Evaluation of seedling ratio monitoring in the Nelson City Council Waterworks Reserve.

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Evaluation of seedling ratio data from an ungulate control area, Nelson

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Summary

Project and Client

- Seedling ratio index data collected in the Nelson City Council Waterworks Reserve in the Maitai/Roding catchments of the Bryant Range from 2013 to 2018 were analysed by Manaaki Whenua – Landcare Research to measure trends in browsing-ungulate impacts on forest understories, and to determine appropriate sample sizes for future surveys. This work was undertaken for the Nelson City Council with MBIE Envirolink funding.

Objectives

- To review protocols for the efficient monitoring of ungulate impacts on forest understories in the Nelson City Waterworks Reserve using the seedling-ratio-index (SRI) method.
- To determine trends in forest understorey condition from 2013 to 2018 in the ungulate control area in the Waterworks Reserve.
- To calculate transect numbers required to detect spatial and temporal changes of specified effect size in SRIs estimates.

Methods

- The seedling ratio method records species present in two height classes (short: 0–29 cm, tall: 30–200 cm) in forest understories and derives an index (SRI) from the relative species richness of short and tall seedlings in three ungulate-preference groups (selected, non-selected and avoided). SRI data were collected from the Maitai/Roding catchments between 2013 and 2018 for Nelson City Council.
- Ungulate diet literature was reviewed to assign plant species recorded during three SRI surveys in the Maitai/Roding catchments to one of the three ungulate preference groups.
- Plant species were also assigned to one of 9 habit classes (climbers, herbs, short ground ferns, tall ground ferns, tall monocotyledons, short woody, tall woody, tree ferns, and supplejack).
- Exclusion of climbers, annual herbs and species that usually do not exceed 30 cm in height is standard practice in SRI surveys, so were excluded from all analyses.
- Fifteen transects, 14 on non-limestone substrates, were measured in 2013 and 2015. Twelve new transects, nine in areas on limestone, were measured in 2018. All 2018 and ten 2013–2015 transects will be measured in future, therefore, only data from these 22 ongoing transects were analysed.
- Using seedling-ratio and ungulate-browse data from the three surveys, SRIs for each preference group and mean browse scores (MBS is a measure from combined non-selected and selected species browse scores)) were calculated for each transect from each survey. Repeated calculations with different combinations of plant habits were performed to determine the most useful combination of species for accurate and efficient SRI measurement. The presence or absence of ungulate faecal pellets, for calculating a faecal pellet index (FPI) was also recorded on SRI transects.

- Power analyses was performed to determine the number of transects required to robustly measure a range of effect sizes for comparing individual preference-group SRIs between years and between the three preference-group SRIs within years.

Results

- Exclusion of tall monocotyledons and tall ferns produced similar SRI and MBI estimates, of similar precision, to when they were included.
- Kāmahi is usually assigned to the selected-preference group in the literature, but it numerically dominated selected seedlings, and had an SRI profile similar to non-selected species in the Waterworks Reserve. It was therefore assigned to the non-selected preference group.
- Survey mean SRIs for selected species (excluding kāmahi) ranged from –0.22 to –0.48. Overall MBIs ranged from 0.41 to 0.62, and FPIs ranged from 14.5% to14.6% over the three surveys.
- Differences of 0.2 in SRI estimates for the three preference groups (about 15% of the possible range of SRI values for selected species) can be detected with 7–9 transects. Just 3–5 transects are required to detect similar sized differences in avoided and non-selected SRIs between surveys but 19 transects are required for selected species, using 20-plot transects.

Conclusions

- Kāmahi seedling height profiles in the Waterworks Reserve resemble those of non-selected species there and elsewhere in New Zealand, therefore kāmahi should be included in the non-selected ungulate preference group.
- Without kāmahi, numbers of selected-species records on 20-plot non-limestone transects were often low (<10) but could be boosted by recording selected species only on additional plots placed midway between existing plots on data poor transects.
- Excluding all ground ferns and monocotyledons from SRI analyses made no difference to SRI and MBI estimates and so these species could be dropped from SRI field protocols.
- Seedling numbers were counted during the three SRI surveys but only presence/absence data is used to calculate SRIs, therefore time-consuming counts could be dropped from the field protocol.
- Restricting browse scores to non-selected and selected species, increasing the browser tier height interval to 15–200 cm, calculating transect means for non-selected and selected browse scores before combining them into MBSs, and recording the presence of browse-tier foliage when tall seedlings of the same species are absent will eliminate wasted effort, increase useable data, and reduce biases in MBIs.
- Ungulate abundance, based on MBIs and FPIs, was stable and their browsing was having a moderately negative impact on selected-seedling regeneration between 2013 and 2018 in the Waterworks Reserve.
- The number of transects analysed (10 on limestone and 12 on other substrates) is sufficient to detect modest (≥0.2 change in SRI, or 15% of potential range) spatial, temporal, and preference group trends in SRIs. Reduction in sample sizes may be

possible if selected species records are increased by increasing plot numbers on low diversity transects.

Recommendations

- All annual-herb, ground-fern, short-woody, tall-monocotyledon and climbing species, except supplejack (*Ripogonon scandens*), should be excluded from SRI field protocols to reduce field effort.
- Only the presence of short seedlings on the 50-cm radius subplot, and tall seedlings on the whole plot (140-cm radius) should be recorded: seedling counts are not required for SRI calculation.
- Kāmahi (*Weinmannia racemosa*) should be classified as a non-selected species.
- Additional plots on which only selected species are recorded should be added to transects that record fewer than 10 selected species records (short and tall records combined) on the first 20 plots. Additional plots should be placed midway between each of the initial plots.
- The browse tier, in which ungulate browse is recorded, should be defined as 15–200 cm above the ground, and browse should be recorded for selected and non-selected species only.
- Mean browse scores should be calculated as the mean of the two preference group MBSs (selected and non-selected groups, calculated separately).
- The presence of foliage from unbrowsed selected and non-selected species within the browse tier needs to be recorded.
- Ungulate control needs to be intensified in the Waterworks Reserve to reduce ungulate abundance and their impacts on selected-seedling regeneration.
- Current sample sizes (22 transects) should be maintained for the next SRI survey, after which they may be reduced depending on the results of the modified protocol to boost selected species sample size.

1 Introduction

Seedling ratio index data collected in the Nelson City Council Waterworks Reserve in the Maitai/Roding catchments of the Bryant Range from 2013 to 2018 were analysed by Manaaki Whenua – Landcare Research to measure trends in browsing-ungulate impacts on forest understories, and to determine appropriate sample sizes for future surveys. This work was undertaken for the Nelson City Council with MBIE Envirolink funding.

2 Background

Pest abundance reduction is a common and widespread management action to protect biodiversity and water quality in New Zealand (Parkes & Murphy 2003; Goldson et al. 2015). The Nelson City Council undertakes invasive browsing ungulate control (fallow deer (*Dama dama*), and red deer (*Cervus elaphus*) and goats (*Capra hurcus*)) in 4,675 ha within the 15,430-ha Waterworks Reserve on the northern flanks of the Bryant Range (Kaitaiki O Nghere 2016), which provides domestic water supply to Nelson City. The Ungulate control area falls within the Maitai and Roding River catchments, immediately north of the Dunn Mountain ultramafic zone, and straddles a floristically diverse limestone belt. Ungulate control comprises a combination of ground and aerial shooting, contracted out to pest-control professionals (currently Trap and Trigger Ltd, Wellington).

To quantify the utility of this control in protecting and restoring forest understoreys, and to identify required changes to the control strategy, Nature Nelson (Nelson City Council) initiated forest understorey monitoring within the pest-controlled catchments in 2013. For this purpose, a network of seedling ratio index (SRI) transects (Sweetapple & Nugent 2004) were established. The SRI method is a simple low-cost tool that quantifies seedling regeneration in forest understoreys by recording the number of species present, within three ungulate-palatability classes in two height classes, on small circular plots. An index (SRI) is calculated for each palatability group from the relative species richness of tall and short seedlings. A low SRI for the most palatable species relative to the SRI for the least palatable species is interpreted as regeneration failure due to the presence of browsing ungulates. SRI values range from 1.0 to –1.0 and values below zero for palatable plants are usually commensurate with ungulate-reduced regeneration. Ungulate browse observed on within-plot vegetation is also recorded to index ungulate abundance and to assist with interpretation of the SRI results.

Nature Nelson contracted Kaitiaki O Nghere in 2013 to establish and measure 15 randomly located SRI transects in the ungulate control area, remeasure these transects in 2015, and establish and measure a further 12 transect in 2018 (Fig. 1). Manaaki Whenua – Landcare Research (MWLR), Lincoln, was contracted by the Ministry of Business, Innovation, and Employment (MBIE) via the Envirolink Fund, to analyse and interpret these SRI data for Nelson City Council, with emphasis on determining sample sizes required to measure spatial and temporal trends in ungulate impacts. This analysis will help inform a review of the ungulate-control program planned for 2022–23.

3 Objectives

- To review protocols for the efficient monitoring of ungulate impacts on forest understories in the Nelson City Waterworks Reserve using the seedling-ratio-index (SRI) method.
- To determine trends in forest understorey condition from 2013 to 2018 in the ungulate control area in the Waterworks Reserve.
- To calculate transect numbers required to detect spatial and temporal changes of specified effect size in SRIs estimates.

4 Methods

4.1 Field surveys

Seedling ratio field surveys were carried out in the Maitai and Roding Catchments of the Nelson City Waterworks Reserve (Bryant Ranges) in 2013, 2015, and 2018. Fifteen randomly located transects were measured in 2013 and remeasured in 2015. A review of the survey design led to the dropping of 5 of these transects and the inclusion of 12 new transects in 2018, to provide 12 transects on non-limestone substrates and 10 transect on limestone. Within the new survey structure, one limestone and nine non-limestone transects were measured in 2013 and 2015, while 12 different transects: nine limestone and three non-limestone transects, were measured in 2018 (Fig. 1). Data from these final 22 transects only were analysed during this review.

All transects comprised 20 plots spaced at 20-m intervals. Line starts were permanently marked but plot centers were not. Each plot comprised a 50-cm search radius in which short seedlings (<30 cm tall) of each plant species present were counted, and a 140-cm search radius in which tall seedlings (30–200 cm tall) of each species present were counted. A browse score was assigned to all species with ungulate browse observed on foliage in the browse tier (30–200 cm above ground level), from plants rooted on the plot or overhanging the plot. It was scored on a 5-point scale: 0 (no browse) or 1–4 corresponding to 25% increments in the proportion of stems browsed, as described by Sweetapple and Nugent (2004). The presence of ungulate faecal pellets on the 140-cm radius plot was recorded, as either pig, deer or goat, during the last two surveys.

Seedling heights were measured to the highest stem tip for woody species, the highest leaf or frond tip for monocotyledons and ground ferns, respectively, and to the top of the trunk for tree ferns. Individual leaves or fronds on monocotyledons and ferns, respectively, were treated as stems for scoring browse.

4.2 Data analysis

Excel spreadsheets containing field data from the three SRI surveys were supplied to MWLR by Nelson City Council. Ungulate diet literature was reviewed to assign each species to one of three ungulate preference classes (avoided, non-selected, selected).

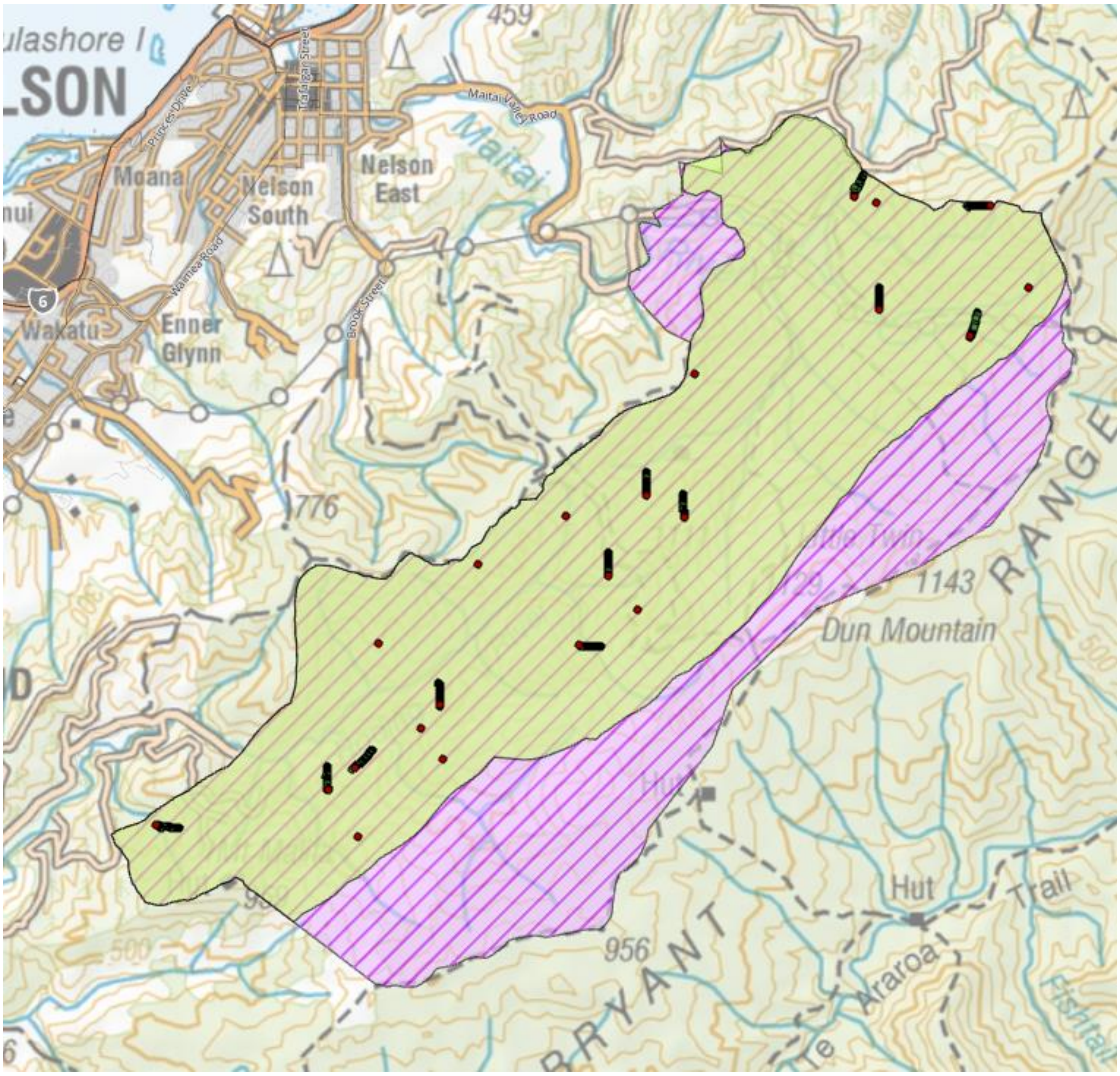

Figure 1. Location of the animal control area (green shaded area) and seedling ratio transects (dots) in the Waterworks Reserve, south-east of Nelson city. The pink shaded areas are 2021 extensions to the animal control area. Single red dots are start points for the 2013–15 transects that were analysed, and the data-point strings are the 2018 transects.

Each species was also assigned to one of the following habit (plant size and structure) classes: climbers, herbs, ground ferns (those without upright rhizomes (trunks) exceeding 30 cm), monocotyledons, tree ferns and woody species. Supplejack (*Ripogonum scandens*) was singled out as a special case because although it is a climber, its seedlings are self-supporting up to a height exceeding 100 cm, and therefore behave like woody-species seedlings. Supplejack seedlings did not include root suckers (soft, leafless, rapidly growing canes) that frequently occur near the base of established mature plants. All plant species were also assigned to one of two height classes: short (those species that normally do not exceed 30 cm in height in absence of browsing ungulates) and tall (all other species).

Herbs, short species, and climbers (but not supplejack) were excluded from all analyses. Supplejack, tree ferns and tall woody species were included in all analyses. Tall ground ferns and tall monocotyledons were included in some analyses to assess the utility of their inclusion in the SRI method.

Selected seedlings were uncommon on some transects in 2013 and 2015. One 2013 transect recorded just one selected seedling (after reassigning kāmahi to the non-selected group; see results). and was, therefore excluded from analyses for selected species.

Seedling ratio indices (SRIs) were calculated for the three ungulate preference groups on each transect using the following formula:

$$SRI_a = \frac{\sum Tall_a - \sum Short_a}{\sum Tall_a + \sum Short_a}$$

where *a* = the ungulate preference group (selected, non-selected or avoided), Tall = tall seedling records on the transect, and Short = short seedling records on the transect. A record is one species present on one plot, with multiple records of both short and tall seedlings possible on each plot.

A mean browse score (MBS) was also calculated for each transect in a two-step process. First, a group browse score (GBS) was calculated for selected and non-selected species, separately, using the following formula:

$$GBS = \frac{\sum BS_a}{\sum Tall_a + \sum overhanging_a}$$

Where *a* = the ungulate preference group (selected, or non-selected), BS = individual species browse scores on all plots within a transect, Tall = tall seedling records on the transect and overhanging = records of species without tall seedlings present but with foliage in the browse tier overhanging the plot area.

The second step calculated the mean of the two GBSs.

A faecal pellet index (FPI) was calculated for each transect for the years faecal pellets were recorded. It was calculated as the percentage of the 20 140-cm plots on which browsing ungulate (goat or deer) pellets were recorded.

Power analyses were performed to determine the samples sizes (number of transects) required to obtain SRI estimates of sufficient precision to detect a range of effect sizes (differences in mean SRIs between years or palatability groups) with 95% confidence. Least significant differences (LSDs) were calculated from transect SRI data to compare palatability groups within and between years. Mean SRIs are considered statistically different if the differences between their means exceed the LSD estimate. To compare palatability group means within years, SRI data were analysed for limestone and non-limestone transects separately. One-way ANOVAs were performed on SRI estimates from the three palatability groups from which the within-groups mean sums of squares (WMS) was used to calculate LSDs for a range (3–30) of transect numbers using the following formula:

$$LSDa,b = t \times \sqrt{}(MS \times \left(\frac{1}{N_a} + \frac{1}{N_b}\right))$$

where t = student's $t_{(0.05)}$, and Na and Nb = number of transects in groups a and b, respectively, being compared. Degrees of freedom for t were calculated as $3 \times N - 2$.

Similar analyses were performed on SRI data for all three individual palatability groups, separately, from all three surveys, to compare SRI estimates between years. Limestone and non-limestone transect data measured in the same year were analysed together, providing LSDs for whole-of-area comparisons between years for each palatability group.

5 Results

5.1 Seedling ratio surveys

Each plant species was assigned to one of four ungulate diet-preference groups (selected (= preferred in Forsyth et al. 2002), non-selected, avoided or unknown) and are listed in Appendix 1. These were largely based on Forsyth et al. (2002). Where classification was ambiguous (more than one preference class was derived from the datasets reviewed by Forsyth et al. (2002)), the most common classification was usually used. Where data were absent or sparse, designation followed Sweetapple & Nugent (2004), were based on the experience of the author or were designated as 'unknown' (Appendix 1).

Appendix 1 also classifies each plant species as an SRI species (included in SRI analyses) or not, based on species habit. Climbers, short species (those with vegetative parts that would not usually attains heights >30 cm in the absence of browsing ungulates) and annual herbs were excluded from all analyses. Monocotyledons and tall ground ferns can rapidly switch between height classes following browse events, or adverse weather, and ungulate browse on them can, in some cases, be indistinguishable from damage due to other agents. They were, therefore, classified as potential SRI species and were used in some, but not all, analyses to assess the utility of their inclusion.

Seedling ratios for avoided and non-selected species ranged from 0.3 to 0.42 throughout the three surveys (Fig. 2). Selected-species seedling ratios ranged from 0.22 in 2013 to –0.13 in 2018, with that difference (0.35) exceeding the least significant difference (LSD) for a nine-transect comparison between years (0.30; see section 5.2), indicating a real difference in selected-species SRIs across the three surveys. These surveys were, however, not directly comparable, as the 2013 and 2015 data were from transects on non-limestone strata, and the 2018 data were new transects on limestone strata.

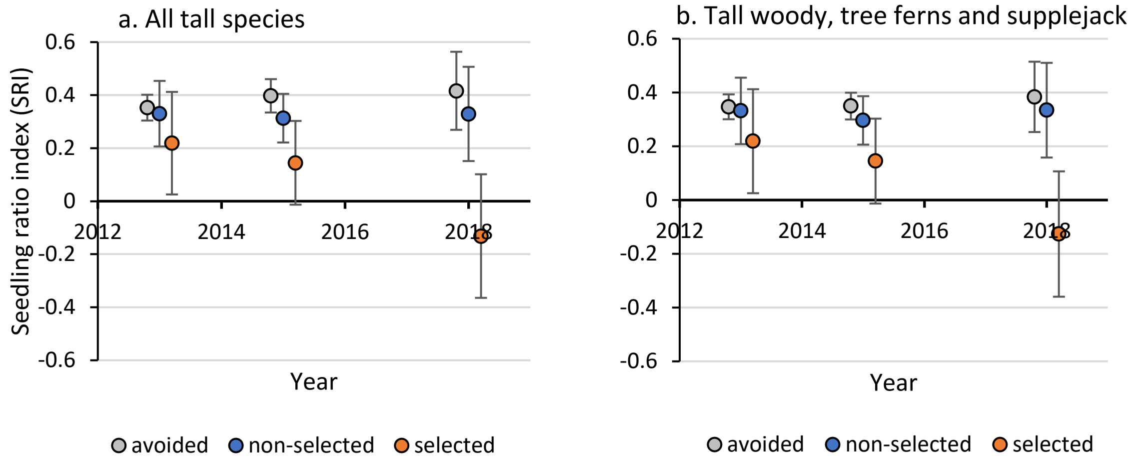

Figure 2. Seedling ratio indices for three plant palatability groups with (a) and without (b) tall ground ferns and monocotyledons, surveyed in 2013, 2015, and 2018 in the Bryant Range by Nelson City Council. Error bars are 95% confidence intervals.

Mean browse scores (selected and non-selected species only) were 0.59 in 2013, 0.41 in 2015 and 0.62 in 2018, with no differences observed between 'all tall' and 'tall-stemmed' species groups (Fig. 3). There was no temporal pattern in MBI over the 3 years (95% confidence intervals overlapped for all estimates, Fig. 3). Although MBIs were low (<0.7 each year) they were variable, especially in 2015 when transect MBIs ranged from 0.17 to 1.20.

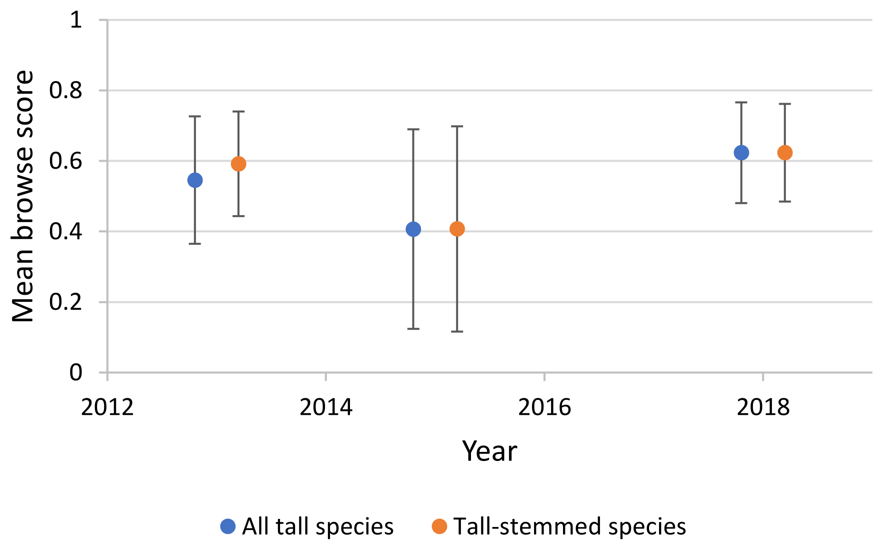

Figure 3. Mean browse scores for all tall plant species (species, excluding annual herbs and non-self-supporting climbers, whose vegetative parts usually exceed 30 cm in height where ungulates are absent) and tall-stemmed species (all tall species excluding ground ferns and monocotyledon) from seedling ratio surveys in the Waterworks Reserve of the Bryant Range (2013–2018). Data for 2018 are for limestone transects and data for 2013 and 2015 are for non-limestone transects. Error bars are 95% confidence intervals.

Faecal-pellet frequencies (FPIs) for browsing ungulates were also consistent over the two surveys they were recorded; FPIs were 14.5% (± 12.0% 95% CL) and 14.6% (± 8.3% 95% CL) in 2015 and 2016, respectively.

Exclusion of all ground ferns and monocotyledons from analysis made no material difference to SRI or MBIs, or the precision of their estimates (Figs 2 & 3).

The SRIs for selected species in 2013 and 2015 (non-limestone transects) appear anomalously high compared with elsewhere in New Zealand (Fig. 4). Conversely, the 2018 selected SRI (limestone transects) is consistent with those from other New Zealand sites (Fig. 4). Those contrasting results can be explained in terms of differences in abundance and regeneration patterns of kāmahi. Seedling ratios for kāmahi were 0.54 and 1.05 higher than for other selected species in 2018 and 2013–2015, respectively (Table 1). Those species and spatial-temporal differences in SRIs were compounded by kāmahi comprising 55% of selected seedling records in 2013–2015 but just 23% of selected species in 2018 (Table 1, Appendix 1). Reclassifying kāmahi as a non-selected species resulted in close agreement between Bryant Range selected species SRIs and those from elsewhere in NZ (Fig. 3), while making little difference to non-selected SRI estimates (Fig. 5). It also resulted in similar SRI estimates for selected species in all three surveys (Fig. 5).

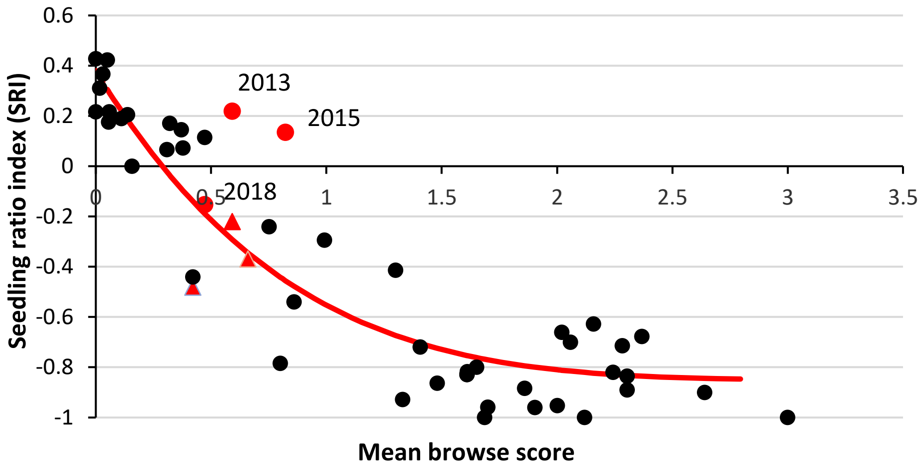

Figure 4. Seedling ratio indices for selected species plotted against mean browse index for the three Waterworks Reserve surveys with kāmahi included (red dots), kāmahi excluded (red triangles) and for 42 surveys undertaken at other New Zealand locations (black dots; unpublished data). The trend line is for selected species from Sweetapple & Nugent (2004).

Table 1. Number of plots with short or tall selected seedlings during three seedling-ratio surveys undertaken in the Waterworks Reserve in the Bryant Range. Data are shown for kāmahi and other selected species separately

Species and year	Plots with short seedlings	Plots with tall seedings	Total (short+tall)	SRI	Browse score
Kāmahi 2013+2015	48	223	271	0.65	0.93
Other selected 2013+2015	152	67	219	-0.39	0.31
Kāmahi 2018	38	58	96	0.21	1.07
Other selected 2018	171	86	257	-0.33	1.05

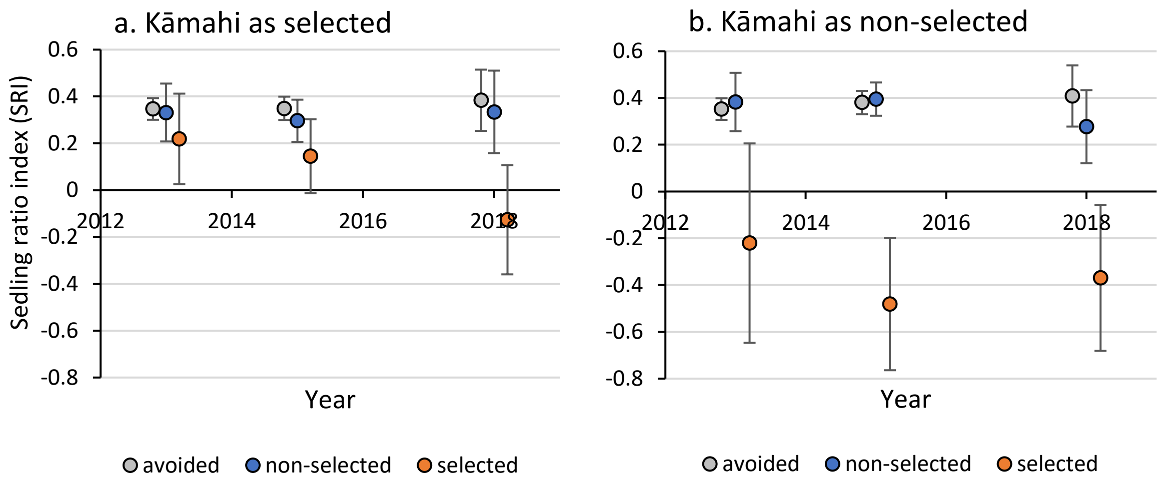

Figure 5. Seedling ratio indices for three ungulate plant palatability groups with (a) kāmahi classified as a selected species and (b) kāmahi classified as a non-selected species. Data were collected in the Maitai and Roding catchments of the Bryant Range. Data for 2018 is for limestone transects and data for 2013 and 2015 is for non-limestone transects. Error bars are 95% confidence intervals. Note Figure 5a is the same as Figure 2a.

5.2 Power analysis

The number of transects required to detect differences in SRI estimates of ≥ 0.2 for difference between palatability groups is 7 and 9 on limestone and non-limestone substrates, respectively, when kāmahi is classed as a non-selected species (Fig. 6). The corresponding sample sizes required to detect a difference of 0.15 are 11 and 16 transects on limestone and non-limestone substrates, respectively, with 95% power. Sample sizes required to detect smaller differences in SRI increase rapidly with declining LSDs (Fig. 6).

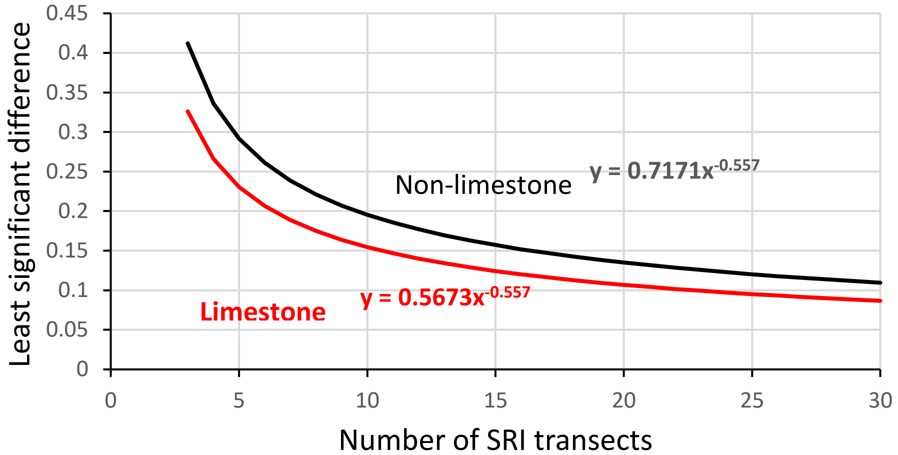

Figure 6. Relationships between sample size (number of SRI transects) and least significant difference (LSD) in SRI estimates for comparing three ungulate palatability groups within years. LSDs are calculated for kāmahi classified as a non-selected species. Limestone-transect data came from nine 2018-transects and one 2015-transect measured on limestone substrate. Non-limestone data came from nine 2015-transects and three 2018-transects measured on non-limestone substrates.

Small sample sizes (4–6 transects) were required to detect between-year differences in SRI estimates of ≥0.2 for avoided and non-selected species groups (Fig. 7). Much larger sample sizes (e.g. 19 transects for SRI ≥0.2) were needed to detect between-year differences in selected-species estimates. This is likely due to low and variable numbers of plots in which selected species were found, particularly on non-limestone substrates (2013 and 2015 data in Table 2). Furthermore, there were less than 10 selected species encounters (short seedling records + tall seedling records) in 8 of 10 transects in 2013 and 4 of 10 transects in 2015.

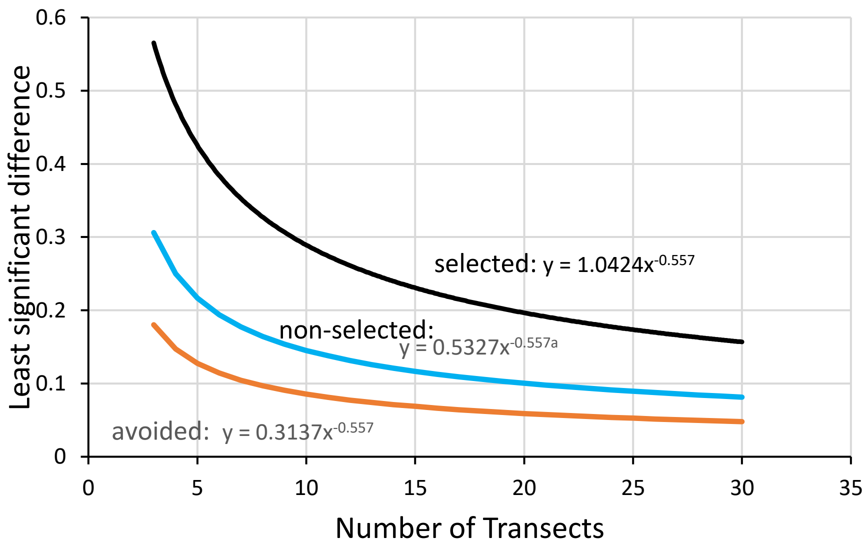

Figure 7. Relationships between sample size (number of SRI transects) and least significant difference (LSD) in SRI estimates for comparing ungulate impact between years. Trend lines are shown for three ungulate palatability groups (avoided, non-selected, selected) separately, with kāmahi classed as a non-selected species. Trend line formulae are also shown. Data are from eight, nine, and twelve transects from the Byrant Range measured in 2013, 2015, 2018, respectively (limestone and non-limestone transects pooled). Data for selected species from one 2013-transect were excluded due to insufficient data (transect NL01 which has one short seedling only) to calculate an SR.

Table 2. Number of species records per transect (N; short seedling records + tall seedling records), SRI variance by palatability class and year of measurement. Data are from 9 transects in 2013 and 2015, and 12 transects in 2018, from the Waterworks Reserve in the Bryant Range

	Ungulate palatability group					
	avoided		non-selected		selected	
Year	N	variance	N	variance	N	variance
2013	35–83	0.004	33–96	0.027	1–18	0.128
2015	47–99	0.009	29–102	0.014	4–29	0.151
2018	69–134	0.011	14–71	0.033	11–44	0.031

6 Conclusions

6.1 Revisions to the SRI protocol

Kāmahi is designated as a selected species by both Sweetapple & Nugent (2002) and Forsythe et al. (2004). Doing likewise for Maitai/Roding data appears to produce anomalous data, at least for data from non-limestone substrates, where selected SRIs were substantially higher than at other New Zealand sites with similar ungulate browse scores and indicated a downward trend in selected SRIs from 2013 to 2018 that is at odds with a lack of trends in ungulate browse (Fig. 3) and faecal-pellet frequencies. These results arise from the numerical dominance of kāmahi seedlings in Maitai/Roding selected-seedling data and the dominance of tall kāmahi seedlings in those data compared with other selected species (Appendix 1). That relative dominance of tall seedlings may be due to kāmahi seedling being predominantly epiphytic, and therefore underrepresented on small seedling sub-plots compared with terrestrial seedlings. Kāmahi, therefore, has a disproportionate and contrasting impact on selected-species-group data in the Maitai/Roding catchments. Kāmahi SRIs from the current survey area are broadly similar to those for kāmahi from other New Zealand sites, but kāmahi does not strongly influence SRIs elsewhere because it is usually a minor component of the seedling population (unpublish data). Kāmahi SRIs are also very similar to those for non-selected species in the Maitai/Roding survey area.

Two published deer diet studies provide preference estimates for kāmahi, one for red deer in the Huhungaroa Range (Nugent et al. 1997) and one for white-tailed deer on Stewart Island (Nugent & Challies 1988). In both studies the preference score for kāmahi is at the lower end of the range used for selected species in Forsythe et al. (2004). A third diet study (goat diet on Mount Taranaki; Mitchell et al. 1987), ranks kāmahi among the four highest preferred foods among woody species, but does not account for the influence of leaf-fall, which likely means the preference for kāmahi is over-estimated in that kāmahi-dominated forest. Therefore, only a minor adjustment to the definition of selected species is required to relegate kāmahi to the non-selected group, where it is a better fit with Maitai/Roding SRI data. Without that change, kāmahi seedling abundance reduces the sensitively of the selected-SRIs to ungulates in the survey area.

A drawback of assigning kāmahi to the non-selected group is that the resulting selected seedling data are often sparse, particularly on non-limestone (2013–2015) transects (Table 2). This results in more transects being needed to detect changes in selected SRIs between surveys, e.g. 19 transects were required to attain an LSD of 0.2 for selected species compared with 6 transects for non-selected species (Fig. 7). A strategy to combat this would be to measure selected seedlings on additional plots if, after 20 plots, selected seedling records (short seedling presences + tall seedling presences) total less than 10. This would most efficiently and appropriately be achieved by measuring an extra plot midway between each plot already measured (returning along the transect), recording just the presence of selected short and tall seedlings. During analysis, selected species data on transects that still had insufficient data (e.g. <5 total selected records) could be excluded. This should result in a similar number of selected seedlings recorded on non-limestone transects as for limestone transects, and reduce the number of transects required to measure selected SRIs to an adequate level of precision (e.g. non selected species in Fig. 7). However, this suggested change it will need to be trialled to confirm the utility of the strategy.

For all three seedling ratio surveys, recording just tall woody and supplejack seedlings, and tree ferns on plots gave similar SRI estimates and precision as did including tall monocotyledons and ground ferns. Survey effort can therefore be reduced by excluding tall monocotyledons and ground ferns from the field protocol, without compromising SRI accuracy or precision. Substantial further reductions in survey effort can be achieved by recording just the presence of target species in the two height tiers, rather than recording the total number of seedlings present of all species (including herbs, climbers, and short ferns), as was done in the surveys to date. These latter data are not required for SRI calculation.

Modifications to the browse-scoring protocol used during the three SRI surveys are warranted. The original protocol (Sweetapple & Nugent 2004) specifies recording ungulate browse on target non-selected and selected species only and defines the browse tier as 20–200 cm above the ground. During the Maitai/Roding surveys browse was scored for all species on vegetation 30–200 cm above the ground. Including browse on target species seedlings shorter than 30 cm (e.g. ≥ 15 cm) will increase the number of non-zero browse records and therefore, increase the robustness of the mean browse scores obtained. For the current assessment browse scores were calculated for non-selected and selected species groups separately (GBSs), before taking the mean of the two scores. That small change from Sweetapple & Nugent (2004) eliminants biases that arise if numbers of non-selected and selected browse score are unequal, and MBSs are calculated from pooled data from both groups without giving equal weighting to the two groups. Finally, the presence of foliage from unbrowsed target species (selected and non-selected species of desired species-groups, e.g. supplejack, tall woody and tree fern species) within the browse tier needs to be recorded on plots to be able to accurately calculate MBSs.

6.2 Condition of forest understories

Using the above revised protocols for SRI calculation from the 2013 to 2018 surveys indicate that browsing ungulates are having a moderate impact (-0.2 < SRI ≥ -0.5) on selected seedlings. SRIs for non-selected and avoided species (0.28–0.41) indicate that their regeneration was not impacted by ungulate browsing; they were strongly positive and were similar to or exceeded SRIs for the same preference groups in the presence of very low or no ungulate browsing elsewhere (Sweetapple & Nugent 2004). A second indicator of impact is whether non-avoided SRIs are lower than those for avoided or non-selected species. By this measure selected species are again identified as impacted because their SRIs are lower than for avoided species by a margin (0.57–0.96) exceeding the LSD for the number of transects measured (0.16–0.20), by a considerable margin, in all years. Comparison of non-selected and avoided species again indicates no impact on non-selected species (Fig. 5).

Treating kāmahi as a selected species concealed the impact of ungulates on that group in 2013–2015, by reducing the difference between selected and avoided SRIs to ≤0.15, which was less than the LSD for the nine non-limestone transects measured (0.20, Figure 5). But it did indicate a declining trend in understorey condition across the three surveys where no such trend existed (Fig. 4). Browse scores also indicated no temporal trend in ungulate impacts (overlapping 95% confidence intervals, Fig. 2).

Faecal-pellet Index (FPI) data (presence/absence of browsing ungulate pellets), which was recorded on all plots in 2015 and 2018, is broadly in agreement with the SRI and browse data. Mean FPIs (14.5% and 14.6%) were low to moderate and stable. Of greater concern is the variability in FPI between transects, ranging from 0 to ≥40%, in both surveys. This demonstrates that ungulates were locally abundant and likely to be having heavy impacts at those localities. Heavy localized impacts have been noted by the animal control contractor (Trap & Trigger, 2021).

Caution is required in assuming stability in ungulate abundance and understorey condition as the 2018 survey is not directly comparable with the earlier two. It was undertaken using new transects in forests on limestone whereas the earlier surveys were predominantly on non-limestone substrates.

6.3 Sample sizes

The current number of SRI transects that Nelson City council plan to measure each survey (10 limestone and 12 non-limestone transects) exceeds the number required to detect SRI differences ≥ 0.20 between the three palatability groups within years and substrate type (7 limestone and 9 non-limestone transects). That effect size is equivalent to about 15% of the possible range of values for selected species (-0.9–0.4). Increasing precision further to achieve an LSD of 0.15 would require a 56% increase in sample size but would reduce the LSD as a proportion of the potential range of SRI values by just 20%. Any further meaningful improvements in precision would require an impractically large number of transects. However, detecting differences in SRI estimates ≥ 0.2 is likely to provide sufficient sensitivity for the management of ungulate impacts on seedling regeneration.

To detect differences in SRI estimates between years will require even fewer transects for avoided and non-selected species, e.g. 3–5 transects are required to detect SRI differences ≤ 0.2. However, 19 transects are required to measure selected species SRIs to this level of precision (Fig. 6), although that does not exceed the number of transects currently planned (22) for future remeasurement. Because selected species are the most sensitive to ungulate browsing, and therefore the most difficult to protect, sample sizes that adequately estimate selected species SRIs should be chosen. The number of transects required to measure selected species to a similar level of precision as for the two other species groups will likely decline substantially if the suggested modification to the selected species measurement (additional plots measured on low count lines: see section 6.1) is adopted. Depending on the results of that modification, future sample sizes might be reduced from the currently planned 10 limestone and 12 non-limestone transects.

7 Recommendations

- All annual-herb, ground-fern, short-woody, tall-monocotyledon and climbing species, except supplejack (*Ripogonon scandens*), should be excluded from SRI field protocols to reduce field effort.
- Only the presence of short seedlings on the 50-cm radius subplot, and tall seedlings on the whole plot (140-cm radius) should be recorded: seedling counts are not required for SRI calculation.
- Kāmahi (*Weinmannia racemosa*) should be classified as a non-selected species.
- Additional plots on which only selected species are recorded should be added to transects that record fewer than 10 selected species records (short and tall records combined) on the first 20 plots. Additional plots should be placed midway between each of the initial plots.
- The browse tier, in which ungulate browse is recorded, should be defined as 15–200 cm above the ground, and browse should be recorded for selected and non-selected species only.
- Mean browse scores should be calculated as the mean of the two preference group MBSs (selected and non-selected groups, calculated separately).
- The presence of foliage from unbrowsed selected and non-selected species within the browse tier needs to be recorded.
- Ungulate control needs to be intensified in the Waterworks Reserve to reduce ungulate abundance and their impacts on selected-seedling regeneration.
- Current sample sizes (22 transects) should be maintained for the next SRI survey, after which they may be reduced depending on the results of the modified protocol to boost selected species sample size.

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Appendix 1 – Number of records, seedling ratio indices (SRI) and mean browse scores (Browse score) for plant species recorded during 2015 and 2018 seedling ratio surveys undertaken in the Nelson City Waterworks Reserve in the Bryant Range

Habit and preference group	SRI species?	Short seedlings	Tall seedlings	SRI	Browse Score
Herbs: unknown preference					
Acaena anserinifolia	No	1	0		
cardus sp	No	1	0		
Dianella nigra	Potential[2]	12	2	–0.71	1.00
Digitalis purpurea	No	9	2		0.00
Haloragis erecta	No	1	0		
Ranunculus foliosus	No	5	1		1.00
Senecio jacobaea	No	1	0		
Urtica incisa	No	3	0		
Total herbs: unknown preference		**33**	**5**		**0.67**
Climbers: avoided		**76**	**95**		**0.01**
Metrosideros diffusa	No	63	68		0.03
Climbers: non-selected					
Clematis vitalba[1]	No	2	0		
Rubus cissoides	No	1	17		0.24
Total non-selected climbers		**3**	**17**		**0.24**
Climbers: Selected					
Clematis paniculata	No	8	6		0.17
Muehlenbeckia australis[1]	No	2	1		1.00
Parsonsia heterophylla[1]	No	0	1		0.00
Total selected climbers		**10**	**8**		**0.25**
Self-supporting climbers: selected					
Ripogonum scandens	Yes	12	8		0.60
Short ferns: avoided					
Blechnum procerum	No	20	15		0.00
Grammitis billardierei	No	31	14		0.00
Hymenophyllum demissum[1]	No	60	33		0.00
Lycopodium fastigiatum[1]	No	4	2		0.00
lycopodium sp	No	1	0		
Lycopodium volubile[1]	No	2	2		0.00
Pellaea rotundifolia	No	2	1		0.00
Pyrossia eleagnifolia	No	5	7		0.00
Tmesipteris tannensis	No	5	15		0.00
Trichomanes reniforme	No	8	6		0.00
Total short ferns: avoided		**138**	**95**		**0.00**

Habit and preference group	SRI species?	Short seedlings	Tall seedlings	SRI	Browse Score
Short ferns: non-selected					
Blechnum fluviatile	No	10	11		0.00
Phymatosorus scandens	No	1	1		0.00
Total non-selected short ferns		**11**	**12**		**0.00**
Tall ground ferns: avoided					
Adiantum cunninghamii	Potential	3	2	–0.20	0.00
Blechnum discolor	Potential	99	177	0.28	0.02
Blechnum novae zelandiae[1]	Potential	1	3	0.50	0.67
Histiopteris incisa	Potential	5	8	0.23	0.00
Hypolepis ambigua [1]	Potential	1	2	0.33	0.00
Lastreopsis hispida	Potential	0	1	1.00	0.00
Leptopteris hymenophylloides	Potential	14	19	0.15	0.00
Pneumatopteris penigera[1]	Potential	0	1	1.00	0.00
Pteridium esculentum	Potential	15	36	0.41	0.00
Pteris macilenta[1]	Potential	0	4	1.00	0.00
Total avoided tall ground ferns		**138**	**253**	**0.29**	**0.01**
Tall ground ferns: Non selected					
Asplenium flaccidum	Potential	3	6	0.33	0.00
Asplenium oblongifolium[1]	Potential	0	1	1.00	0.00
Polystichum richardii[1]	Potential	1	7	0.75	0.00
Polystichum vestitum	Potential	0	1	1.00	1.00
Total non-selected tall ground ferns		**4**	**15**	**0.58**	**0.07**
Tall ground ferns: Selected					
Asplenium bulbiferum[1]	Potential	0	1	1.00	1.00
Tree ferns: avoided					
Cyathea dealbata	Yes	2	57	0.93	0.05
Cyathea smithii	Yes	0	25	1.00	0.00
Total avoided tree ferns		**2**	**82**	**0.98**	**0.04**
Tree ferns: non selected					
Dicksonia squarrosa	Yes	0	4	1.00	0.00
Tall monocotyledons: avoided					
Carex sp.	Potential	57	61	0.03	0.00
Astelia fragrans	Potential	0	1	1.00	0.00
Juncus sp.	Potential	1	0	–1.00	0.00
Microlaena avenacea	Potential	2	3	0.20	0.33
Total avoided tall monocotyledons		**60**	**65**	**0.04**	**0.02**
Tall monocotyledons: unknown pref.					
Cordyline banksii	Potential	0	3	1.00	0.00
Phormium cookianum	Potential	1	0	-1.00	2.00
Dianella nigra	Potential	9	2	-0.64	1.00
Total unknown monocotyledons		**10**	**5**	**0.33**	**0.67**

Habit and preference group	SRI species?	Short seedlings	Tall seedlings	SRI	Browse Score
Short woody: non-selected					
Muehlenbeckia axillaris	No	6	1	–0.71	0.00
Tall woody: avoided					
Dacrycarpus dacrydioides	Yes	2	0	–1.00	0.00
Dacrydium cupressinum	Yes	3	8	0.45	0.00
Hebe spp[1]	Yes	6	12	0.33	0.00
Erica lusitanica[1]	Yes	2	10	0.67	0.00
Kunzea ericoides[1]	Yes	9	12	0.14	0.00
Leptecophylla juniperia juniperia	Yes	14	51	0.57	0.00
Leptospermum scoparium	Yes	4	10	0.43	0.00
Leucopogon fasciculatus	Yes	54	141	0.45	0.05
Metrosideros umbellata	Yes	2	8	0.60	0.63
Myrsine divaricata	Yes	8	11	0.16	0.00
Neomyrtus pedunculata	Yes	2	8	0.60	0.38
Nothofagus fusca	Yes	100	111	0.05	0.08
Nothofagus menziessii	Yes	15	38	0.43	0.29
Nothofagus solandri	Yes	4	10	0.43	0.30
Nothofogaus solandri cliffortioides	Yes	0	2	1.00	2.00
Ozmothamnus leptophylla[1]	Yes	0	1	1.00	0.00
Phyllocladus alpinus? (lowland)[1]	Yes	2	14	0.75	0.21
Phyllocladus trichomanoides	Yes	0	1	1.00	2.00
Podocarpus totara	Yes	4	34	0.79	0.15
Prumnopytis ferruginea	Yes	0	1	1.00	0.00
Pseudopanax anomalus[1]	Yes	2	1	–0.33	2.00
Pseudowintera axillaris[1]	Yes	14	19	0.15	0.16
Pseudowintera colorata	Yes	36	70	0.32	0.06
Urtica ferox[1]	Yes	0	4	1.00	0.75
Total avoided tall woody		**290**	**584**	**0.33**	**0.10**
Tall woody: non-selected					
Aristotelia serrata	Yes	8	15	0.30	1.47
Brachyglottis repanda[1]	Yes	2	7	0.56	1.43
Carpodetus serratus	Yes	30	46	0.21	0.89
Coprosma crassifolia[1]	Yes	0	1	1.00	0.00
Coprosma foetidissima[1]	Yes	48	63	0.14	0.60
Coprosma linariifolia[1]	Yes	1	17	0.89	0.24
Coprosma propinqua[1]	Yes	55	144	0.45	0.17
Coprosma rhamnoides[1]	Yes	15	38	0.43	0.16
Coprosma sp.[1]	Yes	2	7	0.56	0.43
Coprosma dumosa 'tayloriae'[1]	Yes	23	70	0.51	0.43
Coriaria arborea[1]	Yes	0	2	1.00	1.50

Habit and preference group	SRI species?	Short seedlings	Tall seedlings	SRI	Browse Score
Elaeocarpus hookerianus[1]	Yes	2	1	–0.33	0.00
Muehlenbeckia complexa[1]	Yes	0	1	1.00	0.00
Olearia rani[1]	Yes	6	12	0.33	2.17
Pennantia corymbosa	Yes	1	1	0.00	0.00
Pseudopanax crassifolius[1]	Yes	81	80	–0.01	0.84
Prumnopytis taxifolia	Yes	9	15	0.25	0.00
Ulex europaeus[1]	Yes	34	25	–0.15	1.36
Total non-selected tall woody		**310**	**538**	**0.27**	**0.58**
Tall woody: selected					
Alectryon excelsus[1]	Yes	0	1	0.00	1.00
Coprosma grandifolia	Yes	10	10	0.00	1.50
Coprosma lucida	Yes	1	0	–1.00	
Coprosma robusta	Yes	8	3	–0.45	1.33
Griselinia littoralis	Yes	136	37	–0.57	0.59
Hedycarya arborea	Yes	22	10	–0.38	0.80
Melicytus ramiflorus	Yes	16	19	0.09	1.47
Myrsine australis	Yes	10	6	-0.25	0.50
Pseudopanax arboreus	Yes	6	6	0.00	0.33
Schefflera digitata	Yes	1	0	–1.00	
Weinmannia racemosa[3]	Yes	48	165	0.55	1.10
Total selected tall woody		**264**	**257**	**–0.01**	**1.03**
Tall woody: unknown preference					
Leycesteria formosa	Yes	0	2	1.00	0.00
Pseudotsuga menziesii	Yes	0	1	1.00	1.00
Total unknown preference tall woody		**0**	**3**	**1.00**	**0.33**

[1] Preference class designation based on author's personal experience.

[2] Potential SRI species are those that were used in some but not all analyses.

[3] Kāmahi was included in non-selected species for most analyses due to its abundance and strongly positive SRI score in contrast to other selected species SRIs (see section 6.0).