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Factors influencing brushtail possum (*Trichosurus vulpecula*) damage in a *Pinus radiata* plantation on the Coromandel Peninsula, New Zealand

Marco A. Jacometti[1*], Chris M. Frampton[2] and Graham J. Hickling[3]
[1]National Centre for Advanced Bio-Protection Technologies, PO Box 84, Lincoln University, Lincoln 7647, New Zealand
[2]Department of Medicine, Christchurch School of Medicine and Health Sciences University of Otago, PO Box 4345, Christchurch, New Zealand
[3]Department of Forestry Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37966, USA
* Author for correspondence (Email: jacometm@lincoln.ac.nz)

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Abstract: Damage by introduced brushtail possums (*Trichosurus vulpecula*) to *Pinus radiata* trees was assessed in 41 compartments of a commercial forestry plantation on the Coromandel Peninsula, New Zealand. All the trees assessed were less than 3 years old. Possum damage in the compartments was low (median prevalence 3.3%) but highly variable (range 0–30%). Eight of 37 measured habitat factors differed significantly ($P < 0.05$) between the sites with damaged and undamaged trees. The best predictor of mean damage was stand age, but this explained only 21% of the variation in damage among compartments. Including both stand age and New Zealand bracken (*Pteridium esculentum*) cover improved the model significantly and explained 36% of variation in damage. Damage was apparently unrelated to compartment size, distance from the compartment boundary, and possum den-site availability. Surprisingly, the relationship between browse damage and a trap-catch index of possum abundance was weakly negative ($r_S = -0.53$, $P = 0.05$). The dense understorey associated with young pine stands tends to increase possum damage to associated *P. radiata* trees, but the possums in such stands may be less mobile at ground level and thus less easily trapped. Assessment of stand age and understorey characteristics, together with visual inspection for early signs of damage, is likely to be more cost-effective than possum surveys for identifying forest compartments at risk from possum browse.

Keywords: browse damage; introduced mammals; plantation forest

Introduction

Most commercial forestry plantations in New Zealand are composed of compartments of even-aged *Pinus radiata* D. Don. Introduced brushtail possums (*Trichosurus vulpecula* Kerr) living in or adjacent to these plantations commonly use *P. radiata* as a seasonal food source, which subjects the trees to browse and secondary physical damage. Direct feeding damage includes pine-needle consumption, which typically represents less than 10% of the annual diet, but this can increase to over 40% during autumn (Clout 1977). Bark consumption in winter and early spring (Clout 1977; Fitzgerald 1981) and female and male cone consumption are also important. Female cones are eaten in the late summer and autumn, when they can comprise more than 10% of the diet, and male cones are eaten from June to September (Harvie 1973; Warburton 1978), when they can contribute up to 70% of the diet (Clout 1977). Indirect damage comprises mainly leader or lateral breakages that occur as possums move through the canopy (Clout 1977; Keber 1988; Jacometti et al. 1997). The potential economic consequences of such damage have been discussed by Griffiths (1985), Keber (1988) and Butcher (2000), but the prevalence of possum damage is known to be highly variable within and among New Zealand plantation forests (see references in Jacometti et al. 1997). Variables such as stand age (Jacometti et al. 1997; Butcher 2000), understorey composition, food and den-site availability, and possum abundance (Clout 1977; Keber 1988) also impact on damage levels. Possum control and understorey management could reduce this damage, but both activities are costly. It would be advantageous, therefore, if forest managers could identify those forest compartments within a plantation most at risk from possums, so that any management activities could be targeted there.

The relative importance of stand age, understorey composition, food and den-site availability, and possum abundance is uncertain, so this study investigated a range of site factors that might have predisposed *P. radiata* trees to possum damage at Tairua Forest on the Coromandel Peninsula, New Zealand. This analysis extends the study by Jacometti et al. (1997), which described the prevalence of various types of possum damage in the plantation in summer 1996/97.

Methods

Possum damage was assessed in Tairua Forest, Coromandel Peninsula (37°10′ S, 175°51′ E), between November 1996 and January 1997; the forest is described in more detail in Jacometti et al. (1997). Damage assessment was restricted to stands of *P. radiata* aged 3–20 years. Possum damage is common in younger trees but is not easily distinguished from damage by other herbivores; trees over 20 years of age are rarely damaged (Clout 1977). Forest compartments less than 1 ha in size, which made up <1% of the forest area, were also excluded from the survey.

Thirty-six of 239 eligible compartments were randomly selected for assessment. A random transect was run across each compartment; if this was <250 m in length transects were added until their cumulative length exceeded 250 m. At 10-m intervals along each transect, a single *P. radiata* tree was assessed for possum damage; this provided a minimum of 25 assessment sites per compartment (a total of 1244 ‘random’ sites in all).

Five compartments reported by a local possum control contractor to have high levels of possum damage were then assessed to determine whether damage tended to be most pronounced on the boundary or in the interior of such blocks. A 250-m transect was run along the boundary of each compartment, with a *P. radiata* tree assessed every 10 m. Additional 250-m transects were run in parallel 50 m and 100 m inside the compartment boundary, providing a total of 375 ‘high damage’ sites.

Our use of systematic sampling along transects involved a trade-off between strict statistical randomness *versus* improved coverage of the large, sparsely sampled blocks at our study site. Inspection of the residuals from subsequent statistical analyses did not reveal any problems with autocorrelation effects, particularly since our 10-m sampling interval was unrelated to the spacing of the pine trees.

Damage and site assessment

In contrast to Jacometti et al. (1997), who quantified the various types of possum damage at each site, we simply considered the presence/absence of any visible damage on each tree. The likelihood that such damage had been caused by possums (rather than other herbivores or weather) was scored as: 4 = high, 3 = likely, 2 = uncertain, 1 = unlikely and 0 = not possum-related. The percentage ground cover of each of 27 understorey plant species (listed in Table 1) was recorded at each sample point in each site. The availability of den sites, and whether the understorey (0–1 m above ground level) was sparse or dense when viewed horizontally, were scored on five-point scales: from 0 (low/sparse) to 4 (high/dense). Den-site availability was scored on the basis of the relative numbers of logs, hollow stumps, holes in the ground, and dense undergrowth near each site (cf. Harvie 1973). Seven other site factors, including sun exposure and site drainage, were also recorded (see Table 1).

Possum trap-catch assessment

In nine of the 36 random compartments, and in all five high-damage compartments, three transects of eight ‘Victor 1½’ steel-jaw leghold traps were set on ‘best sign’ at 20-m intervals for two fine nights between 28 January and 14 February 1997 (a total of 672 trap-nights). Traps were lured with a cereal-based pellet impregnated with eucalyptus-scented oil. The number of possums caught per 100 trap-nights was calculated for each compartment, with the number of trap nights corrected by deducting 0.5 for each escape, sprung trap, and non-target species captured (Nelson & Clark 1973; Forsyth et al. 2005).

Statistical analysis

Some damage data could not be confidently ascribed to possums (i.e. certainty score <3) and these were omitted from the analysis. Some of this damage may in fact have been caused by possums, so the damage levels reported here are conservative. For all the analyses described below, data from the five ‘high damage’ compartments were pooled with the data from the ‘random’ compartments to increase the likelihood of identifying site factors predictive of possum damage. In contrast, Jacometti et al. (1997) calculated their overall damage estimate using only those data from the ‘random’ compartments.

Initial comparisons of the 36 measured factors (Table 1) at sites with and without possum damage were made using non-parametric Mann–Whitney *U*-tests. Factors significant at $P < 0.05$ in this preliminary analysis (all of which had reasonably normal statistical distributions) were then included in a canonical discriminant function analysis run using the Systat 10.2 software package. A linear function and forward stepwise estimation was specified, with $P = 0.05$ as the criterion for entry and removal of variables. Data were analysed with the statistical software package Systat 2002.

The effect of distance from the compartment boundary on damage levels was assessed in the 'high density' compartments using a non-parametric Kruskal–Wallis test. Mean damage prevalence and the mean value of each habitat factor were calculated for each of the 41 forest compartments. The extent to which variation in damage was associated with variation in the various habitat factors was then explored by multiple linear regression using the GLM procedure in Systat 10.2. Cross-correlation among the various habitat factors was explored by calculating Spearman's rank correlation coefficients (r_S).

Spearman's rank correlation was also used to assess the relationship between possum trap-catch estimates and the other variables. These were weak tests for the biological relationships, as trap-catch data were available for 14 compartments, so some liberties were taken in discussion of two marginally non-significant statistical results (i.e. $0.10 > P \geq 0.05$).

Results

A total of 1745 *P. radiata* trees were assessed, of which 111 (6.4%) exhibited visible possum damage. Of the 36 site factors assessed (Table 1), only eight differed significantly between sites with damaged and undamaged *P. radiata* trees (Table 2). A canonical discriminant function analysis run using the eight site factors listed in Table 2 produced the following decision rule:

Calculate: D=1.936–0.181(STAND AGE) + 5.10(TOETOE) – 0.325(FERN)

Rule: Predict tree is damaged if D > 0, else predict tree is undamaged.

When reapplied to the original data, this rule was only 67% successful in correctly classifying

Table 1. Vegetation cover types and other factors assessed at 1244 'random' sites and 375 'high damage' sites in *Pinus radiata* forest at Tairua during summer 1996/97. Nomenclature follows the Landcare Research online database Ngā Tipu o Aotearoa – New Zealand Plants (http://nzflora.landcareresearch.co.nz/), accessed 6 July 2007.

UNDERSTOREY PLANT SPECIES	
Blackberry (*Rubus fruticosus* agg.)	Pampas grass (*Cortaderia jubata*)
Bracken (*Pteridium esculentum*)	Rangiora (*Brachyglottis repanda*)
Broadleaf (*Griselinia littoralis*)	Scotch thistle (*Cirsium vulgare*)
Bush lawyer (*Rubus* spp.)	Slender birdsfoot trefoil (*Lotus angustissimus*)
Clover (*Trifolium* spp.)	Toetoe (*Cortaderia fulvida*)
Common rush (*Juncus effusus*)	Tree fern (*Dicksonia squarrosa*)
Fireweed (*Senecio hispidulus*)	Tutu (*Coriaria arborea*)
Fivefinger (*Pseudopanax arboreus*)	Wattle (*Acacia baileyana*)
Flax (*Phormium* spp.)	
Gorse (*Ulex europaeus*)	OTHER FACTORS
Grasses (Gramineae)	Stand age (years)
Gum (*Eucalyptus globulus*)	Compartment size (ha)
Kāmahi (*Weinmannia racemosa*)	Diam. at breast height (DBH) of *P. radiata* (cm)
Koromiko (*Hebe stricta*)	Height of *P. radiata* (m)
Kōwhai (*Sophora microphylla*)	Understorey abundance (0–4 scale)
Kūmarahou (*Pomaderris kumeraho*)	Den-site abundance (0–4 scale)
Lemonwood (*Pittosporum eugenioides*)	Pine needles (*P. radiata*)
Māhoe (*Melicytus ramiflorus*)	Exposed to sun (1 = yes, 2 = no)
Mexican cypress (*Cupressus lusitanica*)	Well-drained (1 = yes, 2 = no)

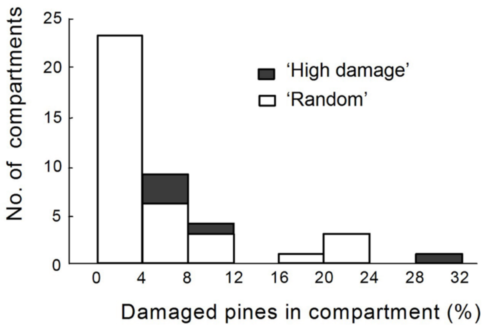

Figure 1. Prevalence of possum-damaged *P. radiata* trees in 36 compartments selected randomly at Tairua Forest, and in five compartments identified a priori as exhibiting 'high' possum damage.

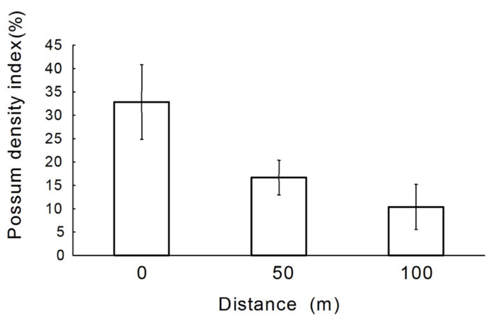

Figure 2. Trap-catch indices of possum abundance at different distances within 'high damage' compartments at Tairua Forest (n = 5 compartments; means presented ±SE).

undamaged trees, and 71% successful in classifying damaged trees. Since damage control measures would normally be targeted towards at-risk compartments, rather than individual trees, we next investigated which site factors best predicted mean damage levels in the various compartments. Mean damage in the 36 'random' compartments ranged from 0 to 22%, with a median of 0.9% and a mean of 4.2% (Fig. 1). The five 'high damage' compartments ranged from 4 to 30%, with a median of 5% and a mean of 10.6%. 'Stand age' was a highly significant predictor of damage to individual trees (P = 0.003), but explained only 21% of the variation in mean damage among compartments. 'Toetoe cover' was marginally significant when added to the 'stand age' model (P = 0.04, with 30% of variation in damage explained), but 'fern cover' had no predictive value (P = 0.26). The best two-factor model was one that incorporated 'stand age' (P = 0.002) and 'bracken cover' (P = 0.006); this explained 36% of variation in damage. We were unable to identify any three-factor models that provided significant improvement on the 'age-bracken' model.

When potentially relevant cross-correlations among factors were examined, stand age was found to be positively related to DBH (r_S = 0.69); negatively related to fern cover (r_S = −0.31); and unrelated to den abundance, understorey abundance, or bracken cover. Bracken cover was positively related to understorey abundance and fireweed cover (r_S = 0.34 and 0.35); negatively related to DBH and fern cover (r_S = −0.34 and −0.37); and unrelated to den availability. There were no significant differences in damage levels at differing distances from compartment boundaries (Kruskal–Wallis test, P = 0.93), and no relationship between damage level and compartment size (r_S = 0.21, P = 0.18).

A total of 68 possums were caught in 238.5 adjusted trap-nights from the nine 'random' compartments that were trapped (i.e. 28.1 possums per 100 trap-nights; range 12.0–54.9). When the data from all 14 trapped compartments were pooled, there was no significant relationship between possum catch and stand size. The relationships between catch and stand age and catch and mean DBH were both weakly positive (r_S = 0.38, P = 0.18 and r_S = 0.59, P = 0.03, respectively). There was no relationship between catch and den abundance, or between catch and understorey abundance. The only indication of any understorey vegetation effect on possum catch was a weak positive association with fern cover (r_S = 0.53, P = 0.05). Possum catch decreased with increasing distance from the edge of the stand boundary (Fig. 2; P < 0.01). The differences in catch between the edge (0 m) and 50 m or 100 m were both significant (Mann–Whitney U-test, P < 0.05 and P < 0.01, respectively), but the difference between the 50- and 100-m transects was not (P = 0.34). Surprisingly, there was a weak negative relationship between possum catch and possum damage (r_S = −0.53, P = 0.05).

Discussion

Possum damage to trees less than 3 years old in Tairua Forest was low overall, but highly variable among compartments (Jacometti et al. 1997). This variability is typical of the findings from previous possum damage surveys in exotic forests (e.g. Barnett et al. 1977; Pracy 1981). Before this study, we anticipated the best predictors of high-damage compartments would be either (1) features of the *P. radiata* stand (e.g. stand age or mean DBH); (2) generic features of the understorey (e.g. understorey abundance, den availability, site dryness or sun exposure); or (3) the abundance of certain preferred understorey species. We also anticipated that our trap-catch index of possum abundance would be positively correlated with browse damage. As is evident from the above analyses, there are indeed statistically significant site differences between damaged and undamaged *P. radiata* trees. Unfortunately, these differences were not sufficient for us to be able to reliably identify the specific trees, or stands, at greatest risk from possum browse.

The best predictor of overall browse damage in a compartment was stand age, with older stands tending to exhibit lower damage. This is consistent with previous studies and has been interpreted as a consequence of increased plant toxins in mature trees and/or the sparse understorey in mature *Pinus* stands (Clout 1977; Keber 1988). Nevertheless, stand age explained only 21% of the variation in damage among compartments; we found that a model that included both stand age and an understorey vegetation factor (bracken cover) explained significantly more (36%) of the variation.

A number of the measured vegetation factors were cross-correlated. For example, bracken cover was positively related to both browse damage and understorey abundance. This supports previous suggestions that early-succession dense understoreys predispose *P. radiata* stands to increased browse damage (Clout 1977; Keber 1988). In Tairua Forest, such understoreys tend to have high fireweed–bracken–toetoe cover, and low fern cover. These four vegetation types were significant in our multivariate analyses, but this result needs to be interpreted cautiously because this particular combination of species would not necessarily be present in *P. radiata* understorey in other parts of New Zealand.

Surprisingly, the relationship between browse damage and possum trap-catch was weakly negative. This was the opposite of the a priori expectation and seems counterintuitive, although Clout (1977) has pointed out that possum damage and abundance are not necessarily directly linked. Possum abundance appears to have been 'decoupled' from possum damage by differences in plant palatability. For example, it could be that possums are abundant at compartment edges but cause less damage to *P. radiata* there because of the availability of alternative palatable plant species. Conversely, reduced abundance of palatable plants inside the compartments may encourage possums to feed more on the pines. The latter could be the case with rangiora, which was more abundant where pines were not damaged (Table 2). Also, two-night catch data, with only 24 traps per compartment, better indicated possum movement at ground level when possums are more easily trapped than absolute possum abundance. Tracks, exposed ridges, and roads increase access for possums (e.g. Leutert 1988), and possum catch was higher on the margins than within the interior of the Tairua Forest compartments. However, browse damage at Tairua Forest was unrelated to distance from the compartment margin. It may simply be that the possums on the compartment boundaries move more freely and therefore are more likely to be trapped there than inside the forest compartment. Although possum catch was not statistically related to understorey abundance ($r_S = -0.33$, $P = 0.27$) it was positively related to fern cover, which is consistent with possums being more mobile and more easily trapped in compartments with a sparse understorey.

To summarise, the current interpretation of these data is that in general the dense understorey associated with young pine stands favours increased possum damage to the associated *P. radiata*. The palatable species in such understorey may help support a larger possum population, and/or the physical structure of the understorey may encourage possums to spend more time above ground, especially during wet weather (Ward 1978). In contrast, the sparse understorey associated with mature pine stands supports fewer possums, but those present will be mobile at ground level and therefore more easily trapped.

A test of this explanation would be to use a more intensive (and expensive) trap-catch protocol that allows for estimation of possum trappability. While this might be feasible in a research context, it is unlikely to be

Table 2. Mean values of the eight habitat factors that differed significantly ($P < 0.05$) between sites with possum-damaged and undamaged *P. radiata*. *P*-values are for Mann–Whitney *U*-tests; % refers to percentage ground cover.

Site factor	Undamaged pines (n = 1634)	Damaged pines (n = 111)	P
Stand age (years)	10.5	8.2	<0.001
DBH (cm)	23.0	18.3	<0.001
Tree height (m)	16.3	12.6	<0.001
Tree fern (%)	11.2	7.4	0.001
Toetoe (%)	0.3	1.4	0.002
Fireweed (%)	13.7	19.9	0.006
Rangiora (%)	2.8	0.7	0.006
Bracken (%)	4.3	8.1	0.041

cost-effective for day-to-day management of plantations (unless damage levels are very high). Indeed, given that field staff's subjective assessments of 'high damage' appear to be valid (see Fig. 1), intensive possum survey work is unlikely to be justified in most plantation forests. Rather, a simple determination of stand age together with a routine survey of understorey density, composition, and maturity may be sufficient to allow for targeting of management activities towards at-risk compartments. It would be helpful to have available an economic analysis that identifies the damage threshold at which losses due to possum browse become sufficient to justify understorey surveys, understorey management, and/or possum control work.

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