

## FORAGE AVAILABILITY AND THE DIET OF FALLOW DEER (*DAMA DAMA*) IN THE BLUE MOUNTAINS, OTAGO

**Summary:** Fallow deer did not prefer either of the two main canopy species (silver beech, *Nothofagus menziesii*, and radiata pine, *Pinus radiata*), or any of the common indigenous shrubs, ferns, herbs and monocotyledons in three habitat types (beech, shrub-hardwood, and exotic forest). They did prefer all the common sub canopy tree species, and these comprised the bulk of diet in all habitats. Broadleaf (*Griselinia littoralis*) was the most important single food, with litterfall being its dominant source. The most important non-woody foods were lichen and fungi (beech forest) and introduced grasses (exotic forest).

Total forage availability did not differ between habitats ( $590 \pm 148$  kg of dry matter  $\text{ha}^{-1}$ ), but composition did. Preferred foods (other than the introduced grasses) were scarce, particularly in the beech forest. A comparison of probable food production and use within the browse zone indicated that, at present densities, deer were not likely to prevent regeneration of the less preferred species (including silver beech). In the beech forest, regeneration of most sub canopy tree species will be minimal while deer densities remain near present levels ( $0.1$  deer  $\text{ha}^{-1}$ ). However, the biomass of silver beech, shrubs, ferns, lichen, and fungi appears adequate to sustain the current deer population even if most of the preferred tree species disappear.

**Keywords:** Fallow deer; Dama dama; diet; feeding habits; food preference; forage availability; Blue Mountains; Otago.

### Introduction

Modification of New Zealand's indigenous forests by introduced deer (see review by Wardle, 1984) is philosophically unacceptable to the Department of Conservation which administers most indigenous forest. As a consequence, the Department places a high priority on minimising the impact of deer, but has limited resources with which to achieve this (Holloway, 1989). The efficient allocation of these resources is hampered by inadequate knowledge of the interactions between deer and the vegetation. Although it is clear that vegetation will respond to major decreases in deer density (Stewart, Wardle and Burrows, 1987; Mark, 1989), the details of this process are not well understood. It is difficult to predict in advance the deer density (and therefore the control resources) required to attain a specific vegetation response. This reflects, in part, the lack of information about the nature and size of deer food sources. There is only one published assessment of deer forage production in a New Zealand forest (Nordmeyer and Evans, 1985).

To assist in the development of a model relating deer impact to deer density, the feeding patterns and food sources of fallow deer (*Dama dama*) in the Blue Mountains, Otago, were investigated as part of a wider study of the status and impact of the deer hunting system in the area (Nugent, 1988). This paper describes deer diet and forage availability for the three main habitat types (beech, shrub-hardwood, and exotic forest). Most emphasis is placed on patterns

within the silver beech (*Nothofagus menziesii*) forest, originally the dominant forest type of the area. It represents one of the two broad categories of indigenous forest in New Zealand, beech forest and podocarp-hardwood forest. This study complements a concurrent investigation of white-tailed deer (*Odocoileus virginianus*) diet in podocarp-hardwood forest on Stewart Island (Nugent and Challies, 1988).

A major finding of both these studies was that deer obtained much of their food after it had fallen from the canopy or sub canopy. The implications of this are discussed in the context of deer impact on plant regeneration and the likely pattern of vegetation response over a range of deer densities.

### Habitat and status of deer

The 227-km<sup>2</sup> Blue Mountains Recreational Hunting Area (45°57'S, 169°22'E) contains approximately 75 km<sup>2</sup> of beech forest (mainly confined to a central strip 34 km wide; Fig. 1). A further 10 km<sup>2</sup> of indigenous shrub-hardwood forest is dominated by broadleaf (*Griselinia littoralis*), marbleleaf (*Carpodetus serratus*), or manuka (*Leptospermum scoparium*) and kanuka (*Kunzea ericoides*). This habitat type has replaced original forest destroyed by fire or logging, and occurs mainly at the northern end of the range. The remaining forested area ('exotic' forest) consists of commercial plantations dominated by radiata pine (*Pinus radiata*), ranging from tall closed canopy forest to newly planted seedlings. A fourth vegetation type,

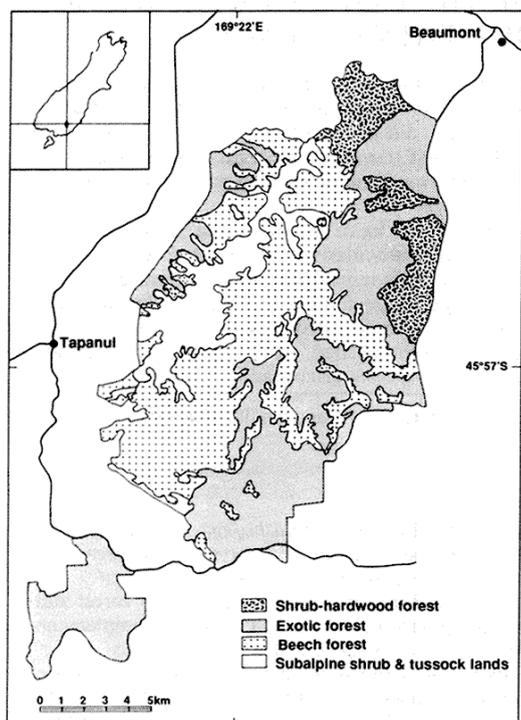


Figure 1: The location of the Blue Mountains study area and distribution of the main deer habitat types.

subalpine shrub and tussock land, is not deer habitat. It is seldom used by deer because the lack of cover renders them vulnerable to hunting.

The Blue Mountains rise to about 1000 m a.s.l. and are not particularly steep (average slope of 16°). Rainfall is frequent throughout the year, with falls of >1 mm on an average of 137 days p.a., but annual rainfall is not high (c. 1000 mm). Snowfalls in winter may occasionally close roads at higher altitudes, but snow seldom covers the forest floor.

The fallow deer population is descended from 13 deer liberated between 1869 and 1871 (Baker, 1972). The herd reached high density soon after liberation, and up to 2000 bucks had been shot by 1910 (Donne, 1924). Despite heavy hunting pressure between 1910 and 1960, the herd remained at high density; 6000 deer were taken from a 40 km<sup>2</sup> section of the area in

2.5 years in the late 1950s (M. Kershaw, unpubl. New Zealand Forest Service report). After 1960 commercial and recreational hunting reduced the population by >80%. In 1985 an estimated 1500 deer were concentrated in the beech and shrub-hardwood forest, away from the road networks providing access for hunters (Nugent, 1988). Present deer reproductive rates are high and nearly all deer deaths result from hunting, rather than from malnutrition or disease (Baker, 1973; G. Nugent, unpubl. data).

## Methods

The study area is divided into 35 hunting blocks. Between 1982 and 1988 samples of rumen contents were obtained from 192 deer shot by recreational hunters. Hunters usually, but not always, reported the deer's sex, age, date of death, and the block where it was shot. Blocks were classified according to the predominant habitat type. The 'beech' blocks seldom contained other habitat types, but 'exotic' and 'shrub-hardwood' blocks sometimes contained substantial areas of the other habitat types.

### Assessment of diet

Samples of about 1-litre of rumen contents were either frozen or preserved in 10% formalin. These were later washed over a 4.0-mm sieve and the retained material was sorted macroscopically using the methods described by Nugent (1983) and Nugent and Challies (1988). Nearly all (>98%) the retained material was assigned to one of 10 food categories (Table 1). The rest was discarded. The material within these categories was assigned to food types, a food type generally being an individual species, but sometimes including a range of indistinguishable species within a particular category. The sorted material, including the unidentified component, was then oven-dried to constant weight and weighed  $\pm 1$  mg).

The importance of broadleaf in the diet was recognised during initial sorting, and the broadleaf material in 121 rumen samples was therefore sorted into three categories; young (apical or seedling) green leaves, mature green leaves, and mature yellow leaves.

The rumen samples were grouped according to habitat type (73 from beech forest, 50 from shrub-hardwood forest, and 69 from exotic forest); sex (70 females, 119 males, 3 unknown); age (49 fawns (<1 yr), 46 yearlings (1-2 yr), 33 adults (>2 yr), and 64 of unknown age); and season (46 taken in autumn (Mar-May), 34 in winter (Jun-Aug), 57 in spring (Sep-Nov) and 50 in summer (Dec-Feb)). The % of dry weight of foods within each rumen was averaged for each of the

age, sex, area, and seasonal groupings of deer to describe how much of each food was eaten.

Differences in diet between groupings were tested using analysis of variance (Nugent and Challies, 1988). As more deer were shot in some seasons than in others, the annual diet was estimated by averaging the four seasonal estimates.

#### *Assessment of forage availability and food preferences*

The dry weight of forage available in the three habitat types was estimated by harvesting all potentially edible material within 1.5 m of ground level on 184 plots (81 in beech forest, 76 in exotic forest, and 27 in shrub-hardwood forest). The 1.14 m radius plots were spaced 500 m apart along c. 2.2 km transects (n = 37) located semi-randomly throughout the area.

Thumb-and-forefinger pressure was used to harvest all green foliage, small twigs, lichen, and fungi from stems within each plot. Green and yellow fallen foliage, and any other potentially edible litter, was collected separately. The harvested material was later sorted and dried to constant weight, as for rumen samples. All the broadleaf harvested was sorted into the three categories of broadleaf described above.

For species that were difficult or time-consuming to harvest alternative procedures were used. For small-leaved *Coprosma* species, kanuka and manuka, the height (up to a maximum of 1.5 m) of each stem bearing some foliage within the browse zone and rooted in the plots was recorded and later converted to biomass estimates using a regression based on a random sample of 100 plants ( $R^2=0.46$ ). The biomass of crown fern (*Blechnum discolor*) was estimated by counting the number of distinct crowns on each plot and multiplying by the mean dry weight per crown of 40 randomly selected crowns. The biomass of mosses was not estimated.

Food preferences were assessed using a modified form of Ivlev's (1961) index of electivity to calculate preference indices (PI), where  $PI = (\% \text{ in diet} - \% \text{ in forest}) / (\% \text{ in diet} + \% \text{ in forest})$ . This formula produces PI values distributed symmetrically about zero (Loehle and Rittenhouse, 1982), ranging from -1 (present on plots, absent from rumen samples) to +1 (absent on plots, present in rumen samples). In each of the three habitats, PI values were calculated for species comprising more than 1 % of summer diet or for which availability exceeded  $1 \text{ kg ha}^{-1}$ . Confidence limits for these habitat-specific indices were calculated by a non-parametric bootstrap technique (Efron, 1981). Mean PI values were then obtained by averaging habitat-specific PIs.

The sampling error of estimates is presented as 95% confidence limits (95% CLs). Because the study was conducted in conjunction with the Stewart Island investigation, botanical nomenclature follows firstly Wilson (1982), but also Allan (1961) and Webb, Sykes and Garnock-Jones (1988) for the remaining vascular species, Martin and Child (1972) for lichens, Stevenson (1982) for fungi.

## Results

### *Plants identified and eaten*

A total of 177 plants were identified to species or genus level, of which 136 were recorded in rumen samples and 130 on plots (Appendix 1). Those found in rumens but not on plots were all rare species. In contrast, some species common on plots did not occur in the rumens.

Each rumen contained, on average,  $18.3 \pm 0.7$  food types (range 2-31), but only  $8.7 \pm 0.4$  comprised more than 1 % of the contents of each rumen. The average number of food types per rumen was significantly higher in beech forest ( $20.2 \pm 1.2$ ) than in the exotic forest ( $16.3 \pm 1.3$ ), with an intermediate value for shrub-hardwood forest ( $18.3 \pm 1.2$ ).

For woody species, nearly all the material eaten was foliage, but some twigs, and the fruits of broadleaf, marbleleaf, and other subcanopy trees were occasionally eaten. Some 'foods' were probably eaten incidentally, particularly mosses and the two main canopy species. Much of the silver beech and pine material consisted of dead (brown or black) leaves and twigs likely to be of limited nutritive value. The silver beech twigs often had remnant pieces of *Usnea* lichen attached, and were probably ingested when deer were eating lichen.

### *Annual and seasonal diet*

Overall the relative importance of the 10 main plant categories in the diet (see Table 1) did not appear to differ between the sexes or between age classes (Anova,  $p>0.1$  for all 20 tests). There were, however, significant differences in diet between habitats and seasons (Table 1; Fig. 2). Separate estimates of annual and seasonal diet were therefore derived for each habitat (Table 1; Fig. 2 respectively).

Woody species (mainly subcanopy hardwood trees) were the most important food, comprising 57-77% of annual diet depending on habitat type (Table 1). Broadleaf was the most important single food type in all three habitats (23-36% of annual diet). The importance of the canopy species may be substantially overstated in Table 1 because the

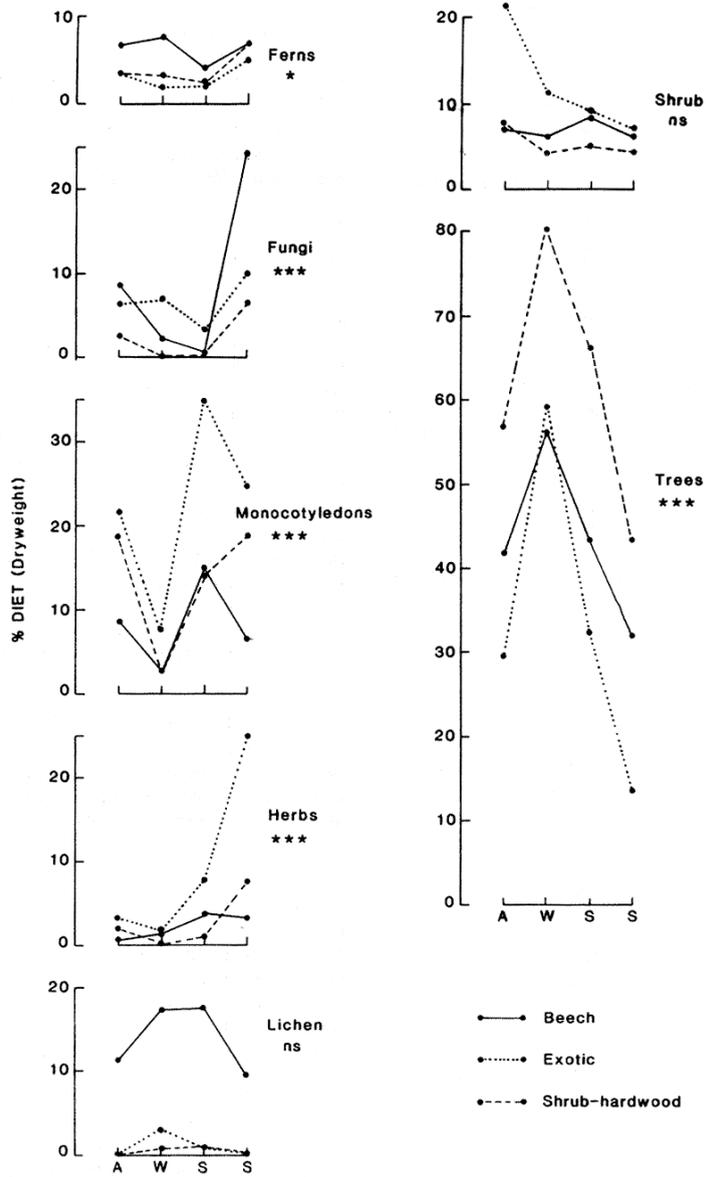


Figure 2: Seasonal variation in the importance of main food categories within habitat types. Probability values indicate the significance of the seasonal effect in a two-way Anova (season and habitat).

Table 1: The annual diet of fallow deer in the three main habitat types in the Blue Mountains. Data are the averages of the mean seasonal % dry weights ( $\pm 95\%$  CLs) for 10 food categories (capitals) and for food types within these categories comprising more than 0.20/0 of annual diet in at least one habitat. Probability values indicate the significance of the difference between habitats.

(Anova, \* $<0.05$ , \*\* $<0.01$ , \*\*\* $<0.001$ ).

	Beech	Exotic	Shrub-hardwood	p
<b>TREES</b>	<b>43.2 <math>\pm</math> 5.8</b>	<b>33.6 <math>\pm</math> 8.8</b>	<b>61.7 <math>\pm</math> 7.8</b>	<b>***</b>
Canopy				
<i>Nothofagus menziesii</i>	5.0 $\pm$ 1.2	0.9 $\pm$ 0.6	1.3 $\pm$ 0.6	***
<i>Pinus</i> spp.	0.1 $\pm$ 0.1	1.3 $\pm$ 0.6	0.2 $\pm$ 0.2	***
Subcanopy				
<i>Griselinia littoralis</i>	31.9 $\pm$ 5.4	22.6 $\pm$ 9.4	36.2 $\pm$ 6.7	***
<i>Carpodetus serratus</i>	3.6 $\pm$ 1.5	2.2 $\pm$ 1.8	7.0 $\pm$ 3.0	**
<i>Pseudopanax crassifolius</i>	1.5 $\pm$ 0.8	2.9 $\pm$ 1.9	5.1 $\pm$ 3.4	**
<i>Pseudopanax simplex</i>	0.4 $\pm$ 0.3	0.0	0.0	**
Other <i>Pseudopanax</i> spp.	0.3 $\pm$ 0.3	0.1 $\pm$ 0.1	0.8 $\pm$ 0.8	ns
<i>Pittosporum</i> spp.	0.1 $\pm$ 0.1	2.5 $\pm$ 2.0	8.7 $\pm$ 2.3	***
<i>Fuchsia excorticata</i>	<0.1	0.9 $\pm$ 1.8	1.6 $\pm$ 0.7	ns
<b>SHRUBS</b>	<b>6.9 <math>\pm</math> 1.9</b>	<b>12.3 <math>\pm</math> 5.4</b>	<b>5.4 <math>\pm</math> 3.0</b>	<b>*</b>
<i>Coprosma</i> spp.	6.1 $\pm$ 1.8	6.1 $\pm$ 2.5	3.9 $\pm$ 2.0	ns
<i>Gaultheria</i> spp.	0.4 $\pm$ 0.2	0.7 $\pm$ 0.4	0.1 $\pm$ 0.1	*
<i>Myrsine divaricata</i>	0.3 $\pm$ 0.2	<0.1	<0.1	*
<i>Leycesteria formosa</i>	0.1 $\pm$ 0.1	4.1 $\pm$ 4.4	0.1 $\pm$ 0.1	ns
<i>Hebe</i> spp.	<0.1	0.7 $\pm$ 0.9	1.1 $\pm$ 1.8	ns
<i>Ulex europaeus</i>	0.0	0.4 $\pm$ 0.4	0.0	ns
<b>CLIMBERS/WOODY EPIPHYTES</b>	<b>0.6 <math>\pm</math> 0.4</b>	<b>1.2 <math>\pm</math> 0.6</b>	<b>1.7 <math>\pm</math> 1.0</b>	<b>*</b>
<i>Rubus</i> spp. (indigenous)	0.2 $\pm$ 0.1	0.7 $\pm$ 0.5	1.5 $\pm$ 0.9	*
<i>Ileostylus micranthus</i>	0.4 $\pm$ 0.2	0.0	0.1 $\pm$ 0.1	
<i>Rubus fruticosus</i>	0.0	0.5 $\pm$ 0.6	0.0	ns
<b>UNIDENTIFIED WOODY PLANTS</b>	<b>8.2 <math>\pm</math> 1.6</b>	<b>9.6 <math>\pm</math> 2.2</b>	<b>7.7 <math>\pm</math> 1.7</b>	<b>ns</b>
stem	8.1 $\pm$ 1.6	8.9 $\pm$ 2.0	7.3 $\pm$ 1.7	ns
leaf	0.1 $\pm$ 0.1	0.7 $\pm$ 0.6	0.4 $\pm$ 0.3	ns
<b>FERNS/FERN ALLIES</b>	<b>6.4 <math>\pm</math> 1.4</b>	<b>3.1 <math>\pm</math> 1.4</b>	<b>3.9 <math>\pm</math> 1.3</b>	<b>**</b>
Unidentified ferns	1.8 $\pm$ 1.3	0.6 $\pm$ 0.4	0.8 $\pm$ 0.6	ns
<i>Polystichum vestitum</i>	0.7 $\pm$ 0.4	1.2 $\pm$ 0.5	1.0 $\pm$ 0.8	ns
<i>Asplenium flaccidum</i>	0.7 $\pm$ 0.3	0.3 $\pm$ 0.1	0.1 $\pm$ 0.1	**
<i>Blechnum fluviatile</i>	0.6 $\pm$ 0.4	0.5 $\pm$ 0.5	1.2 $\pm$ 0.6	*
<i>Phymatosorus diversifolius</i>	0.6 $\pm$ 0.3	0.3 $\pm$ 0.3	<0.1	*
<i>Pyrrosia serpens</i>	0.6 $\pm$ 0.5	<0.1	<0.1	*
<i>Blechnum capense</i>	0.3 $\pm$ 0.3	0.1 $\pm$ 0.1	0.4 $\pm$ 0.3	ns
<i>Cyathea</i> spp.	0.3 $\pm$ 0.3	<0.1	<0.1	ns
<b>MONOCOTYLEDONS</b>	<b>8.2 <math>\pm</math> 3.6</b>	<b>22.4 <math>\pm</math> 2.9</b>	<b>13.5 <math>\pm</math> 5.6</b>	<b>***</b>
Unidentified grasses	7.6 $\pm$ 3.3	21.4 $\pm$ 2.8	13.3 $\pm$ 5.5	***
<i>Holcus</i> spp.	<0.1	0.5 $\pm$ 0.6	<0.1	ns
<b>HERBS</b>	<b>2.8 <math>\pm</math> 1.4</b>	<b>9.8 <math>\pm</math> 3.3</b>	<b>2.6 <math>\pm</math> 2.0</b>	<b>***</b>
<i>Nertera</i> spp.	0.9 $\pm$ 0.5	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1	**
<i>Crepis capillarls</i>	0.6 $\pm$ 1.2	0.4 $\pm$ 0.4	<0.1	***
Unidentified herbs	0.7 $\pm$ 0.7	3.8 $\pm$ 1.4	1.0 $\pm$ 0.9	ns
<i>Trifolium</i> spp.	0.1 $\pm$ 0.1	1.5 $\pm$ 2.2	0.3 $\pm$ 0.4	ns
<i>Lotus</i> spp.	<0.1	3.6 $\pm$ 2.2	1.0 $\pm$ 1.1	**
<b>LICHEN</b>	<b>14.0 <math>\pm</math> 4.6</b>	<b>1.1 <math>\pm</math> 1.4</b>	<b>0.5 <math>\pm</math> 0.4</b>	<b>***</b>
<i>Usnea</i> spp.	13.7 $\pm$ 0.1	1.0 $\pm$ 0.1	0.3 $\pm$ 0.1	***
Unidentified lichen	0.3 $\pm$ 0.2	0.1 $\pm$ 0.1	0.1 $\pm$ 0.1	*

Table 1 Cont ...	Beech	Exotic	Shrub-hardwood	p
<b>FUNGI</b>	<b>9.3 ±2.2</b>	<b>6.8 ±4.0</b>	<b>2.8 ±1.6</b>	<b>**</b>
Mushroom spp.	4.9 ±1.1	1.1±1.2	1.9 ±1.6	*
<i>Cyttaria gunn</i>	2.2 ±2.2	0.0	<0.1	*
Unidentified fungi	1.6 ±0.9	2.8 ±2.6	0.4±0.4	*
Puffball spp.	0.2±0.2	2.7 ±2.2	0.2±0.3	**
<b>MOSSES AND LIVERWORTS</b>	<b>0.4±0.4</b>	<b>0.1 ±0.1</b>	<b>0.2±: 0.2</b>	<b>ns</b>
Moss spp.	0.3 ±0.4	0.1 ±0.1	<0.1	ns

estimates include the dead leaves and twigs which were probably ingested incidentally. These comprised c. 70% of the silver beech material and c. 90% of the pine material in rumens. If dead leaves and twigs are excluded, the green foliage of silver beech and pine comprised less than 1.5% of annual diet in all three habitats.

In beech forest the only shrubs contributing significantly to the diet were the small-leaved *Coprosma* spp., but in exotic forest an introduced species, Himalayan honeysuckle (*Leycesteria formosa*), was moderately important. Overall use of climbers and woody epiphytes was negligible (< 1 %).

The main difference between habitats was in the relative importance of non-woody species. Of these, lichens (14%) and fungi (9%) were the second and third most important food categories in beech forest. Grasses (predominantly introduced) (22%) and herbs (10%) were most important in exotic forest. Ferns comprised less than 7% of the diet in all habitats.

Diet changed significantly between seasons, and the patterns of seasonal change were generally the same in all three habitats (Fig. 2). Use of tree foliage typically peaked in winter and was lowest in summer. Conversely, the amount of fungi in the diet peaked in summer, when it was the second most important food category in beech forest. Monocotyledons and herbs were generally least important in winter and ferns were eaten least in spring. Very little lichen was eaten in the exotic and shrub-hardwood forests, so there appeared to be no overall pattern of seasonal use (Fig. 2). However, in beech forest, deer ate significantly more lichen in winter and spring ( $p < 0.001$ ).

#### Food preferences

Only 14 of the 51 most commonly eaten or occurring food types were preferred by deer (mean PI >0; Table 2). These 14 consisted of all the five common subcanopy trees, two shrubs, three herbs, two types of fungi, one type of grass, and one type of lichen. While the subcanopy trees, fungi, and lichen were indigenous, the preferred shrubs, herbs, and grasses

were all introduced food types found mainly in the exotic forest. Neither of the main canopy species were preferred (mean PI < -0.6).

In contrast to the subcanopy trees, none of the common indigenous climbers, shrubs, ferns, herbs or monocotyledons was highly preferred. Only the small-leaved *Coprosma* and *Nertera* spp. were regularly eaten, the latter usually in small amounts.

#### Food available and habitat quality

The total amount of forage available in the browse zone did not differ significantly between habitats (Anova,  $p = 0.2$ , overall  $\bar{x} = 590:1 \pm 148$  kg ha<sup>-1</sup>), but the forage differed in composition and in abundance of preferred foods (Table 2). Species diversity was greatest in exotic forest (availability estimates exceeded 1 kg ha<sup>-1</sup> for 37 species, compared with 21 and 25 spp. in beech and shrub-hardwood forest respectively).

In the beech forest, woody plants other than silver beech and small-leaved *Coprosma* spp. were scarce (<7.5 kg ha<sup>-1</sup>), and the preferred subcanopy hardwoods comprised only 1.1 % of the forage available. Edible lichen and fungi were also scarce. Most of the potential forage available consisted of the least-preferred ferns, primarily crown fern (46%). The few introduced species in the beech forest were mainly herbs and grasses, and these were generally found near forest margins.

In exotic forest, introduced species comprised about 60% of the available forage, with introduced grasses (24%) and pine species (18%) being the most important. The main indigenous species present were ferns (26%), but *Rubus* spp. were locally abundant. There was twice as much foliage of preferred subcanopy trees available than in beech forest.

In shrub-hardwood forest, the foliage of subcanopy trees was relatively common (7% of forage), but again the bulk of forage consisted of the less-preferred indigenous shrubs (28%), ferns (31%), and monocotyledons (23%). Despite extensive disturbance by fire and logging since the 1860s, introduced species are still relatively rare (13%) in

Table 2: Forage available (including litterfall) within the browse zone in summer 1987 for those food types with estimates exceeding 1 kg ha<sup>-1</sup> or 1 % of summer diet in at least one habitat. Introduced species are denoted by +. The mean PI values are the averages of the habitat-specific PI values. The symbols after each availability estimate indicate whether the habitat-specific PI values were significantly greater or less than zero (+ and - respectively; n indicates non-significance and a blank indicates that no PI was calculated).

	Beech		Exotic		Shrub-hardwood		Mean PI
TREES	<b>73.5 ±</b>	<b>46.2</b>	<b>142.5 ±</b>	<b>180.1</b>	<b>61.8 ±</b>	<b>39.8</b>	
Canopy							
<i>Nothofagus menziesii</i>	67.5 ±	45.7 (-)	9.2 ±	8.1 (-)	19.9 ±	21.5 (-)	-0.6 ± 0.4
+ <i>Pinus</i> spp.			120.3 ±	180.2 (-)	10.1 ±	19.9 (-)	-0.8 ± 0.1
Subcanopy							
<i>Griselinia littoralis</i>	2.9 ±	2.3 (+)	1.6 ±	1.9 (+)	5.1 ±	3.8 (+)	0.9 ± 0.1
<i>Carpodetus serratus</i>	1.7 ±	2.7 (+)	4.7 ±	9.0 (n)	3.3 ±	4.0 (+)	0.6 ± 0.3
<i>Pseudopanax crassifolius</i>	0.6 ±	0.6 (+)	1.1 ±	1.1 (n)	1.2 ±	1.4 (n)	0.3 ± 0.4
<i>Fuchsia excorticata</i>	<0.1	(+)	3.2 ±	5.6 (+)	6.5 ±	12.6 (n)	0.4 ± 0.6
<i>Pittosporum</i> spp.	<0.1		<0.1	(+)	14.0 ±	27.4 (n)	0.8 ± 0.7
SHRUBS	<b>33.9 ±</b>	<b>20.3</b>	<b>47.0 ±</b>	<b>24.5</b>	<b>130.1 ±</b>	<b>72.2</b>	
<i>Coprosma</i> spp.	26.1 ±	20.3 (n)	16.4 ±	8.6 (n)	30.9 ±	24.6 (n)	0.0 ± 0.6
<i>Pseudowintera colorata</i>	7.3 ±	7.2 (-)	8.1 ±	11.2 (-)	88.0 ±	70.2 (-)	-1.0 ± 0.0
+ <i>Leycesteria formosa</i>	0.2 ±	0.5	5.9 ±	10.1 (n)	2.4 ±	4.8 (n)	0.5
+ <i>Cystitis scoparius</i>			7.5 ±	15.0 (n)			0.1
+ <i>Ulex europaeus</i>			3.1 ±	6.1 (n)			-0.1
<i>Cyathodes juniperina</i>			2.6 ±	3.3 (n)			-1.0
<i>Leptospermum scoparium</i>			0.4 ±	0.6	4.9 ±	9.7 (-)	-1.0
<i>Corokia cotoneaster</i>					3.9 ±	7.7 (n)	-1.0
CLIMBERS/WOODY EPIPHYTES	<b>5.2 ±</b>	<b>7.8</b>	<b>23.2 ±</b>	<b>14.1</b>	<b>6.9 ±</b>	<b>11.0</b>	
<i>Rubus</i> spp. (indigenous)	5.2 ±	9.4 (-)	12.8 ±	11.7 (-)	6.0 ±	12.0 (n)	-0.5 ± 0.6
+ <i>Rubus fruticosus</i>			10.1 ±	10.3 (-)			-0.5
FERNS/FERNS ALLIES	<b>372.0 ±</b>	<b>111.5</b>	<b>174.4 ±</b>	<b>91.5</b>	<b>143.4 ±</b>	<b>92.9</b>	
<i>Blechnum discolor</i>	251.5 ±	104.3 (-)	37.4 ±	56.4 (-)	6.8 ±	11.8 (-)	-1.0 ± 0.0
<i>Polystichum vestitum</i>	52.6 ±	50.7 (-)	35.6 ±	34.6 (n)	72.0 ±	79.5 (-)	-0.5 ± 0.5
<i>Hymenophyllum</i> spp.	24.1 ±	21.4 (-)	<0.1				-1.0
<i>Hypolepis</i> spp.	17.8 ±	28.7 (-)	18.2 ±	22.5 (-)	1.7 ±	3.4 (-)	-1.0 ± 0.0
<i>Blechnum capense</i>	10.8 ±	9.1 (-)	12.1 ±	8.4 (-)	33.3 ±	43.3 (-)	-0.8 ± 0.2
<i>Histiopteris incisa</i>	6.1 ±	5.7 (-)	14.6 ±	13.0 (-)	<0.1		-1.0 ± 0.0
<i>Blechnum fluviatile</i>	3.9 ±	4.3 (n)	1.0 ±	1.4 (+)	8.1 ±	8.4 (n)	-0.1 ± 1.1
<i>Cyathea/Dicksonia</i> spp.	2.3 ±	3.0 (n)			2.7 ±	4.1 (-)	-0.5 ± 2.0
<i>Leptopteris superba</i>	1.4 ±	1.3 (-)	2.0 ±	4.0 (-)			-0.7
<i>Pteridium esculentum</i>	0.5 ±	1.0	32.7 ±	30.0 (-)	2.5 ±	3.4 (-)	-1.0 ± 0.0
<i>Paesia scaberula</i>			15.9 ±	29.6 (-)	0.5 ±	1.0	-1.0
<i>Blechnum procerum</i>			2.5 ±	5.0 (-)	2.6 ±	5.1 (-)	-1.0 ± 0.0
<i>Lycopodium</i> spp.			1.4 ±	2.8 (-)	12.4 ±	21.3 (-)	-1.0
MONOCOTYLEDONS	<b>44.0 ±</b>	<b>44.4</b>	<b>205.4 ±</b>	<b>159.0</b>	<b>105.9 ±</b>	<b>103.9</b>	
<i>Uncinia</i> spp.	10.7 ±	15.7 (-)	8.6 ±	8.6 (-)	70.6 ±	85.2 (-)	-0.8 ± 0.2
<i>Phormium</i> spp.	9.1 ±	18.2 (-)	1.7 ±	3.5 (n)			-1.0
<i>Chionchloa</i> spp.	0.3 ±	0.6	27.9 ±	54.0 (-)			-1.0
+ Other grasses (mainly introduced)	23.9 ±	20.0 (n)	167.2 ±	150.9 (n)	35.3 ±	67.5 (+)	0.2 ± 0.4
HERBS	<b>8.5 ±</b>	<b>5.4</b>	<b>81.1 ±</b>	<b>79.0</b>	<b>15.1 ±</b>	<b>26.5</b>	
<i>Nertera</i> spp.	3.5 ±	3.0 (+)	1.3 ±	2.2 (n)	0.4 ±	0.8	0.0 ± 0.5
+ <i>Trifolium repens</i>	1.3 ±	2.5 (n)	0.4 ±	0.6 (+)	0.5 ±	1.0 (n)	0.6 ± 0.6
<i>Astelia fragrans</i>	1.2 ±	2.2 (-)	1.3 ±	2.6 (-)			-1.0 ± 0.0
<i>Acaena</i> sp.	0.6 ±	1.1	10.8 ±	11.4 (-)	0.1 ±	0.2	-0.9
<i>Galium</i> sp.	0.1 ±	0.3	8.6 ±	16.9 (-)			-1.0
<i>Hypochaeris radicata</i>	0.1 ±	0.4	7.5 ±	7.2 (n)			-0.4
<i>Epilobium</i> sp.	0.1 ±	0.1	5.4 ±	10.0 (n)			-0.7
+ <i>Cirsium</i> spp.			29.0 ±	51.0 (-)	12.9 ±	24.0 (n)	-0.8 ± 0.7
+ <i>Crepis capillaris</i>			3.6 ±	4.1 (+)			0.6

Table 2 Cont . .	Beech		Exotic		Shrub-hardwood		Mean PI
+ <i>Lotus</i> spp.			3.2 ±	6.4 (+)			0.9
+ <i>Veronica</i> spp.			3.1 ±	5.1 (n)			-0.9
+ <i>Mycelis muralis</i>			2.8 ±	3.6 (n)			-0.8
<b>LICHEN</b>	<b>11.5 ±</b>	<b>6.3</b>	<b>6.0 ±</b>	<b>10.0</b>	<b>3.4 ±</b>	<b>4.4</b>	
<i>Thallose lichens</i>	7.3 ±	4.3 (-)	0.9 ±	1.4	2.9 ±	4.4 (-)	-0.6 ± 1.2
<i>Usnea</i> spp.	2.6 ±	2.3 (+)	1.5 ±	2.9 (n)	<0.1		0.6 ± 1.0
<i>Cladonia</i> spp.	1.6 ±	1.4 (-)	3.5 ±	7.1 (-)			-1.0
<b>FUNGI</b>	<b>1.1 ±</b>	<b>0.1</b>	<b>&lt;0.1</b>		<b>&lt;0.1</b>		
Mushroom spp.	0.1 ±	0.1 (+)		(+)		(+)	1.0 ± 0.1
<i>Cyttaria gunni</i>		(+)					1.0
<b>TOTAL</b>	<b>549.6 ± 121.9</b>		<b>679.6 ± 334.9</b>		<b>466.6 ± 153.9</b>		

these forests, and consist mainly of herbs and grasses which predominate in small (< 1 ha) clearings and on forest edges.

Overall, the exotic forest appeared to provide the best habitat (nutritionally) for deer, with the greatest abundance of preferred foods (198 kg ha<sup>-1</sup>). These were less common in shrub-hardwood forest (68 kg ha<sup>-1</sup>), and scarcest in beech forest (32 kg ha<sup>-1</sup>).

#### Use of litterfall

Edible litter fall comprised less than 1.5% of available forage in all habitats, and consisted mainly of the common canopy and subcanopy tree species, pepperwood (*Pseudowintera colorata*), and lichen (Table 3).

Litterfall of broadleaf, the most important food species, contained a high proportion of mature yellow leaves (60%; Table 3), but none of the broadleaf foliage growing within the browse zone was yellow.

An approximately similar proportion (71 %) of the broadleaf present in 121 of the rumen samples also consisted of mature yellow leaves, indicating it had been eaten after it had fallen from above the browse zone.

Young seedling or apical leaves comprised only 4% of the broadleaf in these 121 rumen samples, but formed the bulk of the broadleaf foliage growing in the browse zone, particularly in beech forest (76%). Mature live broadleaf foliage was found in the browse zone only where the plants were protected from deer browsing (under other shrubs, or under piles of fallen branches) or in areas seldom frequented by deer (hunter access points and near roads). It is therefore likely that nearly all (>90%) of the broadleaf eaten was litterfall, at least in the indigenous forests.

The overall importance of broadleaf foliage in the 121 rumen samples declined from 40.4% in winter

Table 3: Estimates of the biomass of potentially edible litterfall on the ground in summer 1987. Only the nine species with estimates greater than 0.1 kg ha<sup>-1</sup> are included. Trace amounts of a further 15 species were also recorded as litterfall. The broadleaf component is split into two foliage categories, mature green leaves (G) and mature yellow leaves (Y).

	Beech	Exotic	Shrub-hardwood
<b>TREES</b>			
Canopy			
<i>Nothofagus menziesii</i>	0.4 ± 0.5	0.2 ± 0.5	1.7 ± 1.9
<i>Pinus</i> spp.		2.1 ± 2.5	
Subcanopy			
<i>Griselinia littoralis</i> (Y)	0.6 ± 0.5	0.7 ± 1.4	2.4 ± 2.4
<i>Griselinia littoralis</i> (G)	0.4 ± 0.4	<0.1	1.0 ± 1.2
<i>Pseudopanax crassifolius</i>	0.3 ± 0.5		0.4 ± 0.6
<i>Carpodetus serratus</i>	0.2 ± 0.2	<0.1	0.2 ± 0.2
<b>SHRUBS</b>			
<i>Pseudowintera colorata</i>	0.1 ± 0.1	<0.1	0.6 ± 0.5
<b>CLIMBERS/WOODY EPIPHYTES</b>			
<i>Rubus</i> spp. (indigenous)	<0.1	<0.1	0.3 ± 0.3
<b>LICHEN</b>			
<i>Usnea</i> spp.	0.5 ± 0.4	<0.1	<0.1
<i>Thallose lichens</i>	0.2 ± 0.3		0.1 ± 0.2
<b>TOTAL</b>	<b>3.1 ± 1.3</b>	<b>3.5 ± 3.0</b>	<b>6.8 ± 4.4</b>

samples to 12.6% in summer samples, but the apical and seedling component increased from 0.4% (1.1 % of the broadleaf foliage) in winter to 2.2% (17.4% of the broadleaf foliage) in summer. The increased use of broadleaf seedlings during the season of growth despite the decreased overall use of broadleaf indicates that such seedlings are more preferred by deer than broadleaf litterfall.

Observations of feeding deer, and of browse sign, indicate that deer also obtained other foods produced above the browse zone. The foliage of trees broken down by storms can remain edible for several months, particularly in winter and particularly for species with thick leaves that resist desiccation. For example, canopy breakdown during an unseasonal snowstorm in May 1984 placed huge quantities of tree foliage within the reach of deer, much of which remained edible until September. In addition to tree foliage, broken branches and toppled trees (particularly beech) also carry epiphytic lichens and ferns such as *Phymatosorus diversifolius*, *Pyrrosia serpens*, and *Asplenium fjlaccidum*, and deer were seen eating these. The beech strawberry fungus (*Cyttaria gunni*) was also eaten when it fell from the canopy.

From these observations, it is likely that litterfall comprised between 20 and 50% of annual diet, depending on habitat type (beech c. 40%, exotic c. 20%, and shrub-hardwood c. 50%), and was the predominant food source in winter (beech c. 60%, exotic c. 50%, and shrub-hardwood c. 70%). This heavy overall reliance on litterfall (despite the small quantities found on plots in summer) reflects greater turnover rates for litterfall than for living material growing within the browse zone. For example, litterfall comprised about half the broadleaf foliage harvested in the browse zone in summer 1987 (Tables 2, 3). While the living foliage had probably been produced over the period of a year or more, most of the litterfall component would have been produced within 2 weeks of the harvesting date (broadleaf foliage on branches cut to bait deer traps in the Blue Mountains usually became desiccated and unacceptable to deer within 10 days in summer; G. Nugent, unpubl. data). The annual production of broadleaf litterfall therefore appears to be at least 25 times greater than the production of living broadleaf foliage within the browse zone.

## Discussion

### *Feeding patterns*

In general, fallow deer in the Blue Mountains have much the same feeding patterns and preferences as

other deer species in New Zealand forests. However, the substantial use of fungi and lichen, particularly in beech forest where they together comprised 23% of annual diet, and 33 % of summer diet, has not previously been reported. Mason (1966) recorded lichen in one of 39 rumen samples from deer in Fiordland beech forest, and Lavers *et al.* (1983) noted that deer ate fungi in autumn. In the Blue Mountains, fungi were eaten mainly in late summer, reflecting seasonal availability, as has been recorded in deer diet studies overseas (Jackson, 1977; Harlow and Hooper, 1971). The use of lichen, however, may indicate poor quality habitat, as white-tailed deer in northern USA feed extensively on arboreal lichens (including *Usnea* species) during winter but switch abruptly to other foods when they become available in spring (Hodgman and Bowyer, 1985).

Subcanopy trees in general, and broadleaf in particular, appear to be the main foods of forest-dwelling deer in the South and Stewart Islands, regardless of forest type or deer species (Mason, 1966; Lavers, 1978; Lavers *et al.*, 1983; Nugent and Challies, 1988; C.N. Challies, unpubl. data from West Nelson). The main source of these foods in the Blue Mountains (and on Stewart Island) was litterfall, particularly in winter. In addition to these two quantitative studies, there is anecdotal evidence that deer feed on litterfall in most forest types (Murie, 1951; Mason, 1966 for wapiti (*Cervus elaphus nelsoni*) in Fiordland beech forest; Davidson and Kean, 1960 for red deer (*Cervus elaphus scoticus*) in the Tararua range; K. W. Fraser (unpubl. data) for sika deer (*Cervus nippon*) in the beech forests of the Kaimanawa range; and personal observations for red deer in West Taupo podocarp-hardwood forests). In the Blue Mountains, the predominant component of edible litterfall (the senescent leaves of broadleaf) was less preferred than young broadleaf foliage growing within the browse zone, but the annual production of litterfall was much greater than the amount of living broadleaf produced within the reach of deer. By providing deer with a major food source that is independent (in the short-term) of deer density, litterfall is likely to act as a buffer between changes in deer density and vegetation response, particularly for those plant species which are more attractive to deer than litterfall is.

### *Impact on regeneration*

The impact of deer at present densities on plant regeneration and the likely effect of changes in deer density can be assessed by comparing plant production and use within the browse zone.

Most forest species in New Zealand retain their leaves for at least 1 year (Nordmeyer and Evans, 1985). The 'standing crop' of forage growing within the browse zone (i.e., excluding litterfall) will be approximately equivalent to the maximum likely annual production of living foliage. Total annual use of forage in the Blue Mountains can be estimated by assuming deer densities of 0.10 deer/ha for beech and shrub-hardwood forest and 0.02 deer/ha for exotic forest (G. Nugent, unpubl. harvest data), and an average daily dry matter intake of 0.8 kg/deer/day (combining intake data from Putman (1980) and live weight data from Baker (1973)). These calculations suggest that at present densities, deer are using about 30 kg ha<sup>-1</sup> yr<sup>-1</sup> of forage in beech and shrub-hardwood forest and 6 kg ha<sup>-1</sup> yr<sup>-1</sup> of forage in exotic forest.

Comparison of the standing crop of vegetation with the estimated quantity of each species eaten by deer (total annual food requirement for deer x % of annual diet for each species) indicates that the common plants (> 1 kg ha<sup>-1</sup>) in the Blue Mountains fell into two main groups. For most beech forest species with PI < 0, probable annual production substantially exceeded annual use, making it unlikely that deer have any major effect on their regeneration. For example, the standing crop of silver beech foliage within the browse tier (63 kg ha<sup>-1</sup>) was far greater than its probable use < 0.5 kg ha<sup>-1</sup> yr<sup>-1</sup>. Deer at present densities are therefore unlikely to have any significant impact on beech regeneration patterns, except perhaps on a few localised sites where deer tend to congregate for social, feeding, or other reasons.

In contrast, the quantity of broadleaf eaten in the beech forest (9 kg ha<sup>-1</sup> yr<sup>-1</sup>) far exceeds the estimated production of living material growing within the browse zone (1-2 kg ha<sup>-1</sup> yr<sup>-1</sup>), reflecting the availability and importance of litterfall. Assuming that deer would prefer to eat young growth before litterfall, a major reduction in deer density below present levels would be required before foliage production within the browse zone alone could outstrip demand for broadleaf. It is therefore predicted that broadleaf, most other subcanopy trees, and many of the rare (and probably highly preferred) ferns will not regenerate in the beech forest at present deer densities, except as epiphytes or on bluffs. This pattern appears unlikely to be sensitive to small changes in deer density.

Marbleleaf (the most browse-resistant common subcanopy tree) is an exception to this pattern, as the balance between production and probable use is more even. The regeneration pattern of this species is likely

to be the most responsive to any changes in deer density.

These predictions are supported by local vegetation studies (G.H. Stewart, unpubl. data). Small seedlings (0-15 cm) of silver beech, broadleaf, and marbleleaf were common both inside and outside two exclosures in the beech forest, and tall seedlings (15-135 cm) of all three species were present within the exclosures. However, there were no tall seedlings of broadleaf and lower densities of marbleleaf outside. The density of tall beech seedlings did not differ between inside and outside.

The major reduction in deer density (>80%) in the Blue Mountains since 1960 (Nugent, 1988) must have reduced the population well below carrying capacity. This appears to have reduced the deer impact on some plant species. For example, crown fern was sometimes eaten by deer in the 1950s, when deer densities were high (H. Maunder, former deer culler, pers. comm.), but is now completely avoided. Similarly, the two main canopy species are at present unimportant in the diet, but fallow deer do eat these species if hungry enough (Daniel, 1966; Phillips, 1986). In the 1930s it was difficult to establish pine plantations in some parts of the Blue Mountains because deer ate the seedlings (undated New Zealand Forest Service file note). However, although the impact of deer on these least preferred species has diminished, it has probably not altered for most highly preferred species.

#### *Implications for deer management*

Nugent and Challies (1988) claimed that there would probably be a gradual long-term decline in deer carrying-capacity of podocarp-hardwood forest on Stewart Island because deer were preventing the re-establishment of their main food source - broadleaf. This study suggests that a similar decline in carrying capacity is also likely in the beech forest in the Blue Mountains, even though deer densities have already been reduced well below carrying capacity. Although the Blue Mountains have one of the longest established deer populations in New Zealand (120 years), the deer still rely on a food resource that is not regenerating adequately, and therefore have not yet reached the equilibrium with the vegetation predicted by Caughley (1980).

This has implications for the management of deer in the Blue Mountains specifically, and in indigenous forest generally. The relatively high use of lichen, the scarcity of preferred foods, and the greater number of foods identified per rumen (deer are more selective

when food is plentiful; Wardle, 1984) all suggest that the beech forest of the Blue Mountains is a poorer habitat nutritionally than the exotic forest. This is confirmed by habitat-related differences in deer size. Deer harvested from beech forest during the 1980s were, on average, slightly smaller than those taken from exotic forest (based on a comparison of size using five measurements from each of 737 jaws,  $p < 0.001$ , G. Nugent, unpubl. data). As habitat quality is likely to decline as broadleaf dies out, there appears to be little long-term potential to maintain high densities of high quality trophy animals for recreational hunting in the beech forest. However, the biomass of shrubs, ferns, silver beech, lichen, and fungi appears more than adequate to sustain current densities even if most of the preferred tree species disappear.

It is generally assumed that reducing deer density reverses the process of habitat modification that occurred during deer colonisation. Deer initially feed on the most preferred foods only, but become far less selective as deer density increases (Wardle, 1984). Decreasing deer density therefore presumably allows the deer to become more selective. If all food is produced within the browse zone, any reduction in browse pressure should produce an equivalent increase in regeneration. However, this study and Nugent and Challies (1988) have shown that once deer have eaten out the understorey, litterfall from the canopy becomes a major food source. As a result, a progressive (hypothetical) reduction in a deer population from its carrying-capacity density may not produce the smooth vegetation response expected, but, rather, the following stepped response.

An initial reduction below carrying-capacity would reduce browse pressure on plant species deer preferred less than litterfall but not on those species more preferred. The biomass of the least preferred species would increase. Further small reductions in deer density would only result in more of the litterfall being left uneaten, and there would be little additional response in the vegetation. The overall regeneration pattern would not change substantially until deer densities were reduced to the level at which production of the most preferred species fulfilled or exceeded the food requirements of the deer population.

This model of vegetation response suggests that where deer at carrying-capacity rely heavily on moderately preferred litterfall, a small reduction in deer density would minimise their impact on those species less preferred than litterfall. Further control effort, however, would be effective only if the deer

population was reduced below the regeneration threshold of the most preferred plant species.

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Appendix I: A list of plants identified to generic or specific level. <sup>d</sup> indicates those plants observed only in rumen samples, <sup>b</sup> those only on forest plots.

TREES: *Acer* sp.<sup>b</sup>, *Aristotelia serrata*, *Carpodetus serratus*, *Quercus* sp., *Fuschia excorticata*, *Griselinia littoralis*, *Kunzea ericoides*, *Leptospermum scoparium*<sup>b</sup>, *Melicactus lanceolatus*<sup>d</sup>, *Metrosideros umbellata*<sup>d</sup>, *Myrsine australis*, *Nothofagus fusca*, *Nothofagus menziesii*, *Pennantia corymbosa*<sup>b</sup>, *Pinus* spp., *Pittosporum eugenoides*<sup>d</sup>, *Pittosporum tenuifolium*, *Plagianthus betulinus*<sup>d</sup>, *Podocarpus ferrugineus*<sup>b</sup>, *P. hallii*<sup>d</sup>, *P. spicatus*<sup>b</sup>, *Pseudopanax colensoi*, *P. crassifolius*, *P. simplex*, *Pseudotsuga menziesii*<sup>b</sup>, *Sophora microphylla*, *Sorbus aucuparia*<sup>b</sup>.

SHRUBS: *Archeria traversii*<sup>b</sup>, *Brachyglottis repanda*<sup>b</sup>, *Cassinia* spp.<sup>b</sup>, *Coprosma cheesemani*<sup>d</sup>, *C. ciliata*<sup>d</sup>, *C. crassifolia*<sup>d</sup>, *C. foetidissima*, *C. linariifolia*, *C. propinqua*<sup>d</sup>, *C. pseudocuneata*<sup>d</sup>, *C. rhamnoides*, *C. rotundifolia*, *C. rugosa*<sup>d</sup>, *Coriaria* sp.<sup>d</sup>, *Corokia cotoneaster*, *Cyanthodes juniperina*, *Cystis scoparius*, *Dracophyllum* sp., *Gaullheria antipoda*, *G. depressa*, *Hebe salicifolia*, *Helichrysum aggregatum*<sup>d</sup>, *Leycesteria formosa*, *Myrsine divaricata*, *Olearia arborescens*<sup>d</sup>, *Pseudopanax anomalus*<sup>b</sup>, *Pseudowintera colorata*, *Ribes* spp., *Ulex europaeus*.

CLIMBERS/WOODY EPIPHYTES: *Clematis paniculata*, *Hedera helix*<sup>d</sup>, *Ileostylus micranthus*<sup>d</sup>, *Muehlenbeckia australis*, *Parsonsia capsularis*, *P. heterophylla*<sup>d</sup>, *Ripogonum scandens*<sup>d</sup>, *Rubus australis*, *R. cissoides*<sup>b</sup>, *R. fruticosus*, *R. schmidelioides*<sup>b</sup>.

FERNS/FERN ALLIES: *Asplenium bulbiferum*, *A. flaccidum*, *A. hookerianum*, *A. lyallii*<sup>d</sup>, *A. terrestre*<sup>b</sup>, *Blechnum capense*, *B. discolor*<sup>b</sup>, *B. fluviatile*, *B. minus*<sup>d</sup>, *B. penna-marina*, *B. procerum*, *Cardiomanes reniforme*<sup>b</sup>, *Ctenopteris heterophylla*<sup>d</sup>, *Cyathia smithii*, *Dicksonia squarrosa*, *Grammitis* spp., *Histiopteris incisa*, *Hymenophyllum* spp., *Hypolepis millefolium*<sup>b</sup>, *H. tenuifolia*<sup>b</sup>, *Leptopteris superba*, *Lycopodium* spp.<sup>b</sup>, *Paesia scaberula*<sup>b</sup>, *Phymatosorus diversifolius*, *Polystichum vestitum*, *Pteridium esculentum*, *Pyrrhosia serpens*, *Rumohra adiantiformis*<sup>d</sup>, *Tmesipteris tannensis*.

HERBS: *Acaena* spp.<sup>b</sup>, *Aciphylla* spp.<sup>b</sup>, *Anisotome* spp.<sup>d</sup>, *Aporostylis bifolia*, *Astelia fragrans*<sup>b</sup>, *Australina pusilla*, *Capsella bursa-pastoris*<sup>d</sup>, *Cardamine debilis*, *Cerastium* spp., *Cirsium arvense*, *C. scirpus*<sup>b</sup>, *C. bulgare*, *Corybas* sp.<sup>b</sup>, *Crepis capillaris*, *Dichondra brevifolia*<sup>d</sup>, *Elatine gratioloides*<sup>d</sup>, *Epilobium* sp., *Galium* sp.<sup>b</sup>, *Gonocarpus* sp.<sup>d</sup>, *Helichrysum filicaule*, *Hydrocotyle americana*<sup>d</sup>, *H. moschata*<sup>b</sup>, *H. novae-zealandiae*<sup>d</sup>, *Hypochaeris radicata*, *Lagenifera strangulata*, *Lapsana communis*, *Lathyrus* sp.<sup>d</sup>, *Leontodon taraxacoides*<sup>b</sup>, *Lotus* spp., *Mycelis muralis*, *Myosotis* sp., *Nertera ciliata*, *N. depressa*<sup>d</sup>, *N. dichondraefolia*, *N. scapanioides*<sup>b</sup>, *N. setulosa*<sup>b</sup>, *Ourisia* sp.<sup>b</sup>, *Oxalis* sp., *Pilosella aurantiaca*<sup>d</sup>, *Phleum pratense*<sup>b</sup>, *Plantago* sp., *Pratia angulata*, *Prunella vulgaris*<sup>b</sup>, *Ranunculus* sp., *Rumex acetosa*, *Schizeileme trifoliolatum*<sup>d</sup>, *Senecio jacobea*<sup>b</sup>, *Sonchus* sp., *Spergula arvensis*<sup>d</sup>, *Stellaria media*<sup>b</sup>, *Taraxacum* sp., *Trifolium* spp., *Urtica incisa*, *U. ferox*, *Veronica* spp., *Viola filicaulis*.

MONOCOTYLEDONS: *Agrostis tenuis*, *Aira caryophyllea*<sup>d</sup>, *Anthosanthum odoratum*<sup>b</sup>, *Carex* sp.<sup>b</sup>, *Chionochloa* spp.<sup>b</sup>, *Dactylis glomerata*<sup>b</sup>, *Holcus* spp., *Juncus* spp., *Microlaena avenacea*<sup>b</sup>, *Phormium tenax*<sup>b</sup>, *Rytidosperma* sp.<sup>b</sup>, *Uncinia* spp.

MOSESSES/LIVERWORTS: *Bazzania* sp.<sup>d</sup>, *Dendrocercus* sp.<sup>d</sup>, *Marchantia* sp.<sup>d</sup>, *Mniodendron dendroides*<sup>d</sup>, *Symphyogyna podophylla*<sup>d</sup>.

FUNGI/LICHEN: *Agaricus* sp.<sup>d</sup>, *Cantherellus elsa*<sup>d</sup>, *Coriolus* sp.<sup>d</sup>, *Cyttaria gunni*<sup>d</sup>, *Cladonia* sp., *Pseudocyphellaria* sp.<sup>d</sup>, *Sticta* sp., *Usnea* spp.