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CONSERVATION OF THE THREATENED SHRUB *Hebe cupressoides* (SCROPHULARIACEAE), EASTERN SOUTH ISLAND, NEW ZEALAND

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Abstract

Hebe cupressoides *is an endemic shrub of the rain-shadow eastern mountains of New Zealand's South Island where it is a component of shrubland communities on recent surfaces such as alluvial terraces and colluvial slumps. While* Hebe cupressoides *is grown in cultivation, the range of this species in the wild has declined dramatically this century and is now known to be extant at only 15 of the 33 sites from which it has been recorded. Remaining populations are in general small and comprise predominantly large individuals; seedlings were only seen at three sites. Only one of the 15 remaining populations has > 100 individuals present. Germination of fresh seed is high (89–95%), but is significantly lower for 2-month-old seed. Germination is also substantially higher for seed germinated under full light than under even light shade, and is very low for seed germinated under heavy shade. We hypothesise that although browsing may be a factor in the decline of* Hebe cupressoides, *the almost complete absence of regeneration today is primarily due to an inability of seeds to germinate and seedlings to establish under the heavy shade associated with the introduced grass sward that now dominates at all sites. Restoration of* Hebe cupressoides *populations in the wild will require control of this introduced grass sward. © 1997 Published by Elsevier Science Ltd*

Keywords: Threatened plants, regeneration, invasions, restoration.

INTRODUCTION

Prior to the arrival of humans, New Zealand was largely forested below the climatic treeline. Shrubland and grassland communities were geographically restricted, except in the rain-shadow areas of the eastern South Island where infrequent natural fires (Molloy, 1969) may have played a role in maintaining these shorter stature communities. However, with the arrival of humans, first, Polynesian people some 1000–1200 years ago, and then European people during the last 150 years, extensive deforestation has occurred, especially in lowland areas (McGlone, 1983). In the eastern South Island, deliberate burning has resulted in major changes in the distribution of plant communities, especially reducing the area of woody vegetation (Molloy, 1969). Although fire had a major effect on natural communities during Polynesian settlement, the more frequent use of fire by early European settlers coupled with extensive pastoralism rapidly depleted forest and shrubland communities, often confining these to small fragments (Molloy, 1969; Harding, 1991).

Climatically the eastern South Island is distinctive within New Zealand, having lower rainfall and a greater annual temperature range than most other areas (Coulter, 1975). Summer temperatures are often hot and winter frosts can be severe. Strong dry 'föhn' type winds are also common. These conditions appear to have favoured the development of seral shrubland communities, especially on surfaces that have experienced recent disturbance (e.g. fans and river terraces). Seral shrublands are dominated by a large diversity of small-leaved shrubs, including a number of endemic taxa such as *Hebe cupressoides* (Scrophulariaceae).

As a result of the long fire history and recent extensive pastoralism, these shrublands are now considerably reduced in extent and a number of their component species are threatened with extinction (threat rankings based on the New Zealand threatened plant ranking system (Cameron *et al.*, 1995) except where indicated) including *Carmichaelia hollowayii* (Fabaceae; Endangered — Heenan, 1996), *Chordospartium muritai* (Fabaceae; Endangered), *Hebe armstrongii* (Endangered), *Hebe cupressoides* (Endangered), *Helichrysum dimorphum* (Asteraceae; Endangered), *Muehlenbeckia astonii* (Polygonaceae; Endangered), *Olearia hectorii* (Asteraceae; Endangered), *Chordospartium stevensonii* (Vulnerable),

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Melicytus flexuosus (Violaceae; Vulnerable), *Olearia fragrantissima* (Vulnerable), *Carmichaelia kirkii* (Rare — Heenan, 1996) and *Notospartium torulosum* (Fabaceae; Rare). These shrub and liane species have a number of ecological similarities; all have declined in abundance over the last 100 years and all are represented mainly by small isolated populations with a predominance of older plants. Although there are preliminary, chiefly descriptive, accounts of the communities in which these species occur (Wardle, 1990), less is known about the ecology of individual species (but see de Lange & Silbery, 1993; Given & Pavlik, 1994; Rogers, 1996; Williams *et al.*, 1996) and less especially about options for their long-term conservation.

This paper uses the 'Endangered' shrub *Hebe cupressoides* as a case study to assess the types of problem facing threatened species living in the rain-shadow mountains of the eastern South Island and to make suggestions for their possible conservation management. Specifically, this paper describes the distribution and current status of *Hebe cupressoides*, summarises what we know of the ecology of this species, identifies threats to remaining populations and outlines options for its conservation management. Many of the problems facing *Hebe cupressoides* and associated species in New Zealand are common to species occurring in similar habitats worldwide, especially in lower-rainfall regions where fire and pastoralism have had and continue to have a profound influence on natural communities.

Hebe cupressoides is a greyish-green shrub forming a symmetrical rounded bush 1–2 m tall with small scale-like decussate leaves. Six to eight flowered inflorescences occur at branch tips and flowers vary from white to pale bluish-purple. Plants flower in November–February and seed is ripe in March–May. Seedlings are readily distinguished by the presence of juvenile leaves, which are larger than adult leaves and pinnatifid (Cheeseman, 1914). The genus *Hebe* with *c.* 100 species is centred in New Zealand (about 95 species) where it appears to have speciated during the Quaternary (Garnock-Jones, 1993). *Hebe cupressoides* appears to be most closely related to species in the *Hebe* 'Flagiformes' group (Garnock-Jones, 1993), all of which are endemic to New Zealand, and is most similar morphologically to *Hebe propinqua*, which occurs in the southeast of South Island.

METHODS

Distribution

Information on the historical distribution of *Hebe cupressoides* was obtained from published literature and herbarium records. Assessment of its current distribution and status was based on site visits by the authors and information provided by other botanists who had visited sites we were unable to visit (mainly sites at which *Hebe cupressoides* now appears to be extinct). A total of 70 *Hebe cupressoides* herbarium sheets were held in New Zealand herbaria at the time of this study, of which 54 come from plants collected in the wild (although six of these provide no information on locality). Two further herbarium sheets came from cultivated plants derived from an otherwise unrepresented wild population.

Habitat and population structure

Eleven of the 15 known extant *Hebe cupressoides* populations were visited during this study and information on site physiography and the plant communities in which it grows was collected. At 10 of these sites, plant height, stem diameter at ground level, and canopy spread for the longest axis and the axis perpendicular to this (from which canopy area was derived) were measured. Where possible, all plants were measured at each site, although this was not achieved at all sites because of access difficulties and time constraints.

Seed germination

Fresh seed was collected from the Ahuriri River and Saddle Creek populations in April 1994 and stored in paper bags at room temperature. All germination trials were undertaken using a Contherm Scientific Plant Growth Series 630 growth cabinet (Contherm, Lower Hutt, New Zealand) operating under an 18-h light/6-h dark cycle with temperatures and humidities of 23°C/60% and 13°C/80% respectively. Two germination trials were undertaken. In the first, fresh seed from each population was divided into four replicates of 25 seeds and germinated (trial started 17 days after seed collection). Additional seed was stored, half in plastic bags in a refrigerator and half in paper bags at room temperature. Germination was again assessed after 2 months and 4 months for both storage treatments. Differences in total germination between treatments were tested using analysis of variance. In the second trial, seeds from the Ahuriri River population were germinated under a range of light regimes. Five treatments were used: full growth chamber light, 75% light, 50% light, 25% light and no light. Different light intensities were obtained by using shade cloth of known transmission properties. Because of limited seed availability, only two replicates (of 25 seeds each) were used for each treatment and differences between treatments were not tested for significance.

RESULTS

Distribution and current status

Hebe cupressoides is endemic to New Zealand's South Island, occurring historically along the eastern side of the Southern Alps from Marlborough in the north to Otago in the south, where it has been recorded from at least 33 localities (Fig. 1). *Hebe cupressoides* was first discovered in 1859 or 1860 by Dr Sinclair at the Wairau Gorge and at Tarndale, between the Wairau Valley and

Clarence River in Marlborough (Hooker, 1864; Cheeseman, 1914). Further populations were discovered in the latter part of the 19th century and early 20th century, extending its known range southwards through Canterbury and into Otago (Cheeseman, 1914, 1925). However, localities found since 1925 have not extended this distribution further. It has been suggested that *Hebe cupressoides* was reasonably plentiful in the past (Cheeseman, 1914; Richards, 1956; Molloy, 1984), as is still the case at the largest extant population (Saddle Creek), although it has probably always been confined to localised populations. However, there is little published information from which to further evaluate its past abundance.

The distribution of *Hebe cupressoides* today is substantially more restricted than previously, and it is now known from only 15 populations scattered from North Canterbury to Central Otago (Fig. 1, Table 1). The decline of *Hebe cupressoides* has been most pronounced in the north of its historic range, where it remains at only one of nine localities known from north Canterbury and Marlborough (11%) and three of seven localities from mid and south Canterbury (43%) despite extensive searching at known sites. In contrast, *Hebe cupressoides* is still present at four of five known localities in the Mackenzie Basin (80%) and seven of 12 localities in Otago (58%). The stronghold of this species is now in the Mackenzie Basin and around Queenstown in Central Otago. The reduction in the distribution of *Hebe cupressoides* does not appear to have been recent as Cheeseman noted in 1914 that 'Thirty or forty years ago it was much more plentiful than now' (Cheeseman,

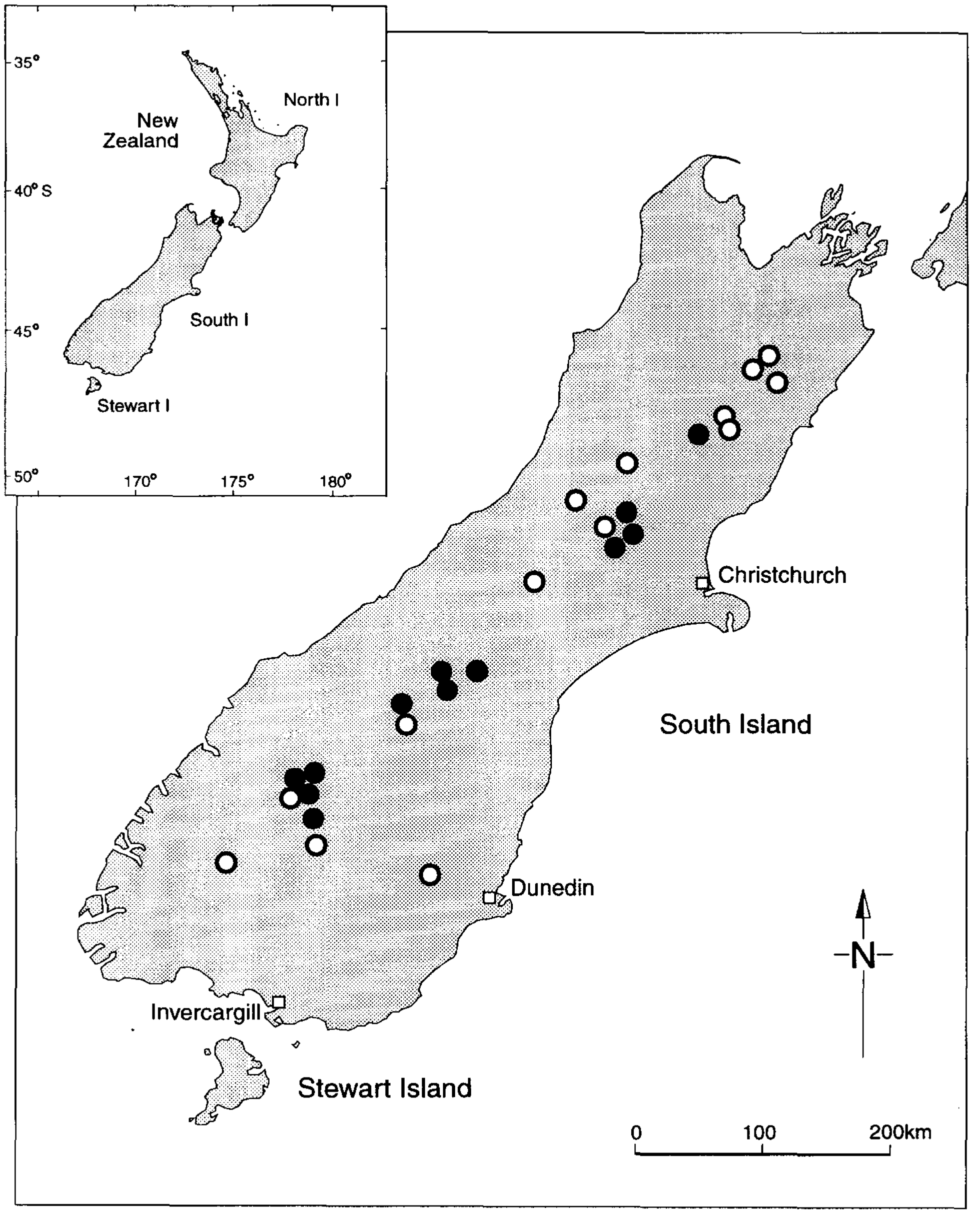


Fig. 1. Historical (○) and extant (●) distribution of *Hebe cupressoides*, eastern South Island, New Zealand. Because of overlap, not all sites are marked.

1914, plate 154). We estimate the total population to comprise some 1580 adult plants and perhaps 150 juveniles, with the majority of plants (>75%) at the Saddle Creek site in Central Otago. Most populations are small (Fig. 2) and all are characterised by a predominance of adult individuals (see below).

Only six of the 15 extant populations occur on land managed for nature conservation purposes. The other populations occur on freehold or pastoral leasehold land that is managed primarily for beef and wool production, although ongoing reviews of land tenure may see some of these sites protected in the future.

Habitat

Nine of the 15 known extant *Hebe cupressoides* populations occur on alluvial terraces or colluvial slumps, while the others occur on bluffs and other steep rocky areas, or amongst bouldery moraine. Cheeseman (1914), in the only published description of the habitat of the now extinct populations in Marlborough, states that it is 'generally an inhabitant of river valleys and terraces'. Alluvial terraces and colluvial slumps appear the most common habitat of *Hebe cupressoides*. Extant sites occur between 500 and 1080 m, and sites from which this species is now locally extinct occupy a similar altitudinal range.

The extant populations occur in climatically similar sites (Table 1), with annual rainfalls of 800–2400 mm. All sites are characterised by cold winters, with mean July minimum temperatures of −1·8 to −5·0°C, and warm summers, with mean January maximum temperatures of 19·1 to 21·5°C. Extreme winter minimums are likely to drop below −15°C and summer maximums to rise above 30°C. Mean annual temperatures are also similar between the extant sites, ranging from 5·5 to 8·7°C.

While the majority of sites with *Hebe cupressoides* have been substantially affected by fire and consequential forest loss, it does appear that at most sites the seral shrubland communities containing *Hebe cupressoides* are located below the regional timberline. The one exception is the north branch Wye Creek site, which at 1080 m is the highest known extant location of *Hebe cupressoides*. Here, *Hebe cupressoides* plants occur in subalpine shrubland above a locally depressed forest timberline.

Hebe cupressoides occurs in open to closed mixed shrubland communities (usually 1–3 m tall) where it is associated with a variety of other indigenous and

Table 1. Numbers of *Hebe cupressoides* individuals present from extant populations

Site	Latitude (S)	Altitude[a] (m)	Rainfall[b] (mm)	Temperature (°C)[c] Min	Mean	Max	N[d]	Regen present[e]	Last survey
North Canterbury									
Boyle River	42° 26′	880	2400	−2·4	7·7	20·6	6	No	Jan 1994
Mid Canterbury									
Broken River[f]	43° 12′	620	1200	−1·8	8·7	21·6	5	No	Apr 1994
Lake Lyndon	43° 17′	880	1200	−2·6	7·4	19·9	2	No	Apr 1996
Red Hill Stream	43° 19′	840	1200	−2·3	7·6	20·0	21	No	Feb 1994
Mackenzie Basin									
Fork River Flats	43° 56′	850	1000	−2.5	7·3	19·5	1	No	Dec 1986[g]
Pukaki Scientific Reserve	44° 08′	660	1200	−2·2	8·1	20·8	c. 100	Yes	Mar 1995
McMillan Stream	44° 08′	800	1200	−2·5	7·4	19·7	c. 100	Yes	Mar 1995
Ahuriri River	44° 28′	660	1400	−3·0	7·9	21·3	18	No	Mar 1995
Shotover									
16 Mile Gorge	44° 40′	600	1400	−2·0	8·2	20·6	8	No	Nov 1994
Mt Greenland[h]	44° 41′	700	1300	−2·3	7·7	20·0	c. 100	No	Nov 1994
Saddle Creek[h]	44° 41′	800	1100	−2·6	7·2	19·3	c. 1200	Yes	Mar 1995
Skipper Creek	44° 48′	700	900	−2·7	7·6	20·3	2	No	Mar 1996
Deep Creek	44° 53′	500	900	−2.2	8·6	21·5	17	No	Nov 1994
Remarkables									
Wye River (N branch)	45° 08′	1080	1000	−5·0	5·5	19·1	3	No	Mar 1995
Wye River (S branch)	45° 09′	940	800	−4·6	6·2	19·9	4	No	Mar 1995

Total number of plants: *c.* 1580

[a]For large populations, altitude refers to centre of population.
[b]Rainfall estimated from New Zealand Meteorological Service Mean Annual Rainfall 1941–70 maps, and Neill Simpson (pers. comm.) for Shotover and Remarkables site.
[c]Temperature estimated using equations in Norton (1985). Mean, mean annual; Min, mean minimum July; Max, mean maximum January.
[d]Number of plants >0·5 m tall.
[e]Presence of seedling plants.
[f]Some 100 further individuals have been planted at this site by the New Zealand Department of Conservation.
[g]Based on a single herbarium record.
[h]These populations consist of a number of subpopulations of variable size.

naturalised shrub species. *Discaria toumatou* (Rhamnaceae) and *Coprosma propinqua* (Rubiaceae) are usually dominant, but *Aristotelia fruticosa* (Elaeocarpaceae), species of *Carmichaelia, Melicytus* and *Olearia*, and other *Coprosma* and *Hebe* species are also commonly present. The naturalised shrub *Rosa rubiginosa* (Rosaceae) was observed at the majority of extant sites, although it was never dominant. Lianes in the genera *Rubus* (Rosaceae), *Parsonsia* (Apocynaceae) and *Clematis* (Ranunculaceae) are also common in these shrublands. Where the shrubland is more open, grassland, usually dominated by introduced grasses such as *Agrostis capillaris* (Poaceae) but also with the native grass species *Festuca novae-zelandiae* (Poaceae) and *Poa cita* (Poaceae), is present. *Hebe cupressoides* occasionally forms small patches, but more commonly, individual plants grow scattered amongst other shrub species. *Hebe cupressoides* has not been recorded from forest.

Population structure

The use of ring counts for aging plants was not possible, as growth rings are indistinct and most stems are too small to core (sectioning stems was not possible in this threatened species). Stem diameter and plant height are only weakly correlated with canopy area (r = 0·577 and 0·543, respectively, both n = 169) but are more strongly correlated with each other (r = 0·764, n = 169). Plant height is used here in preference to stem diameter for describing population structure, as stem diameter was not measured for all plants because of multiple branching at ground level and difficult access in some instances.

Population height–class structures vary between sites (Fig. 3) but two main patterns of height–class distribution are apparent.

1. Five sites (Broken River, Red Hill Stream, Pukaki SR, Ahuriri River, Deep Creek) show no evidence of recent regeneration with all plants > 0·5 m tall. Two further sites have only one plant < 0·5 m tall (Boyle River, Wye River). All of these are characterised by a dominance of plants 1–3 m tall.

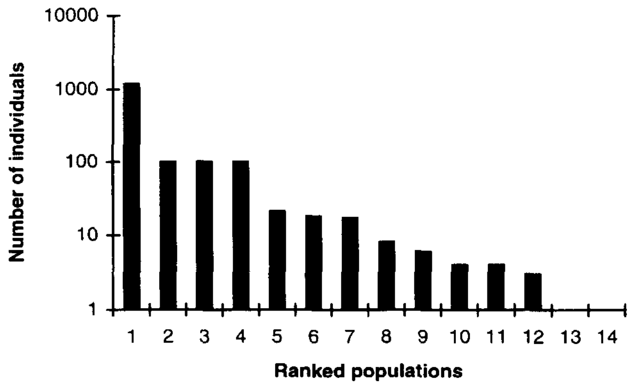


Fig. 2. *Hebe cupressoides* populations rank ordered in terms of the number of adult individuals present.

2. In contrast, the Saddle Creek and McMillan Stream sites have reasonable numbers of smaller plants (< 0·5 m tall) and these are also the only sites at which seedlings were regularly seen (a few seedlings were also present at Pukaki SR). Both of these sites have many more smaller plants than the other sites, with modal size classes of 0·5–1·0 m at Saddle Creek and 0·5–1·5 m at McMillan Stream.

The height-class distributions (Fig. 3) are typical of populations regenerating after episodic recruitment, but the overwhelming impression at all seven sites is the general lack of smaller plants and especially of recent regeneration. Although smaller plants and some seedlings were present at Saddle Creek and McMillan Stream, these appeared to be insufficient to sustain current densities of mature plants in these populations.

Seed germination

In the first germination trial, seed germinated readily with 89 and 95% of seed germinating from the Ahuriri River and Saddle Creek seed lots, respectively. Germination between the two seed lots was not significantly different (F = 3·6, p = 0·101, n = 4). Germination started after 6 days and exhibited the typical sigmoid germination curve typical of many species (Fig. 4(a)). The majority of seed germinated within 20 days. Germination was lower and commenced later for seed stored for 2 months (Fig. 4(a)), with 73% germination for seed stored at room temperature and 51% germination for seed stored in the refrigerator. Germination of 2-month fridge-stored seed was significantly lower than fresh seed for both seed lots (F = 166·6, p < 0·001 and F = 184·7, p < 0·001, respectively, both n = 4), but was not significantly lower for either the Ahuriri Valley and Saddle Creek seed lots stored in the office (F = 5·0, p = 0·066 and F = 3·4, p = 0·114, respectively, both n = 4). Germination commenced after 7 and 9 days, respectively, for the two storage treatments. No seed germinated after 4 months storage, although some additional stored seed did show limited germination after 5 months (storage at room temperature), but there was insufficient seed to assess this formally. The reasons for the germination failure at 4 months are unclear.

Germination of *Hebe cupressoides* seed was strongly affected by light intensity with substantially reduced germination under all shade treatments (Fig. 4(b)). The lower germination in full light than in the earlier trial (84% cf. 89% previously) probably reflects the longer storage time of seed before this experiment commenced (49 days cf. 17 days) and is consistent with the reduction in germination observed after 2 months storage. There was a systematic reduction in germination success with decreasing light, from 30% germination at 75% light to 12% germination under no light (Fig. 4(b)). Date to first germination was also delayed with reduced light from 9 days at 100% light to 13 days under no light.

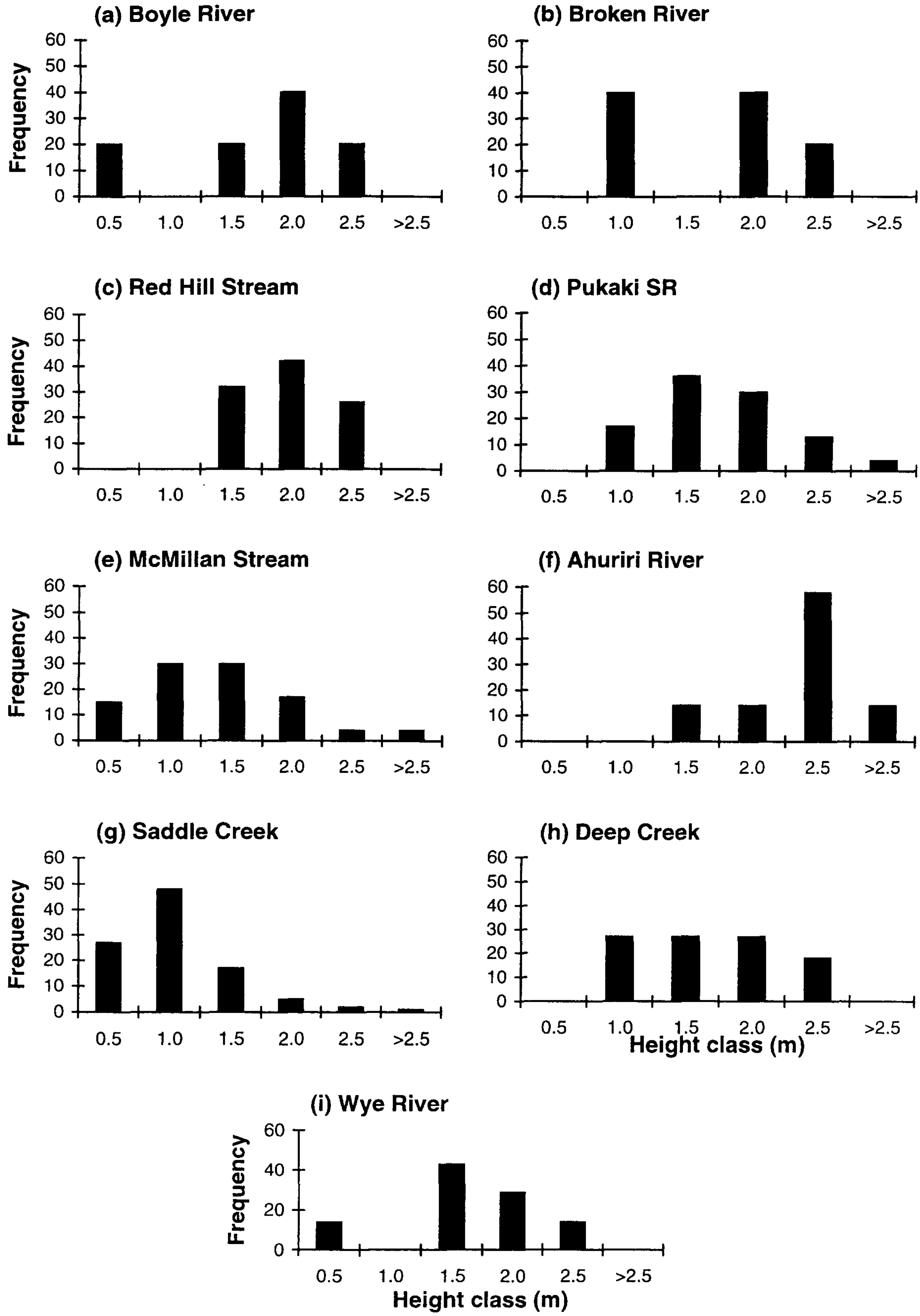
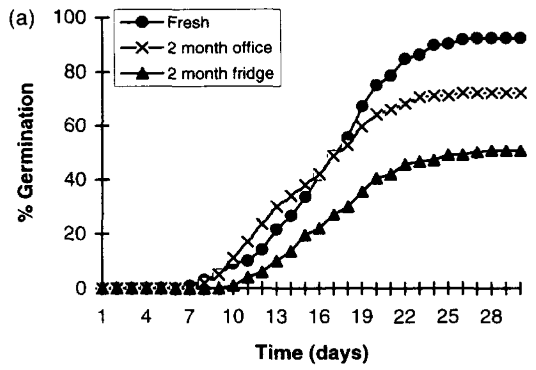


Fig. 3. Height–class percent frequency distributions (0·5 m classes) for nine *Hebe cupressoides* populations: (a) Boyle River (n = 5); (b) Broken River (n = 5); (c) Red Hill Stream (n = 19); (d) Pukaki Scientific Reserve (n = 23); (e) McMillan Stream (n = 53); (f) Ahuriri River (n = 7); (g) Saddle Creek (n = 608); (h) Deep Creek (n = 11); (i) Wye River, north and south branches combined (n = 7).



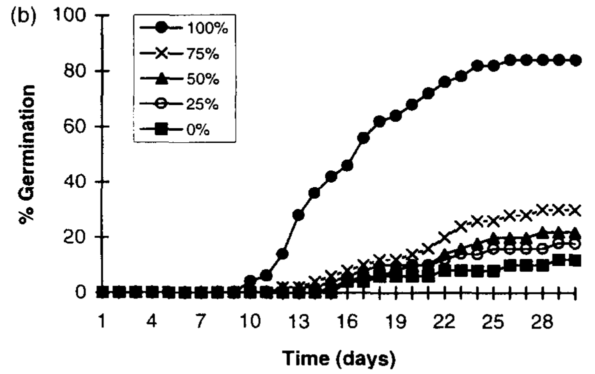


Fig. 4. Percentage germination of *Hebe cupressoides* seeds with (a) different storage time and conditions; and (b) under different light intensities.

DISCUSSION

Historical decline

Hebe cupressoides was clearly more widely distributed in the past than it is today (Fig. 1). There is some evidence to suggest that the decline in distribution started early in the 20th century (Cheeseman, 1914; Richards, 1956) and it appears to be ongoing; some relatively recent records of *Hebe cupressoides* populations could not be relocated during this study (e.g. the 1958 Tims Creek record in mid-Canterbury) and most extant populations are dominated by a few large plants with no evidence of regeneration.

The dry eastern mountains of New Zealand's South Island have a long history of extensive pastoralism involving sheep and cattle. The early European settlers encountered a landscape dominated by a mosaic of grassland, shrubland and forest communities and used fire extensively to increase the area of grassland, and the use of fire has continued to the present day (Harding, 1991). Although the composition and structure of grassland communities have changed as a result of fire and grazing, it has been the shrubland communities that have been most affected by European fire and these are now substantially reduced in extent (Molloy, 1969; Harding, 1991).

Richards (1956) noted that fire had been the dominant factor reducing the abundance of *Hebe cupressoides* and that this species is very flammable, something that we have also noticed. It is also relevant that many of the remaining populations are in sites that are relatively protected from fire (e.g. amongst boulder fields or in topographical locations that are likely to have escaped fire) or are located on farm properties with a known history of conservative fire use (e.g. in the upper Shotover Valley). It would therefore seem likely that the extensive use of fire by farmers has been a major factor in the historical decline of *Hebe cupressoides*, especially if its subsequent regeneration was constrained by other factors (see below).

Current regeneration failure

Most extant populations of *Hebe cupressoides* comprise only a few individuals (Fig. 2) and lack small plants (Fig. 3). The small size of many populations is likely to reflect the effects of 150 years of European fire, but the absence of small plants at most sites suggests that some aspect of *Hebe cupressoides* regeneration or establishment is limiting recruitment of new plants into existing populations. Browsing by introduced animals can be a significant factor limiting regeneration of threatened plants (Loope & Medeiros, 1994). Although browse, probably by rabbits *Oryctolagus cuniculus* (Leporidae) or hares *Lepus europaeus* (Leporidae), is known to affect *Hebe cupressoides* at some sites, we did not see the extensive evidence of browsing that has been observed in studies of other threatened plants (e.g. de Lange & Silbery, 1993; Clarkson & Clarkson, 1994) and it may be that some aspect of this plant's biology makes it unattractive to browsers. Chemical feeding deterrents have been reported for a number of woody plant species (e.g. Bryant *et al.*, 1983) and similar compounds have been found in *Hebe cupressoides* (Perry & Foster, 1994), suggesting that there may be a chemical basis to the limited browse observed. Physical damage to adult *Hebe cupressoides* plants was, however, observed at the Broken River site, most likely from cattle *Bos taurus* (Bovidae). The presence of some *Hebe cupressoides* seedlings at both the McMillan Stream and Saddle Creek sites in the presence of grazing (by both feral and domestic animals) also suggests that grazing is not the predominant limitation to *Hebe cupressoides* regeneration.

The paucity of seedlings may also be due to a failure to set seed or for seed to germinate and successfully establish. Although there is no information on seed banks in these eastern South Island shrublands, the lack of long-term seed viability in *Hebe* species (Simpson, 1976) suggests that seed banks are unlikely to be important. Field observations do, however, show that plants flower prolifically most years and that seed is abundantly produced. Germination under high light conditions is good (89–95%) and is unlikely to be limiting, but germination under even light shade is substantially lower than under full light (Fig. 4(b)). Simpson (1976) has suggested that light is important for successful germination in a range of *Hebe* species and it would seem that *Hebe cupressoides* is no exception to this. Certainly, the only seedlings observed in the field were growing in open sites with no other vegetation present (and in the presence of browsing animals). Despite extensive searching, no seedlings were found underneath existing *Hebe cupressoides* canopies or canopies of other shrub species, or in grassland vegetation, at any sites. It would therefore seem likely that the observed lack of regeneration reflects an absence of suitable high light microsites for regeneration.

The importance of high light microsites for the regeneration of *Hebe cupressoides* fits well with the restriction of this species to sites that have been created by disturbance events (e.g. alluvial terraces, slumps and rock falls). On these disturbed sites, shrubland appears to be successional to forest, in all but the driest areas (Wardle, 1990). Certainly *Hebe cupressoides* has never been recorded growing under a forest canopy and the only regeneration observed in the field has been in open sites lacking other vegetation. It would therefore seem likely that regeneration of *Hebe cupressoides* requires natural disturbances to create open sites suitable for regeneration.

Natural disturbance is important for the regeneration of *Hebe cupressoides*, but natural disturbances also pose two main threats to this species. Firstly, small populations are vulnerable to local extinction by disturbances, especially when adjacent populations are not present to facilitate subsequent recolonisation (Pavlovic, 1994). For example, the McMillan Creek population is located on an active alluvial flood plain and there has already been substantial recent loss of plants from this population due to natural flood processes. Stochastic natural processes like this could have similar impacts on other *Hebe cupressoides* populations (e.g. at Broken River and Lake Lyndon) and could potentially result in local extinction of these populations.

The second and perhaps more significant way in which natural disturbances pose problems for *Hebe cupressoides* is through the rapid colonisation of disturbed sites by invasive naturalised species (Wardle, 1990), resulting in a thick sward of naturalised grasses. Disturbed sites appear to be the preferred establishment site for new *Hebe cupressoides* individuals and are thus essential for sustaining *Hebe cupressoides* populations. We suggest that it is competition with this invasive grass sward, and perhaps also with indigenous and naturalised woody plants tolerant of the grass sward, that is the key factor limiting the regeneration of *Hebe cupressoides* in New Zealand today. Clearly competition for light is important for *Hebe cupressoides* (Fig. 4(b)), although competition for water and nutrients may also be important. Recently disturbed sites with vigorously growing grasses are also attractive to introduced browsers, and this may be a further factor limiting regeneration at these sites.

There has been considerable interest in the role of genetic factors in the rarity of plant species (e.g. Barrett & Kohn, 1991) and the importance of genetic considerations has been emphasised for the recovery of some threatened plant taxa (e.g. DeMauro, 1994). However, genetic factors do not appear to be important in the rarity of *Hebe cupressoides*, where seed set and germination, common indicators of adverse genetic effects such as inbreeding, do not appear limiting. It may well be that in longer-lived woody plants such as *Hebe cupressoides* there have been too few generations for genetic effects to become apparent. However, the reduction in distribution will almost certainly have resulted in a loss of overall genetic variability, which may affect the ability of this species to cope with long-term environmental variability.

The dominant cause of rarity would therefore seem to relate to factors limiting regeneration or eliminating seedlings once established. While there has been and continues to be good documentation of the effects of introduced animals on threatened plants (e.g. Loope & Medeiros, 1994), the data presented here for *Hebe cupressoides* suggest that more attention needs to be given to the effects of introduced plant species on threatened plants, especially in terms of their effects on regeneration opportunities. It is likely that as new plant species successfully naturalise into an area, they will increasingly compete with indigenous species for light, water and nutrients, and may play a key role in their decline.

Current status

Based on the above discussion, it is now possible to evaluate the threat status of *Hebe cupressoides*. Under the revised IUCN threatened species categories (IUCN, 1994), it meets the quantitative criteria for being classified as Endangered as it has an area of occupancy of < 500 km^2 (and populations are severely fragmented and appear to be continuing to decline) and because there are < 2500 individuals. We therefore support the current classification of *Hebe cupressoides* as Endangered (Cameron *et al.*, 1995).

CONCLUSIONS

The history of decline and the predominance of large individuals in remnant populations described here for *Hebe cupressoides* is typical of several other threatened eastern South Island plants; e.g. *Muehlenbeckia astonii* (de Lange & Silbery, 1993), *Olearia hectorii* (Rogers, 1996) and *Chordospartium muritai* (Williams *et al.*, 1996). Key factors in all these cases include habitat loss (primarily as a result of agricultural activities), and browsing by introduced herbivores (domestic and feral) and/or competition with invasive plant species (especially grasses). Similar problems have also been identified in some threatened herbaceous species in New Zealand (e.g. Morgan & Norton, 1992; Molloy, 1994).

The situation described here for *Hebe cupressoides* is certainly not unique within New Zealand and it is likely that comparable situations occur outside New Zealand. For example, Coates (1992) suggested that competition for light and moisture from other plants may be a factor in the poor or absent regeneration of *Discaria pubescens* in Australia. While it is important that we focus on the full range of factors affecting threatened plant taxa, this study has emphasised the importance of invasive plant species in limiting the regeneration of threatened plants such as *Hebe cupressoides*. The successful long-term *in situ* conservation of such species will not be possible until these factors are addressed.

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REFERENCES

Barrett, S. C. H. and Kohn, J. R. (1991) Genetic and evolutionary consequences of small population size in plants; implications for conservation. In *Genetics and Conservation of Rare Plants*, ed. D. A. Falk and K. E. Holsinger, pp. 3–30. Oxford University Press, Oxford.

Bryant, J. P., Wieland, G. D., Reichardt, P. B., Lewis, V. E. and McCarthy, M. C. (1983) Pinosylvin methyl ether deters snowshoe hare feeding on green alder. *Science N. Y.* **222**, 1023–1025.

Cameron, E. K., de Lange, P. J., Given, D. R., Johnson, P. N. and Ogle, C. C. (1995) New Zealand Botanical Society threatened and local plant lists (1995 revision). *N.Z. Bot. Soc. Newslett.* **39**, 15–28.

Cheeseman, T. F. C. (1914) *Illustrations of the New Zealand Flora*, Vol. II. Government Printer, Wellington.

Cheeseman, T.F.C. (1925) *Manual of the New Zealand flora*, 2nd edn. Government Printer, Wellington.

Clarkson, B. D. and Clarkson, B. R. (1994) Ecology of the elusive endemic shrub, *Pittosporum obcordatum* Raoul. *N.Z. J. Bot.* **32**, 155–168.

Coates, F. (1992) Fire and management of a rare plant — Australian anchor plant (*Discaria pubescens*). *Adv. Nature Conserv.* **1**, 15–17.

Coulter, J. D. (1975). The climate. In *Biogeography and ecology in New Zealand*, ed. G. Kuschel, pp. 87–138. W. Junk, The Hague.

de Lange, P. J. and Silbery, T. (1993) Saving the scrubby tororaro (*Muehlenbeckia astonii* Petrie) — an urban approach to threatened plant conservation. In *People, Plants and Conservation. Botanical Gardens into the 21st Century*, pp. 11–19. Royal New Zealand Institute of Horticulture, Wellington.

DeMauro, M. M. (1994) Development and implementation of a recovery program for the federal threatened Lakeside daisy (*Hymenoxys acaulis* var. *glabra*). In *Restoration of Endangered Species*, eds M. L. Bowles and C. J. Whelan, pp. 298–321. Cambridge University Press, Cambridge.

Garnock-Jones, P. J. (1993) Phylogeny of the *Hebe* complex (Scrophulariaceae: Veroniceae). *Aust. Syst. Bot.* **6**, 457–479.

Given, D. and Pavlik, B. (1994) *Helichrysum dimorphum*; obscure, unique and endangered. *Forest and Bird* **272**, 39–41.

Harding, M. (1991) High country high hopes. *Forest & Bird* **261**, 25–32.

Heenan, P. B. (1996) A taxonomic revision of *Carmichaelia* (Fabaceae — Galegeae) in New Zealand (part 2). *N.Z. J. Bot.* **34**, 157–177.

Hooker, J. D. (1864) *Handbook of the New Zealand Flora*. Reeve & Co., London.

IUCN (1994) *IUCN Red List Categories*. IUCN, Gland.

Loope, L. L. and Medeiros, A. C. (1994) Impacts of biological invasions on the management and recovery of rare plants in Haleakala National Park, Maui, Hawaiian Islands. In *Restoration of Endangered Species*, eds M. L. Bowles and C. J. Whelan, pp. 143–158. Cambridge University Press, Cambridge.

McGlone, M. S. (1983) Polynesian deforestation of New Zealand: a preliminary synthesis. *Archaeol. Oceania* **18**, 11–25.

Molloy, B. P. J. (1969) Recent history of the vegetation. In *The Natural History of Canterbury*, ed. G. A. Knox, pp. 340–360. Reed, Wellington.

Molloy, B. P. J. (1984) Potential reserve of *Hebe cupressoides*, 'Birdwood', Ahuriri River. Unpublished Botany Division report, Department of Scientific and Industrial Research, Christchurch.

Molloy, B. P. J. (1994) Observations on the ecology and conservation of *Australopyrum calcis* (Triticeae: Gramineae) in New Zealand. *N.Z. J. Bot.* **32**, 37–51.

Morgan, M. D. and Norton, D. A. (1992) Growth response to light of *Carex inopinata* Cook, an endangered New Zealand sedge. *N.Z. J. Bot.* **30**, 429–433.

Norton, D. A. (1985) A multivariate technique for estimating New Zealand temperature normals. *Weather & Climate* **5**, 64–74.

Pavlovic, N.B. (1994) Disturbance-dependent persistence of rare plants: anthropogenic impacts and restoration implications. In *Restoration of Endangered Species*, eds M. L. Bowles and C. J. Whelan, pp. 159–193. Cambridge University Press, Cambridge.

Perry, N. B. and Foster, L. M. (1994) Antiviral and antifungal flavonoids, plus a triterpene, from *Hebe cupressoides*. *Planta Med.* **60**, 491–492.

Richards, E.C. (1956) *Our New Zealand Trees and Flowers*. Simpson and Williams, Christchurch.

Rogers, G. (1996) Aspects of the ecology and conservation of the threatened tree *Olearia hectorii* in New Zealand. *N.Z. J. Bot.* **34**, 227–240.

Simpson, M. J. A. (1976) Seeds, seed ripening, germination and viability in some species of *Hebe*. *Proc. N.Z. Ecol. Soc.* **23**, 99–108.

Wardle, P. (1990) *Vegetation of New Zealand*. Cambridge University Press, Cambridge.

Williams, P. A., Norton, D. A. and Nicholas, J. M. (1996) Germination and seedling growth of an endangered native broom, *Chordospartium muritai* A.W. Purdie (Fabaceae), found in Marlborough, South Island, New Zealand. *N.Z. J. Bot.* **34**, 199–204.