SHORT COMMUNICATION

Herbivory by hares as a threat to the native brooms *Carmichaelia juncea* and *C. vexillata*

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Published on-line: 29 May 2006

Abstract: Adult mortality, seed production, and seedling establishment of two species of New Zealand broom (*Carmichaelia juncea* and *C. vexillata*) were studied in exclosure trials to determine the level of threat posed by herbivory by introduced mammals. While no effect on mortality was observed for either species, herbivory by hares drastically reduced seed production and subsequent seedling establishment in *C. juncea*. *C. vexillata* seemed less vulnerable to herbivore damage due to its plant architecture, as well as the timing and intensity of the herbivore impact. The results of this trial suggest that species characteristics and the dynamics of herbivore impacts need to be considered in planning targeted herbivore control.

Key words: threatened plants; hare; *Lepus europaeus occidentalis*; browse; mortality; seed production; seedling establishment; *Carmichaelia juncea*; *Carmichaelia vexillata*

Introduction

Herbivory by introduced mammals is considered one of the main threats to the indigenous New Zealand flora. Numerous studies illustrate how introduced herbivores modify the structure and composition of native vegetation (e.g. Nugent *et al.*, 2001; Husheer *et al.*, 2003). However, as most of these studies focus on vegetation structure and communities, they provide little information on the significance of the impact for individual species. Herbivory can lead to the decline of a plant population by causing either an increase in plant mortality or a decrease in seed production. An increase in mortality will lead to a decline in the plant population if the browse-inflicted mortality exceeds the level otherwise incurred. Similarly, reduced seed production will lead to a population decline if it falls to a level at which recruitment becomes limited by seed availability (Crawley, 1983; Hendrix, 1988).

Of the 23 New Zealand *Carmichaelia* species, 14 are listed as threatened or uncommon (de Lange *et al.*, 2004). Severe browse has been observed on most species, and diet studies have confirmed *Carmichaelia* in the diet of a number of introduced mammals (e.g. Blay, 1989; Reddiex, 1998; Yockney and Hickling, 2000). Despite these observations, it is unclear whether herbivory poses an actual threat to the persistence of *Carmichaelia* species. To determine the significance of the threat posed by herbivory, two low-growing dwarf *Carmichaelia* shrubs, *C. juncea* (Nationally Endangered; de Lange *et al.*, 2004) and *C. vexillata* (Gradual Decline), were studied in exclosure trials. Herbivory by introduced mammals has been suggested as a threat to both species (Norton *et al.*, 1998; Wardle, 2000). Specifically, we assessed the effects of herbivory on adult plant mortality, seed production, and seedling establishment.

Methods

Trial design

The performance of *Carmichaelia* plants protected from browse by cages was compared with unprotected plants. The *C. juncea* trial was established on 2 December 1999 in the Waiho River, near Franz Josef, South Westland (43° 22' S, 170° 09' E, 100 m a.s.l., Waiho Ecological District), where *C. juncea* occurs on relatively young and unstable riverbed surfaces. The *C. vexillata* trial was established on 15 December 1999 along the side wall of the Pukaki-Ohau Canal, near Twizel, Mackenzie Basin (44° 16' S, 169° 58' E, 520 m a.s.l., Pukaki Ecological District), where *C. vexillata* grows in a stable grassland community dominated by exotic grasses and herbs. At both sites pairs of comparable neighbouring plants were chosen as replicates. The plants of each pair were randomly assigned to either the caged or uncaged treatment. Cages were 90 × 90 × 45 cm frames with a mesh size of 30 mm for *C. juncea* and 12 mm for *C. vexillata*, thus excluding all herbivores larger than rats (*Rattus* spp.) and mice (*Mus musculus*) respectively.

To reduce the risk of losing trial plants during flood events, the five *C. juncea* replicates were spread over four islands along a 1-km stretch of riverbed. Notwithstanding this, flood events reduced the number of replicates to four (April 2001) and then three (November 2001). At the *C. vexillata* site ten replicates were established in an area of uniform slope and vegetation cover. In October 2000, five of the caged plants were used as part of a different study, reducing the number of replicates to five.

Data collection

On each plant six branches were marked with metal tags tied around the stem base, and a green twist tie around a node further up. The latter formed the base mark for the assessments. For *C. juncea* the branches were primary stems originating from the central rootstock. For *C. vexillata*, the measured branches were of secondary or higher order. Due to the growth habit of *C. vexillata* measurement of primary stems is not possible without major disturbance to the plant. Browse level was assessed by measuring cumulative branch length (defined as the length of the tagged main shoot plus the lengths of all its side shoots above the base mark). Only live tissue was included. If a branch had been browsed or died back below the base mark, a new branch was randomly chosen, marked and measured to keep the total number of measured branches per plant constant. Thus overall plant growth was not assessed but rather we estimated whether browsing was sustained throughout the trial.

Seed production was assessed for *C. juncea* by counting the numbers of flowers and seed pods on the tagged branches. Because the branches of *C. vexillata* are short and produce only a few flowers each, counting the numbers of flowers and pods on the tagged branches did not provide adequate data. Instead a 'flower and pod score' assessment of the number of flowers and pods for a whole plant was used. The score categories were: 0, no flowers/pods present; 1, sparse < 20 flowers/pods; 2, scattered, 20–100 flowers/pods; 3, medium, > 100 flowers/pods, up to half of the branches involved; 4, heavy, > 100 flowers/pods, over half of the branches involved. Seedling establishment was assessed by counting the seedlings found inside the cages and in an equivalent 90 × 90 cm area around the uncaged plants.

Analysis

To assess the intensity of herbivore damage we calculated the cumulative change in branch length. This cumulative change was compared between caged and uncaged plants by comparing the slope of regressions fitted to the data over time. The effect on seed production was assessed by comparing the number of flowers (or flower score) and pods (or pod score) between caged and uncaged plants at each visit. The effect on seedling establishment was assessed by comparing the maximum number of seedlings recorded during the trial period for the caged and uncaged areas. Variability of the data was expressed using one standard error of the mean. Statistical analyses were limited because of small samples sizes, especially for *C. juncea*, and the predominance of zero values. Notwithstanding this, paired *t*-tests, or two-sample *t*-tests for *C. vexillata* when the sample sizes were different, were used to make comparisons between caged and uncaged plants as appropriate.

Results

Browse intensity

Browse on uncaged *C. juncea* plants was intense throughout the monitoring period (Figure 1), although no plants died. Initially, the branches of the trial plants were of similar lengths (caged plants 31.0 ± 2.9 cm, uncaged plants 34.1 ± 6.4 cm; $t_4 = 0.65$, $P = 0.552$). Following trial establishment, the uncaged plants suffered severe browse. They then resprouted with side shoots, but any fresh growth was continually browsed turning the plants into stumps with clusters of short branches. In contrast, each branch of the caged plants gained an average of 2108.6 ± 1009.8 cm in cumulative length, resulting in dense mats of entangled branches inside the cages. The regression slope for the caged treatment was significantly steeper than for the uncaged treatment ($t_4 = 4.76$, $P = 0.004$) indicating that growth was greater for caged plants.

Browse on uncaged *C. vexillata* plants fluctuated during the monitoring period, with only occasional browse observed during summer, but severe browse during winter, although no plants died. There was no difference in branch length between caged (5.0 ± 0.2 cm) and uncaged plants (4.7 ± 0.1 cm) at the start of the trial ($t_9 = 1.07$, $P = 0.311$), and the slopes of regressions fitted to the growth data over the first summer were not significantly different between treatments ($t_9 < 0.01$, $P = 0.998$). However, despite some recovery of uncaged plants during the second summer, the slopes of the growth data regressions were significantly different between the treatments over the rest of the study ($t_{4,9} = 3.39$, $P = 0.005$).

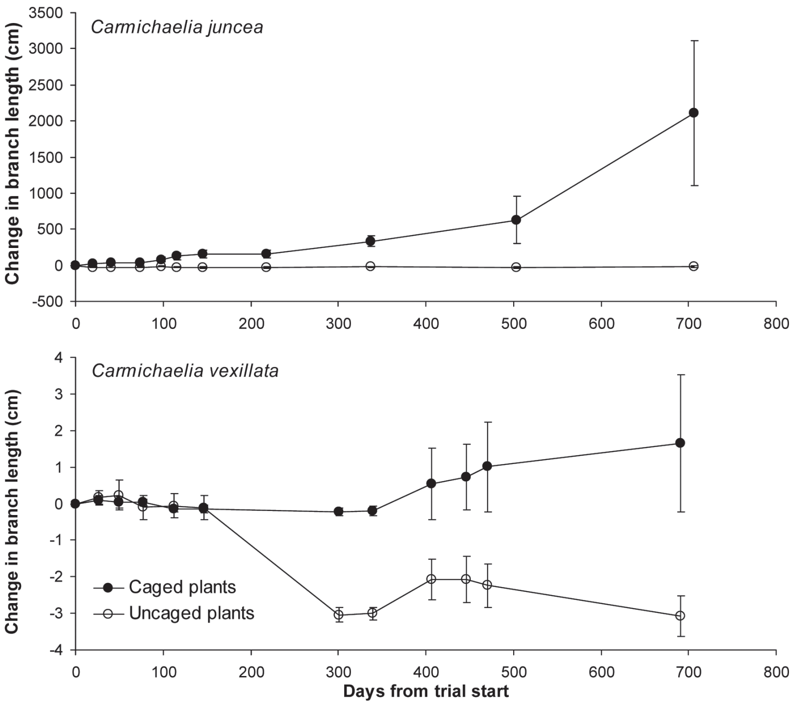

Figure 1. Cumulative change in branch length of caged and uncaged plants of *Carmichaelia juncea*, Waiho River (top), and *C. vexillata*, Pukaki-Ohau Canal (bottom) since the start of each trial.

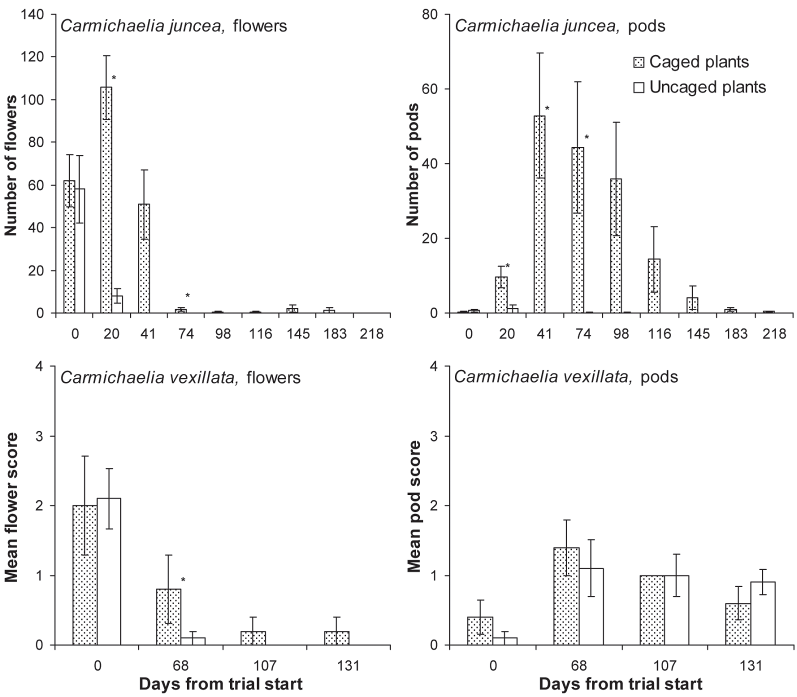

Figure 2. Reproductive activity of caged and uncaged plants of *Carmichaelia juncea*, Waiho River (top), and *C. vexillata*, Pukaki-Ohau Canal (bottom). The asterisk (*) indicates statistically significant differences between caged and uncaged plants.

For both species the branch tips on the uncaged plants were cut at the 45° angle typical for hare (*Lepus europaeus occidentalis*) browse (Wong and Hickling, 1999), and hare fecal pellets were found abundantly around the plants. No other animal sign was observed.

Seed production

The effect of browse on seed production in *C. juncea* was very pronounced (Figure 2). At the start of the trial, there was no significant difference in the numbers of flowers and pods on the branches of caged and uncaged plants (flowers: $t_{4,9}$ = -0.42, P = 0.696; pods: $t_{4,9}$ = 1.54, P = 0.199). However, over the following months the uncaged plants carried significantly (P < 0.05) fewer flowers and pods, or none at all. In contrast both, caged and uncaged plants of *C. vexillata* flowered and fruited abundantly over the study period. Although flower production was significantly higher on caged plants on one occasion ($t_{4,9}$ = 1.93, P = 0.038), there was no statistically significant difference in pod production between the two treatments at any observation time.

Seedling establishment

At the start of the *C. juncea* trial no seedlings were found in any of the trial plots. During the two years of monitoring, seedlings were recorded in all five caged plots, but only two uncaged plots. The mean maximum number of seedlings in caged plots was 853±396, while it was 22±10 in the uncaged plots (t_4 = 2.10, P = 0.052). No seedlings were recorded in any of the *C. vexillata* plots.

Discussion

Herbivory did not affect adult mortality of either *Carmichaelia* species. Both, *C. juncea* and *C. vexillata* showed strong tolerance to herbivore damage with new growth developing after browse events. However, the trial period was relatively short (2 years), and longer term monitoring may well reveal an effect on adult survival. Adult plants are often relatively resistant to herbivore damage, while seedlings and juveniles represent more sensitive stages (Crawley, 1983; Hulme, 1996).

Browse damage almost completely prevented seed production on *C. juncea*, but did not cause any obvious reduction for *C. vexillata*. While *C. juncea* was subject to severe browse throughout the trial period, browse was mainly restricted to the winter months for *C. vexillata* allowing the plants to recover and flower successfully during summer. In addition, the architecture of *C. vexillata* plants appeared to protect flowers and pods from herbivores. Flowers are nestled in between densely arranged branches where they are unlikely to be consumed. In contrast, the open growth habit of *C. juncea* makes its flowers and pods vulnerable to herbivory. Correlations between vulnerability to herbivory and plant architecture have been found for other species, although the exact details vary with the growth form of the plants (Stowe *et al.*, 2000).

Reduced seed production on *C. juncea* subsequently led to a severe reduction in seedling establishment. Although natural seedling mortality is likely to be high, the severity of the effect makes subsequent effects on adult recruitment and overall population dynamics likely. Differences in seedling establishment between treatments were not observed for *C. vexillata*. Despite abundant seed production no seedlings at all were observed. Mature pods and seeds of *C. vexillata* lay on the ground beside the plants throughout the trial period suggesting that factors other than herbivory were limiting seedling establishment.

Our results suggest that the impact of herbivory varies between *Carmichaelia* species. While the observed levels of herbivory are likely to pose a threat to the persistence of *C. juncea* in the Waiho River, they did not pose the same threat to *C. vexillata* at the Pukaki-Ohau Canal. Differences in plant architecture appeared to result in differences in the vulnerability of species to herbivory.

The results of this trial also showed that the nature of the herbivore impact itself (intensity, frequency, and timing) in relation to the life-cycle of the plants needs to be considered. Variations in herbivore pressure are likely to occur depending on the availability of food resources and the density of the herbivore population (Crawley, 1983). Recent observations in the Waiho River confirm that variability in the impact could buffer its detrimental effect. Over summer 2004/05, reduced browsing pressure allowed *C. juncea* to flower and produce abundant seed before another wave of severe browsing in autumn (I. Grüner, pers. obs.). An understanding of such fluctuations in browse pressure is needed to evaluate the level of threat and plan targeted control measures.

In both trials, hares were identified as the key herbivore. In the case of *C. juncea*, they might already have contributed to a decline in this species as plants have not recolonised sections of the riverbed that were flooded in the 1960s, when hares first invaded this area (P. Wardle, pers. comm.). Detrimental impacts of hares on other vegetation have also been reported (e.g., Flux, 1967; Norton, 2001), and since the decline of rabbit populations due to the introduction of the RCD virus, hare numbers have increased (Norbury *et al.*, 2002). However, efficient control methods have not yet been developed. These should be a priority for the conservation of rare *Carmichaelia* and other threatened plants in New Zealand.

Acknowledgements

We thank the Department of Conservation for funding this research (Research Contract 2406). Special thanks to staff at the Franz Josef Waiau Area Office who generously helped with data collection in the Waiho River. We also thank Meridian Energy for allowing access to the *C. vexillata* trial site, and Phil Knightbridge, David Coomes, Peter Bellingham, and two anonymous referees for useful comments on the draft of this paper.

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