Browse on mahoe and kamahi leaf-fall as a trigger for possum control

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Abstract: Introduced brushtail possums (*Trichosurus vulpecula*) are controlled over large parts of New Zealand to protect canopy trees. The condition of canopy trees is one of the cues used to trigger possum control, but selecting an indicator of canopy tree condition is difficult because many factors unrelated to possum browsing can affect canopy condition, and indices based on canopy scoring may not always quickly detect real changes in possum herbivory. We therefore investigated the usefulness of the percentage of fallen mahoe (*Melicytus ramiflorus*) and kamahi (*Weinmannia racemosa*) leaves browsed by possums ('fallen-leaf browse' or 'FLB') as a trigger for control aimed at protecting these tree species. We collected leaves falling from kamahi and mahoe trees every two months for two years at two study areas in the central North Island, one with initially high possum abundance (Oriuwaka) and the other with low possum abundance (Otupaka). We classified each of 92 384 leaves as either not-browsed, possum-browsed or insect-browsed. There was a strong and similar seasonal pattern in the mean number of fallen leaves per tree for both mahoe and kamahi at both study areas; fewest leaves fell in winter, and the most leaves fell in spring and early summer. Mahoe and kamahi FLB exhibited a similar seasonal pattern at both areas, being lowest in winter and highest in spring and early summer. FLB for both mahoe and kamahi declined following control of possums to low densities at Oriuwaka. The proportion of fallen mahoe and kamahi leaves browsed by possums was small compared with those browsed by insects or not browsed. We show that spring/early summer (i.e. September–December) is the best period for sampling FLB and that the mean FLB can be estimated with a CV of 20% if one trap is randomly placed under the canopy of each of 24 randomly located trees. However, CVs were much larger in other seasons and when possum abundance was low. We consider FLB to be a sensible trigger for initiating possum control when the objective of control is to protect canopy trees, but further work is needed to determine the relationships between possum abundance, FLB, canopy condition, and key tree demographic rates.

Keywords: browse; herbivory; insects; kamahi; litterfall; mahoe; possums; possum control; sampling; Whirinaki.

Introduction

The New Zealand Department of Conservation controls introduced brushtail possums (*Trichosurus vulpecula*) over about $1{\times}10^6$ ha at an annual cost of about $12.5 million (Parkes and Murphy, 2003). The strategic approach is to kill a large proportion of the target population and then apply repeated or maintenance control in an attempt to sustain the benefits (Parkes and Murphy, 2003). Maintenance control is applied at a variety of frequencies from almost continuous control or annually (as a 'press' strategy) up to once every seven years (as a 'pulse' strategy) (Parkes and Murphy, 2003). The intensity of each control application may also vary, resulting in different reductions in possum densities and variable mean densities of possums between control events. Managers choose to apply different frequencies of maintenance control based on different monitoring cues. Some managers apply control at set time intervals (e.g. every five years). Other managers monitor the possum population as it recovers and reapply control when some density is reached. Still other managers monitor the conservation resources affected by the possums and react with more control when the impacts become unacceptable.

The 'press' strategy will maximise benefits at the chosen areas but, because it is the most expensive strategy per hectare per year, a fixed national budget would treat only a small part of the total possum problem if this was the only strategy applied. In contrast, the 'pulse' strategies treat increasingly larger areas but are likely to provide increasingly fewer benefits as the control frequency increases (Choquenot and Parkes, 2000). These costs (control frequency, control intensity and monitoring costs) and net benefits (acceptable conservation benefits multiplied by the area treated) are being investigated under an adaptive experimental management project (Parkes *et al*., in press) in which monitoring cues are set at different levels to trigger different frequencies of maintenance control.

One of the triggers for possum control is resource condition, but selecting a suitable indicator to monitor is difficult (Parkes and Choquenot, 2000). The condition of forest trees affected by possums is the measure of benefit of possum control most often used by the Department of Conservation. A protocol (Payton *et al*., 1999) using ground-based scoring of the percentage of canopy foliage that has been browsed by possums ('foliar browse index' or 'FBI') and/or the percentage cover of foliage in the tree's canopy ('foliage cover index' or 'FCI') has been widely used in New Zealand to monitor the effects of possums on tree condition (e.g. Payton *et al*., 1997; Pekelharing *et al*., 1998). Aerial photography has also been used to estimate large-scale changes in canopy tree condition (e.g. Rose *et al*., 1992). However, there are at least three potential problems with using these indices as triggers for possum control. First, many factors unrelated to possums (and beyond the control of managers) can affect canopy condition (e.g. Veblen and Stewart, 1982), resulting in no improvement in canopy condition following possum control. Second, the indices may only be able to reliably detect large changes in canopy condition, with biologically important impacts of possums not detected for many years (i.e. a time lag between impacts and their detection). Nonlinear relationships between possum abundance and some impacts (Nugent *et al.,* 2001) may also contribute to important impacts not being detected for many years. Third, impacts on the same plant species vary between areas with apparently similar possum densities (e.g. Sweetapple and Nugent, 1999) for reasons not well understood (Payton, 2000).

One possible solution to these problems is to use a more immediate measure of possum herbivory, such as the percentage of possum-browsed leaves collected in leaf-fall traps ('fallen-leaf browse' or 'FLB'; Numata, 1998). Numata (1998) showed that the fallen-leaf browse of northern rata (*Metrosideros robusta*) at Whirinaki Forest Park declined after possums were controlled, but concluded that further work was required to determine the suitability of this technique as a trigger for possum control.

Our study was designed to achieve the following four objectives. (1) To determine how fallen-leaf browse from kamahi (*Weinmannia racemosa*) and mahoe (*Melicytus ramiflorus*) changes following a large reduction in possum abundance. Kamahi and mahoe are two common tree species that form a significant proportion of possums' diet in many forest habitats (Nugent *et al*., 2000) and are commonly monitored using indices of canopy condition (e.g. Payton *et al.*, 1997). (2) To determine the best month(s) for sampling fallen-leaf browse. (3) To determine the sample sizes required for estimating fallen-leaf browse with a CV of ≤20%. Thompson *et al.* (1998) suggested that a CV of ≤20% is desirable in monitoring studies. (4) To determine which of kamahi and mahoe is the best species for monitoring using fallen-leaf browse.

Methods

Study areas

We conducted our study at two areas in the central North Island (see Powlesland *et al.*, 2003 for a detailed description and location map). Elevations in the 3900-ha Oriuwaka area ranged from 475 to 600 m a.s.l., whereas the elevations at 2200-ha Otupaka area ranged from 600 to 900 m a.s.l. Nichols (1976) classified the vegetation in this region as rimu-matai-hardwood forest. The two study areas had similar vegetation, with an almost continuous forest of occasional kahikatea (*Dacrycarpus dacrydioides*), rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), and matai (*P. taxifolia*) among frequent tawa (*Beilschmiedia tawa*), kamahi and mahoe (Morton *et al*., 1984). Other species present included hinau (*Elaeocarpus dentatus*), totara (*Podocarpus totara*), *Nestegis* spp., red beech (*Nothofagus fusca*), wheki (*Dicksonia squarrosa*), *Cyathea smithii*, pepperwood (*Pseudowintera colorata*), wineberry (*Aristotelia serrata*), and kaikomako (*Pennantia corymbosa*) (Morton *et al.*, 1984). However, above 750 m at Otupaka there was a mixture of rimu, miro, red beech and Hall's totara (*Podocarpus hallii*), and above 840 m an almost continuous red beech canopy (Morton *et al.*, 1984).

Although the two areas were separated by only 4 km, they were managed as 'independent' units by the Department of Conservation. Oriuwaka had no recent history of possum control. The possum trap-catch index ('TCI'; Warburton, 2000) in February 2000, estimated using six lines of 20 leg-hold traps, was 32.9% (95% confidence interval; 21.7–44.0%). Although the TCI is a nonlinear index of abundance, an estimate of >30% indicates high possum densities (Forsyth *et al*., 2005). In 2001, Oriuwaka was subdivided into 14 blocks. Trapping to control possums was conducted on a block-by-block basis during April–August 2001 and July–November 2002. A post-control TCI was estimated in each block using three lines of 20 traps each or five lines of 10 traps each. The highest mean TCI recorded in a block post-control was 5.0%. Hence, possums were reduced from high abundance to low abundance.

In contrast to Oriuwaka, possums at Otupaka had been reduced from high abundance to low abundance six months prior to our study. A pre-control survey in February 2000, using six lines of 20 traps each, estimated a TCI of 31.4% (23.2–39.6%). An aerial control operation was conducted on 17 May 2000 using 0.05% 1080 in carrot. A post-control survey in May 2000, using six lines of 20 traps each, estimated a TCI of 4.4% (1.7–7.1%).

Study design

We aimed to monitor patterns of browse on 30 individuals of each of mahoe and kamahi in both study areas. We attempted to randomly select individuals of both species by locating the nearest adult canopy or sub-canopy tree at 30 randomly generated locations in each study area. We used a hand-held global positioning system (Garmin® eTrex or 12XL, Garmin International Inc., Olathe, KS, U.S.A) to navigate to each location and then searched in ever-increasing concentric circles until a tree was found. However, at some sites we could not locate an individual of each species; when this occurred we located additional trees within sites in which we knew that species to be present (i.e. in sites that we had previously searched). At Oriuwaka we monitored leaf-fall under 28 mahoe trees at 22 sites and 27 kamahi trees at 21 sites. At Otupaka we monitored leaf-fall under 34 mahoe trees at 21 sites and 28 kamahi trees at 17 sites.

Two leaf-fall traps (Beveridge, 1965) were randomly located under the canopy of each selected tree. The mouth of each trap had a surface area of 0.283 m^2 (i.e. a diameter of 60 cm) and was installed 110–120 cm above the ground. The 'net' of each trap was made of free-draining gauze. The contents of each trap were emptied into a plastic bag every two months and frozen as soon as possible, typically within two days of collection.

Mahoe and kamahi leaves (*n* = 92 384) were sorted by staff at Landcare Research, Lincoln, into four classes: 'possum-browsed, 'insect-browsed', 'not-browsed', and 'browsed by an unknown herbivore'. The first three classes were defined following Fig. 1 in Payton *et al*. (1999); see also Fig. 3 in Meads (1976). We also fed kamahi and mahoe leaves to captive possums at the Landcare Research animal care facility, Lincoln, and made a reference collection from the resulting partially consumed leaves. Leaves partially eaten by insects were smooth, but leaves partially eaten by possums were torn. However, sorters were sometimes uncertain about some browsed leaves; these leaves were set aside and later classified by P. Sweetapple (Landcare Research, Lincoln). Since none of the sorters collected the samples in the field or was familiar with the study design, we effectively had a single-blind study design.

We defined each tree as occupying either the canopy or sub-canopy. We also scored the FCI of each tree at the start (November 2000) and end (November 2002) of our study. The FCI was scored by standing under the canopy and estimating the amount of foliage present in 10 classes from a minimum of 5% to a maximum of 95%.

Statistical analyses

Means and 95% confidence intervals for the numbers of fallen leaves and the percentages of fallen leaves in the four classes were calculated for each tree (i.e. the mean of the two traps under each tree was used). 95% confidence intervals for means were calculated using 10 000 bootstrap samples (Manly, 1997).

We also used bootstrapping to evaluate the relationship between the coefficient of variation (CV) and the number of traps per tree and the number of trees sampled. Simulations were conducted for both kamahi and mahoe at Oriuwaka, and kamahi at Otupaka, using the January 2001 data. Simulations could not be conducted sensibly for mahoe at Otupaka because 94% of traps under that species had no possum-browsed leaves, resulting in high CVs.

Results

Patterns of leaf-fall and browse

There was a strong and similar seasonal pattern in the mean number of fallen leaves per trap for both mahoe and kamahi at both study areas (Figs. 1 and 2). The lowest numbers of fallen mahoe leaves were recorded in the July samples, but thereafter the numbers increased to a maximum in the January samples before declining to a winter minima. The lowest numbers of fallen kamahi leaves were recorded in the July and September samples, but thereafter the numbers increased to maximums in the January and March samples before declining to a winter minima.

Mahoe FLB exhibited a similar seasonal pattern at both study areas (Figs. 1b and 2b), being lowest in winter and highest in the September, November and January samples. Mahoe FLB was higher at Oriuwaka than at Otupaka in the first 12 months of the study, but there was little difference in the second 12 months; this pattern corresponded with the higher abundance of possums at Oriuwaka in 2001, but thereafter the abundance of possums at both study areas was similarly low. The 95% confidence intervals for FLB of both mahoe and kamahi at Otupaka always included zero. The relatively high FLB recorded at Otupaka in November 2002 was caused for mahoe by all five leaves in one trap being browsed by possums, and for kamahi by one leaf in one trap being browsed by possums. Kamahi FLB followed a similar seasonal pattern to mahoe, with highest FLB at both study areas in the September, November and January samples, and

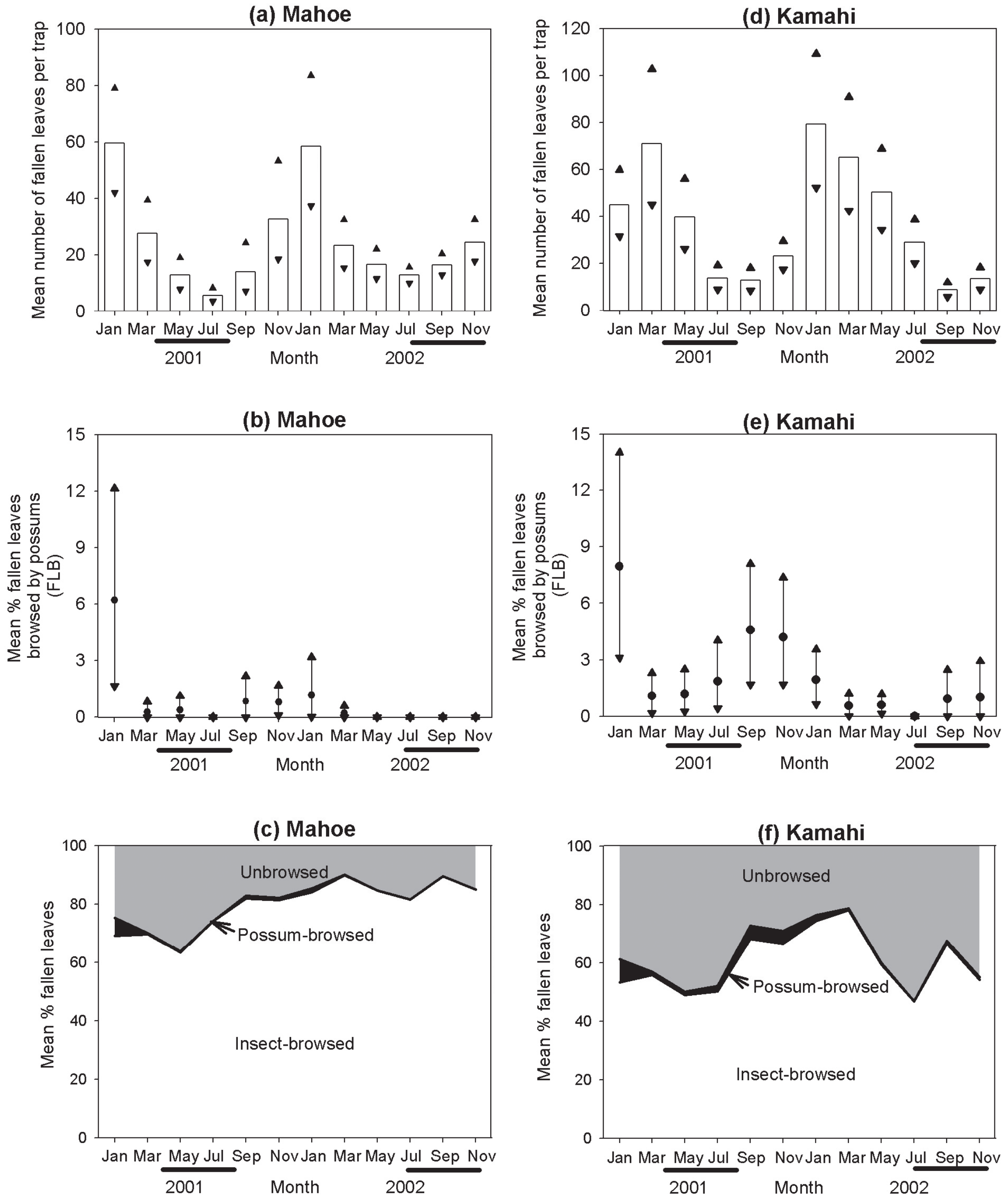


Figure 1. Bi-monthly pattern of fallen leaves and fallen leaf-browse at the Oriuwaka study area, 2001–2002. Upward and downward triangles represent the upper and lower 95% confidence limits, respectively. Leaf-fall traps were emptied in the labelled months. Trapping to control possums was conducted on a block-by-block basis during April-August 2001 and July-November 2002; horizontal lines below the months indicate these periods.

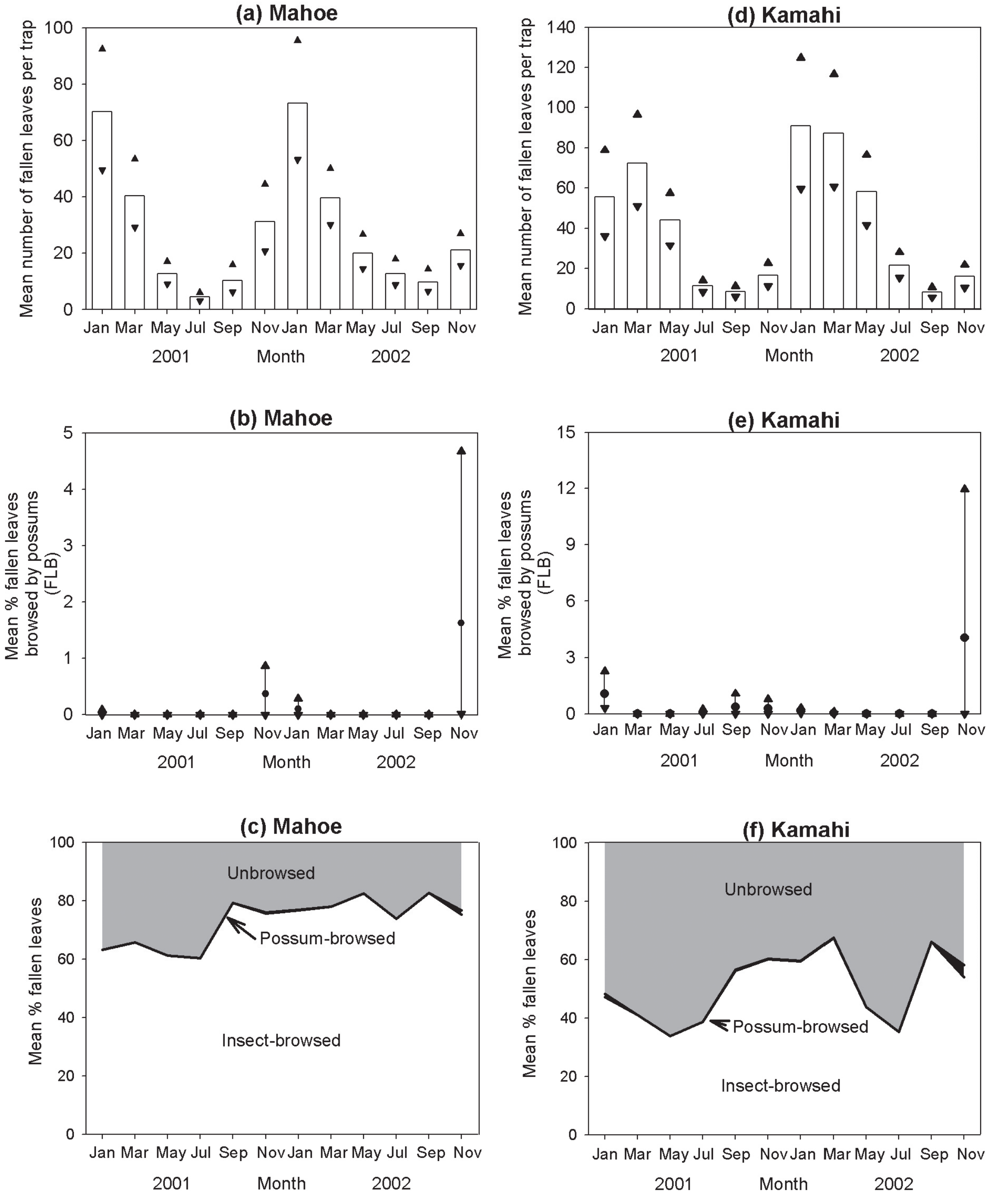


Figure 2. Bi-monthly pattern of fallen leaves and fallen leaf-browse at the Otupaka study area, 2001–2002. Upward and downward triangles represent the upper and lower 95% confidence limits, respectively. Leaf-fall traps were emptied in the labelled months.

lowest FLB in the March, May and July samples (Figs. 1e and 2e). As for mahoe, kamahi FLB was higher at Oriuwaka than at Otupaka in the first 12 months. However, kamahi FLB at Oriuwaka was lower in all samples in the second 12 months compared to the first 12 months, but remained higher than at Otupaka for most corresponding samples in the second 12 months.

Although there was a seasonal pattern in FLB, the proportion of mahoe and kamahi leaves browsed by possums was small compared to those browsed by insects, or unbrowsed (Figs. 1c, 1f, 2c, 2f). The percentages of leaves browsed by an unknown browser were small at both areas: ≤2.5% and ≤3.8% for mahoe and kamahi, respectively, at Oriuwaka, and ≤1.9% and ≤1.8% for mahoe and kamahi at Outupaka. The two sampling sessions conducted at Oriuwaka prior to possum control beginning in April 2001 indicate the maximum level of fallen leaves browsed by possums in the study area (Figs. 1c and 1f). However, ≥50% of both mahoe and kamahi fallen leaves had been browsed by insects, and 20–30% had not been browsed. At both study areas a higher percentage of fallen mahoe leaves had been browsed by insects compared with kamahi. The seasonal change in the percentage of fallen mahoe and kamahi leaves browsed by insects mirrored that of FLB, with insect browse generally lowest in the May and July samples and generally highest in the September-March samples.

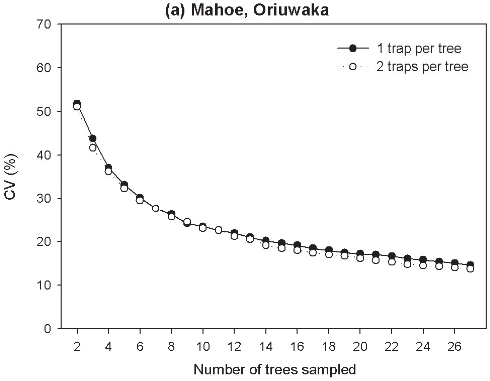
Sampling intensity and precision of FLB in January 2001

The correlations (r_p) between FLB in traps under the same tree collected in January 2001 were as follows: kamahi at Oriuwaka, 0.90; mahoe at Oriuwaka, 0.99; kamahi at Otupaka, 0.98. Bootstrapping revealed a similar relationship between CV and the number of trees sampled for the three cases we examined (Fig. 3a–c). The CV decreased sharply as the number of trees sampled increased from two to eight, but less thereafter. Using two rather than one trap under each tree did not decrease the CV greatly. Our simulations indicate that to obtain a CV of ≤20%, using one trap per tree, at least 24 trees need to be sampled.

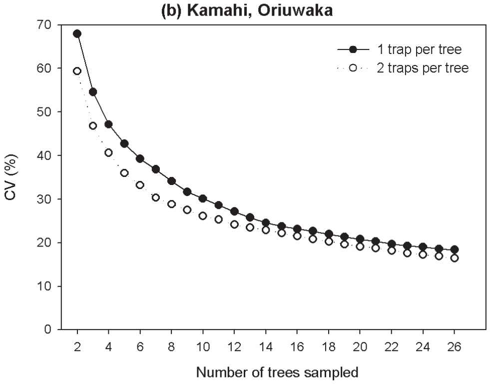
Changes in foliage cover index

FCIs for both species at both study areas changed little during our study. For mahoe, the mean FCIs (95% CIs) changed from 59.5% (55.9–63.1%) to 55.6% (52.1–59.1%) at Otupaka, and from 53.0% (48.8–57.2%) to 51.3% (45.4–57.2%) at Oriuwaka. For kamahi, the mean FCIs changed from 58.9% (55.4–62.4%) to 61.4% (58.2–64.6%) at Otupaka, and from 58.1% (54.5–61.7%) to 60.0% (56.8–63.2%) at Oriuwaka.

(a) Mahoe, Oriuwaka



(b) Kamahi, Oriuwaka



(c) Kamahi, Otupaka

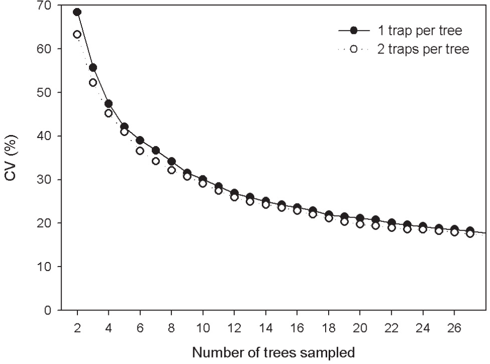


Figure 3. Relationship between CV (%) and number of trees sampled and number of traps sampled per tree for mahoe and kamahi at Oriuwaka (a, b), and for kamahi at Otupaka (c).

Possum versus insect browse

Pooling data from both study areas, kamahi trees that had fewest leaves browsed by insects also had fewest browsed by possums ($F = 4.9$, d.f. = 59, $P = 0.03$), but there was no evidence of such a relationship for mahoe ($F = 0.06$, d.f. = 59, $P = 0.8$). Whether the tree was in the sub-canopy or canopy also seemed to affect patterns of browse. Possum browse on fallen kamahi leaves was less frequent when the tree was in the canopy compared with the sub-canopy ($\chi^2 = 32$, d.f. = 1, $P < 0.001$), but insect browse on fallen kamahi leaves was similar under sub-canopy and canopy trees ($\chi^2 = 0.3$, d.f. = 1, $P < 0.06$). For mahoe, browse by both insects ($\chi^2 = 606$, d.f. = 1, $P < 0.001$) and possums ($\chi^2 = 124$, d.f. = 1, $P < 0.001$) was most frequent on leaves collected under sub-canopy trees.

Discussion

Changes in FLB and possum abundance

FLB apparently responded quickly to control-induced changes in possum abundance in the Oriuwaka study area. In particular, FLB was reduced in most samples for mahoe and kamahi in the year after control began in April 2001 (e.g. compare the January and March samples of 2001 with the January and March samples of 2002; Figs. 1b and 1e). Unfortunately, sample sizes were too small to sensibly compare FLB in the treated and untreated blocks in Oriuwaka over the extended control period (April 2001 to November 2002). We also note that FLB was much greater on both kamahi and mahoe in Oriuwaka (33% TCI) compared with Otupaka (4% TCI) prior to possum control beginning in the former during April 2001. Numata (1998) observed an immediate reduction in FLB on northern rata at nearby Whirinaki Forest Park after intensive possum control. Interestingly, FCIs of both kamahi and mahoe did not increase following possum control at Oriuwaka. Payton *et al.* (1997) also noted that the foliar browse index may be less sensitive to changes in possum herbivory than browsed leaves and stem damage. We believe that FLB is a sensible indicator of changes in possum browse on canopy leaves that can be monitored at the management scale.

Best month(s) for sampling FLB

There was a strong seasonal pattern in FLB for mahoe and kamahi at both study areas, being lowest in winter and highest in spring and early summer. Again, our results match those reported by Numata (1998) for FLB on northern rata. We therefore suggest that the best two-month periods for sampling mahoe and kamahi FLB are September–October and November–December. Payton (1983) showed that artificial defoliation of new southern rata (*Metrosideros umbellata*) foliage in those months can depress shoot growth and kill branches, suggesting that estimates of FLB in spring/early summer might have important biological meaning for kamahi and mahoe. It is also easier to work in the field during spring/early summer than at some other times of the year because of higher temperatures and more daylight hours.

The strong seasonality of leaf-fall observed for both mahoe and kamahi at both study areas was similar to that reported in previous studies. For example, Cowan *et al.* (1985) showed that mahoe leaf-fall in the Orongorongo Valley, Rimutaka Range, was highest in spring and summer, but kamahi leaf-fall was highest in summer and autumn. Hosking (2003) observed a seasonal pattern of leaf-fall under northern rata trees at Whirinaki similar to that observed for kamahi and mahoe in this study.

A recent review of diet studies showed that kamahi and mahoe are often a dominant food for possums in New Zealand (Nugent *et al.*, 2000). However, there are fewer studies describing the seasonal diet of possums in areas where both kamahi and mahoe are present, and these studies do not show consistent patterns. For example, mahoe was eaten most in spring at Mt Bryan O'Lynn (Westland; Coleman *et al.*, 1985) but was eaten least in spring and summer in the Orongorongo Valley (Wellington; Fitzgerald, 1978) in some years (Allen *et al.*, 1997). Although seasonal differences in the amount of kamahi in the diet of possums appear less than for mahoe in those studies, the FLB of kamahi at Oriuwaka showed a stronger seasonal pattern than mahoe. However, some leaves may be completely eaten by possums, and browsing by possums may stimulate leaf-fall in some species (Meads, 1976). Hence, FLB should not be used to estimate the absolute number of leaves eaten, or browsed by possums, in a tree.

Sample sizes

Our simulations (Fig. 3) indicate that the precision of FLB estimates increase non-linearly with the number of trees sampled. However, using two traps rather than one trap per tree did not increase precision substantially. We recommend that at least 24 randomly located trees be sampled in September–October or November–December if a CV of ≤20% is desired. However, CVs were much higher in other periods and after densities of possums were lowered by control. We note that other methods for estimating required sample sizes for proportions and percentages estimated using simple random sampling are given by Cochran (1977).

Although randomly sampling trees was considerably more difficult and expensive than sampling only near roads and tracks (termed 'convenience sampling'; Anderson, 2001), random sampling means that every kamahi and mahoe tree had an equal probability of being included in our sample. Hence, our inferences apply to all of the study area rather than a smaller and poorly-defined subset of the study area as would have been the case if we had sampled trees only near roads and tracks. We therefore consider random sampling to be a critical component of FLB monitoring (see also National Possum Control Agencies, 2002).

Which is the best tree species to monitor?

Our data do not indicate that one species is 'best', with FLB similar for the kamahi and mahoe within each study area during the period of recommended sampling (i.e. spring/early summer). Since the condition of forest canopy trees affected by possums is the measure of benefit of possum control most often used by the Department of Conservation, we suggest that managers identify the tree species of most concern and ensure that an appropriate number of trees is sampled.

Patterns of leaf herbivory

We observed high proportions of insect browsing on fallen leaves of both kamahi and mahoe at both study areas in all seasons, but always more on mahoe than kamahi. Numata (1998) observed even higher proportions of insect browsing on fallen northern rata leaves at Whirinaki. These findings suggest that insect herbivores have important effects on the leaf dynamics of at least some canopy tree species, and that this topic deserves further work.

Our results also highlight some potential interactions between patterns of browse by insects and possums and whether the tree was in the sub-canopy or canopy. First, the leaves collected under kamahi (but not mahoe) trees that were least browsed by insects were also least browsed by possums. Second, possum browse on leaves collected under kamahi trees was lower when the tree was in the canopy, but insect browse was similar on leaves collected under sub-canopy and canopy trees. Both insect and possum browse was higher on leaves collected under sub-canopy trees. Our study was not designed to test such interactions, so we present them as hypotheses to be tested in subsequent studies.

Other aspects of monitoring with FLB

The major cost of the FLB method is the labour involved in setting up the leaf-fall traps and collecting and then sorting the leaf-fall samples. Our traps consisted of a wire mouth, shade cloth and three wooden stakes; the cost of materials for one trap was $12 in 2001. It might be possible to reduce sorting costs by estimating the number of leaves per leaf-fall trap required to estimate FLB with a given precision, and methods for doing this are given in Cochran (1977).

Further work, based on larger sample sizes than used here, is required to evaluate the relationships between possum abundance, FLB, canopy condition, and key tree demographic rates (e.g. survival and reproduction). One approach to gaining that knowledge is a management-scale experiment, with replicated and randomly assigned treatment (i.e. possum control) and non-treatment areas. We have attempted to implement such a study to evaluate how different frequencies of possum control affect canopy condition at 14 sites in the central North Island (Parkes *et al.*, in press). Canopy condition at those 14 sites is currently being monitored with FBI and FCI, but other response variables could be added to the design. See Parkes *et al.* (in press) for a thorough discussion of the background to, and the practical difficulties of implementing and sustaining, that study. Another approach is to use a meta-analysis to estimate parameters of interest from many 'small' studies (e.g. one treatment and one non-treatment) conducted at different times and places (Gelman *et al.*, 2004). Either approach could also investigate how possum control affects components of forest communities/ecosystems other than trees.

Conclusions

Identifying a trigger for possum control to protect canopy trees is problematic because many factors unrelated to possum browsing can affect canopy condition, and indices based on canopy scoring may not always quickly detect real changes in possum herbivory. Our study indicates that % fallen-leaf browse on mahoe and kamahi decreased quickly following a large reduction in possum abundance. We suggest that September-October and November-December are the best times for sampling FLB, and that one trap be randomly placed under the canopy of each of at least 24 randomly located trees. We consider FLB to be a sensible trigger for initiating possum control when the objective of control is to protect canopy tree condition, but further work is needed to determine the relationships between possum abundance, FLB, canopy condition, and key tree demographic rates.

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