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Impact of an exotic vine *Clematis vitalba* (F. Ranunculaceae) and of control measures on plant biodiversity in indigenous forest, Taihape, New Zealand

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Abstract The exotic vine, *Clematis vitalba* L. (F. Ranunculaceae), has been in forest reserves around Taihape in the Rangitikei Ecological Region of the central North Island, New Zealand, for about 70 years. Before this weed was abundant, Taihape forests were rich in species of indigenous vascular plants, especially woody species. *Clematis vitalba* and its control are contributing to a loss of forest structure and of indigenous biodiversity at the ecosystem and species levels, to a lack of recruitment of indigenous species, to an influx of other weeds and to changes in growth forms of indigenous shrubs. Species that have disappeared or become uncommon in forest with *C. vitalba* tend to be those that are nationally threatened or uncommon, have restricted distributions or are biogeographically significant. Current control of *C. vitalba* in the Taihape forest is piecemeal and long-term. It is based on mechanical and chemical methods, followed by grazing with sheep to prevent regeneration. Recommendations are made for rapid removal of *C. vitalba* from all untreated parts of the reserve, followed by manual control or spot-spraying, permanent removal of sheep, control of other serious weeds and implementation of a restoration programme.

Key words: biodiversity, biogeography, *Clematis vitalba*, disjunct species distributions, environmental weed, indigenous forest, old man's beard, threatened species.

INTRODUCTION

Clematis vitalba in New Zealand

The woody vine, *Clematis vitalba* L. (F. Ranunculaceae) – 'old man's beard' – was first recorded as a weed in New Zealand in 1940 (Webb *et al.* 1988), although it was known much earlier in gardens and as a local garden plant escapee. It is thought to have come to New Zealand as a garden plant from Europe and the first herbarium specimen of a wild plant was collected in 1936 (West 1992). *Clematis vitalba* now occurs as an adventive species almost throughout the lowlands of New Zealand, except for regions north of latitude 37°S (Atkinson 1984; Webb *et al.* 1988; West 1992).

Clematis vitalba is probably the most publicised environmental weed in New Zealand, and community groups, government departments, local authorities, schools and paid contractors have tackled infestations over large and small areas, either mechanically or chemically (Timmins 1995). It has come to public notice mostly because it invades and smothers indigenous forest. In 1998 it was the subject of 37% of complaints about plant pests to the Regional Council that covers our study area, which was more than any other species, including agricultural weeds (Rowatt 1998).

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Clematis vitalba at Taihape

Infestations of *C. vitalba* in forest reserves, gardens, road margins and other places around Taihape in the central North Island, New Zealand (Fig. 1), are believed to have originated from a garden 1.5 km from the Taihape town centre. The source plant(s) was immediately across the road from a forested reserve that borders the entrenched, meandering course of the Hautapu River, a tributary of the Rangitikei River. [The areas of public land with indigenous forest around Taihape township are in several different titles, most of which lie in Taihape Scenic Reserve (80.36 ha) and Taihape Recreation Reserve (53.94 ha). For the purposes of this paper, we refer to all the public land by the informal name of Taihape Reserve.] Local opinion is that this escape of *C. vitalba* occurred in the 1920s, although West (1992) cited one opinion that it was not until the 1940s. The first herbarium specimen of *C. vitalba* from Taihape was collected after 1960. Small parts of Taihape Reserve appear to have never had *C. vitalba*, although most of the reserve has been blanketed for three decades or more (C.C.O., personal observation). In this study, we quantified the impacts of *C. vitalba*, on indigenous biodiversity in forest at the species and ecosystem levels at Taihape and assessed the significance of these impacts on biodiversity at broader geographical scales.

STUDY AREA

Hautapu River and its setting

The Hautapu River rises in native tussock grasslands east of Waiouru (Fig. 1) and in 640 ha of wetlands

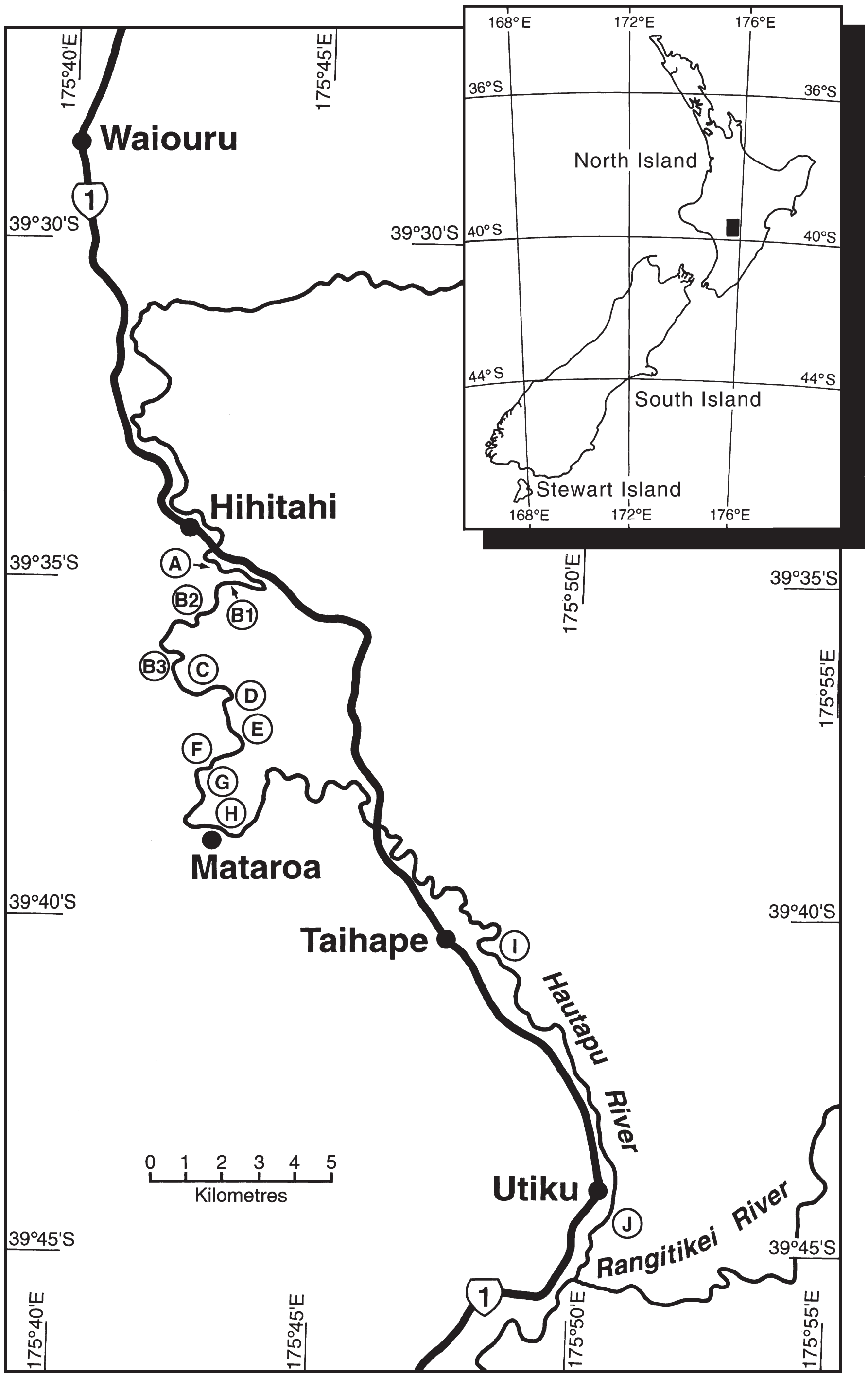

Fig. 1. Map of the Hautapu Valley, central North Island, New Zealand, showing 12 forest remnants identified by letters A–J (as used in Tables 2 and 3). Reserves are: A, Kaitapa + Turangarere; B1–B3, Ngaurukehu; H, Paengaroa; I, Taihape; J, Utiku. C–G, privately owned remnants.

Table 1. Climatic data for the Hautapu Valley

Climate station	Dates covered by records	Altitude (m)	Mean annual rainfall (mm)	Mean annual no. rain days	Mean monthly no. rain days		Min. monthly no. rain days		Extreme grass min. temp. in Jan (°C)		Extreme grass min. temp. in July (°C)		Max. no. ground frosts/ month	
					Jan	Jul	Jan	Jul	Mean	Lowest	Mean	Lowest	Jan	Jul
Hihitahi	1931–80	738	1213.5	180	12.0	18.2	2.0	8.0						
Mataroa	1941–88	564	1115.3	176	11.1	17.8	1.0	8.0						
Taihape	1970–98	433	918.9	189	13.0	19.6	2.0	7.0	1.0	−4.0	−7.3	−9.6	1	21
Kahui	1971–87	518	849.6	149	10.0	16.1	8.0	8.0	2.7	−0.5	−5.7	−7.7	0	17

Rain days > 0.1 mm rain.

south-west of Waiouru (Rogers 1993). From Waiouru it flows south through mostly pastoral farmland with remnants of a previously continuous cover of indigenous forest, through Taihape, the largest town in the valley, and joins the Rangitikei River near Utiku. For much of its course the river has cut into mudstones of Waitotaran and Opoitian age (Kingma 1962). South of Waiouru the river is flanked by alluvial terraces but, as it approaches Taihape, high mudstone cliffs are common on one or other banks until, further south, it becomes entrenched in a narrow gorge, with old terraces bordering the gorge's rims.

From Kaitapa Scenic Reserve (Fig. 1, site 'A') at 740 m a.s.l., the Hautapu River descends to 380 m a.s.l. at Utiku (Fig. 1). The valley lies in the rain shadow of Mount Ruapehu, 50 km to the north-north-west of Taihape and, compared with land of similar altitude to the west and east, it has a cooler, drier climate with a marked summer dry period. There are no strictly comparable sets of climatic data from recording stations that cover the whole valley but Table 1 presents some on rainfall and temperature from four stations, namely Hihitahi (1.5 km north of Kaitapa Scenic Reserve), Mataroa, Taihape and Kahui (4 km from Utiku) (Fig. 1). Mean annual rainfall decreases from north (Hihitahi) to south (Kahui) by about one-third. There can be a marked summer dry period, especially at Mataroa (Table 1). Frosts have been recorded in all months at Taihape (Table 1) and local opinion supports this for Mataroa also.

Letters A–J on Fig. 1 indicate the largest remnants of indigenous podocarp broadleaved forest on the river's banks and adjoining terraces. From north to south, the formally protected areas are the contiguous Kaitapa and Turangarere Scenic Reserves (12.8 ha in total; site 'A'), Ngaurukehu Scientific Reserve (87.1 ha; sites 'B1–B3'), the contiguous Paengaroa Scenic Reserve and Te Kapua Conservation Area (109.1 ha in total; site 'H'), the Taihape Reserves (138.1 ha in total; site 'I') and Utiku Scenic Reserve (25.1 ha; site 'J'). The other forest remnants shown in Fig. 1 are in private tenure and are each <10 ha in area. Burns *et al.* (1999) described the forest in Paengaroa Scenic Reserve as old-growth forest that regenerates by continuous replacement. They obtained age estimates for podocarp trees of up to 716 years for *Dacrycarpus dacrydioides* (A. Rich.) Laubenf. and 1358 years for *Prumnopitys taxifolia* (D. Don) Laubenf. Taihape Reserve was probably similar before it was infested by *C. vitalba*. Of the reserves, only Taihape and Utiku have been infested with *C. vitalba*; control of the vine is being undertaken in both.

The present forest at Taihape

We undertook a reconnaissance of Taihape Reserve in 1998 and noted that, where control of *C. vitalba* has not yet been undertaken, tall podocarp trees, mostly *D. dacrydioides* and *P. taxifolia*, emerged mostly from a dense smothering blanket of *C. vitalba* vines. Where *C. vitalba* had been controlled over the past decade, the podocarps emerged from a broken canopy of scattered broadleaved trees over a ground cover of exotic pasture grasses. Canopy gaps occupied >50% of this forest. *Clematis vitalba* has been stated to be capable of smothering tall forest trees, including podocarps, dramatically altering the forest structure (Williams & Timmins 1990), although Atkinson (1984) doubted that it could overgrow and kill podocarps >25 m in height. Our reconnaissance suggested that sheep, introduced to control regrowth of *C. vitalba*, were maintaining the grass sward allowing little natural regeneration. Many low-stature indigenous shrubs had browsing damage. Under trees and in canopy gaps there were scattered shrubs or loose thickets of divaricating shrubs, of which *Melicytus micranthus* Hook. f. was the most abundant species. Live plants of *C. vitalba* were seen, having been missed during manual control efforts, or which had regenerated since. Dead hanging vines of *C. vitalba* were still evident, especially where control had been within the previous 5 years. Large masses of dead vines had collapsed from the canopy and remained in heaps, mainly around tree bases. Some dead indigenous trees were still standing but others had fallen, with resulting damage to surrounding trees and the understorey. Creation of canopy gaps appeared to have resulted in the wind-throw of living trees. In this paper we refer to such forest as '*C. vitalba* present' (CVP). This includes places where it was obvious that *C. vitalba* had been removed.

During the same reconnaissance of the reserve we found some small pockets of forest that appeared unaffected by *C. vitalba*. Such forest was recognisable primarily by its structure, comprising emergent podocarp trees from a continuous canopy of broadleaved trees at about 5–8 m in height, a dense understorey of mostly divaricating shrubs between 0.5 m and 2.5 m in height and a ground cover of shrub seedlings, ferns and bryophytes. The structure of this forest resembled closely that at Paengaroa Scenic Reserve, about 7 km away to the north-west (Fig. 1). *Clematis vitalba* is not known at Paengaroa. Paengaroa's forest contains natural canopy gaps because it regenerates by continuous replacement (Burns *et al.* 1999). *Clematis vitalba* is known to invade forest from the edges or in canopy gaps (Atkinson 1984; Williams & Timmins 1990; Buddenhagen *et al.* 1998), which means that different parts of Paengaroa, Taihape or, most likely, any other forest remnants of the Hautapu Valley, would be more or less vulnerable to *C. vitalba* at any given time. Therefore, the existence of uninfested pockets within a forest otherwise infested with *C. vitalba* is to be expected.

Other characteristics of forest unaffected by *C. vitalba* in Taihape Reserve, either directly or indirectly, were the absence of dead or living vines of *C. vitalba* and the absence of pasture grasses or weeds of open sites such as thistles (*Cirsium* spp.). Such forest also lacked evidence of sheep browsing on divaricating shrubs or other low-growing plants, even though there were no barriers to sheep entry. In this paper we refer to such forest as '*C. vitalba* absent' (CVA), even though we found a few seedlings of *C. vitalba* in it.

Control of *Clematis vitalba* in Taihape Reserve

To assist the understanding of our methodology and interpretation of results and conclusions, it is necessary to describe the chequered history of *C. vitalba* control in Taihape Reserve. The local council kept the weed under control prior to 1962 but then abandoned it (West 1992). Another 18 months of control occurred in 1972–73 until finances ran out. This control consisted of cutting vines anywhere between ground level and 1 m up and painting the cut stumps, up to 200 mm diameter, with 2,4,5-T (Smith 1984). The same control techniques were used in 1975 for a short period but funds were soon exhausted again. By this stage, some 25 000 person-hours had been spent in the reserve. Control began again in 1976 in areas of relatively light infestation. Some young vines were killed successfully by spraying with a combination of 2,4,5-T and Multi-film penetrant (Smith 1984). Beginning in 1989–90, staff of the Manawatu Wanganui Regional Council undertook a systematic programme of *C. vitalba* control in the reserve. The area was divided into management units, each of about 16 ha, and one unit was targeted for *C. vitalba* control per year. The use of sheep to eat *C. vitalba* regrowth and seedlings was a new element in this control. Each of the six units treated up to the end of 1996 was treated as follows.

- Fence the unit sufficient to confine sheep.
- Introduce about 30 sheep/ha for about 3 weeks.
- Remove the sheep and cut all hanging vines of *C. vitalba*.
- Wait for *C. vitalba* regrowth and spray with 1% glyphosate.
- Reintroduce sheep after 6–8 weeks to break down dead vines and young *C. vitalba*.
- Commence a regime of light rotational grazing, consisting of about 5 sheep/ha, then remove the sheep when a reduced grass supply indicates that the sheep would be about to put more browsing pressure on native regrowth. (The number of sheep and their duration in a management block are dictated by the condition of the vegetation.)

METHODS

Our reconnaissance of Taihape Reserve suggested that *C. vitalba* has had and continues to have many different kinds of impacts upon the forest community. Some are direct impacts, such as the physical smothering and collapsing of indigenous forest and loss of indigenous plant species. Some are indirect, such as the influx of exotic plants into gaps or grazing damage by sheep. In practice, it is difficult to decide whether some changes in the reserve were direct or indirect consequences of *C. vitalba*. Ultimately, the *C. vitalba* infestation can be blamed for a wide range of changes but for future management of Taihape Reserve it was important to assess the conservation importance of what remains there and to identify the environmental costs of management practices already being used. We employed four different methods to quantify some aspects of these problems, as follows.

1. Impacts of *Clematis vitalba* on forest composition and structure

Data were collected in Taihape Reserve to assess how the vine and its control have affected the composition and structure of the forest. Sampling was done in the largest pocket of CVA forest that we could find (see 'The present forest at Taihape', above) and in forest identified as CVP close by. Some comparisons were made with forest in Paengaroa Scenic Reserve at Mataroa, up-river from Taihape (Fig. 1). The measurements were taken as follows.

(a) A 25-m transect was marked in CVA forest. The position and length of this transect were constrained by the small area of such forest. A high density of shrubs in the understorey limited forward visibility to <10 m, thus reducing bias in laying out the transect line. A similar transect was laid out in CVP forest, its origin being about 30 m from that in the CVA forest.

We recorded the identity of all woody plants (trees, shrubs and lianes) within 1 m of each transect line, their size in height classes and, for individuals ≥2 m tall, their diameter at breast height (d.b.h.). The height classes were: Class 0: <250 mm; Class 1: ≥250 mm, <500 mm; Class 2: ≥500 mm, <750 mm; Class 3: ≥750 mm, <1 m; Class 4: ≥1 m, <2 m; Class 5 ≥2 m. No lower height limit was used; the only woody plants not counted were those in the cotyledon stage and seedlings of the abundant indigenous vine *Parsonsia* (*P. capsularis* (Forst. f.) R. Br. and *P. heterophylla* A. Cunn.). Commencing at the origin, data were recorded for the first 2.5 m along the transect, making a quadrat 2 m × 2.5 m, and quadrats of identical shape and size were placed at 5, 10, 15 and 20 m from the origin, making five 5-m^2 quadrats per transect. A list of non-woody vascular plants was made for each quadrat but these plants were not counted or measured. The number of woody species for each transect was calculated by averaging the number of species present in every combination of a given number of quadrats, and species/area curves were plotted. Similar data collected in 1996 along a 20-m transect in Paengaroa Scenic Reserve were added to this analysis, although only four 2 m × 2.5 m quadrats could be placed along this shorter transect. Another difference in the Paengaroa data was that plants <200 mm tall were not recorded, meaning that any species occurring only as small seedlings would have been missed.

For plants >2 m tall in Taihape Reserve, the width of the two transects was increased to 2.5 m either side of the 25 m mid-line, and the d.b.h. was measured for each shrub or tree.

(b) To investigate possible browsing effects of sheep on low-growing native shrubs, measurements were made of 50 individuals of the divaricating shrub *M. micranthus* on each transect line. The measured individuals were the two shrubs closest to each whole metre mark along the transect. For each shrub we measured its stem diameter at ground level and the vertical height of the tallest living shoot.

2. Species biodiversity at the local level

Impacts of *C. vitalba* were assessed by comparing the existing vascular plant flora of Taihape Reserve with that recorded in the past. In 1972, A. P. Druce of the Botany Division, Department of Scientific and Industrial Research, compiled a list of indigenous plants for forest 'in the vicinity of Taihape, based on observations 1946–72' (Druce 1972). The only forest 'in the vicinity of Taihape' is our study area. Druce (1972) annotated 23 of the 146 species that he listed as being 'uncommon'. From visits over the past decade, one of us (C.C.O., in Druce & Ogle 1990) has maintained a list of vascular plants for the reserve, to compare with the list of Druce (1972).

3. Ecosystem diversity at the district level

The importance of Taihape Reserve lies, at least in part, in the degree to which it differs from other forest remnants of the Hautapu Valley. In the absence of detailed information on the structure and composition of each forest remnant, we used an indicator of ecosystem diversity, namely the occurrence of native vascular plant species in the forest remnants of the valley, and we related these to climatic and geographical gradients.

Lists were made of the indigenous flora in each of 12 forest remnants along the Hautapu Valley. These incorporate the lists for specific reserves (Druce 1972; Druce & Ogle 1988, 1990; C.C.O., unpublished data). The lists have been ordered from the northernmost (up-river) to the southernmost (down-river) forest patches. Climate data were obtained from the National Institute of Water and Atmospheric Research (NIWA) (Table 1).

4. Hautapu Valley and biodiversity at the national level

The importance of the Hautapu Valley's forests in relation to forest patterns elsewhere in New Zealand was assessed from existing information. Ogle & Barkla (1995) showed that although the Hautapu Valley lies west of the North Island's axial ranges, its forest remnants are more like those east of the ranges. They suggested that forests of the Hautapu and nearby valleys may be derived from forest that was once continuous with that of the eastern North Island, having been separated by uplift of the axial ranges over the past 1 million years. Part of the evidence lies in species of the Hautapu Valley which are otherwise absent from, or rare, west of the North Island's axial ranges (Ogle & Barkla 1995). At least some of these species have been regarded as indicators of environmentally stressed conditions (Rogers 1989, 1996; Clarkson & Clarkson 1994). Building upon Rogers's (1989) analysis of disjunct species distributions, we compiled a list of species that are found in one or more forest remnants of the Hautapu Valley but which occur otherwise only sparsely in the North Island and then generally east of the axial ranges. Almost all of these disjunct species also occur east of the main mountain ranges of the South Island. Those that are rated as being nationally threatened or uncommon (de Lange *et al.* 1999) were noted.

RESULTS

1. Impacts of *Clematis vitalba* on the forest ecosystem

(a) The frequency and size classes of shrubs and trees in Taihape Reserve are compared for the two transects

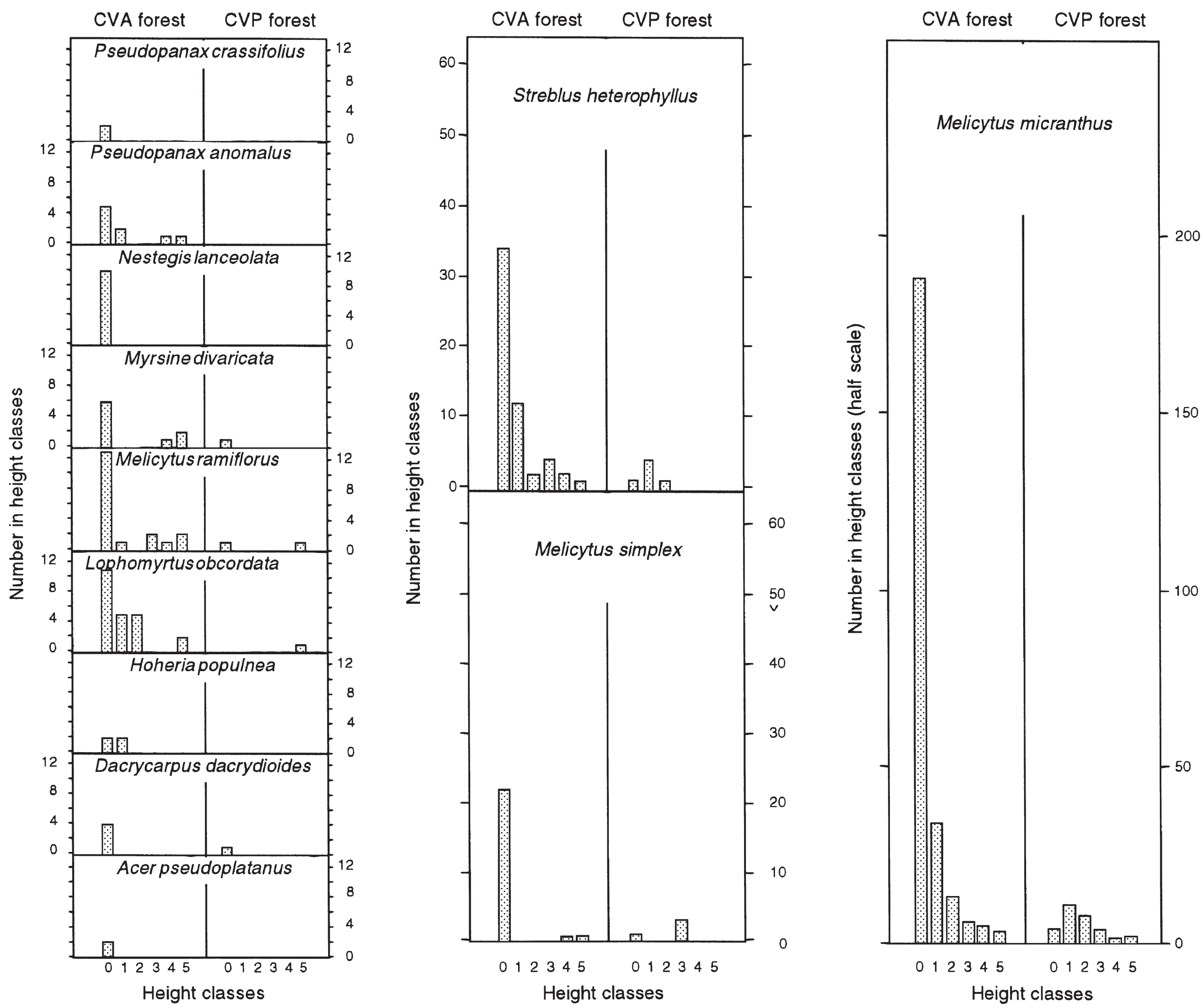

Fig. 2. Frequency and size of shrub and tree species in forest where *Clematis vitalba* is present and has been controlled (CVP forest), and forest where *C. vitalba* is absent (CVA forest). The vertical scale is the same for all species except *Melicytus micranthus*, for which the scale is halved.

in Fig. 2. The frequency/size classes of each species were plotted as histograms, with the results displayed side-by-side for CVA and CVP forests. For simplicity, the figure does not include the 10 indigenous and one exotic species that were recorded only once. The CVA forest transect contained 17 species, 12 of them shown in Fig. 2; two were exotic species. The CVP forest contained 12 species, seven of which are shown in Fig. 2; one was an exotic species and eight of the 12 were present as single individuals.

Differences were more marked between the two transects in the densities of shrub and tree species. With almost 16.5 indigenous shrubs/m^2, the density in the CVA forest transect was more than eight times that in the CVP transect with 2.0 shrubs/m^2. A divaricating shrub, *M. micranthus*, was the only species found consistently in both transects, but 76% were under 50 mm in height in CVA forest, compared with 13% in CVP forest. If totals for *M. micranthus* are excluded, the density of shrubs in the CVA transect was 6.6 shrubs/m^2, which is 8.25 times that in the CVP transect.

The indigenous plants >2 m in height in the 5 m × 25 m transect comprised just four indigenous plant species (seven individuals) in CVP forest, compared with 21 species (74 individuals) in the corresponding CVA forest transect (Fig. 3). Of these species, four (57%) of the individuals had diameters >100 mm in CVP forest, compared with nine (12%) of the individuals in CVA forest. In other words, there have been proportionately greater losses of shrubs and smaller trees in the forest invaded by *C. vitalba*.

In the CVA forest transect in Taihape Reserve almost as many species were found in four quadrats (total area 20 m^2) as were found in five (total area 25 m^2). This is shown by the levelling off of the curve in Fig. 4. This suggests that an area of 20–25 m^2 contains most of the woody species present in this kind of forest in the reserve. However, for CVP forest the climbing curve shown in Fig. 4 shows that an area of 20–25 m^2 would not contain most of the woody species. Although it would be unwise to estimate the peak of this curve by extrapolating it, there is at least a suggestion that there are about the same number of species in CVA and CVP forest but, because the plant density is lower in CVP forest, a larger area needs to be sampled in order to find them. Substantially more species were found in the transect from Paengaroa (Fig. 4); the climbing graph suggests that even more would have been found had more quadrats been sampled.

(b) The heights and basal diameters of *M. micranthus* shrubs sampled in the two transects are plotted in Fig. 5. The data were plotted as log(height) versus

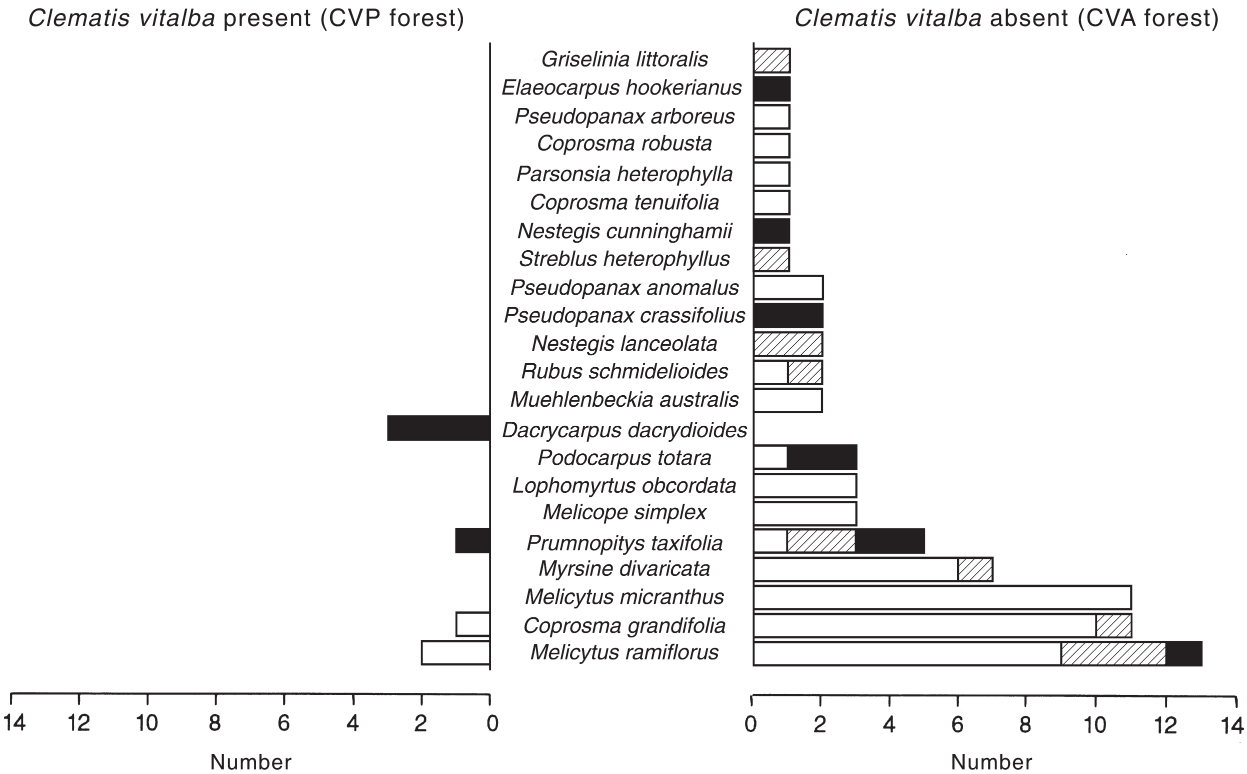

Fig. 3. Cumulative frequency and diameters of indigenous species ≥2 m tall in forest where *Clematis vitalba* is present and has been controlled (CVP forest) and forest where *C. vitalba* is absent (CVA forest). Diameter (d.b.h.) class: □, <50 mm; ▨, 50–100 mm; ■, >100 mm.

log(basal diameter) and an analysis made of the significance of differences between grazed and ungrazed transects.

The dotted lines are the regression lines of $\log_e$(*height*) on $\log_e$(*diameter*), fitted separately in the two transects. However, these do not differ significantly ($F_{2,100} = 2.13$; $P = 0.12$) from the solid parallel lines, which both have a slope = 1.0. These imply that the relationship between height and diameter is a simple ratio, with *height* = 7.58 × 80 *diameter* in the CVA transect and *height* = 5.14 × *diameter* in the CVP transect, the difference in ratios being highly significant ($P < 0.0001$).

2. Impacts of *Clematis vitalba* on species biodiversity at the local level

Of the 146 species listed for Taihape Reserve (Druce 1972), we have found 111 (76%) since 1990 (Druce & Ogle 1990) (Table 2). Some plant groups have suffered more losses of species than others, for example shrubs and small trees have lost 24.4% of species, herbaceous flowering plants have lost 19 of 51 species (37% loss) and there have been no losses of tall tree species. The species lost from Taihape Reserve are listed by Druce & Ogle (1990); some are shown in Table 3.

3. Ecosystem diversity at the district level

Each forest remnant in the Hautapu Valley has a different character that is reflected in differences in species composition. Twelve remnants that have been studied in some detail contain collectively a total of 290 species of indigenous vascular plants (C.C.O., unpublished data). Many of these are nationally widespread, and the distribution of 15 of these within the 12 Hautapu Valley forest remnants is shown in Table 4, in which the sequence of forest remnants, A–J, is from north to south. Climatic data (Table 1) show gradients of rainfall decrease and temperature increase down the Hautapu Valley, and the 15 species were selected because their occurrences nationally suggest that they are limited by climatic factors such as drought or frost. Species that in other parts of New Zealand are intolerant of drought and/or characteristic

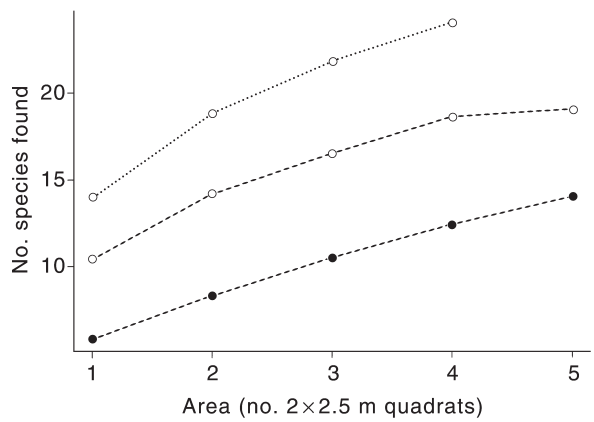

Fig. 4. Counts of indigenous shrub, tree and liane species from quadrats in three forests of the Hautapu Valley: Paengaroa Scenic Reserve (·····), and parts of Taihape Reserve (- - -) where *Clematis vitalba* is present and has been controlled (●, CVP forest) and where *C. vitalba* is absent (○, CVA forest).

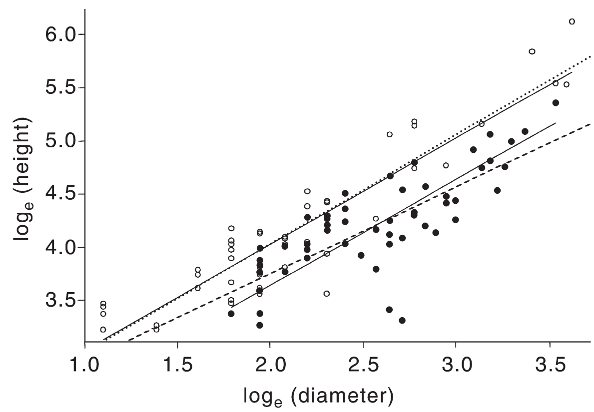

Fig. 5. Shrub height versus stem basal diameter of *Melicytus micranthus* in forest lacking *Clematis vitalba* (·····, CVA forest) and forest where *C. vitalba* is present (●) and has been controlled (○) (– – –, CVP forest); ——, line with slope 1.0.

Table 2. Losses of indigenous plant species from Taihape Reserve between 1972 and 1998

Plant group	No. of species in 1972	No. of species in 1998	Loss of species (%)
Tall trees (all taxonomic groups)	16	16	0
Dicotyledonous shrubs and small trees	45	34	24.4
Dicotyledonous lianes	11	10	9.1
Ferns	23	19	21.7
Monocotyledonous herbs	27	16	40.7
Dicotyledonous herbs	24	16	33.3
Total	146	111	24.0

of montane forests are confined to, or are only common in, the northern forest remnants of the valley. *Podocarpus hallii* Kirk, *Dacrydium cupressinum* Lamb., *Dicksonia lanata* Col., *Asplenium bulbiferum* Forst. f. and *Blechnum colensoi* (Hook. f. in Hook.) Wakef. are examples. In the south, including Utiku Scenic Reserve, the forest contains species typical of forests in the more temperate and drier climate of the lower Rangitikei Valley. Such species tend to be drought-tolerant and, in some cases at least, unable to cope with the heavier frosts further north. Examples are *Alectryon excelsus* Gaertn., *Coprosma areolata* Cheesem., *Coprosma crassifolia* Col., *Myrsine australis* (A. Rich.) Allan, *Rubus squarrosus* Fritsch and *Passiflora tetrandra* DC. (Table 4). The flora of Taihape Reserve tends towards the more temperate, drought-tolerant species (e.g. Taihape has *C. areolata* and *C. crassifolia* and lacks the five species named above for the northern forests of the valley) (Table 4). Taihape Reserve is the only forest in the Hautapu Valley with the widespread North Island lowland tree *Beilschmiedia tawa* (A. Cunn.) Benth. et Hook. f., the forest grass

Table 3. Distribution of nationally disjunct forest species in forest patches of Hautapu Valley

Species	Status	A	B1	B2	B3	C	D	E	F	G	H	I	J
Trisetum drucei Edgar			U										
Clematis quadribracteolata Col.					U								
Coprosma linariifolia Hook. f.		U		U	U	U		U			X	U	
Coprosma rubra Petrie				X	X		X	X			X	U	
Poa matthewsii Petrie				U	U				X	X	X		
Tupeia antarctica (Forst. f.) Cham. et Schlecht.	d			U				U			X		
Acaena juvenca Macmillan					X	U		X	X	X	X	X	
Coprosma virescens Petrie							X	U	X	X	X	U	
Coprosma wallii Petrie	d		U					U		U	X		
Hoheria angustifolia Raoul									X	X	X	U	
Coprosma obconica Kirk	v								U	X	X		
Olearia gardneri Heads	c		U							X	U	E	
Melicytus flexuosus Molloy et A.P. Druce	d		U							U	X	E	
Lagenifera petiolata Hook. f.										X	X		
Teucridium parvifolium Hook. f.	d										X	E	
Korthalsella clavata Cheesem.											U		
Pittosporum obcordatum Raoul	r										U		
Brachyglottis sciadophila (Raoul) Nordenstam	s										U		
Anemanthele lessoniana (Steudel) Veldk.	s										U	E	

Patches are labelled A-J, from north (A, Kaitapa Scenic Reserve) to south (J, Utiku SR). H, Paengaroa Scenic Reserve; I, Taihape Reserve. Status: threatened (c, critical; e, endangered; v, vulnerable); d, declining; r, recovering (conservation dependent); s, naturally uncommon (sparse) in New Zealand (de Lange *et al.* 1999). X, common; U, uncommon in that patch; E, presumed extinct (but present until at least 1972).

Table 4. Distribution of some nationally common species in forest patches of Hautapu Valley

Species	A	B1	B2	B3	C	D	E	F	G	H	I	J
Dicksonia lanata Col.	U											
Cordyline indivisa (Forst. f.) Steudel		U										
Blechnum discolor (Forst. f.) Keys.	X	X	X	X								U
Podocarpus hallii Kirk	X	X	X	X	U					U		
Dacrydium cupressinum Lamb.	X	X	X	U	U		U			U		U
Podocarpus totara G. Benn. ex D. Don.	X		X	U	X	X	X		X	X	X	X
Corokia cotoneaster Raoul	U		U				X	X	X	X	X	
Kunzea ericoides (A. Rich.) J. Thompson								U		U		X
Echinopogon ovatus (Forst. f.) P. Beauv.										X	X	
Myrsine australis (A. Rich.) Allan										U	X	X
Coprosma crassifolia Col.										U	X	X
Coprosma areolata Cheesem.											U	X
Rubus squarrosus Fritsch												X
Passiflora tetrandra DC												X
Alectryon excelsus Gaertn.												X

Patches are labelled A–J, from north (A, Kaitapa Scenic Reserve) to south (J, Utiku SR). H, Paengaroa Scenic Reserve; I, Taihape Reserve. X, common; U, uncommon, in that forest patch.

Microlaena polynoda (Hook. f.) Hook. f. and the sedge *Carex testacea* Boott. (Druce & Ogle 1990; C.C.O., unpublished data). [In September 1999, a 0.3-m seedling of *B. tawa* was found in Paengaroa Reserve. It was growing in mid-slope forest, that is to say it was above the valley floor and not subject to cold-air inversions and poor drainage. It is not known whether this seedling indicates that there is an undiscovered tree of *B. tawa* in Paengaroa or whether it grew from a seed carried here from forest beyond the valley by, for example, a New Zealand pigeon (*Hemiphaga novaeseelandiae*).]

4. Impacts of *Clematis vitalba* on biodiversity at the national level

Nineteen species in one or more forest remnants of the Hautapu Valley have disjunct distributions in the North Island. Some of these species have a nationally threatened or uncommon conservation status (de Lange *et al.* 1999) (Table 3). Taihape Reserve is represented by column I in Table 3, where it can be seen that nine nationally disjunct species have been recorded, of which four were listed by de Lange *et al.* (1999). Paengaroa Scenic Reserve (column H, Table 3) has 17 disjunct species, nine of which were listed as nationally threatened or uncommon (de Lange *et al.* 1999). Taihape Reserve's nine disjunct species are still present in Paengaroa Reserve but only five of these (55.5%) have been seen in Taihape Reserve since 1990 (Table 3). Four of these five are woody plants and all are rare now in the reserve. They comprise just two small browsed shrubs of *Coprosma virescens* Petrie, four adult shrubs (and no juveniles) of *Coprosma linariifolia* Hook. f., about six adult shrubs of *Coprosma rubra* Petrie and two slender saplings of the tree, *Hoheria angustifolia* Raoul. The one disjunct species that is still common is a creeping herb, *Acaena juvenca* Macmillan. The four disjunct species that appear to have become extinct in the reserve comprise three shrubs and a tall grass; they are also the four that have a nationally threatened or uncommon status (Table 3). No species recorded in Paengaroa Scenic Reserve is known to have become extinct since the 1970s and of the 17 nationally disjunct species only five are uncommon there (Table 3).

One of us (C.C.O.) visited Taihape Reserve with A. P. Druce in 1973 and collected material of three shrub species for a personal herbarium. These were the disjunct species *Melicytus flexuosus* Molloy et A. P. Druce (as *Hymenanthera angustifolia* R.Br. ex DC.), *Coprosma virescens* and *Olearia gardneri* Heads (as *O. hectorii* Hook. f.). The first two of these collections were made in an area that is still smothered in *Clematis vitalba*, below Oraukura Road. This area has been searched thoroughly but it now has few native shrubs and no sign of *M. flexuosus* or *Coprosma virescens*. *O. gardneri* was growing on a slope just opposite a picnic ground beside the Hautapu River. Several searches of this site since about 1990, most recently in 1998, did not reveal any *O. gardneri*. *Clematis vitalba* had smothered the site in the 1980s and was controlled here in 1994. The site now comprises pasture grasses under an open canopy of the invasive exotic tree, sycamore (*Acer pseudoplatanus* L.).

DISCUSSION

As pointed out by Williams & Timmins (1990), the precise interaction between the native and weed flora has seldom been studied in New Zealand. There have been many New Zealand reports which state that weeds smother indigenous vegetation, that they suppress regeneration and that they cause a loss of species diversity but usually in qualitative terms only, for example Williams & Timmins (1990, 1999), Polly & West (1996), Buddenhagen *et al.* (1998), Reid (1998). Some of these reports use *C. vitalba* as one example. Even to the casual observer in Taihape Reserve, it is obvious that uncontrolled *C. vitalba* smothers and collapses the forest canopy, leaving tall emergent trees, and that there is little regeneration in areas where the vine has been cleared. Our studies at Taihape Reserve have quantified, first, changes in forest biodiversity that can be attributed to *C. vitalba* or its control and second, some of the differences between forests in Hautapu Valley that are infested or not infested by *C. vitalba*. Fundamental to our interpretation is an understanding of the relationship of this reserve to other forests of the Hautapu Valley, to the wider district and to other parts of New Zealand.

We have also shown that weed control may be as damaging to a site as the weed itself and we are not aware of this finding in other New Zealand studies. Further quantification of the impacts of weeds on indigenous species and natural processes (e.g. Reid 1998; Standish & Robertson 1998) should be a focus for future research. Studies undertaken of weed impacts beyond New Zealand are summarised by Adair & Groves (1998).

Clematis vitalba impacts at Taihape Reserve

In 1998, we collected data in a part of the reserve where, 4 years earlier, *C. vitalba* had been cut and sprayed with herbicide. Sheep have grazed intermittently in this area since the initial control. Our data showed that where *C. vitalba* had occurred there were many fewer indigenous species, and that those present were in smaller numbers than in adjoining forest which had not been infested by *C. vitalba*. In particular, the

C. vitalba infestation appears to have eliminated many of the understorey shrubs and small trees and this finding confirms the data derived from a comparison of 1972 and 1998 species lists for the reserve. The ground cover of the area cleared of *C. vitalba* has few seedlings of indigenous woody species compared with the abundant seedlings of many species in the non-infested area. An example is shown by the high numbers of *M. micranthus* seedlings in CVA forest compared with CVP forest. CVP forest comprises patches of exotic grasses and annual weeds among the scattered shrubs and tall emergent trees that survived *C. vitalba* and its control. Sheep are used to control regrowth of *C. vitalba*; we suspect that they are important factors in preventing regeneration of native forest species as well. Our measurements of stem heights and diameters of the reserve's most common divaricating shrub species, *M. micranthus*, showed significant browsing impacts that result in 'hedged' shrubs with thicker stems for their height than those in adjoining unbrowsed (CVA) forest.

In the presence of sheep, *M. micranthus* shrubs that survived smothering by *C. vitalba* and the direct impacts of vine control in 1994 are unlikely to grow above the height to which sheep can reach. Like most other indigenous shrubs in the areas browsed by sheep, *M. micranthus* seedlings are rare. Similar browsing effects could probably be shown for other species with a divaricating growth form, and were noted on the only two shrubs found in Taihape Reserve of the disjunct species, *Coprosma virescens*.

Our finding that the numbers and variety of understorey trees and shrubs have been severely reduced following the infestation of *Clematis vitalba* correlates with observations of the growth habit of *C. vitalba*. The vines ascend to the canopy of forest but are unable to climb large diameter emergent trees unless shrubs and smaller trees provide a series of 'stepping stones' to the crown of tall trees. This is in accord with our finding that the reserve has retained all 16 species of tall tree recorded by Druce (1972).

Biogeography of indigenous plants in the Hautapu catchment

A feature of the forests of the entire Hautapu Valley floor is the absence of certain species that are common or even dominant in forests only a few kilometres distant, at similar altitudes and latitudes. Among these are the trees *Weinmannia racemosa* Linn., *Metrosideros robusta* A. Cunn., *Nothofagus* spp., *Laurelia novae-zelandiae* A. Cunn., *Knightia excelsa* R.Br. and *Elaeocarpus dentatus* (J.R. et G. Forst.) Vahl, and the tall shrub *Macropiper excelsum* (Forst. f.) Miq. These absences indicate that the Hautapu Valley forests are not typical of those of the wider region. A consequence for nature conservation is that forest remnants of the Hautapu Valley are not represented by forest reserves outside the valley.

Within the Hautapu Valley, climatic gradients are reflected in patterns of plant distribution in the forest remnants. A result of this correlation of forest types with climatic gradients in the Hautapu Valley is that each remnant is important for an understanding of the whole sequence. Paengaroa and Utiku Reserves are 18 km apart. They have different climates and, even not allowing for the likely losses that have occurred in the small and damaged Utiku Reserve, have notable floristic differences. Taihape Reserve is relatively extensive and can be regarded as ecologically intermediate between Paengaroa and Utiku Reserves. The past and on-going degradation of the valley's largest remnant, Taihape Reserve, is creating a gap in the sequence of valley forests for which no other remnant can be a substitute.

Perhaps the most distinctive aspect of the Hautapu's forests is the coexistence of a group of species with disjunct distributions, namely those which occur only sparsely in the rest of the North Island and then generally east of the axial mountain ranges. A large number of the disjunct species are shrubs with a divaricating growth form but some are herbaceous and a number of the disjunct species are rated as being nationally threatened or uncommon. Of the forest remnants of the Hautapu Valley, the greatest concentration of disjunct species is in Paengaroa Scenic Reserve, 7 km upriver from Taihape. Patterns of plant distribution in the valley suggest that some disjunct species might be expected in Utiku Scenic Reserve, at the lower end of the Hautapu Valley. However, there was no botanical survey of Utiku prior to 1990. The reserve is a relatively small forest patch that has been damaged throughout by *C. vitalba* and its control, similar to that in Taihape Reserve. Although sheep are not used deliberately in Utiku Reserve there is a continuing problem with illegal stock trespass, by both sheep and cattle (H. Dorrian, personal communication).

All nine disjunct species recorded at Taihape are still present at Paengaroa. Paengaroa has never had *C. vitalba* and has lost no indigenous plant species since the first detailed botanical survey in the 1970s (Druce 1974; Druce & Ogle 1999). In 1972, when the first recorded botanical survey was made of Taihape Reserve (Druce 1972), *C. vitalba* was already present. Searches from 1990 onwards have confirmed the survival of only five of the nine disjunct species. Among the 21% of shrub and small tree species lost since 1972 are three disjunct species that also are on the national list of threatened and uncommon plants (de Lange *et al.* 1999), namely *Olearia gardneri*, *Melicytus flexuosus* and *Teucridium parvifolium*. Druce (1972) had annotated the last two of these as 'uncommon' within the Taihape

Reserve. The four disjunct shrub species now remaining in the reserve are all uncommon but none of these were annotated as 'uncommon' by Druce (1972) and none is on the list of nationally threatened and uncommon species (de Lange *et al.* 1999).

We conclude that species that were significant elements of the reserve in terms of their biogeography and/or by being nationally threatened or uncommon have been affected disproportionately by the *C. vitalba* infestation. For these significant species, over the period 1972–98, the presence of *C. vitalba* has tended to result in the extinction of those that were already uncommon in the reserve; species with disjunct distributions nationally but which had not been rated previously as uncommon in the reserve, became uncommon there. We do not suggest a mechanism by which a weed might impact more severely upon nationally threatened or uncommon or disjunct species than upon the widespread species growing with them. More study of the phenomenon of rarity in the New Zealand flora might provide some answers, as implied by de Lange & Norton (1998).

Implications for future management of Taihape Reserve

Taihape Reserve is the largest forest remnant in the Hautapu Valley and although *C. vitalba* has damaged its integrity as a natural forest ecosystem, it retains about 75% of its indigenous species and has some structural features of an indigenous forest community. It has the capacity to be restored as podocarp broadleaved forest that reflects its particular location in the Hautapu Valley. The first step is to remove, by 2002 at the latest, all mature *C. vitalba* vines from the reserve and its surrounds and to control subsequent *C. vitalba* regeneration without the use of sheep. More specifically, the management needs are as follows.

1. Remove all remaining vines of *C. vitalba* from those management units of the reserve that have been substantially cleared since 1989. These units should be retired from sheep grazing and regrowth of *C. vitalba* should be controlled manually and/or by spot-spraying.
2. Undertake primary control of *C. vitalba* in all parts of the reserve that have not been treated to date. Total control of *C. vitalba* in all lands of all tenures surrounding the reserve should also be undertaken, to prevent reinvasion of the reserve.
3. Undertake control of the other species of invasive weeds, especially ivy (*Hedera helix* L.), Darwin's barberry (*Berberis darwinii* Hook.), sycamore and Japanese honeysuckle (*Lonicera japonica* Thunb.).
4. Propagate the reserve's 'missing species' from the nearest known natural populations, to establish the propagated plants in the reserve, in habitats that have been assessed as optimal for each species.

There would be major roles for community groups to play in each of the above tasks.

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