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RESEARCH

Vegetation assessment of an urban restoration at Styx Mill Conservation Reserve, Christchurch, Aotearoa New Zealand

Emma J. Walters[1], Mark Bloomberg[1] and Sarah V. Wyse[1]*

[1] Te Kura Ngahere | School of Forestry, University of Canterbury
*Author for correspondence: (Email: sarah.wyse@canterbury.ac.nz)

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Abstract: Human impacts in Aotearoa New Zealand have considerably damaged native ecosystems, and conservation efforts must therefore preserve remaining ecosystems and restore degraded areas. However, restoration efforts must address several challenges including species authenticity, plant survival and seedling regeneration in the presence of exotic competition, browsing mammals, and vagaries of climate. Styx Mill Conservation Reserve (SMCR), Christchurch, contains a remnant freshwater wetland in a floodplain complex where restoration activities were initiated in 2000 under a 40-year plan. This study assesses the restoration progress at SMCR in the face of challenges such as invasive exotic plant competition and defining ecological integrity. Thirty-three vegetation plots were sampled across the reserve and hierarchical cluster analysis was used to define vegetation communities. Species composition of these communities was compared against species lists representing the putative historical plant associations of the Christchurch area to assess ecological integrity of the restoration. Three vegetation communities were identified at SMCR based on vascular species composition: low forest, marshland/low shrubland, and high grassland. The low forest (restoration) community was the most distinct and was the only community in which species regarded as native to SMCR dominated plant diversity and biomass. This community was characterised by planted trees and shrubs. Seedling regeneration of native woody plants including *Coprosma robusta*, *Griselinia littoralis*, *Pittosporum tenuifolium*, and *Plagianthus regius* was occurring in the low forest plots. Native herbaceous species *Carex secta* and *Phormium tenax* were the dominant species across the marshland/low shrubland plots, although taller species such as *Cordyline australis* occurred in some plots. The high grassland community was dominated by exotic grasses and forbs. Restoration at SMCR is still in the early stages, with abundant exotic plant species present, limited seedling regeneration, and enrichment planting still to be undertaken. The high grassland and marshland/low shrubland sites will require further management attention.

Keywords: ecological integrity, ecosystem restoration, ordination, vegetation analysis

Introduction

Human activity in Aotearoa New Zealand (NZ) has resulted in significant declines in native biodiversity, including the loss of approximately 90% of lowland wetlands through land conversion or fragmentation (Finlayson & Moser 1991). Efforts to avert further biodiversity decline have focused on preserving the remaining native species in remnant habitats and active restoration. However, due to the dominance of urban and productive landscapes in lowland areas, conservation of lowland ecosystems is often lacking (Ewers et al. 2006). Restoration and conservation of lowland ecosystems has, therefore, predominantly centred on public land primarily managed by the Department of Conservation (DOC) on offshore islands and the mainland. However, there is a recent recognition that the focus of conservation must also include restoration of productive landscapes and degraded urban remnant ecosystem fragments, as these areas are important reservoirs of many of NZ's remaining native species (Saunders & Norton 2001; Towns et al. 2019).

Restoration projects, particularly urban restoration projects, face several challenges, including ensuring that ecological integrity is achieved by the restoration regime, and the ongoing management of exotic species. Urban restoration projects often occur in relatively small remnant patches, which are at high risk of invasions of exotic plants and animals from the surrounding urban environment (Clarkson et al. 2007; Stow et al. 2015). Pest animals can impact restoration progress through herbivory of planted or naturally establishing seedlings, reductions in seed set or dispersal through predation of pollinators and seed dispersers, and through seed predation (Allen & Lee 2006; Elgar et al. 2014), while pest plants can compete with planted individuals for resources and inhibit regeneration. Controlling pest species is therefore a common goal in many urban restoration projects and requires continued attention even after establishment of native plantings (Saunders & Norton 2001). For ecological restoration to be successful, management must be adaptable and aware of the pest species

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hindering restoration efforts. Even after successful restoration, reversion to a degraded state can occur if invasive species control is stopped. Therefore, commitment to ongoing pest control is critical to success (Norton 2009).

The survival of plants in restoration projects is critical to ensure progress towards successful restoration occurs; however, plant survival rates are often unmonitored in restoration projects (Sullivan et al. 2009). The time taken for canopy closure may be reduced by choosing to plant with container-grown seedlings instead of direct seeding or assisted natural regeneration (Porteous 1993). However, using container-grown stock can result in the seedlings experiencing transplant shock, potentially resulting in a high mortality rate (Burdett 1990; Anton et al. 2015). Successful establishment of seedlings is highly species- and site-specific, but the mortality rate of seedlings generally decreases over the first two years following planting, after which the chance of plant survival is relatively high (Ledgard & Henley 2009). Therefore, there is an opportunity to combat the problem of seedling mortality with a labour and resource-intensive pest control regime for a relatively short period after planting (Douglas et al. 2007). Reducing time to canopy closure in turn reduces the impact of smothering ground weeds, which are usually light-demanding species, thus allowing for the regeneration of native species (Sullivan et al. 2009).

Restoration projects become almost impossible without seedling regeneration since expensive and ongoing active plantings are the only alternative (Elgar et al. 2014). Removing domestic livestock from the restoration area is always a beneficial step in achieving seedling regeneration. However, this will not be sufficient to promote regeneration of desirable plant species if plants unpalatable to livestock dominate the site, local seed sources have become extinct, shifts in ecosystem processes have occurred, or if feral mammalian herbivores are still present in the reserve (Coomes et al. 2003; Norton et al. 2018). Many exotic species within restoration sites have redirected successional processes so native seedling regeneration does not occur (McQueen et al. 2006). In extensively degraded areas, natural seed sources are often absent, meaning that seedling regeneration cannot occur even if all other conditions are ideal (Norton et al. 2018). There can also be a legacy effect of exotic species on belowground communities that can have ongoing effects on plant species composition (Dickie et al. 2014).

Finally, the issue of ecological integrity is a key concern for any restoration project. Ecological integrity (see also “ecological authenticity”; Dudley 1996) can be measured by the extent to which an ecosystem reflects the naturally occurring ecosystem’s composition and functioning, and can be used as a standard when measuring the conservation value of disturbed areas (Dudley 1996; McGlone et al. 2020). At small spatial scales, the requirements for ecological integrity are a functional ecosystem and communities that are dominated by species indigenous to the region, while at larger spatial scales the absence of key species becomes of increasing concern (McGlone et al. 2020). The purpose of defining a standard of integrity is to identify the characteristics of a functioning ecosystem of a certain area, not to create a theoretically perfect forest (Xia et al. 2021). Many early active restoration projects in NZ simply focussed on planting species native to NZ as a whole, with little consideration for the native distributions of species within NZ. In some cases, these actions led to native plants that have acted invasively outside their natural range and hybridisations with local congeners (Butt 2017). The current standard approach is to only source plant material locally (ecosourcing) to eliminate these issues, ensure local adaptations are maintained, and facilitate the formation of ecologically authentic reserves. To define ecological integrity for a particular forest, it is important to have information about the original ecosystem. Methods to determine the standard for integrity include using ecological studies on surviving natural forests, determining past vegetation patterns using historical data and palaeoecological information, and using ecological theory to estimate any remaining unknowns (Dudley 1996; Lucas et al. 1997).

Styx Mill Conservation Reserve (SMCR) is a 60 ha Metropolitan Regional Park managed by Christchurch City Council (CCC) located in the suburb of Northwood, 10 km north of the City of Christchurch (Styx Living Laboratory Trust 2023). The reserve is a remnant freshwater wetland that follows the natural corridor of the Pūharakekenui Styx River and is widely used for recreation (McCoombs 2003). Located on poorly drained Te Kakahi soils (McCombs 2002), SMCR was once a diverse wetland habitat that had high importance to Māori for resources such as food, materials, and medicine (Christchurch City Council 1993).

In recent years, significant efforts have been made to restore SMCR to its pre-European state as it contains high ecological values (Christchurch City Council 2003). These efforts include native plantings and invasive species control run by Pūharakekenui Styx Living Laboratory Trust (SLLT) and the CCC. In 2000, a 40-year vision document for the Styx was developed to detail the steps to restore SMCR (Christchurch City Council 2003). Halfway through this 40-year period, it is now opportune to analyse the progress of the restoration efforts. This research therefore assesses the ecosystem restoration at SMCR by: (1) understanding how plant species composition varies spatially and temporally across the reserve, (2) assessing the ecological integrity of the restoration efforts being undertaken by determining whether the plant communities present are representative of the historic ecosystem of this area, and (3) identifying whether, and where, natural regeneration is occurring.

Methods

Sampling Method

Eight transects were systematically laid c. 100–200 m apart over a map of SMCR (Fig. 1). The transects were placed north to south, and any large bodies of water were not included. Thirty-three plots were located along the transects, with a minimum of 20 m distance between plot centres. We used a stratified random approach to locate plots along the transects, which ensured representation of vegetation types and avoided footpaths, waterways, and wetlands that were too deep and unsafe to enter. Plots and transects were located using a Garmin eTrex10 global positioning system unit. Vegetation communities were assessed at each plot using the reconnaissance (RECCE) method, with a variable area approach (Hurst & Allen 2007). Plots were square, with size determined according to the structure of the vegetation and ranging from 1.5×1.5 m^2 for turf communities to 20×20 m^2 for high forest (Table 1). The standard RECCE height tiers were used for sites where vegetative cover is predominantly non-woody, with the addition of Tier 2 as necessary in the forested plots (Tier 1 = > 25m, 2 = 12–25 m, 3 = 5–12 m, 4 = 2–5 m, 5A = 1–2 m, 5B = 0.3–1 m, 6A = 0.1–0.3 m,

Figure 1. location of the transects and vegetation plots at Styx Mill Conservation Reserve. The red-shaded area (actively grazed farmland) and open water or deep wetlands were excluded.

Table 1. Criteria for determining plot dimensions for Styx Mill Conservation Reserve vegetation sampling.

Vegetation	Vegetation Description	Plot area (m^2)	Plot side length (m)
Turf	Cut and maintained grass.	2.25	1.5
Low grassland	Only grasses, non-vascular plants, or weeds are present in the plot.	20.25	4.5
High grassland	Most of the plot is grassland, with minimal trees/shrubs that appear to have been planted recently. There is no overhead canopy cover. Trees/shrubs do not exceed breast height.	49	7.0
Low shrubland	Young trees (saplings/poles) or shrubs that are still clearly planted, open canopy, ground covered in grass. The average canopy height does not exceed 2 m. Although grass is present, the tree species dominate the plot marginally.	81	9.0
High shrubland	Young trees (saplings/poles) or shrubs with canopy height below 5 m, open canopy with grass still present on the ground, or canopy could be closed but not tall enough to stand under.	144	12.0
Low forest	Forest with a closed canopy, open underneath the canopy. Canopy height below 12 m.	196	14.0
High forest	Mature forest with a closed canopy, open underneath canopy. Canopy height above 12 m.	400	20.0

6B = < 0.1 m). The standard cover weights were used for all plant species within the RECCE plot (1 = < 1%, 2 = 1–5%, 3 = 6–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–100%). Any native seedling regeneration present was recorded by species and number of seedlings.

Ecological integrity standard for Styx Mill Conservation Reserve

The Ōtautahi Christchurch Ecosystems Map (Lucas et al. 1997; Lucas Associates 2021) was used as a standard to assess the ecological integrity of the SMCR restoration. This interactive map shows the native ecosystems and native species occurring in Christchurch and adjoining rural land. The ecosystems are physical-biological units composed of landforms/soils, naturally or potentially dominant plant species, and wildlife habitat. The land surfaces of Christchurch were mapped by their approximate age, soil development, and drainage. The natural mature vegetation and component species for each unit was reconstructed by comparison with surviving remnant forests and historic accounts.

Styx Mill Conservation Reserve is primarily composed of the Te Kakahi Complex ecosystem, aside from a northern strip across the top of the reserve in the Houhere ecosystem (Lucas Associates, 2021). Te Kakahi Complex is a mixture of soils primarily from the wet Kahikatea ecosystem interwoven with the Tī Kōuka and Tussock ecosystems of dry and stony riverbed sites. Te Kakahi Complex is thus composed of three plant lists. These are wet plains: Kahikatea (selected from vegetation natural to wet Tai Tapu soils); dry plains: Tussock (selected from vegetation natural to droughty and shallow Selwyn soils); and dry plains: Tī Kōuka (selected from vegetation natural to droughty and shallow Waimakariri soils). The Houhere ecosystem comprises one plant list, dry plains: Houhere (selected from vegetation natural to moist deep Waimakariri soils).

Statistical analyses

As a proxy for species' relative biomass in each plot, we calculated an importance value (IV_i) for every species (i) present by multiplying cover abundance scores (c_{ij}) with the corresponding tier multiplier (t_j) and summing across height tiers (j) (Equation 1), following Burns and Leathwick (1996). Cover weights were the mid-point of the cover class range, while tier weights were the upper limit of the tier height range. These importance values were then re-scaled by taking their log (base 10) for subsequent analyses.

$$IV_i = \sum_{j=1}^{7}(t_j \times c_{ij}) \quad (1)$$

A dissimilarity matrix for the species composition of the sampled plots was calculated using the Bray-Curtis dissimilarity measure. Using this dissimilarity matrix, we performed a hierarchical cluster analysis to classify the plots into discrete vegetation communities using Ward's minimum variance method. We ordinated and visualised the plot data using non-metric multi-dimensional scaling (nMDS) using the *metaMDS* function in the vegan library (Oksanen et al. 2022) using R version 4.2.2 (R Core Team 2022). Environmental vectors were fitted on the ordination using the *envfit* function in the vegan library to examine the relationships between the ordination and the variables canopy height, species diversity, exotic species diversity, planting age, and drainage. Soil drainage was visually assessed at the time of sampling following the RECCE protocol using the categories good (fast runoff and little accumulation of water after rain), moderate (slow runoff, water accumulation in hollows for several days following rain), and poor (water stands for extended periods). These classifications were converted to numeric ordinal categories from one to three, where one represented good drainage, and three represented poor drainage.

We assessed the ecological integrity of the different vegetation communities by using analysis of variance (ANOVA) to compare the contributions of species of different provenances to the total species diversity and the summed importance values per plot (i.e. contribution to plot biomass). Species provenance was defined according to species status as either exotic to NZ, present on the plant species lists for the communities historically present in the SMCR area according to the Ōtautahi Christchurch Ecosystems Map (i.e. native to SMCR), or absent from these lists but native to NZ. For both variables (contribution to plot diversity and contribution to plot summed importance value) we used two-way ANOVA with an interaction term between the variables vegetation community and species status (provenance). Post-hoc pairwise comparisons were undertaken by computing least-squares means using the emmeans library (Lenth 2023).

Results

Characterisation of vegetation communities at SMCR

The hierarchical cluster analysis identified three distinct vegetation communities across the 33 plots from SMCR: low forest, high grassland, and marshland/low shrubland (Fig. 2). The nMDS ordination for the site showed clear separation of these communities, suggesting they were each compositionally distinct, with the closest similarity between the high grassland and marshland/low shrubland plots (Figs 2 and 3).

The diversity of species within each plot, canopy height, plant age, canopy cover, and soil drainage index were all significantly correlated with the ordination ($P < 0.05$), with exotic species diversity marginally correlated with the ordination ($P = 0.052$; Fig. 3). The low forest plots had higher species diversity, greater canopy cover and height, and were older plantings, with planting age and canopy cover the variables most strongly correlated with the ordination ($r^2 = 0.847$ and 0.742, respectively). The marshland/low shrubland plots had the poorest drainage ($r^2 = 0.670$), while high grassland plots (Fig. 3) showed a weak correlation ($r^2 = 0.169$; $P = 0.052$) with higher exotic species diversity.

The low forest vegetation community was characterised by trees and shrubs native to the Styx Mill Conservation Reserve area including (in order of dominance) *Cordyline australis*

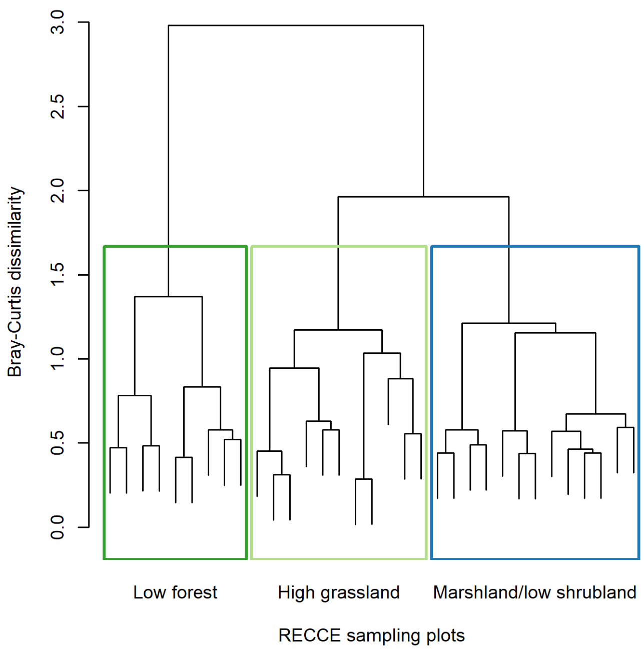

Figure 2. Hierarchical cluster analysis of the vegetation plots at Styx Mill Conservation Reserve, indicating three distinct vegetation communities.

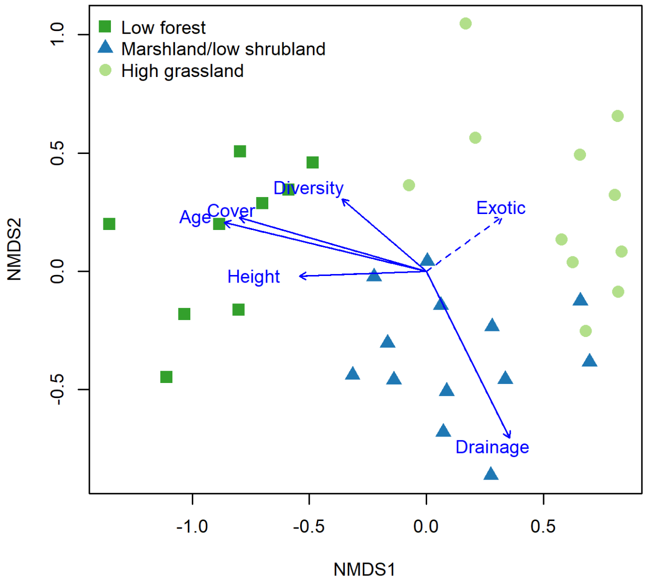

Figure 3. nMDS ordination for the vegetation plots at Styx Mill Conservation Reserve, with points coded according to the vegetation communities identified by the cluster analysis. Arrows indicate vector fits for variables significantly correlated with the ordination ($P < 0.05$; solid lines) or marginally significantly correlated with the ordination ($P = 0.063$; dashed line). Note that the drainage vector points towards increasingly poorly drained sites.

(Fig. 4b), *Plagianthus regius*, *Pittosporum tenuifolium* (Fig. 4e), *Coprosma robusta*, *Griselinia littoralis*, *Pittosporum eugenioides*, and *Podocarpus totara*. The large (up to 5 m tall) liliaceous perennial tussock, *Phormium tenax*, was also common in many of the low forest plots (Fig. 4d), while exotic species, including *Rubus fruticosus* and *Salix fragilis*, were also abundant. The plots comprising the low forest vegetation community were all approximately 23 years since the initial planting, and their average top height ranged from 3–12 m (mean = 7.2 m).

The high grassland vegetation community was dominated by exotic grasses and herbs, including (in order of dominance): *Anthoxanthum odoratum*, *Holcus lanatus*, *Lotus pedunculatus* (Fig. 4c), *Achillea millefolium*, *Ranunculus repens*, *Agrostis capillaris*, *Phleum pratense*, and *Plantago lanceolata* (Fig. 4f). *Phormium tenax* (Fig. 4d) and the native rush *Juncus edgariae* dominated some plots, but there was an absence of native trees like *C. australis* (Fig. 4b) and *P. tenuifolium* (Fig. 4e). The high grassland plots ranged from 0–6 years since restoration planting (mean = 1.7 years), and average top height ranged from 1–3 m.

Native tall tussocks *Carex secta* (Fig. 4a) and *P. tenax* (Fig. 4d) were the species with the highest importance values across the marshland/low shrubland plots. Exotic forbs *L. pedunculatus* (Fig. 4c), *Erytranthe guttata*, and *R. repens* were also common features. Of the native trees and shrubs, *C. australis* occurred in approximately half of the plots

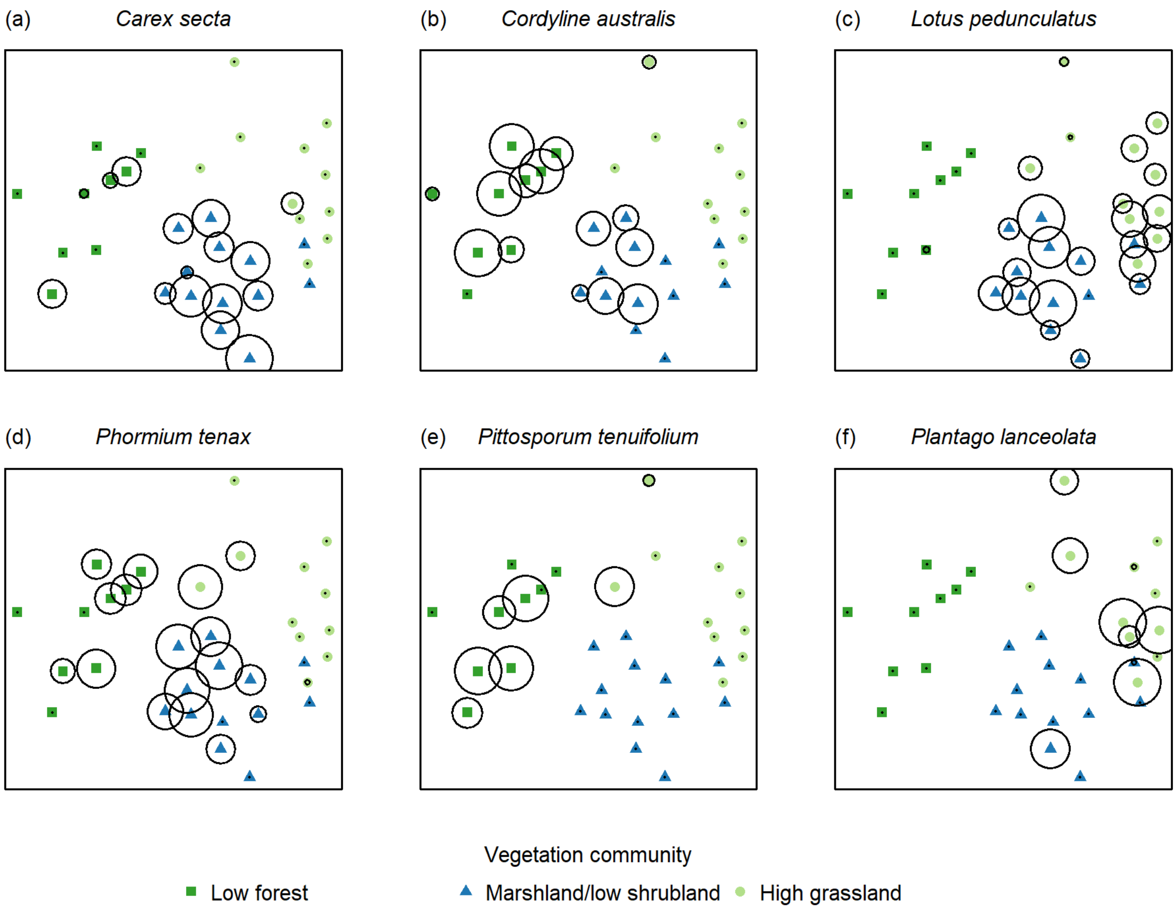

Figure 4. nMDS ordinations for six selected species in the vegetation plots at Styx Mill Conservation Reserve, with points coded according to the vegetation communities identified by the cluster analysis. Black circles indicate the plots where each of the six selected species was present, with circle size proportional to the species importance values per plot.

(Fig. 4b), while *Dacrycarpus dacrydioides* and *C. robusta* were present in five and three of the 13 plots, respectively. The marshland/low shrubland plots ranged from 1–13 years following restoration planting (mean = 4.8 years) and varied considerably in their average top height with a range of 1–20 m (mean = 4.5 m). The only species that occurred in a height tier above 12 m in these plots was *S. fragilis*, and native species typically occurred in Tier 4 (2–5 m) or below. The exception was a single plot where *D. dacrydioides*, *C. australis*, and *C. robusta* occurred in the 5–12 m height tier (Tier 3).

A total of 115 plant species were recorded across the 33 sampling plots, of which 31% were native to the area of SMCR, 16% were native to NZ but not SMCR, and 53% were exotic (Table 2). The composition of the species diversity per plot differed significantly among the three vegetation communities (Fig. 5a), with an ANOVA indicating a significant interaction between species' provenance and vegetation community ($P < 0.0001$). Exotic species were significantly more prevalent in the marshland/low shrubland and high grassland communities than in the low forest community, which had a significantly

Table 2. Plant species identified at Styx Mill Conservation Reserve and their status as either exotic to Aotearoa New Zealand (exotic), native to Styx Mill Conservation Reserve (Native-Styx), or native to Aotearoa New Zealand but not Styx Mill Conservation Reserve (Native-NZ). Plants native to Styx Mill Conservation Reserve were determined using the Ōtautahi Christchurch Ecosystems Map plant species lists.

Scientific name	Common name	Species code	Status
Achillea millefolium	Common yarrow	ACHMIL	Exotic
Agrostis capillaris	Colonial bent	AGRCAP	Exotic
Alnus cordata	Italian alder	ALNCOR	Exotic
Alnus glutinosa	Common alder	ALNGLU	Exotic
Anemanthele lessoniana	Gossamer grass	ANELES	Native-Styx
Anthoxanthum odoratum	Sweet vernal grass	ANTODO	Exotic
Aristotelia serrata	Makomako/wineberry	ARISER	Native-Styx
Arrhenatherum elatius	Tall oat grass	ARRELA	Exotic
Austroderia richardii	Toetoe	AUSRIC	Native-Styx
Betula pendula	Silver birch	BETPEN	Exotic
Blechnum minus	Swamp kiokio	BLEMIN	Native-NZ
Bromus mollis	Soft brome	BROMOL	Exotic
Calystegia sylvatica	Large bindweed	CALSIL	Exotic
Calystegia tuguriorum	New Zealand bindweed	CALTUG	Native-Styx
Carex geminata	Rautahi/cutty grass	CARGEM	Native-NZ
Carex secta	Pukio	CARSEC	Native-Styx
Centaurium erythraea	Common centaury	CENERY	Exotic
Centella uniflora	Centella	CENUNI	Native-NZ
Cerastium fontanum	Mouse-ear chickweed	CERFON	Exotic
Chenopodium album	Common lambsquarters	CHEALB	Exotic
Cirsium arvense	Creeping thistle	CIRARV	Exotic
Cirsium vulgare	Bull thistle	CIRVUL	Exotic
Conium maculatum	Poison hemlock	CONMAC	Exotic
Coprosma crassifolia	Mikimiki	COPCRA	Native-Styx
Coprosma lucida	Shining karamū	COPLUC	Native-Styx
Coprosma propinqua	Mingimingi/mikimiki	COPPRO	Native-Styx
Coprosma robusta	Karamū	COPROB	Native-Styx
Cordyline australis	Tī kōuka/cabbage tree	CORAUS	Native-Styx
Corokia cotoneaster	Korokio	CORCOT	Native-Styx
Crepis capillaris	Smooth hawksbeard	CRECAP	Exotic
Cytisus scoparius	Scotch broom	CYTSCO	Exotic
Dacrycarpus dacrydioides	Kahikatea	DACDAC	Native-Styx
Dactylis glomerata	Cocksfoot/orchard grass	DACGLO	Exotic
Discaria toumatou	Matagouri/tumatakuru	DISTOU	Native-Styx
Dryopteris filix-mas	Male fern	DRYFIL	Exotic
Elaeocarpus hookerianus	Pōkākā	ELAHOO	Native-Styx
Epilobium billardiereanum	Smooth willowherb	EPIBIL	Native-NZ
Epilobium ciliatum	Fringed willowherb	EPICIL	Exotic
Epilobium pallidiflorum	Tarawera/swamp willowherb	EPIPAL	Native-NZ
Erigeron canadensis	Horseweed	ERICAN	Exotic
Erythranthe guttata	Seep monkeyflower	ERYGUT	Exotic
Ficinia nodosa	Knobby clubrush	FICNOD	Native-NZ
Galium palustre	Common marsh-bedstraw	GALPAL	Exotic
Gastrodia molloyi	Molloy's potato orchid	GASMOL	Native-NZ
Griselinia littoralis	Kāpuka/papauma/broadleaf	GRILIT	Native-Styx
Hedera helix	Common ivy	HEDHEL	Exotic
Hoheria angustifolia	Narrow-leaved houhere	HOHANG	Native-Styx
Holcus lanatus	Yorkshire fog	HOLLAN	Exotic
Hydrocotyle novae-zeelandiae	New Zealand waternavel	HYDNOV	Native-NZ
Hypochaeris radicata	Common cat's-ear	HYPRAD	Exotic

Table 2. Continued.

Scientific name	Common name	Species code	Status
Hypolepis ambigua	Common pig fern	HYPAMB	Native-Styx
Juncus edgariae	Wiwi	JUNEDG	Native-Styx
Juncus effusus	Soft rush	JUNEFF	Exotic
Juncus pallidus	Giant rush	JUNPAL	Native-NZ
Kunzea ericoides	Kānuka	KUNERI	Native-Styx
Lemna disperma	Common duckweed	LEMDIS	Native-NZ
Leptospermum scoparium	Mānuka	LEPSCO	Native-Styx
Lolium arundinaceum	Tall fescue	LOLARU	Exotic
Lophomyrtus obcordata	Rōhutu/NZ myrtle	LOPOBC	Native-Styx
Lotus pedunculatus	Greater bird's-foot-trefoil	LOTPED	Exotic
Machaerina rubiginosa	Common twig rush	MACRUB	Native-NZ
Malva neglecta	Dwarf mallow	MALNEG	Exotic
Malva parviflora	Cheeseweed mallow	MALPAR	Exotic
Marrubium vulgare	White horehound	MARVUL	Exotic
Mentha spicata	Spearmint	MENSPI	Exotic
Muehlenbeckia australis	Pōhuehue	MUEAUS	Native-NZ
Myoporum laetum	Ngaio	MYOLAE	Native-Styx
Myosotis arvensis	Field forget-me-not	MYOARV	Exotic
Myriophyllum propinquum	Water milfoil	MYRPRO	Native-NZ
Myrsine australis	Mapou	MYRAUS	Native-Styx
Nasturtium officinale	Watercress	NASOFF	Exotic
Olearia avicenniifolia	Mountain akeake	OLEAVI	Native-NZ
Olearia paniculata	Akiraho	OLEPAN	Native-Styx
Onopordum acanthium	Scotch thistle	ONOACA	Exotic
Ozothamnus leptophyllus	Tauhinu	OZOLEP	Native-Styx
Pennantia corymbosa	Kaikōmako	PENCOR	Native-Styx
Persicaria hydropiper	Waterpepper	PERHYD	Exotic
Phleum pratense	Timothy grass	PHLPRA	Exotic
Phormium tenax	Harakeke/flax	PHOTEN	Native-Styx
Pittosporum eugenioides	Tarata/lemonwood	PITEUG	Native-Styx
Pittosporum tenuifolium	Kōhūhū/black matipo	PITTEN	Native-Styx
Plagianthus regius	Mānatu/lowland Ribbonwood	PLAREG	Native-Styx
Plantago lanceolata	Ribwort plantain	PLALAN	Exotic
Plantago major	Greater plantain	PLAMAJ	Exotic
Podocarpus totara	Tōtara	PODTOT	Native-Styx
Prumnopitys taxifolia	Mataī	PRUTAX	Native-Styx
Prunella vulgaris	Common selfheal	PRUVUL	Exotic
Prunus lusitanica	Portuguese laurel	PRULUS	Exotic
Pseudopanax arboreus	Whauwhaupaku/five finger	PSEARB	Native-Styx
Pseudopanax crassifolius	Horoeka/lancewood	PSECRA	Native-Styx
Ranunculus repens	Creeping buttercup	RANREP	Exotic
Ranunculus sceleratus	Cursed crowfoot/celery-leaved buttercup	RANSCE	Exotic
Rubus fruticosus	European blackberry	RUBFRU	Exotic
Rubus idaeus	Red raspberry	RUBIDA	Exotic
Rumex acetosella	Sheep's sorrel	RUMACE	Exotic
Rumex conglomeratus	Clustered dock	RUMCON	Exotic
Rumex obtusifolius	Broad-leaved dock	RUMOBT	Exotic
Salix cinerea	Grey willow	SALCIN	Exotic
Salix fragilis	Crack willow	SALFRA	Exotic
Sambucus nigra	European black elderberry	SAMNIG	Exotic
Senecio glomeratus	Cutleaf burnweed	SENGLO	Native-NZ
Senecio minimus	Coastal burnweed	SENMIN	Native-NZ
Solanum chenopodioides	Tall nightshade	SOLCHE	Exotic
Solanum dulcamara	Bittersweet nightshade	SOLDUL	Exotic
Sophora microphylla	Kōwhai	SOPMIC	Native-Styx
Stellaria graminea	Lesser stitchwort	STEGRA	Exotic
Trifolium pratense	Red clover	TRIPRA	Exotic
Trifolium repens	White clover	TRIREP	Exotic
Typha orientalis	Raupō	TYPORI	Native-NZ
Ulex europaeus	Gorse	ULEEUR	Exotic
Urtica sykesii	Sykes's bush nettle	URTSYK	Native-NZ
Verbascum thapus	Great mullein	VERTHA	Exotic
Verbascum virgatum	Wand mullein	VERVIR	Exotic
Veronica anagallis-aquatica	Blue water-speedwell	VERANA	Exotic
Veronica salicifolia	Koromiko	VERSAL	Native-Styx

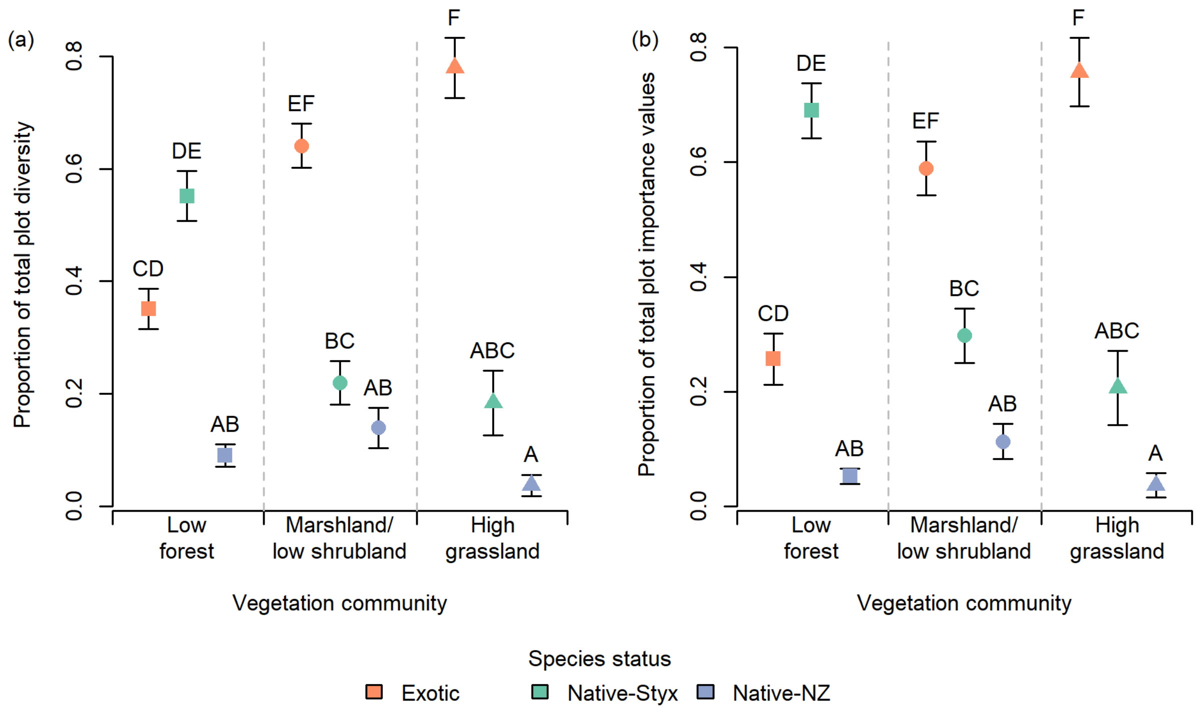

Figure 5. the mean proportion of (a) plot plant species diversity and (b) plot summed species importance values, made up of exotic plant species, plant species native to Styx Mill Conservation Reserve (Native-Styx), and plant species native to Aotearoa New Zealand but not SMCR (Native-NZ) for each vegetation community. Plants native to SMCR were determined using the Ōtautahi Christchurch Ecosystems Map plant species lists. Error bars represent the standard error of the mean. Capital letters above the data points signify statistically significant differences ($P < 0.05$).

higher proportion of species native to SMCR ($P < 0.05$). The proportion of plot diversity comprising species native to NZ but not SMCR did not differ significantly among communities ($P > 0.05$). The high grassland community had the highest proportion of exotic species (78 ± 5.4%) per plot, whereas the low forest plots had an average of 55 ± 4.4% species native to the SMCR area.

The pattern of summed importance values of species with respect to provenance and community type was similar to that for species diversity (Fig. 5b). An ANOVA indicated a significant interaction between species' provenance and vegetation community for this variable ($P < 0.0001$). The proportion of the summed importance values per plot comprising exotic species was significantly higher in the marshland/low shrubland and high grassland communities than in the low forest community ($P < 0.05$). The high grassland community had the highest mean proportion of exotic species by importance value of the three vegetation communities (76 ± 6.0%). The proportion of summed importance values comprising species native to SMCR was significantly higher in the low forest plots than in the marshland/low shrubland or high grassland habitats ($P < 0.05$). In the low forest plots, species native to SMCR dominated plant biomass, comprising a mean of 69 ± 4.8% of the proportion of summed importance values.

A total of seven woody species native to the SMCR area were found regenerating in the sampled plots (Fig. 6). Seedling regeneration was predominantly restricted to the low forest plots, with seedlings of at least one native woody species occurring in 78% of these plots. *Coprosma robusta* was the only native woody species found regenerating in the marshland/low shrubland plots, occurring in just a single plot, while no seedlings of native woody species were found in any of the high grassland plots. As of the time of the study, the high grassland plots were no longer being mown or grazed. Within the low forest plots, *C. robusta* and *G. littoralis* were the native woody species showing the most abundant regeneration (0.38 seedlings m^{-2} and 0.25 seedlings m^{-2} in the plots in which they occurred, respectively). Five of the seven native woody species found as seedlings in the plots sampled here were bird-dispersed.

Discussion

Characterisation of vegetation communities at SMCR

Differences in species composition across SMCR are expected due to variability in the underlying environmental characteristics of the site and interspecific niche differences (Ozinga et al. 2005; Sheth & Angert 2014). However, the pattern of variation in species composition between the three vegetation communities identified at SMCR is likely to primarily relate to the stage of the restoration. The high grassland community is in the earliest stage of restoration due to the high abundance of exotic species within these plots, such as *A. millefolium*, *H. lanatus*, *Dactylis glomerata*, and *L. pedunculatus*. Conversely, the low forest community is in the most mature stage of restoration within the reserve, having become dominated by forest canopy species such as *P. regius*, *P. tenuifolium*, *C. robusta*, and *G. littoralis*. Therefore, the high grassland communities require the most management intervention, including active planting and weed control, to expedite restoration. Conversely, the low forest communities will likely only need regular predator trapping and weed control to ensure that exotic species will not disrupt natural

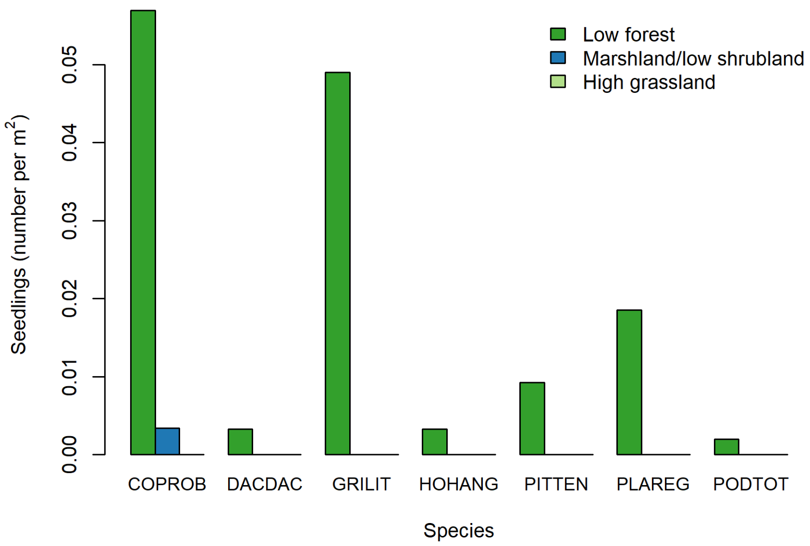

Figure 6: Number of seedlings of tree and shrub species native to the Styx Mill Conservation Reserve (SMCR) summed across all plots per vegetation community, proportional to the total plot area sampled for each vegetation community type. Species native to SMCR were determined according to the Ōtautahi Christchurch Ecosystems Map plant species lists. See Table 2 for the definition of species codes.

processes such as bird seed dispersal and seedling regeneration (Saunders & Norton 2001). Thus, with time, as succession or restoration occurs in the high grassland community, management requirements at SMCR should decline.

It can be assumed that as the planted seedlings in the high grassland and marshland/low shrubland communities increase in age and canopy cover these sites will become closer in composition to the low forest plots. The exotic species that dominate these plots are primarily light-demanding pasture species and herbaceous weeds, and thus increasing canopy cover should effectively control these species (Timmins & Williams 1991). However, exotic physiognomic dominants like *Salix* spp. will still require control. It is expected that the underlying gradients in soil drainage are and will become the primary factors influencing species composition. Urban edge effects are likely to create a decay gradient of exotic species from the urban source, but shade-tolerant and bird- or wind-dispersed species will continue to be problematic (Ozinga et al. 2005; Clarkson et al. 2007).

Comparison of plant communities to pre-European colonisation ecosystems

If the low forest vegetation community can be considered the vegetation state most representative of the likely trajectory the SMCR restoration will take, then the restoration is proceeding towards ecological integrity as species native to the SMCR area dominate the plots in terms of both species diversity and plant biomass. However, nearly one third of the mean summed importance values for the low forest plots still comprised exotic species, most of which were in the lower height tiers (with *R. fruticosus* the dominant exotic species) but with two plots containing *S. fragilis* in the upper tiers. Nine percent of the species recorded in these plots were native to NZ, but not the SMCR area. Further, the marshland/low shrubland and high grassland communities remain far from ecological integrity due to the high dominance of exotic species. Canopy closure as the restoration proceeds should improve this situation in the drier sites, but if the canopy remains open in the more poorly drained sites, then this exotic dominance could persist. To increase the ecological integrity of SMCR, management interventions should continue to aid in shifting the species composition of the marshland/low shrubland and high grassland communities towards that of the low forest community.

Although restoration projects in NZ often aim for a site to be restored to its natural pre-human state, this can sometimes be unachievable due to considerable alteration to the biotic and abiotic environments that have occurred since human arrival, leading to novel or recombinant ecosystems (Hobbs et al. 2009; Meurk 2011). Such a situation may be the case at SMCR due to the small size of the reserve and the proximity to urban surroundings that are an ongoing source of invasive flora and fauna (Norton et al. 2018; Towns et al. 2019). Being realistic about the state to which SMCR can be restored is important for setting appropriate restoration goals. For example, the 2000–2040 vision for SMCR aims to "restore a range of viable habitats that reflect the range of indigenous ecosystems in this area based on the underlying soils" (Christchurch City Council 2003). While this vision clearly frames success in terms of ecologically authentic plant communities, more specific goals against which success can be measured should be developed. Such goals may specify an acceptable and achievable low level of exotic flora within the communities.

Seedling regeneration

Seedling regeneration of native species deemed authentic was identified within eight plots at SMCR. This indicates that important ecosystem processes such as pollination and seed dispersal are occurring at the site (McQueen et al. 2006), while the environmental conditions within the low forest plots are suitable for the successful establishment of seedlings of these species. This finding also suggests that pests in SMCR are not completely disrupting seedling regeneration. However, that is not to say that seedling regeneration will not increase by eradicating the browsing pests in SMCR (Coomes et al. 2003; Allen & Lee 2006). Nonetheless, seedling regeneration was only identified in low forest plots, aside from one seedling being identified in a marshland/low shrubland plot. This may be due to lack of shade-forming taller plants that suppress competing exotic grasses. The presence of tall, fruit-producing plants such as *C. australis* in approximately half the marshland/low shrubland plots should aid in the dispersal of seeds of bird-dispersed native woody species into these areas, so it is likely that regeneration of native woody species in the high grassland and marshland/low shrubland communities is being disrupted by ground-covering weeds, which prevent the seedlings from establishing. Such species include *L. pedunculatus*, *R. repens*, *A. odoratum*, *H. lanatus*, *E. guttata*, and *R. fruticosus* which are abundantly present in all communities except the low forest community. The presence of native woody regeneration in the low forest plots indicates that grass competition is suppressed and they are beginning to become self-sustaining, indicating that only minimal ongoing pest management interventions will be required.

Conclusions and recommendations

This study has improved our understanding of the restoration progress at SMCR, and the results will enable SLLT and CCC to make informed management decisions regarding further restoration of the reserve. Based on results, such as the abundance of exotic species and lack of seedling regeneration in all areas except for the low forest sites, restoration at SMCR can be considered incomplete. The wider reserve has yet to fully develop key natural ecosystem processes found in the more mature areas of the reserve. The areas of the reserve that require the most attention by management have been highlighted (high grassland and marshland/low shrubland sites), and efforts should be made to manage these areas towards a species composition matching that of the low forest sites. Future research should aim to provide more detailed soil mapping and examine both invertebrate and bird communities to improve our understanding of ecosystem structure and function. Finally, this study provides a model for assessing ecological integrity for restoration projects throughout NZ.

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Ethics: ethics approval was not required for this research.

Data availability: data is lodged with the National Vegetation Survey databank (https://nvs.landcareresearch.co.nz/).

Author contributions: MB conceived the idea; EJW, MB, and SVW designed the research; EJW undertook the data collection; EJW and SVW undertook the analyses; EJW and SVW wrote the manuscript, with editorial contributions from MB.

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