SHORT COMMUNICATION

Rapid recovery of kohekohe (*Dysoxylum spectabile*) following possum control

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Abstract: We document the rapid recovery of kohekohe (*Dysoxylum spectabile*) canopy cover following the control of brushtail possums (*Trichosurus vulpecula*) in Motatau Forest, Northland, New Zealand. Possum trap-catch rates were reduced from 25.6 ± 14.9% (mean ± SE) in 1997 (prior to control) to 2.7 ± 3.1% in 1999, but were little changed in Okaroro, an uncontrolled area nearby. Mean canopy cover scores for kohekohe in Motatau increased from 16.1 ± 4.5 % in 1997 to 52.6 ± 5.2% in 1999, but increased far less at Okaroro, from 42.3 ± 6.3% to 48.0 ± 7.75%. Changes of a similar nature, but of a much smaller scale, were recorded for four of the five other species monitored. For all six species combined, the increase in canopy cover at Motatau was much greater for the trees most heavily browsed initially, but there was no such pattern at Okaroro, further confirming that at least part of the observed increase in canopy cover was a response to the removal of possums.

Keywords: brushtail possums; foliar cover index; indicator species; kohekohe; response to possum control.

Introduction

Despite an immense effort over the last 50 years to protect forest canopies from browsing by brushtail possums (*Trichosurus vulpecula*), there are surprisingly few published examples of positive and substantial responses in canopy cover after possum control (Norton, 2000). The New Zealand Department of Conservation (DOC) currently spends at least $6 million annually on possum control (Department of Conservation, 2000). Much of that expenditure is aimed at canopy protection, either in its own right or to protect habitats for threatened species. Ideally, expenditure of this magnitude should be guided by a good understanding of the expected responses, but the present reality is that it is based more on presumption than on empirical data. However, more widespread and consistent monitoring of the outcomes of pest control since the mid-1990s (e.g. Saunders, 2000) means that the necessary empirical data is now accumulating rapidly, and this paper is intended to contribute to that.

We document the rapid recovery of heavily defoliated kohekohe (*Dysoxylum spectabile*) and also lesser responses for some other possum-preferred species. The study is part of a unique partnership between an iwi (an indigenous tribal group, Ngāti Hine), a state-owned research agency (Landcare Research) and a state management agency (DOC) that is aimed primarily at restoring the kūkupa (native pigeon, *Hemiphaga novaeseelandiae*) population and their habitat at Motatau in Northland. Kohekohe is culturally significant, partly as a food source for kūkupa, but also because the name kohe (ko = the action of, he = wrongdoing) denotes a connection between this plant and a person's spirit that helps that person become aware of wrong doing. Traditionally, when a person was extremely ill, kohekohe leaves were boiled up, and the patient bathed in the water for as long as was necessary for them to realize the wrongdoing that had caused the illness (K. Prime, *pers. comm.*).

In addition to kohekohe, we selected four other tree species and one tree fern as indicators of possum impacts on canopies. We monitored canopy condition immediately before and 2 years after possum control at Motatau. We used the Foliar Browse Index method (Payton *et al.*, 1999) that is now widely used as a tool to assess whether possum control does actually produce the desired benefits in the form of healthier forest canopies.

Methods

Motatau Forest (35°36'S, 174°04'E) is a 350 ha remnant of mixed angiosperm forest approximately 30 km northwest of Whangarei. The area is of special significance to the tangata whenua (the local Māori people), Ngāti Hine, because it is named for their maunga tapu (sacred mountain), Motatau, which lies just to the west of the native forest remnant. In the early 1990s, Ngāti Hine attempted to reduce possum numbers using a community employment scheme (Prime, 1993), but the effectiveness of those efforts is not known and the operation was not sustained. In 1994, Ngāti Hine formally took co-management responsibility (with DOC) for the forest, and in 1996 the research-and-management partnership outlined above was established. Intensive pest control (our experimental 'treatment') was initiated in spring 1997, using bait stations placed systematically throughout the area and repeatedly filled with poisoned bait (initially with sodium monfluoroacetate as the toxin and then brodifacoum).

In both Motatau forest (the 'treatment' area) and a broadly similar remnant, Okaroro (an approximately 250 ha 'non-treatment' area lying about 8 km to the north-west), we established five permanently marked transects. In September 1997 and 1999, we assessed both possum abundance and canopy cover of the six most common species known to be browsed by possums [kohekohe, taraire (*Beilschmiedia tarairi*), māhoe (*Melicytus ramiflorus*), towai (*Weinmannia silvicola*), tōtara (*Podocarpus totara*) and mamaku (*Cyathea medullaris*)] along the transects. We also monitored possum abundance at two other times over the 2-year period (Table 1). The experimental design is an unreplicated BACI (Before-After-Control-Impact) design (Underwood, 1993).

Possum abundance was assessed using a standard trap-catch method (National Possum Control Agencies, 2000), with 20 Victor No. 1 leg-hold traps spaced at 20-m intervals along each of the five transects, with catch monitored for three fine nights. Because kiwi (*Apteryx australis*) are present, traps were placed on raised platforms (i.e., as raised sets) 70 cm above ground level. In 1997, trapped possums in both areas were mostly released if uninjured, but in subsequent years they were all killed, so the 1999 traplines were placed parallel to, but 150 m away from, the permanent vegetation transects.

In each of the two areas, we located and tagged 8 to 46 individuals of each indicator plant species, using the 1997 trap sites as plot centres. For tōtara and mamaku, the least common species, all scoreable individuals (i.e., those whose canopies could be satisfactorily distinguished from those of neighbouring trees) within a 20-m radius of the plot were tagged. For the more common species we marked up to two individuals per plot, choosing those closest to the plot centre when more than two candidate individuals were available. In Motatau, very few tōtara were found on five main transects, so extra totara were marked on an additional transect placed in a different part of the poisoned area where they were common.

We recorded all of the standard measurements prescribed in the Foliar Browse Index method (Payton *et al.,* 1999), but, in this paper, draw only on the Foliage Cover score (FC: canopy cover expressed as a percentage of the canopy area) and the Browse score (the percentage of foliage browsed by possum, in five classes; unbrowsed, 1-25%, 26-50%, 51-75%, and 76-100% browsed).

The percentage of trees browsed (browse score > 0) was compared for each species, and for all species combined, between years and areas using Fisher's exact test. We calculated the change in foliar cover over the 2 years by subtracting the 1997 score from the 1999 score for each tree. For each species, the mean changes in foliar cover were then compared between years and areas using analysis of variance (SYSTAT, 1996), in which we treated the transect means rather than the individual trees as sampling units. To compare responses between browse classes, trees were categorised using the initial browse score as unbrowsed (1997 browse score = 0), lightly browsed (1-25%), or heavily browsed (> 25%). Trees were also categorised (and compared) into three broad 'degree of defoliation' classes using the initial FC scores as proxies for the classes (i.e., 1997 FC ≤ 25%, 35-55%, and ≥ 65%). Analysis of variance was then used to test for differences in canopy response between browse or defoliation classes, and whether the interaction between browse class or defoliation and area was significant. Finally, for all species and both areas combined, we compared mortality rates between the three defoliation classes using a two-way contingency table.

Results

Initial possum densities at Motatau and Okaroro appeared to be broadly similar (Table 1). By September 1998, possum control had successfully reduced densities at Motatau by approximately 90% while those at Okaroro (the non-treatment area) were little changed. The apparent increase at Okaroro over spring 1997 is believed to reflect a seasonal change in possum trappability, possibly combined with a good breeding season.

Table 1: Trap-catch rates (% ± 95% confidence limits) on raised sets at Motatau and Okaroro over the 1997–99 period.

		Motatau	Okaroro
September	1997	25.6 ± 14.9	32.6 ± 4.2
December	1997	11.7 ± 5.7	60.8 ± 11.0
September	1998	2.0 ± 4.1	30.4 ± 7.9
September	1999	2.7 ± 3.1	43.0 ± 15.2

In 1997, the percentages of kohekohe, mamaku and taraire browsed at Motatau were approximately twice those at Okaroro, but for the remaining three species the percentage of trees browsed was broadly similar (Table 2). For all species combined, the percentage of trees browsed at Motatau decreased from 79% in 1997 to 1% in 1999 (Fisher's exact test $P < 0.001$). Note, however, that the percentage of trees browsed also fell substantially in Okaroro, from 67% to 33% ($P < 0.001$).

In 1997, the mean foliar cover (FC) for each species was generally similar in both Motatau and Okaroro, apart from kohekohe and mamaku, for which markedly lower FCs were recorded in Motatau (Fig. 1). By 1999, the mean FC for all species had increased at both Motatau and Okaroro, with the largest improvements being seen at Motatau. By far the most dramatic response was for kohekohe at Motatau, with a mean FC increase of 36.4%. This compares with a significantly smaller increase of only 5.8% at Okaroro ($F_{1,6} = 28.84$, $P = 0.002$). Despite the small number of marked individuals, mamaku also showed a significantly greater increase in mean FC at Motatau (18.8%) than at Okaroro (3.8%; $F_{1,4} = 8.98$, $P = 0.04$). There was weak evidence suggesting that increase in FC for māhoe was also larger at Motatau than at Okaroro ($F_{1,8} = 4.04$, $P = 0.079$), but there were no significant improvements in FC at Motatau relative to those at Okaroro for towai, tōtara or taraire. For taraire, mean FC actually increased more at Okaroro (12.2%) than at Motatau (4.5%) ($F_{1,8} = 4.74$, $P = 0.06$).

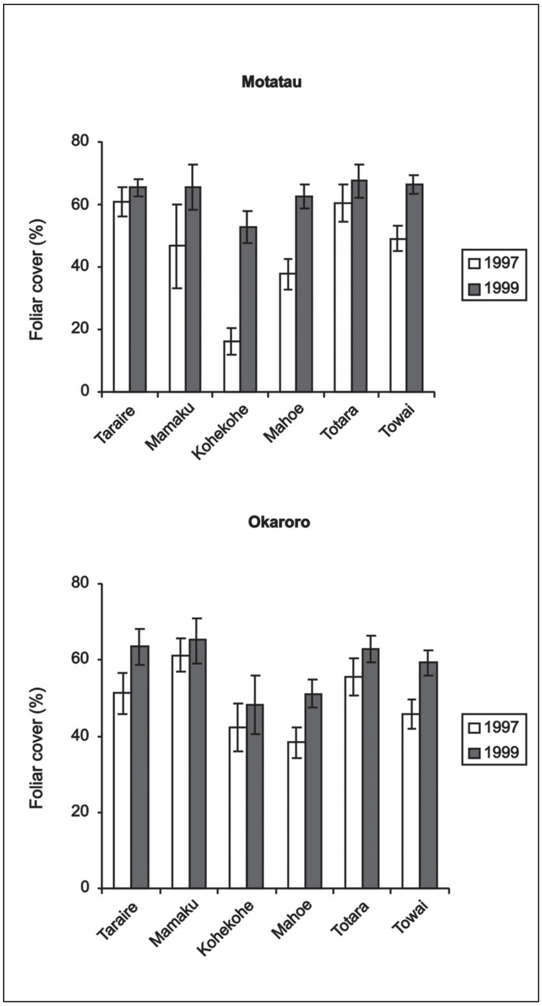

Figure 1. Foliar Cover (mean ± 95% confidence interval) scores for six plant species in 1997 and 1999 at Motatau and Okaroro.

Table 2: Percentage of trees browsed in 1997 and 1999 at Motatau and Okaroro.

	Motatau			Okaroro		
	n	1997	1999	n	1997	1999
Taraire	42	38.1	0.0	32	15.6	0.0
Mamaku	13	84.6	0.0	8	37.5	0.0
Kohekohe	46	91.3	0.0	37	56.8	27.3
Māhoe	45	82.2	0.0	42	81.0	45.0
Tōtara	22	100.0	9.1	47	100.0	70.2
Towai	35	94.3	0.0	32	78.1	12.5
Total	**203**	**79.3**	**1.0**	**198**	**66.7**	**33.3**

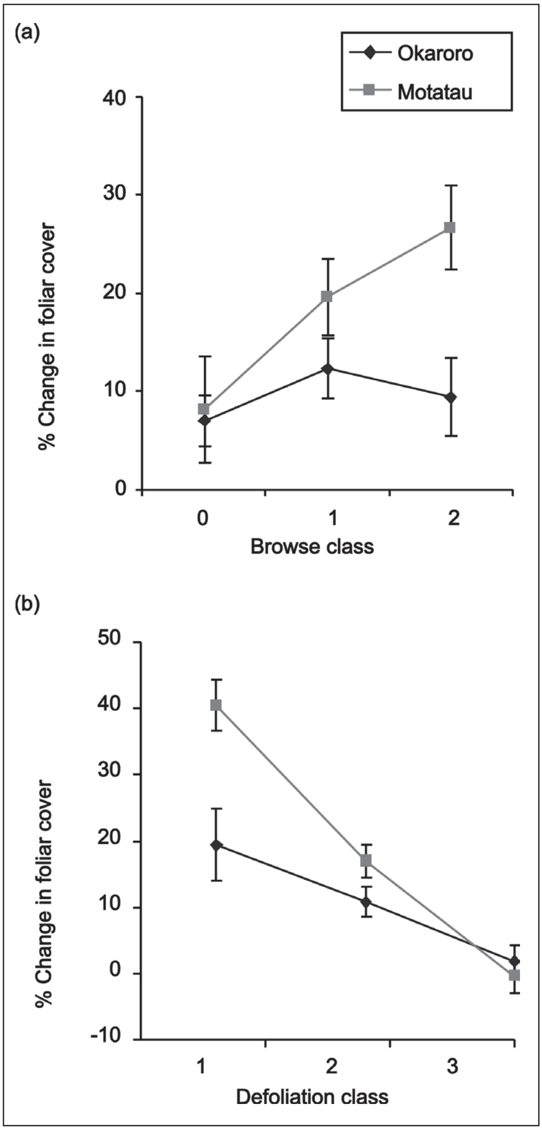

Figure 2. Changes in Foliar Cover for all species combined (mean ± 95% confidence intervals) by (a) initial browse class (0 = not browsed in 1997; 1 = ≤ 25% of leaves browsed; 2 = > 25% of leaves browsed); (b) initial degree of defoliation class (1 = 1997 FC ≤ 25%, 2 = 35-55%, and 3 = ≥ 65%) at Okaroro and Motatau.

For all species combined, the trees at Motatau that were more heavily browsed in 1997 showed the largest improvements in foliar cover, but there was no difference between major browse classes at Okaroro (Fig. 2a; $F_{2, 378} = 39.63$, $P < 0.001$). Although the same pattern held for most of the indicators, kohekohe was the only species for which this interaction effect between browse class and area was significant ($F_{1, 6} = 8.05$, $P = 0.03$). In both forest blocks, mean FC increased far more for trees that initially had low cover scores (1997 FC ≤ 25%) than for trees with intermediate scores (1997 FC = 35-55%) and changed little for trees with high initial foliar cover (1997 FC ≥ 65%; Fig. 2b). The recovery of defoliated trees was far more marked at Motatau than at Okaroro, as shown by the significant interaction effect between these broad defoliation classes and block ($F_{2, 376} = 19.4$, $P < 0.0001$).

The rapid recovery of kohekohe is most clearly illustrated by comparing the 1997 and 1999 distributions of FC at Motatau and Okaroro. In 1997 most trees at Motatau were heavily defoliated, but by 1999, 85% had FCs > 25%, whereas about one-third of trees at Okarora had FC scores ≤ 25% in both years (Fig. 3).

At Okaroro, 11% (n=4) of the kohekohe and 4.8% (n=2) of the māhoe tagged in 1997 had died by 1999, but just 2.2% (n=1) of each species had died at Motatau. No other trees died at Okaroro, but 2.9% (n=1) of the towai and 7.7% (n=1) of the mamaku at Motatau died. Both of these latter two trees had been heavily browsed in 1997 and had low initial FC scores. Although there were no significant differences in mortality for the individual species between the two blocks, mortality across both areas combined was significantly higher for those trees most heavily defoliated in 1997 ($\chi^2_2 = 25.8$, $P < 0.001$), and only affected trees with 1997 FC scores below 35%.

Discussion

The decrease in possum browse pressure at Okaroro, even though possum catch rates remained as high or higher than in 1997, is puzzling. Possible explanations are (i) observer bias; i.e., observers may have consistently overestimated the percentage of leaves browsed in 1997, (ii) a temporary reduction in possum density along the transects for some months after possum removal during successive trappings, or (iii) possums may have switched to other foods such as fruit that may not have been as abundant in early 1997. The increase in mean foliar cover for all six species at Okaroro (Fig. 1) strongly suggests there was a real reduction in possum browse pressure in both areas, but it is clear the reduction in browse pressure was far more marked at Motatau. By 1999, possum browsing of foliage of all species at Motatau, other than totara, had fallen to zero even though about 10% of the possum population remained. For tōtara the decline in browse pressure was proportional to the decline in possum density. This suggests a shift in possum diet to other foods such as fruit, flowers, or highly preferred but rare foliar foods, parallel with that recorded after possum

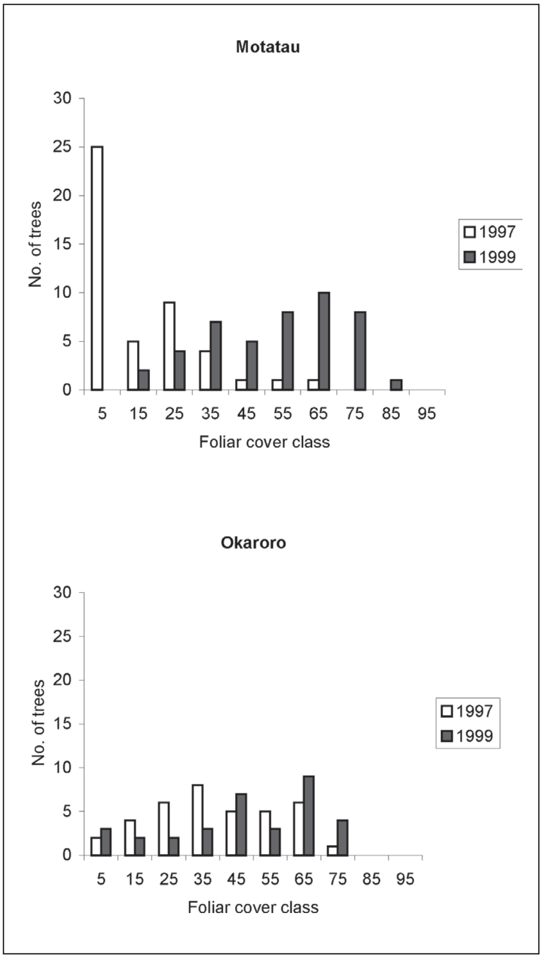

Figure 3. Distribution of Foliar Cover scores for kohekohe in 1997 and 1999 at Motatau and Okaroro.

control in angiosperm forest in the central North Island (Nugent *et al.,* 2000).

Despite the lack of replication in our study, the large increase in foliar cover of the most heavily browsed trees at Motatau (Fig. 2a) leaves little doubt that most of the increase was a direct response to the removal of possums and the subsequent reduction in browse pressure (particularly for kohekohe). The lesser improvement of the heavily defoliated trees at Okaroro (Fig. 2b) makes it clear that the difference between blocks is not just a consequence of the greater initial level of defoliation at Motatau. The low mean foliar cover for kohekohe recorded at Motatau in 1997 is consistent with, but even lower than, that reported in other areas of Northland (e.g. Puketi Forest) where possum impacts were severe (Payton *et al.,* 1999). Within just 2 years of sustained possum control at Motatau, however, mean FC for kohekohe had recovered to within 10-15 percentage points of the FC score recorded on possum-free Waiheke Island in the Hauraki Gulf (Payton *et al.,* 1999). Whether the kohekohe will continue to recover, or stabilise near present levels (because the environment at Motatau differs from that on Waiheke Island) will be determined by ongoing monitoring, but the preliminary indications are that the recovery continued in 2000.

The reduction of the possum population at Motatau appears to have been timely. The 5.5% p.a. mortality observed for kohekohe at Okaroro was apparently averted at Motatau even though many of trees at Motatau were initially almost totally defoliated. The mortality rate at Okaroro matches the 2.0-2.6% p.a. mortality of kohekohe over 10 years recorded on two plots in the Coromandel Ranges by Ogden and Buddenhagen (1995) but, in contrast to their study where mortality affected all sizes of kohekohe, the trees that died in our study were all small (9-15 cm trunk diameter) individuals. Ogden and Buddenhagen (1995) regard kohekohe as a “critical indicator” of the health of the conifer-angiosperm forests of the northern North Island at sites where it is a dominant canopy forming species, as “it is potentially a long-term component of the forest canopy”. If so, an important question is what level of possum control is necessary to protect kohekohe, and thus maintain the biodiversity and structural integrity of these forests?

Browse pressure (and therefore canopy condition and, ultimately, mortality rate) is clearly linked in some way to possum density, and for each species in each area there will be a trap-catch rate below which a species is adequately protected from possums (i.e., a protection threshold level). For example, midway through a current 10-year study we have found little evidence of major possum impacts on mean FC for tawa (*Beilschmiedia tawa*), kamahi (*Weinmannia racemosa*) and mahoe at raised set trap-catch rates below about 20% (G. Nugent, *unpubl.*). In contrast, foliar cover of fuchsia (*Fuchsia excorticata*) in South Westland forests declined once trap-catch exceeded 5%, and most died within a few years once trap-catch exceeded 25% (Pekeharing *et al.,* 1998). Likewise, a mistletoe species (*Tupeia antarctica*) appeared likely to persist in the Waihaha catchment, central North Island, only when trap-catch rates were below 5% (Sweetapple *et al.*, 2002).

The magnitude of the recovery in kohekohe at Motatau was obviously only possible because the trees were so heavily defoliated initially. However, the speed of the recovery at Motatau suggests the protection threshold is well above the 3% trap-catch recorded there, especially since that catch rate is for raised sets that sometimes catch fewer possums than ground sets (G. Nugent, *unpubl.*). Payton *et al.* (1997) reported a much smaller response over 4 years in kohekohe following possum control at Waipoua than in this study, and the improvement was not statistically significant. Ground-set trap-catches there were 22% before control and 7-9% after control. Ignoring the possibility that protection thresholds may vary between areas, this suggests the threshold is at or just below 7% trap-catch using ground sets. However, we consider that the lack of a statistically significant response at Waipoua is likely to have been a Type II statistical error (i.e., there was a real response but because it was small in size the null hypothesis of no change could not be rejected). We believe this is a result of the low levels of defoliation at the start of that study, which meant there was little scope for any major response. The low levels of initial impact are consistent with possums having not long been present (< 30 years) at Waipoua at the start of the study, and with evidence from an adjacent area where possums were not controlled, in which the degree of defoliation in kohekohe and several other species increased significantly during the 5-year period. Elsewhere, mean kohekohe FC scores of *c.* 50% (i.e., below the 60-70% recorded in possum-free areas) have been recorded at trap-catch rates of 10-20%, but scores > 60% have also been recorded in areas with TC > 20% (P. Sweetapple, *unpubl.*).

On balance, we consider it likely that where kohekohe is common its canopies will generally be protected when ground-set trap-catch rates are reduced below about 10%. Kohekohe may be more susceptible in areas where it is uncommon, because there is an apparent tendency for possums to favour a species more when it is rare relative to other similarly preferred tree species (Nugent *et al.*, 2000). Maintaining possum densities at levels that protect kohekohe appears likely to also protect māhoe, mamaku, towai and taraire, as these species were less seriously affected initially.

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