

1 Comparison of species richness and frequency cover of forest
2 floor plants and lichens in sites with and without the invasive
3 club moss *Selaginella kraussiana* (Kunze) A. Braun.

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13 Summary

14 ***Selaginella kraussiana*, or the African club moss, is a fern ally in the family**
15 ***Selaginellaceae* invasive to several countries including New Zealand. This study was**
16 **carried out to compare species richness and frequency cover in adjacent forest floor**
17 **botanical communities with and without *S. kraussiana* using a paired experimental**
18 **design. Sites with *S. kraussiana* had reduced species richness, particularly the number of**
19 **conifer and flowering plant species. Frequency cover (excluding *S. kraussiana*) was not**
20 **significantly affected.**

21 **Keywords: *Selaginella kraussiana*, invasive species, species richness, frequency**
22 **cover.**

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Introduction

Invasive plant species can potentially alter ecosystem structure and function, generally reducing native plant species richness and abundance (Gooden *et al.* 2009; Oswalt *et al.* 2007), attributed to displacement of adult plants and/or juvenile recruitment failure (Yurkonis *et al.* 2005). Invasive alien plant species can have a range of competitive advantages, including faster growth rates, more efficient dispersal, fewer natural enemies, efficient usage of light, nutrients and space, shade tolerance, and allelopathy (Catford *et al.* 2012; Gooden *et al.* 2009). Barton *et al.* (2007) in a study on the effects on the native flora of successful biological control of mist flower (*Ageratina riparia*(Regel) R.M.King & H.Rob.) in New Zealand, found that the African club moss (*Selaginella kraussiana*(Kunze) A. Braun) was the most frequently-occurring exotic plant species, invading both mist flower plots and control plots. Furthermore, they found that, over time, there was a negative relationship between native species richness and percentage cover of *S. kraussiana* in their plots. It was not clear from the study of Barton *et al.* (2007) if invasion by *S. kraussiana* affected particular plant groups or altered overall community structure.

Selaginella kraussiana is an invasive plant of lowland sites in the North Island of New Zealand, and is also found in scattered areas in the South Island and the Chatham Islands. The species is native to Africa and several island groups near Africa, but has been naturalised in New Zealand since at least 1919, when it was first recorded in the wild (Webb *et al.*, 1988). It has also naturalised in Australia, Europe and North, Central and South America. It is characterised by having sterile leaves of two sizes, creeping irregularly-branched stems which form a loose mat, and being spread by fragmentation and spores (Popay *et al.*, 2010). The species is designated with a ‘Surveillance’ status in the Auckland Regional Pest Management

1 Strategy (RPMS) and is listed by the National Pest Plant Accord (Auckland Regional Council
2 2007).

3 We hypothesise that sites with *S. kraussiana* will have lower species richness than sites
4 in the same area without this species. This study was carried out to compare the community
5 structure, species richness and frequency cover of conifers and flowering plants, bryophytes,
6 ferns and fern allies, and lichens in sites invaded by *S. kraussiana*, and directly adjacent
7 uninvaded sites.

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9 **Methods**

10 *Field Sampling*

11 This study was carried out in March 2011 at Spragg Bush, a 21ha remnant of warm-temperate
12 kauri/podocarp forest in the Waitakere Ranges (36°54'S, 174°32'E) in the Auckland region
13 of New Zealand (Beever 1984). This site was chosen because of the known presence of
14 *Selaginella kraussiana* along tracksides.

15 The methods used in this study were based on Stephens *et al.* (2008) and Marchand and
16 Houle (2006), and are as follows. Patches of *S. kraussiana* growing in Spragg Bush were
17 identified and mapped. All patches were adjacent to tracks and did not extend far into the
18 forest. Fifteen patches of *S. kraussiana* of at least 1m in diameter were chosen as study sites.
19 It was necessary for the patches to exceed 1m² in order to reliably estimate cover for
20 comparative purposes, which inevitably excluded newly established patches. To sample areas
21 which were environmentally similar apart from the absence of *S. kraussiana*, we adopted a
22 paired design by selecting comparably sized “control” study sites directly adjacent to each of
23 the fifteen study sites.

24 The approximate central point of each study site was determined. Three quadrats were
25 positioned 25 cm from the central point, corresponding to north, east and south. For each

1 quadrat, a 30cm x 30cm wire mesh grid with squares each measuring 2cm x 2cm was used to
2 estimate species frequency cover. Species were identified and then the numbers of squares in
3 which they occurred were counted within the quadrat to give an estimate of frequency cover.
4 All species present in each square were recorded. Voucher specimens of plant material were
5 taken and lodged in the Unitec herbarium (UNITEC). Environmental variables (light
6 readings, soil pH, soil moisture and organic content) were tested once at each study site to
7 test that the study sites were similar and thus comparable (Table 1). Light readings were taken
8 from the central point of each study site between 11.00-15.00 on a cloudless day (on the same
9 day), using a PASPort light sensor. Soil cores were taken at the central point of each
10 site (*Selaginella* and non-*Selaginella*). An 8cm bore cylinder was used to extract a core 10cm
11 deep of topsoil (Williams 1987). These samples were then tested to determine pH, organic
12 matter and soil moisture. The pH was determined by taking 100g from each soil core, mixing
13 with 250mL of deionised water, and allowing it to stand for two hours. The pH of the solution
14 was then read with a Mettler Toledo SevenEasy pH meter. Soil water content was
15 determined by placing a representative 100g of soil into a pre-weighed crucible and recording
16 total weight of soil and crucible. The soil was then placed in a drying oven at 90°C for 24
17 hours and crucible and dried soil reweighed to calculate the percentage soil water content.
18 The organic content of the soil was calculated using 10g of the oven dried soil, which was
19 ground in a pestle and mortar. The ground soil was then placed into a crucible and placed
20 over a bunsen flame for 15 minutes to incinerate all organic material. The weight of the burnt
21 soil was then subtracted from weight prior to burning.

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23 *Statistical analysis*

24 Two paired study samples were removed prior to analysis as the control study sites were
25 found to contain *S. kraussiana*. Paired t-tests were used to investigate differences in species

1 richness, frequency cover (abundance) and Simpson's D diversity indices (Simpson
2 1949) between the 13 paired study sites (excluding *Selaginella* from the data set for all
3 analyses as *a priori* site selection was part of the experimental design). Multidimensional
4 Scaling (Primer 6) and ANOSIM (Community Analysis Package 4.0) were performed in
5 order to compare the plant communities observed.

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7 **Results**

8 Soil moisture, light levels, soil pH and organic content were not measurably different
9 between study sites with and without *Selaginella*, indicating broadly similar environmental
10 conditions (Table 1). During the study, a total of 112 species of plants and lichens were
11 recorded, comprising 46 species of flowering plants and conifers, 10 ferns and fern allies, 30
12 mosses, 19 liverworts and 7 lichens. Study sites invaded by *S. kraussiana* had significantly
13 lower species richness than non-invaded study sites overall (Table 2), with 0-14 other species
14 present in quadrats in study sites with *Selaginella*, and 6-19 species identified when
15 *Selaginella* was not present. Only two lichen species were found in sites invaded by *S.*
16 *kraussiana*, while seven species were found in uninvaded sites. When the data was analysed
17 by plant group, flowering plants and conifers as a group had significantly lower species
18 richness than non-invaded sites, whilst no significant effect could be detected for mosses,
19 liverworts, lichens or ferns and fern allies (Table 2).

20 Study sites invaded by *Selaginella* had a higher total frequency cover of overall plant and
21 lichen species than non-invaded sites, although this was non-significant (Table 3), and we
22 could detect no effects when the data was analysed by plant group. Simpson's D diversity
23 index showed that diversity was measurably lower ($t = -2.43, p=0.03, d.f.=12$) when
24 *Selaginella* was present ($\bar{x}=3.04, SE=0.39$) than when absent ($\bar{x}=4.08, SE=0.43$).

1 Multidimensional Scaling showed that the *Selaginellasites* were generally relatively similar
2 to each other and formed a recognisable cluster within a diverse scatter of non-*Selaginellasites*
3 (Figure1). ANOSIM indicated that there was a measurable difference between the species
4 composition of sites with and without *Selaginella*, although the differences observed were
5 weak ($R=0.0617$, $p=0.026$) which was probably attributable to the *Selaginellasites* cluster
6 being within the scatter of non-*Selaginellasites*.

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8 **Discussion**

9 Sites with *S. kraussiana* at Spragg Bush had lower overall species richness,
10 particularly flowering plants and conifers as a group, when compared with sites without *S.*
11 *kraussiana*. This is in agreement with the findings of Barton *et al.* (2007), and similar results
12 have been noted in studies on other invasive plant ground covers. Stephens *et al.* (2008)
13 found that invasion of *Eucalyptus* woodland in Australia by bridal creeper (*Asparagus*
14 *asparagoides* (L.) Druce) had a negative effect on native plant biodiversity by reducing
15 species richness and abundance (frequency). They also found that bridal creeper had a greater
16 vegetation height than native species, reached 90-100% cover and reduced the amount of
17 light reaching the soil. Similarly, Standish *et al.* (2001) found that species richness and
18 seedling abundance in New Zealand podocarp/broadleaf forest remnants decreased with
19 increasing biomass of *Tradescantia fluminensis* Vell., an invasive groundcovering perennial
20 herb. They attributed this to a decrease in light availability. They also argued that invasion by
21 *Tradescantia* is likely to result in changes to the composition of the forest, with species such
22 as *Piper excelsum* G.Forst. particularly sensitive to increases in *Tradescantia*. In another
23 example, invasion of American forests by the mat-forming grass *Microstegium*
24 *vimineum* (Trin.) A.Camus was found to reduce native species richness and seedling density
25 (Oswalt *et al.* 2007). They suggested that this was due to competition for sunlight, nutrients

1 and water, seeds physically being prevented from reaching the soil. Similar examples have
2 been reported for woody shrubs, for example invasion by *Lantana camara* L. reduces native
3 species richness and abundance and alters community composition (Gooden *et al.* 2009).
4 In our study, sites with *S. kraussiana* had lower overall species richness but did not seem to
5 have a specific assemblage of species, and the same species were generally found in invaded
6 and non-invaded sites. This was confirmed by inspection of the MDS plot, where *S.*
7 *kraussiana* sites form a cluster within a scatter of non-*Selaginella* sites. Conversely, Stephens
8 *et al.* (2008) found that invasion by bridal creeper did not affect the presence of more
9 frequent native plants but negatively affected the rarer native plants. The suggestion that
10 some level of biotic homogenisation could be occurring as a result of invasion by *S.*
11 *kraussiana* is interesting, and warrants further study.

12 As *Selaginella* invades a site, it forms dense mats of stems and leaves, compared with sites
13 with no *Selaginella*, where the vegetation cover is sparser with some bare patches of soil.
14 Native plants and lichens do persist in mats of *Selaginella*, possibly with reduced species
15 richness for mosses and lichens. Mosses, liverworts and lichens were found in lower
16 frequency cover in sites with *S. kraussiana* present (although not significantly so). This
17 makes management of *Selaginella* with herbicides difficult, as other species would be
18 affected. Examination of the raw data showed that sites with *S. kraussiana* often had larger
19 sedge and grass plants when compared with uninvaded sites, which may explain the slightly
20 higher frequency cover observed for flowering plants and conifers.

21 It should be noted that it is impossible to know if invasion by *S. kraussiana* has caused
22 reduced species richness, or whether areas with lower species richness have been invaded
23 preferentially. Repeated measurements of species richness and abundance at the same sites
24 would be useful. It would be also be valuable to repeat this study in other forest types in

1 which *S. kraussiana* has invaded in order to examine any effects on species richness and
2 abundance.

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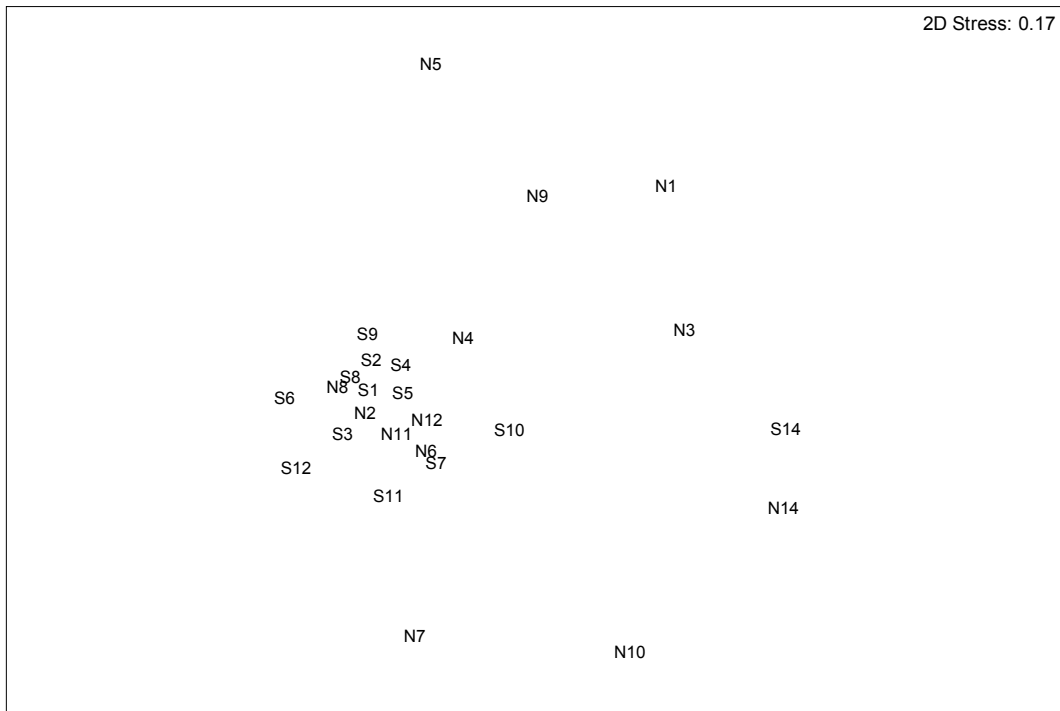
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20 altered community dynamics. *Journal of Ecology* 93, 1053-1061.

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4 **Figure1.MDS plot showing *Selaginella* sites (S) and non-*Selaginella* sites (N) (created in**
5 **Primer 6).**

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3 **Table 1. Mean and standard error of basic environmental variables for 13 paired study**
4 **locations. Paired *t* test tests (*ns* = non-significant; $p > 0.05$) were utilised to investigate variation**
5 **between locations.**

Environmental variable	<i>Selaginella</i>		<i>Selaginella</i>		<i>Paired t test</i>
	<i>present</i> (n=13)		<i>absent</i> (n=13)		
	\bar{x}	<i>SE</i>	\bar{x}	<i>SE</i>	
Soil moisture (%)	48.72	2.79	45.80	2.45	<i>ns</i>
Soil pH	5.75	0.07	5.54	0.12	<i>ns</i>
Organic content (g)	1.71	0.11	2.25	0.32	<i>ns</i>
Light ($\mu\text{mol.m}^2.\text{sec}$)	1.48	0.24	1.11	0.18	<i>ns</i>

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