Benefits of aerial 1080 possum control to tree fuchsia in the Tararua Range, Wellington.

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Abstract: The Department of Conservation established tree fuchsia (*Fuchsia excorticata*) monitoring in the Tararua Range in 1994 to determine the effectiveness of large-scale (66 000 ha) possum control for protecting fuchsia. We present results from data collected from 39 permanent plots on fuchsia tree stem survival, growth, and canopy condition between 1994 and 2004 using standard permanent plot and foliar assessment methods. Plots were established in four areas where possums were controlled or 'treated' by aerial application of sodium monofluoroacetate (1080) poison, and in one untreated area. More fuchsia stems died in the untreated area (29.8%) than in the treated areas combined (mean of 7%) over the duration of the study. Stem mortality was offset by a mean 3% (± 1.1% SEM) increase in fuchsia basal area in the treated areas, whereas basal area declined by 15% in the untreated area. Stem mortality occurred largely in smaller size-classes (<21 cm diameter) in all areas. Mean foliar cover showed a greater decline (42%) in the untreated area than in the treated areas (range 0 to 26%). Within two of the four treated areas, foliar cover declined as the interval between possum control operations lengthened. Our results clearly show that the conservation goal of preventing 25% mortality of tree fuchsia between 1994 and 2004 was successfully achieved in upland possum control areas.

Key words: Aerial 1080 poisoning, conservation outcome, *Fuchsia excorticata*, possum control, vegetation monitoring.

Introduction

Tree fuchsia (*Fuchsia excorticata*; kotukutuku) stands are important components of temperate New Zealand forests. They colonise and stabilise landslips, and may facilitate the succession of taller, longer-lived trees such as silver beech (*Nothofagus menziesii*) (Wardle, 1964). Their flowers and berries provide seasonal food for many native birds including kereru (*Hemiphaga novaeseelandiae*), tui (*Prosthemadera novaeseelandiae*) and bellbird (*Anthornis melanura*) (Thomson, 1880; Kirk, 1892). The nutritional attributes of fuchsia flowers and fruit, and the palatability of its leaves, also make fuchsia an attractive plant to the introduced possum (*Trichosurus vulpecula*) (Mason, 1958; Batcheler, 1983; Sweetapple and Nugent, 1999). Tree fuchsia is a preferred food of possums throughout New Zealand forests, particularly in the Westland and Wellington regions (Kirk and Bendall, 1919; Kean and Pracy, 1953; Mason, 1958; Franklin, 1967; Fitzgerald, 1976; Batcheler, 1983; Campbell, 1984; Atkinson, 1992; Rose *et al*. 1993; Owen and Norton, 1995; Pekelharing *et al.* 1998; Sweetapple *et al*. 2004). Palatability of fuchsia to possums is linked to high levels of macro nutrients (P, N, K, Mg, Ca) in foliage, and variation in palatability appears to be related to local site factors (Sweetapple and Nugent, 1999).

The severity of possum impacts on fuchsia can vary from browsing, defoliation, dieback, and death of individual trees, to localised extinction of fuchsia stands (Kean and Pracy, 1953; Batcheler, 1983; Campbell, 1984). Possums are selective in the species they target, and can have a disproportionate influence on some species that are naturally low in abundance, thereby altering forest composition (Mason, 1958; Owen and Norton, 1995). Although these impacts have been severe in places, some stands appear relatively unaffected by browsing despite a long history of possum occupation and high possum densities (Batcheler, 1983; Sweetapple and Nugent 1999).

The effects of browsing can persist through time, so that plant condition depends on the cumulative effects of browsing in previous years (Atkinson, 1992; Pekelharing *et al.* 1998). Where possum numbers have been managed or controlled to low densities (i.e. < 5% residual trap-catch index), there is evidence that fuchsia recovers its foliar canopy condition over time (Atkinson, 1992; Rose *et al*. 1993; Pekelharing *et al.* 1998; Bockett, 2001).

Fuchsia is potentially a useful indicator of possum numbers and impacts on forest vegetation. For example, a significant relationship between fuchsia defoliation and possum numbers was detected in Westland forests, where possums defoliated and killed fuchsia within two years once the possum trap-catch index exceeded 25% (Pekelharing *et al.* 1998).

The Department of Conservation has been monitoring tree fuchsia populations in the Tararua Range since 1994, to assess the effectiveness of possum control. The justification for the control programme was an observed decline in fuchsia within the upland silver beech (*Nothofagus menziesii*) forests between 1975 and 1985 (Field, 1993), where 25 % of fuchsia stems were lost in 10 permanent plots (PJB unpublished data). There were also historical observations of mature fuchsia trees killed by possums in the Tararua Range, with impacts particularly severe at lower altitudes, resulting in the local elimination of stands (Kean and Pracy, 1953; Franklin, 1967). The conservation goals of the Tararua possum control programme were to protect the foliar canopy cover of fuchsia stands, and reduce tree stem mortality below 25% in treated areas over 10 years (Field, 1993). Seven operational areas of between 7000 to 13000 ha were treated on a rotational basis once every seven years, since 1994.

In this paper, we focus on tree fuchsia survival and canopy condition in four areas treated by aerial application of 1080, and one untreated area. We test the hypotheses that possum impacts on fuchsia are less severe in treated areas, and that plant condition is better than in a comparable area without possum control.

Methods

Study Area

The axial mountains of the Tararua Range are mainly composed of sub-metamorphic sandstone (greywacke), with local argillites and occasional intrusive volcanics (Suggate *et al.* 1978). Average annual rainfall varies from 1200 mm to 6000 mm, and increases with altitude (Thompson, 1982). Gale force winds occur on at least 150 days each year, fog occurs on the tops on around 200 days, and snowfalls are common at higher altitudes in winter (Thompson, 1982).

The Tararua Range is being uplifted at about 2 mm a year, and the high rainfall leads to high erosion with accompanying high sediment yields (Pillans, 1986). As a consequence natural disturbances are frequent, with heavy rainfall, high winds, and earthquakes resulting in slips, extensive windfalls, and landslides. Tree fuchsia colonises new surfaces following natural disturbances, and stands are found throughout the range in upland forests (Holloway *et al.* 1963).

Field sampling

The stands of fuchsia we sampled varied in altitude from 570–1020 m. These stands overlap between subalpine silver beech forest and montane forests of silver beech, red beech (*N. fusca*) and kamahi (*Weinmannia racemosa*) (Franklin, 1967). Silver beech forest covers ca. 17 000 ha in the central and southern Tararua Range, forming a treeline at ca. 1200 m in parts of the eastern side of the range, although it is lower in the west and in gullies (Franklin, 1967). Tree and shrub species associated with fuchsia stands include broadleaf (*Griselinia littoralis*), horopito (*Pseudowintera colorata*), haumakoroa (*Raukaua simplex*), putaputaweta (*Carpodetus serratus*), Tararua lacebark (*Hoheria* sp. 'Tararua'), kanono (*Coprosma grandifolia*), and tree daisies (*Olearia arborescens, O. lacunosa*).

We surveyed fuchsia stands by aeroplane in winter from 1993 to 1996. The deciduous tree fuchsia stands were distinguished from surrounding vegetation as red-brown areas. Stands were marked onto 1:50 000 topographic maps within the 1080 possum control

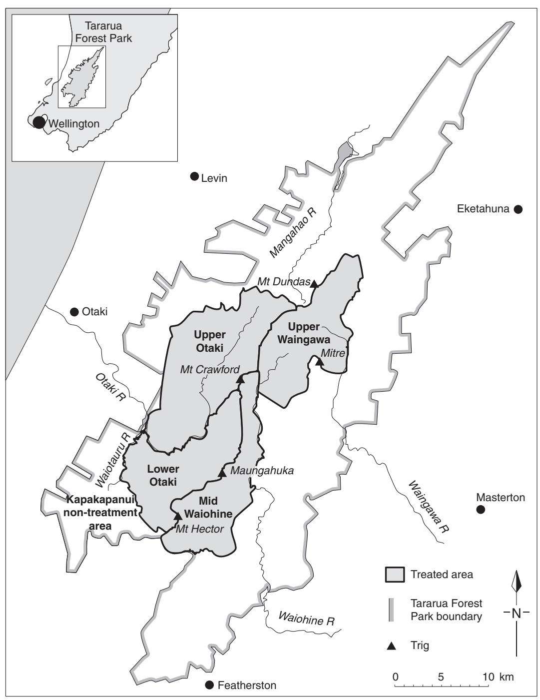

Figure 1. Map of the Tararua Range showing the four possum control areas, and the non-treatment area. These management areas contain the fuchsia (*Fuchsia excorticata*) monitoring plots.

Table 1. Possum-controlled areas in the Tararua Range. Where two figures are presented under 'Area', the second figure is the core control area plus an additional area treated in the return operation. Also shown are the numbers of fuchsia monitoring plots established to track tree fuchsia dynamics and condition.

Operational Area	Years treated	Area (ha)	No. fuchsia plots	No. fuchsia plots remeasured
Treated				
Upper Waingawa/Upper Waiohine	1994, 2001	7300, 9500	9	9
Mid Waiohine	1995, 2002	7600	8	8
Upper Otaki	1996, 2003	9500, 13000	5	5
Lower Otaki	1997	8600	8	7
Untreated				
Kapakapanui	N/A	8900	10	10

operational areas, and subjectively selected for sampling within each possum control area to reflect the altitude, aspect, and topographic variability.

We established 39 permanent plots in four of the seven possum treated areas on both sides of the range from 1994 to 1997 (Fig .1). Four of these areas were treated in different years, and three received a second treatment (Table 1). Ten permanent plots were established in Kapakapanui (c. 9000 ha), which was left untreated. Limited private possum trapping occurred at Kapakapanui in the montane zone in 2003, but we consider this is unlikely to alter our results, because we understand it was a small one-off harvest combined to the accessible ridge tops (Colin Giddy, Department of Conservation, Wellington, N.Z., *pers comm.*).

We compared the range of plot altitudes between the treated and untreated plots. Plots in the untreated area were at slightly lower altitude on average (783 $\pm$ 33 m SEM, n = 10, range 620–1000 m) than in the treated areas (884 $\pm$ 18 m SEM, n = 29, range 570–1020 m). Kapakapanui is also closer to the coast, and there may be local climatic differences influencing possum densities compared with the main range. However, both sets of plots had similar overstorey composition, with fuchsia stands typically surrounded by silver beech and occasional other hardwood canopy species. Horopito was ubiquitous in the understorey. A TWINSPAN analysis was conducted on understorey species composition with respect to altitude, but no clear separation between treated and untreated areas was observed (Philippa Crisp, unpublished data).

Stand dynamics

Permanent fuchsia monitoring plots were established based on the methods of Allen (1993). Plot size was reduced to 10 m × 20 m (200 m^2), sufficient to incorporate at least 10 fuchsia trees within each plot. The size and shape of fuchsia patches, often in narrow gullies, also precluded a larger plot size. Reduced plot size meant each plot was divided into eight contiguous 5 m × 5 m subplots. Within these subplots, we tagged and measured all stems of all woody species ≥ 3 cm DBH (diameter at breast height).

Foliar canopy cover measurements were recorded from 1996 using the techniques developed by Payton *et al.* (1993; 1999). The frequency at which different plots were remeasured varied from 3–7 years. We present results from the 39 plots which had at least two remeasurements of foliar parameters, and/or two permanent plot measurements. Results from treated areas are compared with untreated plots. Some plots were unable to be remeasured in 2002 in the untreated area and in one of the treated areas (lower Otaki), so were remeasured the following year. As we compared canopy cover between the initial and most recent assessments, we combined plot scores from 2002 and 2003 to show the differences between plots within an area over time.

Changes in foliar cover between sampling periods were compared using paired t-tests (Payton *et al.* 1999:37–39). Eighteen observers were used to assess canopy cover over the duration of the study. Although calibration between observers occurred and one of us (PJB) observed in every year (but not in every plot), it is likely that there was observer error between years. It is also possible that we may have initially over-estimated canopy cover due to inexperience with the technique. Consequently, we used a higher significance threshold (P<0.01) to detect differences between means.

Possum population dynamics

An index of possum density was calculated according to the National Possum Control Agencies trap-catch protocol (NPCA, 2002). The residual trap-catch rate (RTC) is an expression of how many possums are caught per 100 trap nights. Transects with 5–20 leg-hold traps, spaced 20 m apart, were randomly placed throughout each operational area for three consecutive fine nights, three months before and after possum control. The number of trap-lines varied in different operations with the size of the operational area (NPCA, 2002). Before 2002, possum trap-catch methods were done according to earlier versions of these protocols. The earlier methods may have provided a higher index of possum density compared with trap-catch indices done since 2002; however, we did not consider that this was likely to be significant enough to alter our interpretation.

Results

Stand dynamics

All areas lost fuchsia stems through mortality over the sampling period (Table 2). The untreated Kapakapanui area lost more stems in both absolute (81 of 272), and relative (29.8%), terms than the four treatment areas combined (48 of 678, or 7%). All untreated plots suffered stem mortality, with rates ranging from 13–83% of stems lost in individual plots. In contrast, not all plots in possum-treated areas had fuchsia mortality

Table 2. Change in tree fuchsia stem density (≥3 cm dbh) in four possum controlled areas, and an untreated area (Kapakapanui), in the Tararua Range since 1994. Note: Lower Otaki includes one plot first measured in 1995 (PC2) and one plot remeasured in 2002 (OT2).

Operational Area	No.	Total no. fuchsia stems			Range of	No. plots in
	Plots	1994/5	2002/3	% change	change in plots	which stems lost
Untreated						
Kapakapanui	10	272	191	-29.8%	-13% to -83%	10
Treated		**1995**	**2003**			
Upper Waingawa	9	196	179	-8.7%	0 to -25%	4
		1996	**2003**			
Mid-Waiohine	8	186	174	-6.5%	0 to -13%	5
		1996/7	**2003/4**			
Lower Otaki	7	179	164	-8.4%	0 to -21%	6
		1997	**2001**			
Upper Otaki	5	117	113	-3.4%	0 to -8%	2

Table 3. Change in mean (±1 SEM) tree fuchsia basal area (m^2 ha^{-1}), in four possum controlled areas and an untreated area (Kapakapanui) in the Tararua Range since 1994. Note: lower Otaki includes one plot first measured in 1995 (PC2) and one plot remeasured in 2002 (OT2).

Operational Area	No.	Mean plot basal area ± 1 SEM			Range of	No. plots in which
	Plots	1994/5	2002/3	% change	change in plots	basal area lost
Untreated						
Kapakapanui	10	36.2 ± 3.8	30.8 ± 4.5	-15%	+14% to -79%	7
Treated		**1995**	**2003**			
Upper Waingawa	9	52.5 ± 10.2	53.5 ± 9.5	+1.9%	+14% to -13%	1
		1996	**2003**			
Mid-Waiohine	8	46.9 ± 5.1	47.7 ± 5.7	+1.7%	+12% to -6%	3
		1996/7	**2003/4**			
Lower Otaki	7	39.3 ± 4.4	40.0 ± 5.2	+1.8%	+7% to -15%	3
		1997	**2001**			
Upper Otaki	5	44.4 ± 13.9	47.3 ± 4.1	+6.5%	+11% to +3%	0

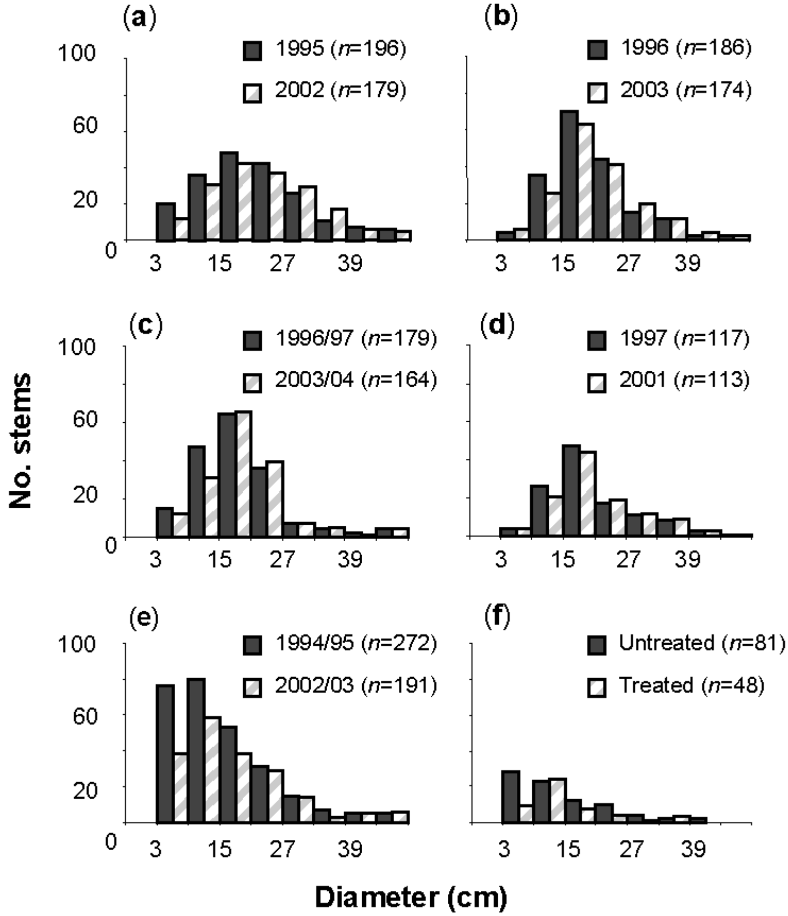

Figure 2. Change in fuchsia (*Fuchsia excorticata*) size-class frequency distributions over time in five operational areas, either treated with 1080 poison or untreated in the Tararua Range (**a**–**e**): (**a**) Upper Waingawa/Waiohine, (**b**) Mid-Waiohine, (**c**) Lower Otaki, (**d**) Upper Otaki (all treated), and (**e**) Kapakapanui (untreated). Also shown are size-class frequency distributions for dead stems in treated and untreated areas (**f**).

(41%). The magnitude of stem loss in plots was also lower, with a maximum loss rate of 25% of stems (upper Waingawa).

The untreated area had a reduction in fuchsia basal area of 15% (Table 3). In contrast, basal area increased by 1.7–6.5 % in the possum treated areas. The increase in fuchsia basal area in the treated areas offset losses due to the stem mortality in these plots. Only 25 % of 29 plots lost basal area in the four treated areas combined, compared to 70 % of the 10 untreated plots.

We examined fuchsia population structures to determine if there were differences in size-class frequency distributions between treated and untreated areas (Fig. 2). Size-class structures in each operational area had one modal peak (Figs 2a–e), suggesting that the majority of stems were recruited within individual areas around the same time. This assumes that growth rates were broadly similar within each area. Relatively even-aged cohort recruitment is consistent with the early colonising of fuchsia role after disturbance. All treated areas had > 50% stems between 3 and 20.9 cm DBH at their initial measurement, suggesting that populations were dominated by relatively small/young stems. Each size-class distribution peaked in the 15–20.9 cm diameter class in the treated areas, whereas the peak occurred in the 9–14.9 cm class in the untreated area (Fig. 2e). The untreated area had the greatest proportion (77%) of stems <21 cm DBH, suggesting that the population was slightly younger in the untreated area.

In the four treated areas, fuchsia population structures changed over time as stems moved into larger size classes (Figs 2a–d). Mortality in all plots was concentrated in smaller size-classes, suggesting self-thinning was occurring (Fig. 2f). However, mortality was two-fold higher in the untreated area than the four treated areas combined.

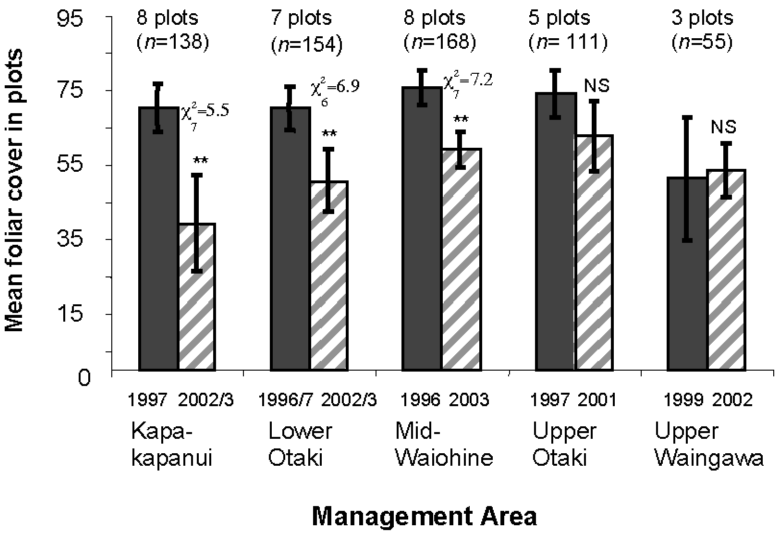

Figure 3. Change in mean foliar cover (±95% C.I) of fuchsia (*Fuchsia excorticata*) between years in different management areas either treated with 1080 poison or untreated in the Tararua Range. * = P<0.01, ** = P<0.001, NS = not significant.

Fuchsia canopy condition

Mean fuchsia foliage cover declined significantly in the untreated area, and in two of the treated areas (Fig. 3). Mean foliage cover assessed in 1996 and 1997 was similar (> 70% canopy cover) in these three operational areas. However, the decline in cover was greater in the untreated plots than in any of the treated areas. Mean foliar cover declined to <40 % by 2002/03 in the untreated plots. The greater relative decline in canopy cover in the untreated area compared with treated areas, suggests that there were real differences in fuchsia canopy condition.

There was also a significant decline in mean plot canopy cover in the lower Otaki and mid-Waiohine treatment areas over the same period (Fig. 3). Initial measurements at lower Otaki were made just before the possum control operation in 1997. Foliage canopy cover assessments done over the 2002 and 2003 years were 5–6 years after possum control. Canopy recovery after possum control appeared to be slow in mid-Waiohine. Canopy cover measurements were made 6–9 months after possum control in 1995 and 2002. However, average canopy cover in the 2003 measurement was significantly less than the initial assessments done in 1996 (Fig. 3).

To examine these changes in foliar cover patterns in more depth, we present data from individual plots in the three areas that had significant differences in mean cover between years (Fig. 4).

Seven of the eight untreated plots had significant declines in mean foliar cover (Fig. 4a). The decline occurred between 1997 and 1999 in four plots, and in the three plots that received their second assessment in 2001. One plot (KP 2) had the steepest decline in cover, and also suffered 83% stem mortality after 1997. No recovery in foliar condition was evident in the plots following the most recent assessments. However, two plots had further canopy decline between the second and third set of assessments.

Most plots in the treated areas at mid-Waiohine (Fig. 4b) and lower Otaki (Fig. 4c) also experienced a significant decline in canopy cover between the first and second assessments. In mid-Waiohine, mean canopy cover remained relatively stable between 2000 and 2003. Following the 1080 possum control operation in 2002, six of the eight plots showed signs of improving canopy cover by 2003.

In contrast, mean foliar cover continued to decline in Lower Otaki as the interval lengthened since possum control in 1997 (Fig. 4c). There were significant declines in canopy cover in four of the seven plots. Two plots (KI 1 and KI 2) had comparable canopy conditions to the untreated area by 2004, almost seven years after possum control.

Possum population dynamics

Possum numbers were comparable before possum control between the four treated areas (Table 4). Possum RTC's peaked from 6.9% to 10.9%. Possum RTC's were reduced by between 0.3% and 2.6% after the possum control operations. Between control operations, trend monitoring showed possum numbers increased substantially within three years in the lower Otaki and five years in the upper Waingawa. After five years, possum RTC was higher than pre-control levels in the upper Waingawa area.

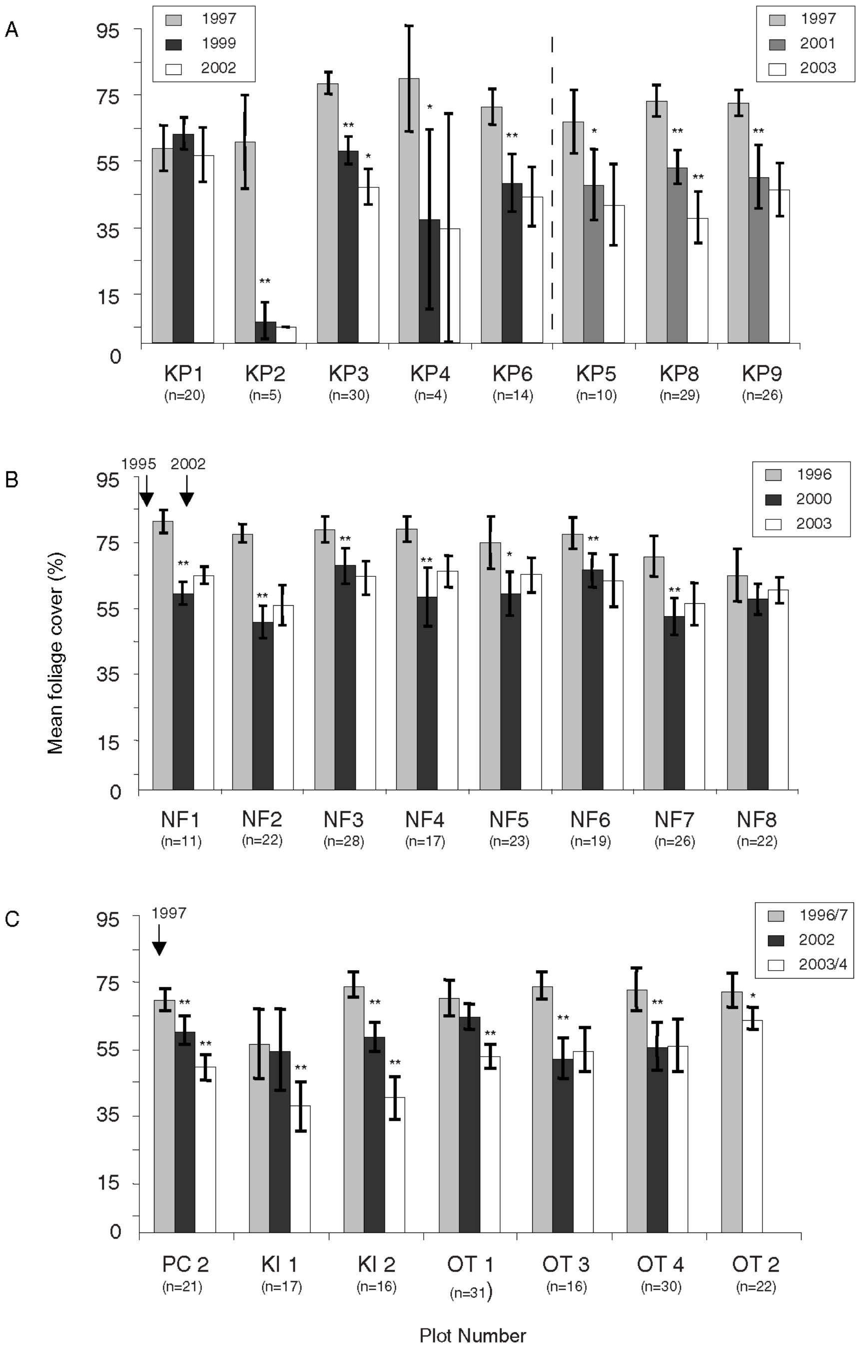

Figure 4. Change in mean foliar cover (± 95% C.I) of fuchsia (*Fuchsia excorticata*) assessed at different times over 7 years in three management areas of the Tararua Range. Kapakapanui (**a**) had no treatment, mid-Waiohine (**b**) had two 1080 operations to control possums, and lower Otaki (**c**) one 1080 application in 1997. The arrows represent the timing of aerial application of 1080 in the treated management areas (**b**, **c**). Asterisks represent significant differences between years (* = P<0.01, ** = P<0.001).

Table 4. Mean (±1 SEM) possum density index calculated by residual trap-catch (RTC) in possum controlled areas, and an untreated area, in the Tararua Range since 1994. ND is no data. Trend monitoring is monitoring of possum numbers between aerial 1080 operations, or in the absence of control.

Operational Area	Date pre-possum control monitoring	RTC (%)	Date post-control monitoring	RTC (%)	Trend monitoring
Treated					
Upper Waingawa	August 1994	6.9 ± 0.5	October 1994	0.3 ± 0.2	7.5 ± 2.1 (March 1999)
	August 2001	10.6	December 2001	2.0	
Mid-Waiohine	August 1995	10.4 ± 1.6	November 1995	0.7 ± 0.1	
	Not done		January 2003	2.6	
Upper Otaki	July 1996	7.3 ± 0.8	November 1996	1.4 ± 0.6	
	April 2003	9.7 ± 1.1	March 2004	2.2 ± 0.5	
Lower Otaki	Not done		November 1997	0.7 ± 0.2	6.2 ± 3.5 (November 2000)
	April 2004	10.9 ± 1.9			
Untreated					
Kapakapanui					15.5 ± 3.0 (July 2003)

Possum RTC was not done in the untreated area until July 2003, when trap-catch was 15.4% (Table 4). This was about 40% higher than the highest RTC in the four possum control areas (10.9% in the lower Otaki in 2004).

Discussion

Possum impacts on fuchsia stand dynamics

Our results show that there was substantially less fuchsia mortality and basal area loss, and greater mean foliar cover in areas with possum control (Tables 1 & 2, Fig. 3) than in areas without possum control. This is consistent with our hypothesis that possum impacts were likely to be less severe in treated areas, and that foliar cover would be greater. However, the evidence we present for possum impacts as the cause of mortality is indirect. Fuchsia size-class stem mortality patterns suggest there were probably a range of factors influencing stem death. We would have predicted *a priori* that mortality would be concentrated in larger (older) size-classes, due to cohort senescence (Veblen and Stewart, 1982; Mueller-Dombois, 1983). Stands originating after disturbance reach maturity, and begin to decline with old age, predisposing them to mass mortality. Persistent possum browse in old-growth stands can cause widespread dieback, in effect synchronising mortality (Payton, 1988; Stewart and Rose, 1988). Size-class structures in our study showed that stands were generally in the stem exclusion and understorey reinitiation phases (*sensu* Oliver, 1981). As most stems that died were in the smaller size-classes (3–20.9 cm diameter) in all management areas, it is likely that natural self-thinning was occurring. Mortality rates are highest for small stems (up to 18 cm diameter) in New Zealand forests as growing space becomes limited and competition intensifies (Coomes *et al*. 2003). However, natural stand thinning does not explain the severe mortality in several untreated plots, nor the greater decline in mean foliar cover relative to the treated areas.

We speculate that possum impacts may have hastened the mortality of stems already experiencing strong competition for resources from their neighbours. We have direct evidence from our observations of possum impacts on canopy foliage from leaf browsing, and territorial bark biting and scratching (unpublished data). Others have attributed foliar cover decline and mortality of tree fuchsia in lowland areas to possums defoliating stems (Rose *et al*. 1993; Smale *et al*. 1995; Pekelharing *et al.* 1998; Bockett 2001; Sweetapple *et al*. 2004). At four sites in south Westland with varying possum densities, Pekelharing *et al*. (1998) found that at low possum densities, there was evidence of defoliation but little mortality. This is consistent with our results in the four possum control areas. At higher possum densities, Pekelharing *et al*. (1998) showed that defoliation of fuchsia increased and mortality ensued (see also Rose *et al*. 1993). This is also what occurred in our untreated areas, where possum RTC's were higher than the treated areas. The mortality rate of stems ≥3 cm diameter in the untreated area was also over double the long-run average annual mortality rate of tree species in New Zealand forests (Bellingham *et al*. 1999).

Sampling design

Our study increases the understanding of possum impacts in upland areas, where impacts may be less obvious due to lower possum densities than occur in lowland areas. Possum densities in upland areas may fluctuate due to more severe climatic conditions and less favourable habitats, and this may affect the severity and duration of impacts. Our study suggests possum impacts are still occurring and affecting long-term forest processes, over a century since possums were first introduced to the Tararua Range (Pracy, 1962). These impacts were not just confined to the untreated area. Even following possum control, foliar cover declined in two of these four treated areas, particularly in the lower Otaki plots (Fig. 4c). Smale *et al*. (1995) identified a similar level of decline in fuchsia foliar cover despite intensive large-scale possum control in central Westland. Other studies have shown that fuchsia is highly preferred and sought after by possums, often resulting in severe impacts on this species (Fitzgerald, 1976; Owen and Norton, 1995; Sweetapple *et al.* 2004).

This interpretation of our results presumes that possum control is the significant variable between the treated and untreated areas. We consider it unlikely that the only native bird capable of extensively stripping leaves, the kereru, caused the damage we observed, as fuchsia buds and leaves are not a preferred food of this species (Ralph Powlesland, Department of Conservation, Wellington, N.Z., *pers comm*.). Therefore, we consider the history of possum management to be the most significant factor influencing fuchsia stem survival and condition. Possum numbers at the untreated area were about 40% higher than in the treated areas (Table 4). Higher possum densities in the untreated area could be an important factor in the differences in mortality and foliar cover observed. The 15% residual trap-catch (RTC) in the untreated area appears to be the threshold for intensive possum damage to fuchsia stands to occur in these upland forests, which is substantially below the 25% RTC suggested by Pekelharing *et al*. (1998) for Westland forests.

We are confident that a decline in fuchsia foliage cover did occur, particularly in Kapakapanui and lower Otaki operational areas (Fig. 4). However, we acknowledge that there was probably variation between observers, and between observers in different years (c.f. Payton *et al*. 1999). Sampling generally occurred between February and March each year, although some sampling was done in January and April depending on staff availability and weather conditions. Even allowing for these factors and potential overestimation of canopy cover in our initial measurements, we feel the differences in mean foliar cover were real. The important point is the magnitude of the decline in mean foliar cover between the treated and untreated areas, which was greater in the untreated area. Similar patterns have been found between catchments with different possum control histories in Westland. Between 2001 and 2003, mean foliar cover of 44%–56 % was recorded at nine sites under sustained possum control in Westland, while mean foliar cover of 33–46% was recorded in three untreated areas during the same period (Fiona Bockett, Department of Conservation, Hokitika, unpublished data).

Conservation management

Our results clearly demonstrate that the Department of Conservation has achieved its conservation goal of preventing a 25% decline in tree fuchsia stem numbers over the last 10 years by sustained possum control. It shows possum control seven years apart was adequate to maintain tree fuchsia in upland forests.

This study demonstrates the benefits of possum control to an ecologically important tree species in large tracts of forests. Other studies have demonstrated vegetation recovery following removal of possums (Atkinson, 1992), or the relationships between possum density and length of occupation with vegetation condition (Pekelharing *et al*. 1998; Sweetapple *et al.* 2004), but there is a shortage of information on long-term vegetation survival and condition in response to sustained 1080 possum control (Smale *et al*. 1993; Bockett, 2001). This is surprising given the substantial investment in possum control by the Department of Conservation over the past 15 years or so, particularly the widespread use of aerial 1080 poisoning. In areas treated with 1080 to control possums, we clearly show that fuchsia is more likely to survive and maintain a healthier foliar condition than untreated areas.

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References

Allen, R.B. 1993. *A permanent plot method for monitoring changes in indigenous forests*. Manaaki Whenua–Landcare Research, Christchurch, N.Z.

Atkinson, I.A.E. 1992 (unpublished). Effects of possums on the vegetation of Kapiti Island and changes following possum eradication. *DSIR Land Resources Contract report 92/52*. DSIR, Lower Hutt, N.Z. 68p.

Batcheler, C.L. 1983. The possum and rata-kamahi dieback in New Zealand: a review. *Pacific Science 37:* 415–426.

Bellingham, P.J.; Stewart, G.H.; Allen, R.B. 1999. Tree species richness and turnover throughout New Zealand forests. *Journal of Vegetation Science 10:* 825–832.

Bockett, F. 2001 (unpublished). *Foliar Browse Index (FBI) monitoring report: canopy condition of indicator species within the Landsborough management unit: 1994–2000*. Department of Conservation, Hokitika, N.Z.

Campbell, D.J. 1984. The vascular flora of the DSIR study area, lower Orongorongo Valley, Wellington. *New Zealand Journal of Botany 22:* 223–270.

Coomes, D.A.; Duncan, R.P.; Allen, R.B.; Truscott, J. 2003. Disturbances prevent stem size-density distributions in natural forests from following scaling relationships. *Ecology Letters 6:* 980–989.

Cowan, P.E. 1990. Brushtail possum. *In:* C.M. King (Editor), *Handbook of New Zealand mammals,* pp. 67–98. Oxford University Press, Auckland, N.Z.

Field, D. 1993 (unpublished). *Department of Conservation, Wellington Conservancy, possum control Tararua Forest Park, operations plan: 1994–1998*. Department of Conservation, Wellington, N.Z.

Fitzgerald, A. 1976. Diet of the opossum *Trichosurus vulpecula* (Kerr) in the Orongorongo Valley, Wellington, New Zealand, in relation to food-plant availability. *New Zealand Journal of Zoology 3:* 399–419.

Franklin, D.A. 1967. The synecology of the Tararua indigenous forests. *Technical Paper 53*. New Zealand Forest Service, Wellington, N.Z.

Holloway, J.T.; Wendelken, W.J.; Morris, J.Y.; Wraight, M.J.; Wardle, P.; Franklin, D.A. 1963. Report on the condition of the forests, subalpine-scrub lands and alpine grasslands of the Tararua Range. *Technical Paper 41*. New Zealand Forest Service, Wellington, N.Z.

Kean, R.I.; Pracy, L.T. 1953. Effects of the Australian opossum (*Trichosurus vulpecula*, Kerr) on indigenous vegetation in New Zealand. *Proceedings of the 7th Pacific Science Congress 4:* 1–8.

Kirk, H.B.; Bendall, W.E. 1919. Report on Kapiti Island as a plant and animal sanctuary. *Transactions of the New Zealand Institute 51:* 468–469.

Kirk, T. 1892. On heterostyled trimorphic flowers in the New Zealand *Fuchsias*, with notes on the distinctive characters of the species. *Transactions and Proceedings of the New Zealand Institute 25:* 261–268.

Mason, R. 1958. Foods of the Australian opossum (*Trichosurus vulpecula*, Kerr) in New Zealand indigenous forest in the Orongorongo Valley, Wellington. *New Zealand Journal of Science 1:* 590–613.

Mueller-Dombois, D. 1983. Canopy dieback and successional processes in Pacific forests. *Forest Science 37:* 317–325.

National Possum Control Agencies. 2002. *Protocol for possum population monitoring using the trap-catch method.* National Possum Control Agencies, Wellington, N.Z.

Oliver, C.D. 1981. Forest development in North America following major disturbances. *Forest Ecology and Management 3:* 153–168.

Owen, H.J.; Norton, D.A. 1995. The diet of introduced brushtail possums *Trichosurus vulpecula* in a low-diversity New Zealand *Nothofagus* forest and possible implications for conservation management. *Biological Conservation 71:* 339–345.

Payton, I.J. 1988. Canopy closure, a factor in rata (*Metrosideros*)-kamahi (*Weinmannia*) forest dieback in Westland, New Zealand. *New Zealand Journal of Ecology 11:* 39–50.

Payton, I.J.; Pekelharing, C.J.; Frampton, C.M. 1993. (unpublished) *Monitoring possum–related damage in native forests*. Landcare Research, Christchurch, N.Z.

Payton, I.J.; Pekelharing, C.J.; Frampton, C.M. 1999. *Foliar browse index: a method for monitoring possum* (Trichosurus vulpecula) *damage to species and forest communities*. Landcare Research, Christchurch, N.Z. 62p.

Pekelharing, C.J.; Parkes, J.P.; Barker R.J. 1998. Possum (*Trichosurus vulpecula*) densities and impacts of fuchsia (*Fuchsia excorticata*) in South Westland, New Zealand. *New Zealand Journal of Ecology 22:* 197–203.

Pracy, L.T. 1962. *Introduction and liberation of the opossum* (Trichosurus vulpecula) *into New Zealand*. New Zealand Forest Service, Wellington, N.Z.

Rose, A.B.; Pekelharing, C.J.; Platt, K.H.; Woolmore, C.B. 1993. Impact of invading brushtail possum populations on mixed beech-broadleaved forests, south Westland, New Zealand. *New Zealand Journal of Ecology 17:* 19–28.

Smale, M.C.; Rose, A.B.; Frampton, C.M.; Owen, H.J. 1995. The efficacy of possum control in reducing forest dieback in the Otira and Deception catchments, central Westland. *Science for Conservation 13*. Department of Conservation, Wellington.

Stewart, G.H.; Rose, A.B. 1988. Factors predisposing rata-kamahi (*Metrosideros umbellata-Weinmannia racemosa*) forests to canopy dieback, Westland, New Zealand. *GeoJournal 17:* 217–223.

Suggate, R.P; Stevens, G.R.; Te Punga, M.T. (Editors). 1978. *The Geology of New Zealand*. 2 vols. NZ Geological Survey. Government Printer, Wellington, N. Z.

Sweetapple, P.; Fraser, K.W.; Knightbridge, P.I. 2004. Diet and impacts of brushtail possum populations across an invasion front in south Westland, New Zealand. *New Zealand Journal of Ecology 28:* 19–33.

Sweetapple, P.; Nugent, G. 1999. Provenance variation in fuchsia (*Fuchsia excorticata*) in relation to palatability to possums. *New Zealand Journal of Ecology 23:* 1–10.

Thompson, C.S. 1982. The weather and climate of the Wairarapa region. *New Zealand Meteorological Service Miscellaneous Publication 115 (11).* New Zealand Meteorological Service, Wellington, N.Z.

Thomson, G.M. 1880. On the fertilisation of New Zealand flowering plants. *Transactions and Proceedings of the New Zealand Institute 13:* 241–288.

Veblen, T.T.; Stewart, G.H. 1982. The effects of introduced wild animals on New Zealand forests. *Annals of the Association of American Geographers 72:* 372–397.

Wardle, J. 1964. *Report on the resurvey of forests and scrubland of Tararua Range*. Unpublished NZ Forest Service Report, Christchurch, N.Z.

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