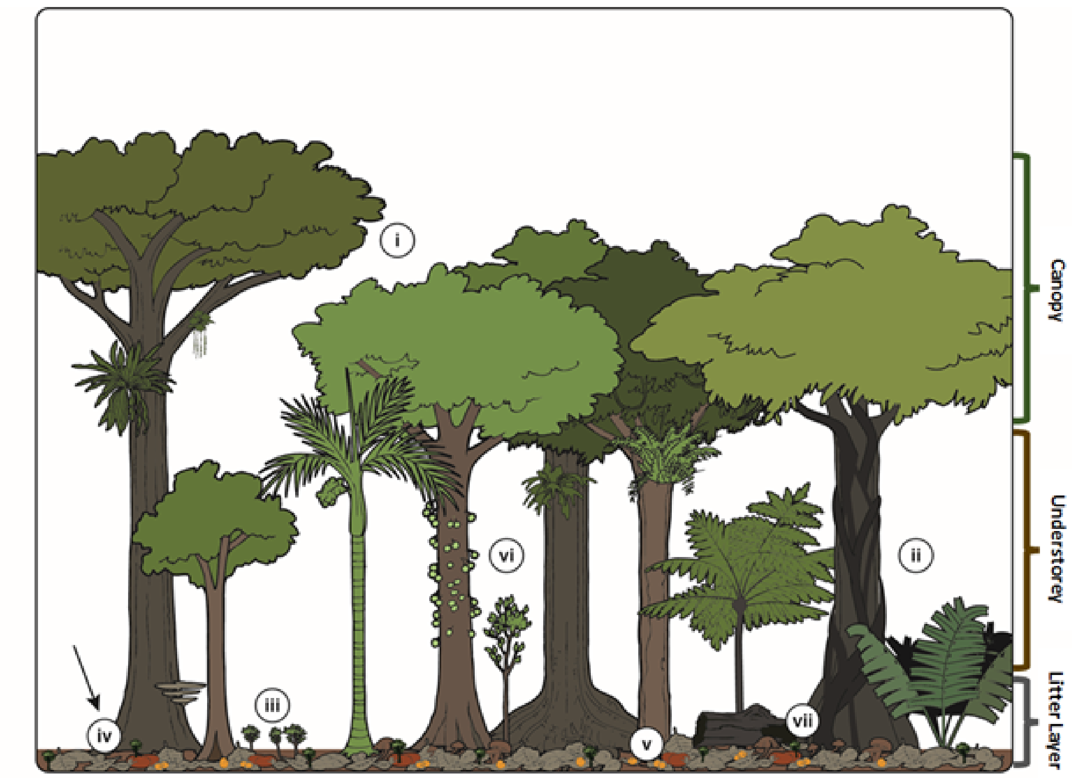


Figure 2. Reflections on planting an urban forest - don’t miss important elements and stages in development after initial plantings occur! i. Planting and management to hasten canopy closure and reduce light gaps is crucial, ii. Getting trees established means you can introduce important plant groups like vines later on, iii. Canopy closure causes sun-loving herbaceous weeds to die back so shade-tolerant native seedlings can regenerate, iv. Seeds from external sources may be introduced, and in cities these are often weeds so, vigilance is required to suppress these in early years after planting, v. Maturing trees can create a leaf litter layer on the forest floor, making conditions for desired native seedling germination, vi. Enrichment planting of late-successional plant species is typically vital in cities because forests are too far apart for natural seed dispersal to occur, and vii. Decomposition of old leaves, sticks and trunks is recycling of nutrients for living plants, and important habitat for invertebrates, this ‘woody debris’ should be left where it falls. (Figure from our research output: Wallace & Clarkson 2019).

measured the size of the forest patch to determine if this affected the seedlings we found growing there. This way we could discover what forest structures, environments, and sizes allowed regeneration to occur best.

Findings

General Forest Development

We found that urban forests planted from scratch generally tend to develop in a predictable pattern, where multiple aspects (or properties) of the forest change simultaneously, and in fact sometimes trigger each other to change (Fig. 3). This can inform how we manage these forests to fully develop into biodiverse, functioning, enduring ecosystems.

When observing newly-planted forests through to those getting further along in their development (age in years since initial planting increased), we saw the basal area (e.g., tree size) increase from 0.004m2 to 1.84m2 per 200m2 plot (Fig. 4A) and canopy openness decreased drastically from 88.82% to 5.89% (Fig. 4B). Forests with low canopy openness hosted lower herbaceous ground cover (a drop from 96.88% to 0%; Fig. 4C), likely because less sunlight could get to the forest floor. Low canopy openness also meant less fluctuation of air temperature (43.6 ^{0}C swings in open canopies, became 17.5 ^{0}C swings in closed canopies; Fig. 4D), and lower maximum air temperatures (34.7 ^{0}C maximum in open canopies, became 22.86 ^{0}C under mostly closed canopies; Fig. 4E). Highly variable and generally hot air temperatures (and indeed direct sunlight) can have a large, detrimental

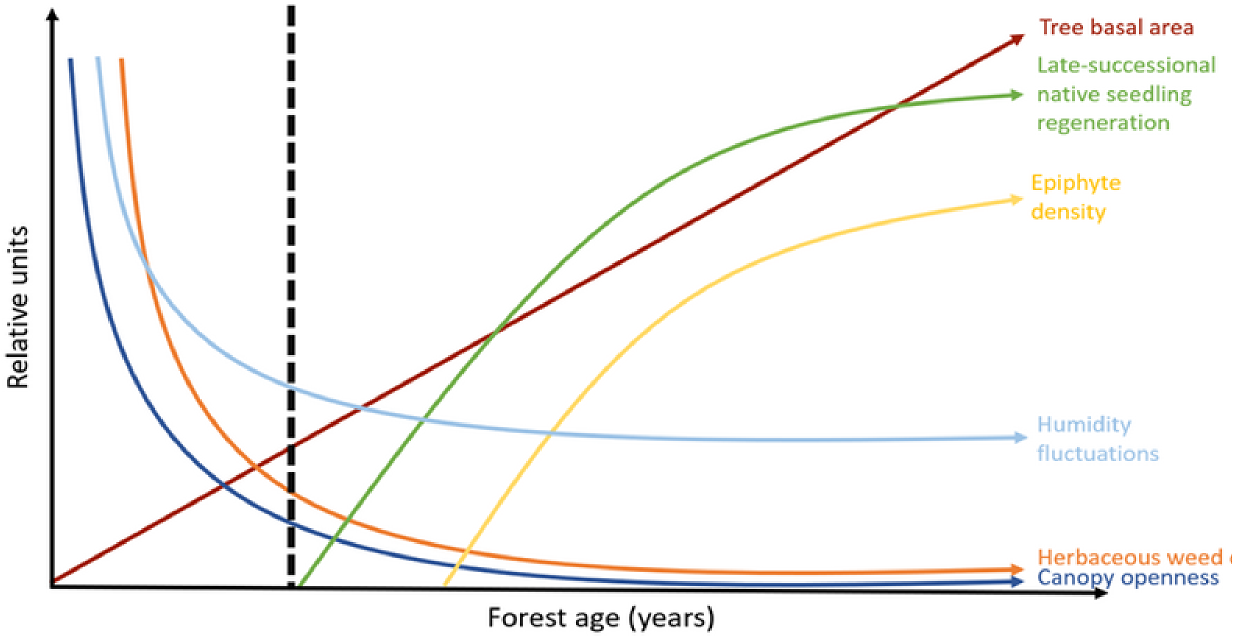
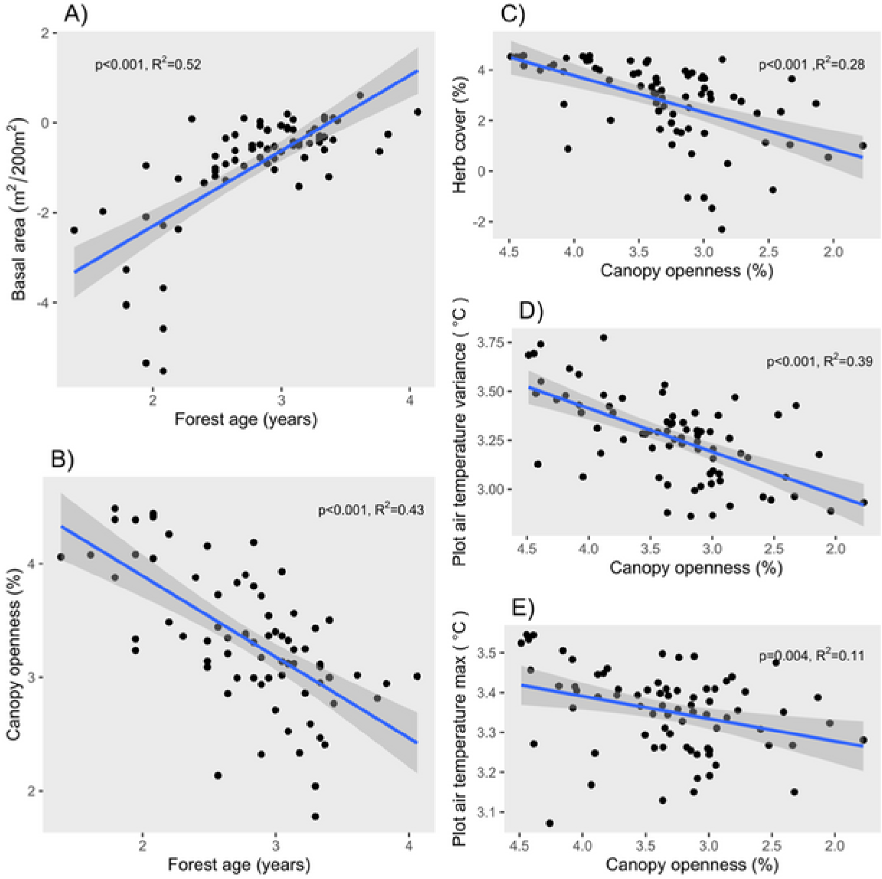


Figure 3. The journey of change for different forest properties as a planted forest develops. We can see how forest properties change drastically during canopy development (dark blue line) after initial restoration plantings (beginning at the far left corner of the graph and moving right with forest age). There is a critical threshold (dashed line) where a series of significant events co-occur, typically between 10-20 years after initial plantings. At this threshold, first, tree basal area increases, then the canopy openness drops, along with decreases in herbaceous weed cover and humidity fluctuations, all ultimately facilitating suitable conditions for late-successional native plant regeneration (Figure from our research outputs: Hall 2020; Wallace et al. 2017).

Figure 4. Changes in forest properties that affect native tree seedling regeneration and recruitment during forest development after initial restoration planting. Axes are log scale. With greater forest age we observed adult tree basal area A) increase, while canopy openness decreased B), so these two properties display opposite trends during forest development. As canopy openness decreases, so does herbaceous ground cover C), swings in air temperature variation D), and E) maximum air temperature (sample size for these data is 75 plots). Scatterplot points represent individual restored forest sites, solid lines represent the fitted values from a linear regression model on log transformed data, and dark grey areas represent 95% confidence intervals.



effect on regenerating seedlings, so forests should be managed to avoid these conditions on the forest floor.

From these findings about forest development, we know there are predictable trajectories forest properties will take. We also know they occur over the time scale of roughly 60 years (the age range of these forest plots, on the x axes).

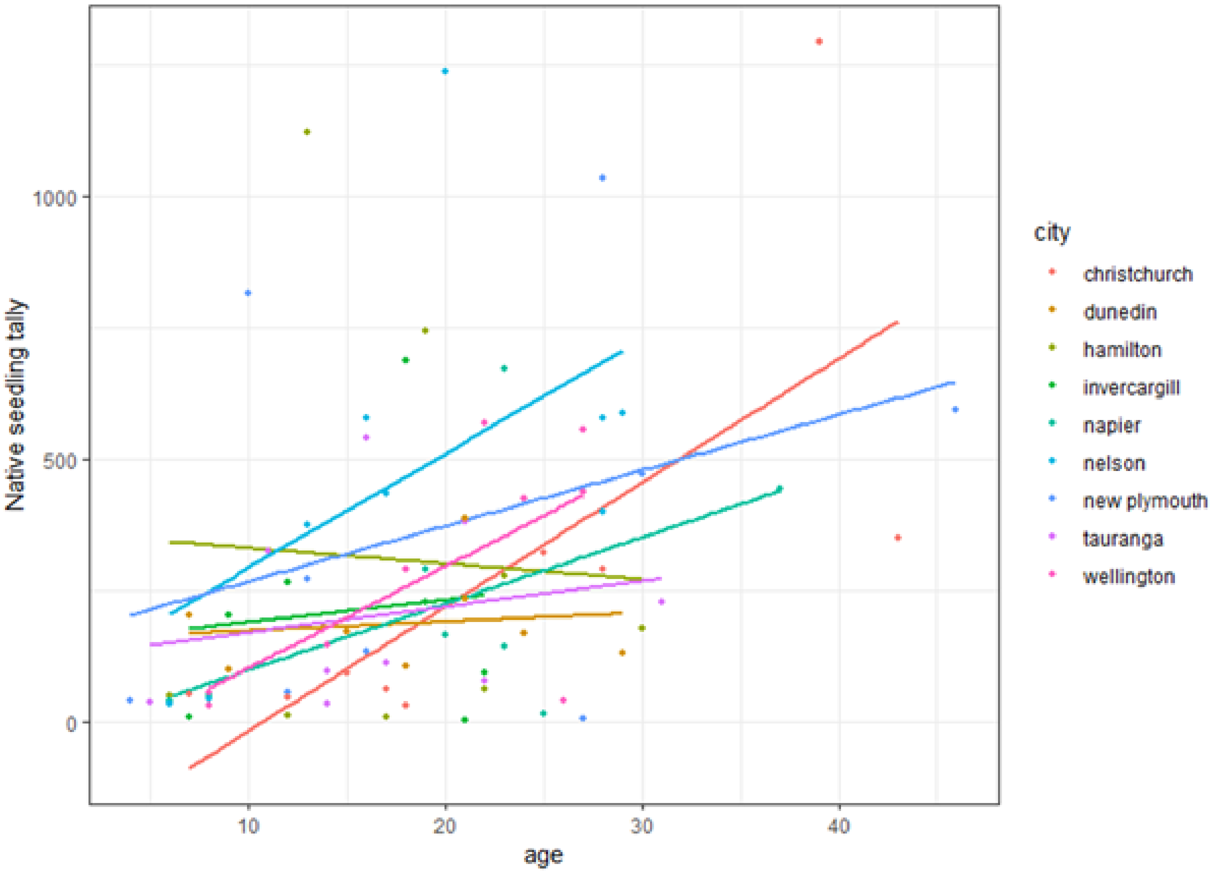
Native tree seedling regeneration

A total of 39,664 native tree seedlings were identified in the 79 developing forest plots across the country. This included native seedlings of all successional categories (early, mid, late) and growth stages (smallest to largest: germinating, recruited, sapling stages of growth). Seedling counts were generally highest in New Plymouth, Nelson, and Hamilton, but seedling numbers were more strongly determined by the degree of canopy openness than city location. This suggests that actions taken at a local forest management level to produce a closed canopy are a more powerful way to get native tree seedling regeneration than either local climate or landscape context (e.g., proximity to other forest for seed sources etc.). Meaning, no matter where our forest is, your management can determine the successful regeneration of the next wave of tree seedlings.

> Actions taken at a local forest management level to produce a closed canopy are a more powerful way to get native tree seedling regeneration than either local climate or landscape context.

Now we know that the developing forest's age and related canopy openness (Fig. 5) are two major determinants of tree seedling regeneration. One of the reasons for this is that as forests age and their canopies develop, the canopies block light from reaching sun-loving herbaceous weeds on the forest floor. We also observed how this reduced competition and good conditions on the forest floor favour native seedling germination in specially focussed study at Waiwhakareke Natural Heritage Park in Kirikiriroa Hamilton (Fig. 6).

However, we also learned that not all regenerating trees respond to the aging forests in the same way. In fact, the way the regenerating trees respond depends on both their growth stage (e.g., height) and their successional status (early, mid and late) (Fig. 7). Meaning, late successional species require a different set of forest environmental conditions from what early successional species require. It also means that a tiny freshly-germinated seedling needs different conditions than its older brother, even if they are the exact same species (Fig. 7).



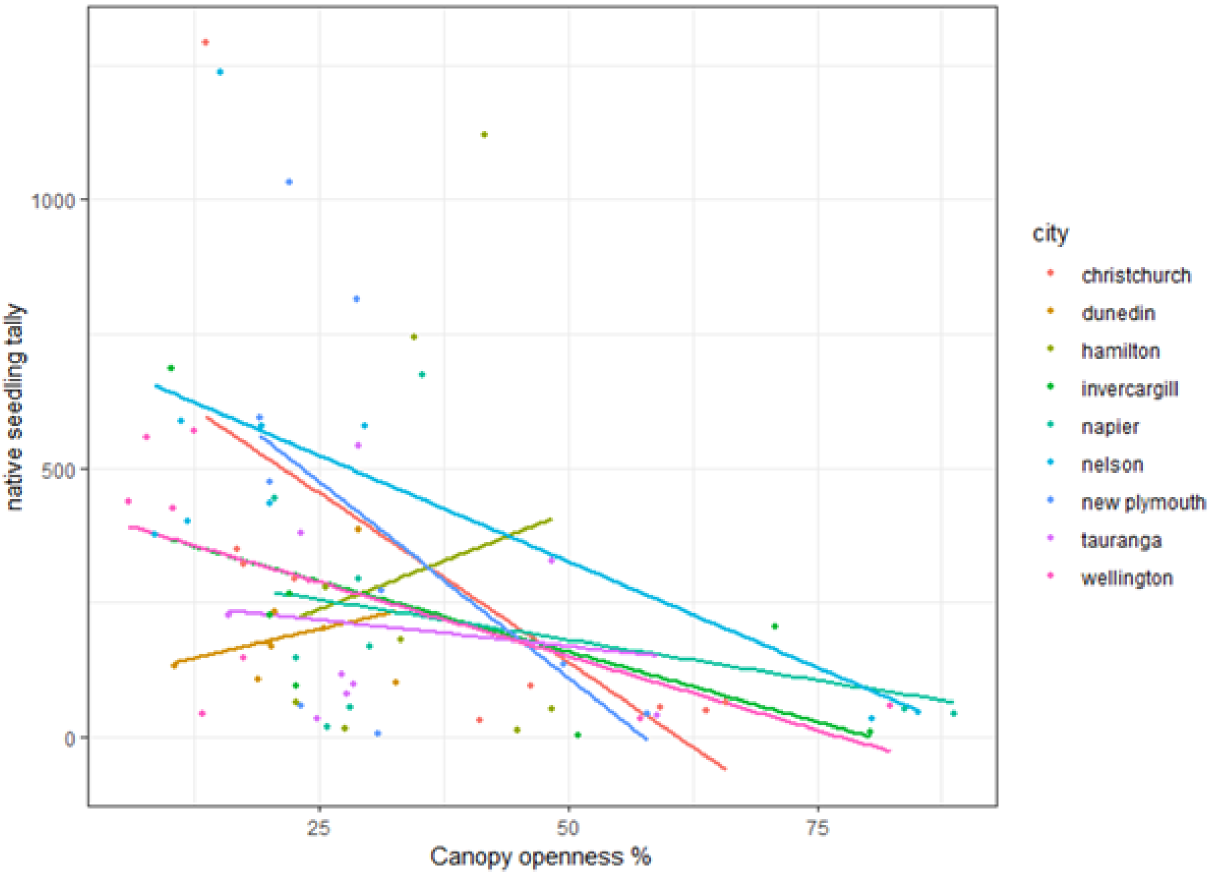


Figure 5. These graphs show the number of native seedlings tallied in each of the 79 plots along with the associated degree of forest age (graph above) and canopy openness (graph below). Each point represents a plot. We see that older, more closed canopies result in higher numbers of seedlings. The general trend in seedling numbers for each city is shown with different coloured lines. (Data unpublished)

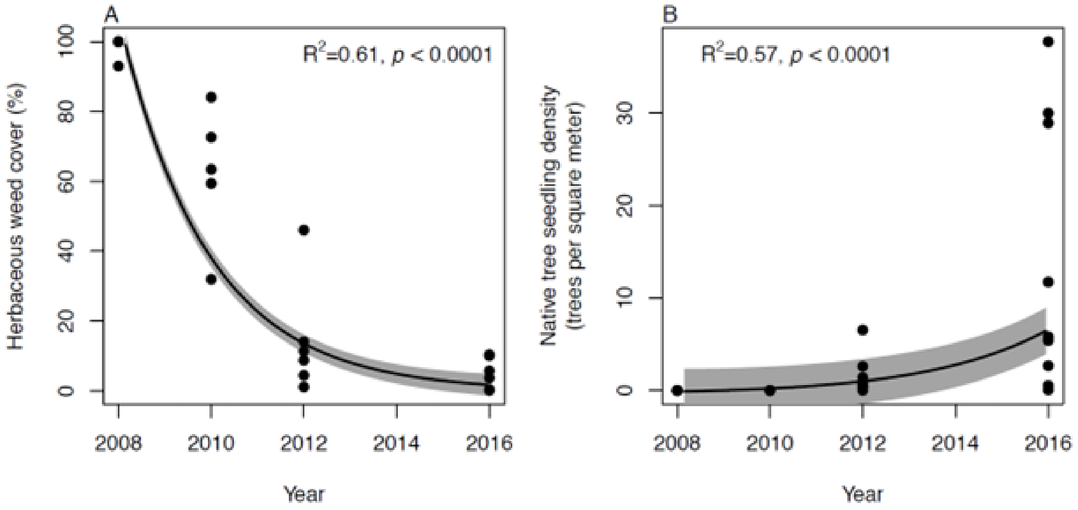


Figure 6. Changes in (A) herbaceous weed cover (%), and (B) native tree seedling regeneration density over time in plots initially planted in 2007. Over a period of eight years since planting we see a decline from 100% herbaceous cover to almost 0%, and the appearance of as many as 35 seedlings per m2 where there were previously none. Black lines represent fitted generalized additive mixed model predictions, and shaded area represents 95% confidence intervals. (Figure from our research output: Laughlin & Clarkson 2018)

The early successional juveniles of all growth stages (i.e., heights) grow more abundantly in older forests (Fig. 7A, 7C, 7E), probably due to the protection from the elements those older forests offer. In comparison, mid-late successional regenerating tree abundance has no statistically significant relationship with forest age (Fig. 7B, 7D, 7F). The abundance of the younger growth stages, the 'germinated' and 'recruited' early successional trees, appears to increase with forest age, while abundance of 'germinated' and 'recruited' mid-late successional species has no relationship with forest age (Fig. 7).

This growth stage analysis indicates a very important discovery, that older forests are not necessarily going to cater for the particular microclimate conditions needed by the all-important mid and late successional species unless their forest structures (i.e., canopy closure) is suitable. So tall, big trees spaced widely are not adequate. This is evident when observing that the degree of canopy openness is actually the main determinant of abundance of mid and late successional species (Fig. 8) (not forest age), with less open canopies allowing mid and late successional species to thrive when they are very small.

However, interestingly, once the mid and late successional species reach the taller sapling growth stage (Fig. 8F) this relationship breaks down and a wider variety of canopy openness is tolerable for these mid and late successional species. It's likely that at this point the saplings are reaching an important physiological threshold where they are old enough to withstand harsher, exposed environmental conditions as a tradeoff to get more light through canopy gaps. This fulfills another natural process in forest succession, whereby older canopy trees die off and younger understorey trees grow up to fill the new canopy gaps.

Older forests are not necessarily going to cater for the particular microclimate conditions needed by the all-important mid and late successional species unless their forest structures (i.e., canopy closure) is suitable.

In summary, planted forest age and canopy closure are key developments that create conditions suitable for native

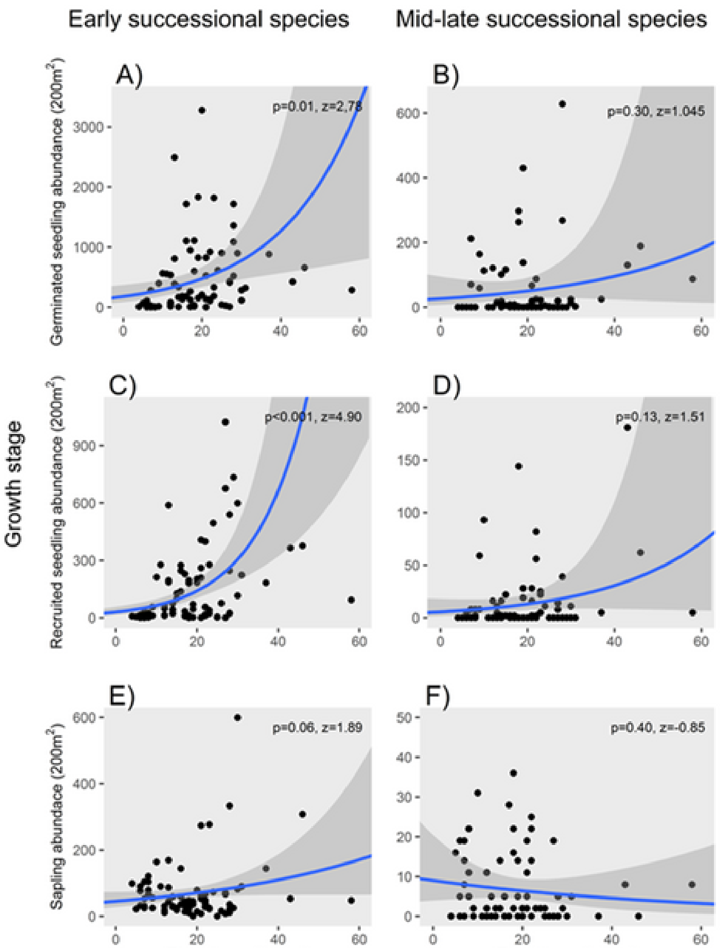


Figure 7. Abundance of regenerating native juvenile trees of early successional species (left) and mid-late successional species (right) per plot (200m2) as related to forest age in planted urban forests (sample size of 75 plots). Regenerating seedlings are shown in three growth stages: 'Germinated seedlings' (0-15 cm tall), 'Recruited seedlings' (16-135 cm tall) and 'Saplings' (over 135 cm, but no more than 2.5 cm diameter at breast height). Scatterplot points represent individual restored forest sites, solid lines represent the fitted values from a negative binomial generalised linear model, and the dark grey areas represent 95% confidence intervals. Z scores are reported according to convention when using the negative binomial error distribution and represent the number of standard deviations the reported values fall below or above the mean. (Figure from our research output: Busbridge 2020)

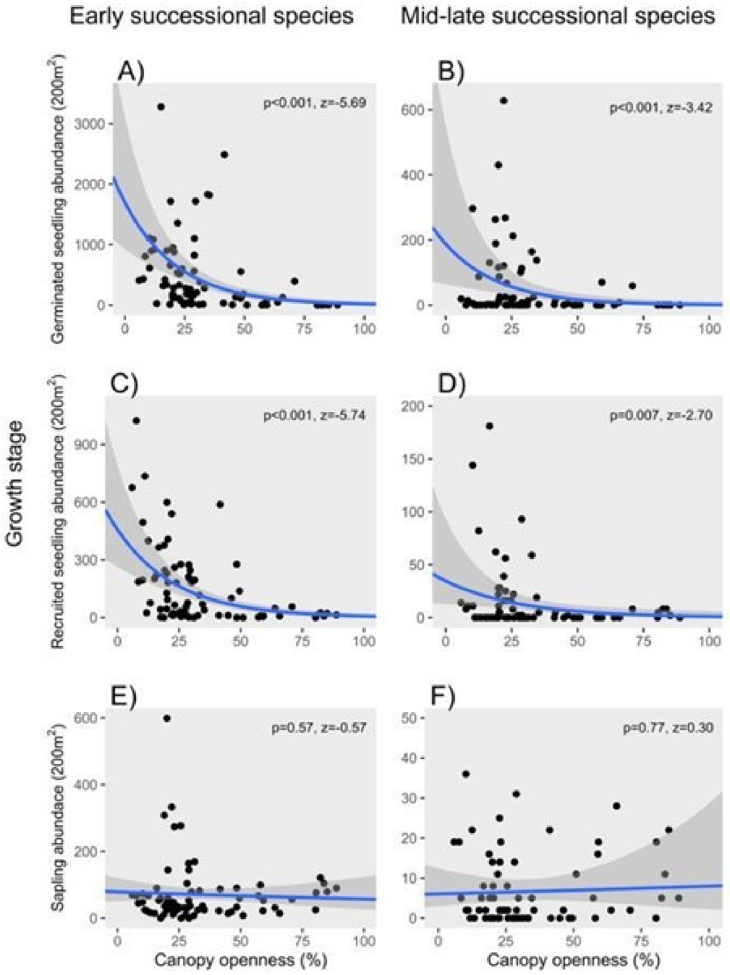


Figure 8. Abundance of regenerating native juvenile trees of early successional species (left) and mid-late successional species (right) per plot (200m2) as related to canopy openness in planted urban forests (sample size of 75 plots). Regenerating seedlings are shown in three growth stages: 'Germinated seedlings' (0-15 cm tall), 'Recruited seedlings' (16-135 cm tall) and 'Saplings' (over 135 cm, but no more than 2.5 cm diameter at breast height). Scatterplot points represent individual restored forest sites, solid lines represent the fitted values from a negative binomial generalised linear model, and the dark grey areas represent 95% confidence intervals. Z scores are reported according to convention when using the negative binomial error distribution and represent the number of standard deviations the reported values fall below or above the mean. (Figure from our research output: Busbridge 2020)

seedling regeneration (Bertacchi et al., 2016). As forests age, increases in tree size cause decreases in canopy openness which is related to reduced competitive herbaceous ground cover and air temperature fluctuations, and a reduction of maximum understory air temperatures.

> Planted forest age and canopy closure are key developments that create conditions suitable for native seedling regeneration.

These results have important implications for the management of restored urban forests. First, to promote natural (i.e. spontaneous) regeneration, management approaches should vary depending on the age of a restored forest. Early in forest development, practitioners should prioritise canopy closure and removal of herbaceous weed species to encourage regeneration and recruitment of small native tree seedlings. Later in forest development when saplings are evident in the understory, a small amount of canopy thinning can be undertaken to create small light gaps and recruit these mid-late successional saplings to the canopy.

Second, management actions should be tailored to forest patch size. In small restored patches affected by limited seed dispersal and edge effects such as drying

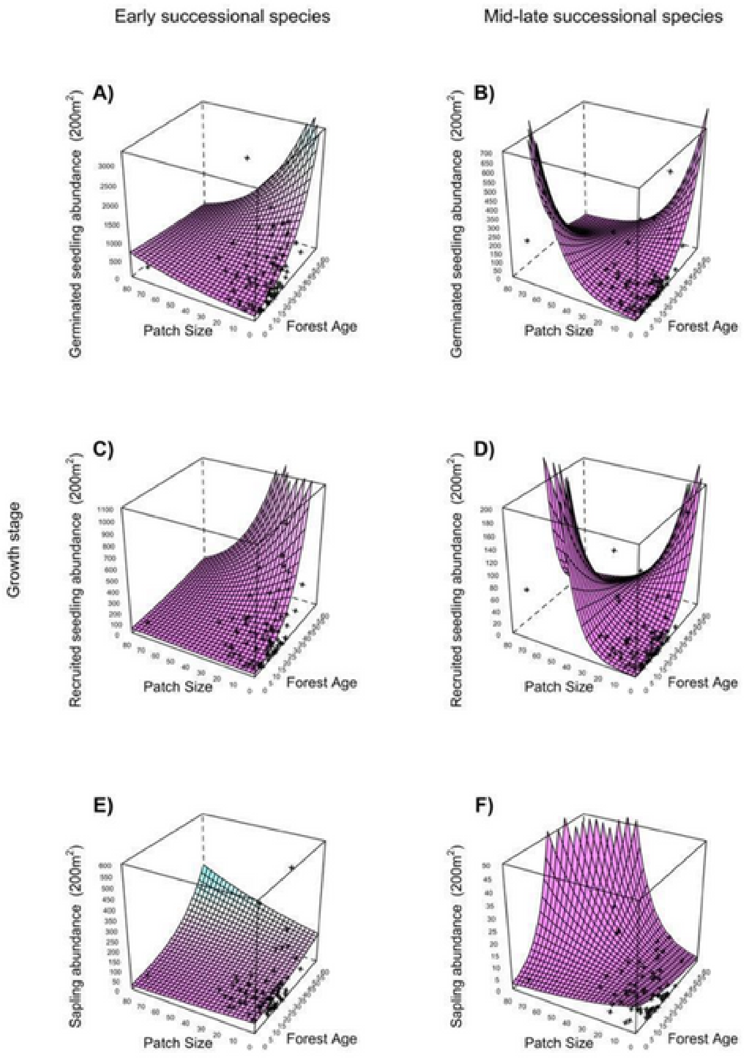


Figure 9. Regenerating tree juvenile abundance as predicted by restored forest patch size and forest age (time since initial planting). This shows that even though forest age generally always plays an important role in juvenile tree regeneration, with older forests being more hospitable, the forest patch size is only important for younger seedlings (bigger patches and their protective environments are better). When it comes to saplings, especially of mid and late successional species, they are tolerant enough to grow in much smaller patches with more exposure to pressures like wind, light and weeds.

winds, enrichment planting of mid-late successional species is vital to ensure forest successional progression (Fig. 9). Restoration practitioners should invest in large mid-late successional seedlings (>100cm) to maximise their resilience and survival in urban environments.

These results show that drivers of native tree seedling recruitment differ according to species successional status and the growth stage of seedlings in restored urban forests. The effects of canopy openness appear to be generalizable across successional status, while the effects of microclimate and patch size vary. Once juvenile trees reach the sapling growth stage an ontogenetic shift occurs and the positive effects of full canopy cover on seedling survival becomes neutral. At this point, saplings no longer require canopy cover for survival and instead likely require more light for growth to recruit into the canopy. For establishment of early successional species, forest age is the most important factor, but mid-late successional species require the cooler microclimates associated with low canopy openness and larger patch size. Small forest patches are less likely to host natural regeneration of mid-late successional tree species because of sensitivity at the seedling stages, but still provide conditions suitable for the persistence of more resilient saplings if they are introduced through enrichment planting.

KEY FINDINGS: REGENERATION

1

Urban forests planted from scratch generally tend to develop in a predictable pattern

2

Forest management for canopy closure is a more powerful way to get native tree seedling regeneration than either local climate or landscape

3

Older forests don't necessarily provide microclimate conditions needed by mid/late successional species unless their forest structure is suitable.

2

Enrichment

- What factors limit successful enrichment planting in urban forest restoration?

Background

This research focuses on what management is required after the first wave of tree planting grows into a forest with a canopy overhead. We ask what conditions are right for people to plant the next generation of late successional forest plants in the understorey (i.e., enrichment planting). Successful ecological restoration requires we manage initial plantings to end up as highly biodiverse, stable, self-perpetuating forest ecosystems. This often requires active intervention to transition them to a late-successional state (Fig. 1). However, little research has explored specific conditions required for introducing late-successional plant species into urban forests undergoing restoration, especially for plant groups besides trees (such as shrubs, vines and epiphytes).

Due to lack of late-successional plant species in the urban environment's seed banks and seed rain (e.g., seed sources), and limitations posed by introduced mammal seed predation, forests undergoing restoration will often require people's intervention through enrichment planting of late-successional tree seedlings or saplings after formation of an early-successional tree canopy (Overdyck et al. 2013, Suganuma and Durigan 2015). This is frequently the case in urban areas, where forests undergoing restoration are typically geographically separated from native seed sources and pollinators, dispersal agents are limited, and control of seed predators is difficult.

Enrichment planting of most late-successional plant guilds is typically necessary in urban forest patches undergoing reconstruction from scratch, but may also be needed in existing urban forest remnants that have merely been degraded or severely isolated from other forest. As with forest species richness generally, it is vital to be aware of what late-successional species may be missing through monitoring what successional classes are present. Despite altered conditions (i.e. microclimates) in the urban context, it is likely that urban forests are actually suitable for a large proportion of the plant species found in rural remnants and should be enriched accordingly with representation from all groups, including trees, shrubs, herbs, epiphytes, and perhaps even specialist plant groups like hemiparasites (mistletoes) and parasitic plants such as *Dactylanthus taylorii*. Using local flora records can help you determine what plants are missing from your forest patch. This investigation was designed to determine the conditions required in the understorey for managers to be able to plant these all-important missing late-successional plant species. By knowing best planting conditions, forest managers can reduce resource investment but still see optimal late-successional plant establishment.

Methods

We selected 27 plots in Hamilton, Napier and New Plymouth (9 in each city) which ranged from 6-48 years since initial forest planting, with an even spread of ages in each city. Six enrichment plants were planted under the forest canopy in each plot: two epiphytes (*Griselinia lucida*, Akapuka), two understorey shrubs (*Piper excelsum*, Kawakawa) and two canopy trees (*Dacrydium cupressinum*, Rimu).

Initial measurements of enrichment plant size were collected immediately prior to their planting to create a baseline and then again 1 year after planting. Each plant's height and stem diameter was measured, along with its total number of green leaves (that were >50% intact). Only the *P. excelsum* and *G. lucida* individuals' leaf numbers were counted because *D. cupressinum* leaves were too small for reliable counts. One year after planting, plants were rated as: 'good', 'marginal' or 'poor' health, 'standing dead' or 'missing'.

Planting locations of the enrichment plants within each restored forest plot consisted of two individuals of the canopy tree and understorey shrub species being planted within ~4 m of the plot centre (Fig. 10). The epiphytic *G. lucida* were tied onto the southern side of two largest native trees within each plot, 1.5 m from the ground.

Findings

Enrichment Plantings

Not all late successional species can be introduced via enrichment planting under the same forest conditions. The three late-successional enrichment species planted for this experiment had varying growth responses to changes in canopy openness in forests of different ages. For example, *Griselinia lucida's* (Akapuka) growth rate is positively related to canopy openness (Fig. 11A), meaning the more open the canopy, the better it grew, despite more variable humidity and temperature conditions under those more open canopies.

> Not all late successional species can be introduced via enrichment planting under the same forest conditions.

In contrast, the growth rate of *Piper excelsum* (Kawakawa) is negatively affected by canopy openness (Fig. 11D), so we know it grows best under closed canopies. This is

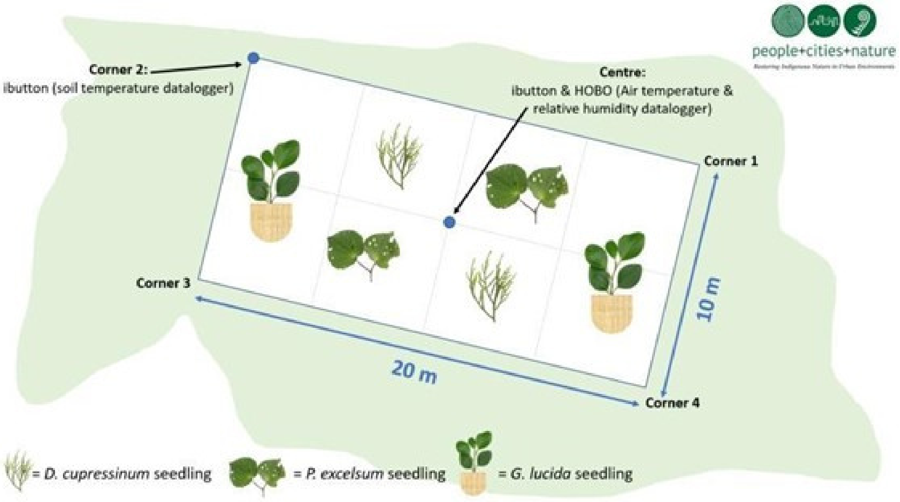


Figure 10. An example People, Cities & Nature research plot layout within a hypothetical restored forest patch (light green background). These plots were used for both Research Question 1 and 2 data collection. We include illustration of the placement of the late-successional plant species (from Research Question 2) and the microclimate dataloggers used in both Research Questions. The epiphytic *G. lucida* were placed within sphagnum moss baskets (shown in the hatched baskets) and tied to trees, the two *Piper excelsum* seedlings were planted in the ground diagonally to the *Dacrydium cupressinum* seedlings from the centre of the plot.

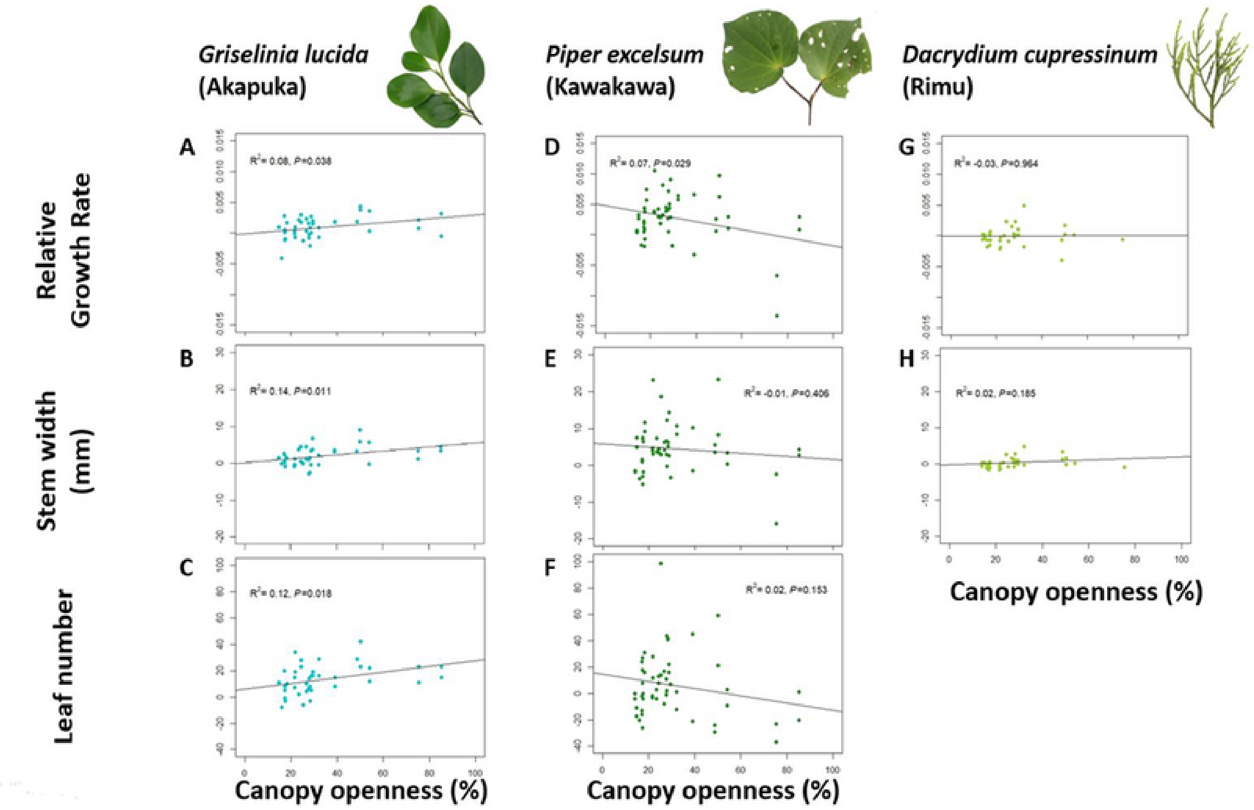


Figure 11. The relationship between canopy openness on the x-axis and enrichment plant growth variables (relative growth rate, stem width, leaf number) on the y-axis for each of the three species, *Griselinia lucida* (A-C, sample size = 53), *Piper excelsum* (D-F, sample size = 50) and *Dacrydium cupressinum* (G & H, sample size = 48) (linear regressions are shown). Each point represents an individual enrichment plant, excluding dead or missing individuals. *Dacrydium cupressinum* leaf number was purposely not measured, because the leaves were too small. Statistical significance codes: '***' <0.001, '**' <0.01, '*' <0.05, '.' <0.1, ' ' >1. (Figure from our research output: Hall 2020).

not surprising, as late-successional understorey shrub species, like *P. excelsum*, are often shade tolerant with growth increasing outside of high light environments. This likely comes as a trade-off to take advantage of sheltered understorey conditions, as *P. excelsum* is frost tender. *Dacrydium cupressinum* (Rimu) growth rate is not affected by the canopy openness at all (Fig. 11G).

If we look at another growth metric, the change in stem width, *G. lucida's* stems grow wider is under greater canopy openness (Fig. 11B), whereas the change in stem width of *P. excelsum* and *D. cupressinum* is not affected by the canopy openness at all (Fig. 11E, Fig. 11H). Finally, when measuring the number of leaves, *G. lucida* has more leaves under a more open canopy (Fig. 11C) whereas the number of leaves of *P. excelsum* is not affected by the canopy openness at all (Fig. 11F) (and we did not count the tiny *D. cupressinum* leaves). Therefore, we can conclude that different guilds of late-successional species respond very differently to understorey conditions created by forest canopy development.

These findings indicate it is important to conduct enrichment planting of late-successional species during forest development with particular regard to those individual species' environmental condition requirements. Awareness of different requirements of different plant groups (e.g., epiphyte, shrub, tree) can be helpful, as well as recognition that juvenile plants are generally less tolerant to extremes than adults.

For the epiphyte *Griselinia lucida* (Aka puka) the primary driver of growth is light. Secondarily, the stable microclimate conditions (e.g., temperature and humidity) created by canopy presence are likely to be necessary for it, as long as the plant receives adequate light. Thus, *G. lucida* should be "planted", or attached to host trees at high positions in their crowns to get adequate light, hence requiring planted

Key Drivers


Kawakawa-humidity


Rimu-stable temp


Akapuka-light

forest age to be high before planting can occur, at least several decades old.

For *Piper excelsum* (Kawakawa) the primary driver for growth is high humidity. Regions of Aotearoa New Zealand with higher mean humidity levels will provide better results in *P. excelsum* growth than drier areas, but microclimate within each forest should also be considered as a humid microclimate is possible to create even in a dry region. Planting under a closed canopy that causes humid understorey conditions could also increase leaf growth and plant survival. Additionally, when planting culturally significant taonga species like *P. excelsum*, it is important to consider cultural implications in restoration practice.

For *Dacrydium cupressinum* (Rimu) the primary driver of plant height growth is higher air temperatures with less fluctuation. Thus, ideal planting conditions are present in older restored forests with closed canopies. These closed canopies will also limit light reaching the forest floor, reducing the introduced herbaceous weed competition and creating a microclimate that buffers the temperature fluctuations. However, *D. cupressinum* needs management so it is present under a small canopy gap in order to become a tall emergent. Furthermore, areas with a warmer mean air temperature will likely cause more rapid responses in *D. cupressinum* plant height growth. To overcome competition from shade-tolerant introduced herbaceous weed weeds (e.g., *Tradescantia fluminensis*, wandering willie), it is best to plant taller enrichment juveniles. Taller plants will also be more resilient to any harsh environmental conditions.

In another part of our research on successional species we found present in our plots, we found that the species

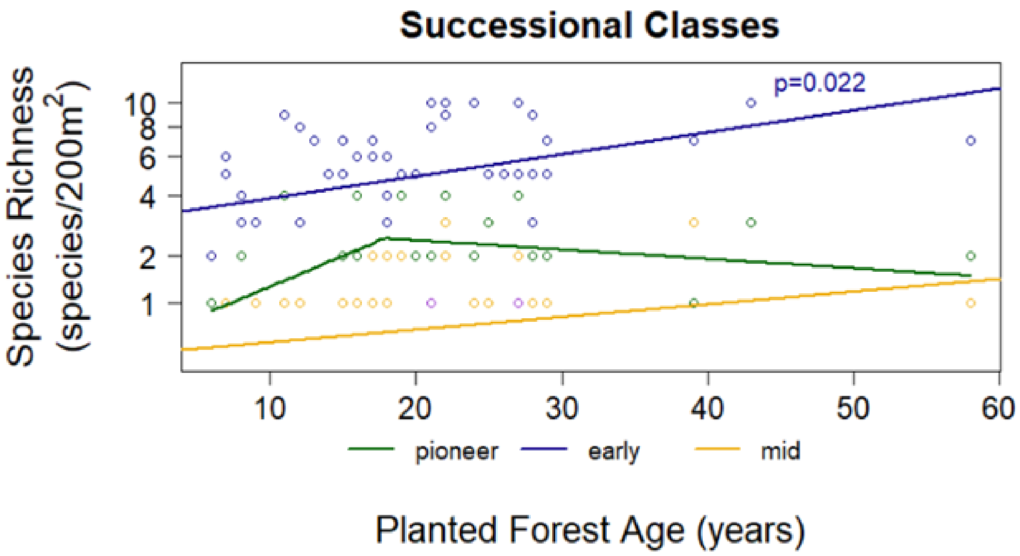


Figure 12. Changes in canopy tree species traits across a planted forest chronosequence (linear regression models shown). We can see changes in species richness within successional classes. Purple points within the successional class plot represent late successional species which a linear model would not fit to due to a lack of data points. (Figure from our research output: de Silva 2019)

richness in woody plant successional classes differed depending on forest age (Fig. 12). These data were from a special analysis of the south island urban forest plots from research aim 1 that classed pioneer species as the first to arrive after disturbance, followed by early successional and mid successional species. These results showed that as forests develop after planting pioneer species richness (number of species) reach a peak and then drop. Early successional species tend to continue growing in numbers over the first 60 years, and so do mid successional species, although these do not start appearing much until about 15 years after first plantings.

In summary, this research demonstrates the importance of understanding late-successional plant species' environmental needs in order to conduct successful enrichment planting in urban forest restoration. Introducing late-successional plants into urban forests benefits all urban-dwellers through the manifold ecosystem services they provide. However, to be successful in the restoration of these species, careful urban forest restoration planning must include knowledge about their requirements to increase their chances of survival and growth.

KEY FINDINGS – ENRICHMENT

1

Not all late successional species can be introduced via enrichment planting under the same forest conditions.

2

Enrichment planting of late-successional species should be done with individual species' environmental condition requirements in mind.

3

As forests develop after pioneer plantings, species richness (number of species) reaches a peak and then drops.

Recommendations

Implications for best-practice urban forest restoration:

- When establishing newly-planted urban forests, practitioners should **prioritise fast canopy closure and reduction of herbaceous weed species** as early as possible to encourage regeneration of native woody seedlings of all successional statuses.
- Dense initial planting is an effective strategy to help fast track canopy closure, but to later recruit planted late-successional saplings to the canopy, **small light gaps** may need to be created (after 20-30 years if they have not self-thinned already).
- **Enrichment planting** of mid-late successional species should be an important part of all urban restoration projects, but is absolutely vital in small planted forest patches to ensure successional progression, as very young juvenile seedlings in this successional category cannot grow there.
- Enrichment planting **timing and strategy depends on the requirements of the species** being planted.
- Juvenile trees and shrubs used in **enrichment planting should be >100cm** tall to maximise their chances of survival, since they get tougher as they get older.
- Restoration project monitoring should include **measures of plant regeneration** processes as indicators of success.
- All restoration projects should include **formal restoration plans** with clearly defined objectives that extend beyond establishing an initial canopy.
- **Ongoing monitoring** of plantings is crucial to ensure projects are progressing towards objectives, and to inform adaptive management.
- **Stakeholder engagement** from the outset is important to avoid setbacks and secure long-term project support.

What does this mean for building forests in cities?

Using scientific underpinnings to inform forest planting and restoration to completion can reduce resource use and maximise success. We also encourage land managers and restoration practitioners to look beyond the purely ecological elements of their work and consider the wider strategy the project sits within, especially engagement with people. After all, in the urban context, the stakeholders and community surrounding a bit of land being planted can make or break a project in the long term, so building the right relationships is worth every bit of investment.

Restoration Plan
STEPS

1

Engage with all relevant partners

Examples:

local government, iwi, community groups, businesses

2

Define restoration goals

Examples:

target ecosystem, weed removal, ecological functions

3

Build landscape-scale vision

Examples:

Understand connectivity with neighbouring ecosystems

4

Form long-term timeline

Examples:

For a forest this should be decade to century length

5

Create accurately scaled project budget

Examples:

Plant, labour and administration costs

6

Acquire funding

Examples:

Granting agencies, local government, donations

7

Form science-based restoration methods

Examples:

planting density, large-enough plants, timely enrichment

8

Perform restoration actions with partners

Examples:

Conduct plantings /follow-up care with partners present

9

Monitor outcomes to gauge success

Examples:

Annual monitoring of plant survival, photo points, quantitative

10

Adapt methods moving forward

Examples:

Change species mix based on survival monitoring results

References

Alberti M. 2005. The effects of urban patterns on ecosystem function. International Regional Science Review. 28(2):168-192.

Aronson MFJ, La Sorte FA, Nilon CH, Katti M, Goddard MA, Lepczyk CA, Warren PS, Williams NSG, Cilliers S, Clarkson B et al. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proceedings of the Royal Society B: Biological Sciences. 281(1780):20133330.

Brown G, Schebella MF, Weber D. 2014. Using participatory GIS to measure physical activity and urban park benefits. Landscape and Urban Planning. 121:34-44.

Bazzaz, F. (1979). The physiological ecology of plant succession. Annual Review of Ecology and Systematics, 10(1), 351-371.

Clarkson BD, Wehi PM, Brabyn LK. 2007. A spatial analysis of indigenous cover patterns and implications for ecological restoration in urban centres, New Zealand. Urban Ecosystems. 10(4):441-457.

Clarkson BD, Kirby CL. 2016. Ecological restoration in urban environments in New Zealand. Ecological Management & Restoration. 17(3):180-190.

Connell, J. H., & Slatyer, R. O. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. The American Naturalist, 111(982), 1119-1144.

Dobbs C, Escobedo FJ, Zipperer WC. 2011. A framework for developing urban forest ecosystem services and goods indicators. Landscape and Urban Planning. 99(3–4):196-206.

Dornelas, M., Magurran, A. E., Buckland, S. T., Chao, A., Chazdon, R. L., Colwell, R. K., … Vellend, M. (2013). Quantifying temporal change in biodiversity: Challenges and opportunities. Proceedings of the Royal Society B: Biological Sciences, 280(1750). https://doi.org/10.1098/rspb.2012.1931

Doroski DA, Felson AJ, Bradford MA, Ashton PM, Oldfield EE, Hallett RA, Kuebbing SE. 2017. Factors driving natural regeneration beneath a planted urban forest. Urban Forestry & Urban Greening. 29:238-247.
Drinnan IN. 2005. The search for fragmentation thresholds in a Southern Sydney Suburb. Biological Conservation. 124:339-349.

Endreny T, Santagata R, Perna A, Stefano CD, Rallo RF, Ulgiati S. 2017. Implementing and managing urban forests: A much needed conservation strategy to increase ecosystem services and urban wellbeing. Ecological Modelling. 360:328-335.

Groffman PM, Cadenasso ML, Cavender-Bares J, Childers DL, Grimm NB, Grove JM, Hobbie SE, Hutyra LR, Darrel Jenerette G, McPhearson T et al. 2016. Moving Towards a New Urban Systems Science. Ecosystems.1-6.

La Sorte FA, Aronson MF, Williams NS, Celesti-Grapow L, Cilliers S, Clarkson BD, Dolan RW, Hipp A, Klotz S, Kühn I. 2014. Beta diversity of urban floras among European and non-European cities. Global ecology and biogeography. 23(7):769-779.

Miller BP, Sinclair EA, Menz MHM, Elliott CP, Bunn E, Commander LE, Dalziell E, David E, Davis B, Erickson TE et al. 2016. A framework for the practical science necessary to restore sustainable, resilient, and biodiverse ecosystems. Restoration Ecology. 25(4):605-617.

Oldfield EE, Felson AJ, Auyeung DSN, Crowther TW, Sonti NF, Harada Y, Maynard DS, Sokol NW, Ashton MS, Warren RJ et al. 2015. Growing the urban forest: tree performance in response to biotic and abiotic land management. Restoration Ecology. 23(5):707-718.

Overdyck E, Clarkson BD, Laughlin DC, Gemmill CEC. 2013. Testing broadcast seeding methods to restore urban forests in the presence of seed predators. Restoration Ecology. 21(6):763-769.

Ruiz-Jaén MC, Aide TM. 2006. An integrated approach for measuring urban forest restoration success. Urban forestry & urban greening. 4(2):55-68.
Samuel CZ, Jason S, Aditya S, Christopher JK, Philip AT, Steven PL, II. 2016. Urban heat island impacts on plant phenology: intra-urban variability and response to land cover. Environmental Research Letters. 11(5):054023.

Suganuma, M. S., & Durigan, G. (2015). Indicators of restoration success in riparian tropical forests using multiple reference ecosystems. Restoration Ecology, 23(3), 238-251.

The World Bank 2014. In: United Nations Population Division WUP, editor.

Threlfall CG, Williams NSG, Hahs AK, Livesley SJ. 2016. Approaches to urban vegetation management and the impacts on urban bird and bat assemblages. Landscape and Urban Planning. 153:28-39.

Trammell TLE, Ralston HA, Scroggins SA, Carreiro MM. 2012. Foliar production and decomposition rates in urban forests invaded by the exotic invasive shrub, Lonicera maackii. Biological Invasions. 14(3):529-545.

Wallace KJ, Laughlin DC, Clarkson BD. 2017. Exotic weeds and fluctuating microclimate can constrain native plant regeneration in urban forest restoration. Ecological Applications. 27(4):1268-1279.

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