Climbing spindle berry (*Celastrus orbiculatus* Thunb.) biology, ecology, and impacts in New Zealand

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Climbing spindle berry (*Celastrus orbiculatus* Thunb.) biology, ecology, and impacts in New Zealand

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ABSTRACT

This paper summarises the world literature on climbing spindle berry (*Celastrus orbiculatus*) and provides observations made throughout New Zealand on its history of introduction and spread, biology, ecology, and ecological impacts. Although climbing spindle berry began to invade native vegetation in New Zealand about 30 years ago, today it is still at an early stage of invasion. It has a very localised, but widely dispersed, distribution in the northern North Island, and it is most common in the Taupo–Rotorua area. This pattern of distribution suggests that there are large areas of habitat suitable for climbing spindle berry which are currently not infested, simply because it has not yet arrived. In the future it is likely to spread over wide areas of central New Zealand. At our study sites, climbing spindle berry produces abundant fruit that are dispersed by birds, and contributes up to 50% of the canopy cover over areas of up to 1.5 ha. Currently, it is spreading mainly in early successional vegetation where it can outcompete or smother native vegetation. Seeds can germinate, and some seedlings can grow, in the shade which may allow climbing spindle berry to invade more established forest in the future. A variety of chemical sprays have been used successfully to kill climbing spindle berry. As climbing spindle berry still has a very limited distribution throughout most of New Zealand, there is the potential to eradicate any new infestation that is found in a new catchment or Conservancy, as soon as it appears.

Keywords: *Celastrus orbiculatus*, climbing spindle berry, Oriental bittersweet, envionmental weed, weed ecology

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1. Introduction

Climbing spindle berry (C*elastrus orbiculatus* Thunb.), or Oriental bittersweet as it is known internationally, has become recognised as a weed of conservation concern in New Zealand only within the last decade; it was not listed by Williams & Timmins (1990) as a weed of New Zealand's protected natural areas. It is present in a few Department of Conservation (DOC) conservancies where it appears to be only just starting to spread (Owen 1997). Potential impacts of climbing spindle berry in New Zealand may be underestimated, as it has had a very heavy impact in some parts of the world e.g. North America, where the climate is less benign for this species than in New Zealand. Recognition of climbing spindle berry as a potentially serious invasive weed, still at an early stage of invasion on a national scale in New Zealand, prompted a literature review, a field survey of known infestations, and an investigation into climbing spindle berry in New Zealand.

The fieldwork and a literature review for this study were completed in 1999. During subsequent reviewing and editing, some references that came to our notice have been added but we have not attempted to fully update the literature to 2003. We have also gathered additional information on the distribution of climbing spindle berry in New Zealand but, apart from adding additional points to the species' distribution map, we have not reviewed our initial impression of this species. This account, therefore, stands as a window into the past and a point against which the spread, or successful control, of climbing spindle berry can be compared.

2. Objectives

The objectives of this study were to:

- Review the biology and ecology of climbing spindle berry (C*elastrus orbiculatus*) in its native range and the rest of the world
- Make predictions about its possible impacts and future spread in New Zealand
- Recommend control strategies for climbing spindle berry in New Zealand protected natural areas

3. Methods

Both international and New Zealand literature was searched for information about climbing spindle berry. DOC Area Offices, and other sources within DOC, were asked for informal information about climbing spindle berry ecology and control. Over 5 days in April 1999, when vines were readily visible because their leaves had their bright yellow autumn colour, we visited North Island areas where climbing spindle berry is conspicuous. We travelled from Wellington to the Taupo basin, across the King Country, and then across to Rotorua.

At each site visited, brief notes were taken in a systematic manner on the nature and extent of climbing spindle berry infestation; its reproductive stages; and composition of the vegetation being invaded (Appendix 1). Colleagues in the central North Island subsequently made additional observations on the flowering and fruiting phenology of climbing spindle berry, and similar information was gleaned from New Zealand herbarium specimens.

The following account follows a format similar to that adopted for biological floras. Summaries from the literature, mainly from North America, and our original observations are presented together, under the relevant section.

4. Results and Discussion

4.1 TAXONOMY AND DESCRIPTION

4.1.1 Taxonomy

Celastrus orbiculatus Thunb., family Celastraceae

Standard common name: climbing spindle berry

Other names: Oriental bittersweet (USA); Asian bittersweet; Asiatic bittersweet; round-leaved bittersweet

Climbing spindle berry has a chromosomal count of 2n = 23. It hybridises with the North American native bittersweet (*Celastrus scandens*) (White & Bowden 1947).

4.1.2 Description

Climbing spindle berry is a perennial climbing woody vine with terete, greyish-brown branches growing up to 12 m high (Webb et al. 1988). Branches have noticeable lenticels and the outermost scales of the winter buds are often transformed into sharp spines 1–2 cm long. Plants with stems 5 cm diameter at breast height (dbh) are common in USA and some reach 14 cm dbh.

Leaves are suborbicular, obovate or elliptic, glabrous and commonly 5.0–10.0 cm long (up to 15 cm long in the shade), crenate, and with obtuse to acuminate tips. Petioles are 1–2 cm long. Leaves are deciduous and turn bright yellow in autumn (Fig. 1)

Flowers are borne on short pedicels in one to many flowered cymes, or occasionally male flowers are terminal. Flowers are 4–10 mm diameter with five sepals and five petals that are green, narrowly oblong, and separated. Male flowers often have reduced petals and sepals and they have five stamens, about as long as the petals, inserted at the edge of a cup-shaped disk around a vestigial pistil. Female flowers have vestigial stamens, a three-lobed stigma, columnar style and a well developed superior ovary, sometimes embedded in the disk (Gleason & Cronquist 1991).

Fruits are globose capsules, 6–8 mm diameter, green when immature but changing to yellow then to a yellow-orange colour (Fig. 2). Capsules are three-valved, with each locule containing one to two brown seeds completely enclosed in a fleshy red aril. Upon ripening, the yellow outer capsule valves split open to reveal the red aril. Valves are deciduous.

Figure 1. *Celastrus orbiculatus* in autumn, Rotorua.

Figure 2. Leaves and fruit of *Celastrus orbiculatus*, Ahititi, Taranaki.

4.2 HISTORY AND DISTRIBUTION

4.2.1 Native range in Asia

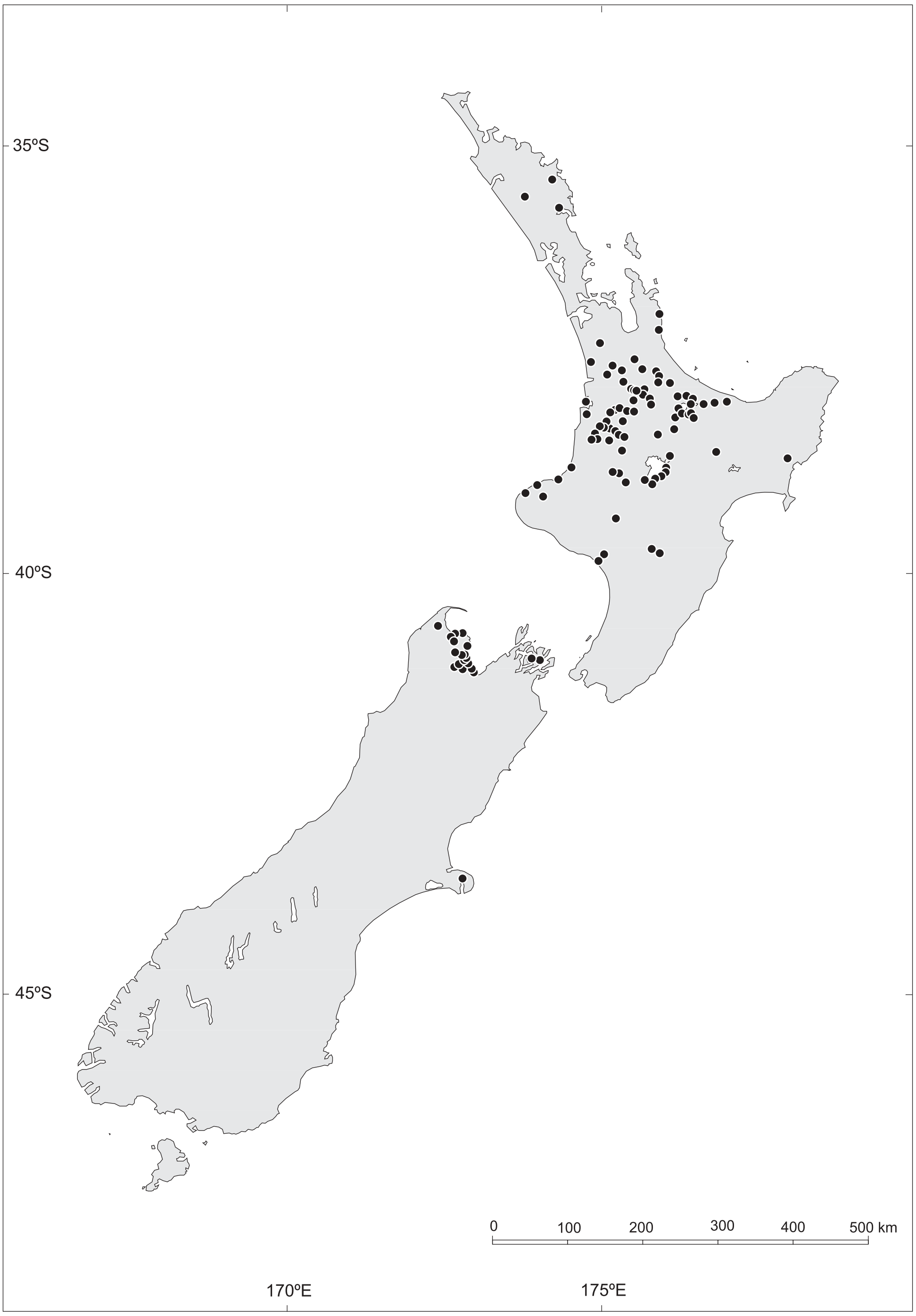
Climbing spindle berry is native to temperate east Asia, including central and northern Japan, Korea, and China north of the Yangtze River (Hou 1955) but, unlike some of its close relatives, it does not extend into India and the Malay Peninsula (Li 1963).

4.2.2 New Zealand

Climbing spindle berry was first offered for sale via nursery catalogues in the Auckland and Coromandel areas in 1905 and by the mid-1960s, in Hawke's Bay and Manawatu, and in Taranaki in 1993 (R. Allen pers. comm.). More recently, it was offered by only one nursery, in Hawke's Bay (Gaddum 1997, 2000) and according to the *New Zealand Plant Finder*, it is currently offered by none (www.plantfinder.co.nz, viewed on 26/05/03).

Climbing spindle berry was first collected in the wild in New Zealand in 1981 near Tairua on the Coromandel Peninsula. At the time of the preparation of *Flora of New Zealand: Volume IV*, it was known only from this collection and it was apparently absent from the South Island (Webb et al. 1988). Contrary to that first collection, the oldest plant we aged, found at Tarawera, must have established itself about 1975. By 1999, climbing spindle berry was known from several widely dispersed locations in the North Island from Northland to the southern Volcanic Plateau, south to Mangaweka, and west to Taranaki (Fig. 3; Appendix 1). It mainly occurs in isolated, small patches, although it is more common from Taupo to Turangi, through parts of the King Country, and particularly in the Rotorua region. It appears to be absent from the eastern and southern North Island. In the South Island, while it is in cultivation, the only naturalised plants are in very localised infestations in the Marlborough Sounds, Nelson, and Banks Peninsula (Fig. 3).

Figure 3. Distribution of *Celastrus orbiculatus* in New Zealand. About a third of these sites were visited by the authors during their April 1999 field trip (see Appendix 1). Further records were contributed by Weed Technical Support Officers subsequently. In addition, the distribution records of Sullivan & Stephens (2002) have been added. This is the distribution of climbing spindle berry known to the authors, and recorded on the DOC Bioweb Weeds Database, in September 2002.



Climbing spindle berry was not listed among the weeds of conservation land in the late 1980s (Williams & Timmins 1990). However, subsequent age estimates from cut stems suggest it was well established at many sites by then (see Section 4.4.1). By 1994, it was considered a potential threat in the Bay of Plenty, Waikato and Tongariro/Taupo Conservancies, and in the latter it was controlled in at least one site (Timmins & Mackenzie 1995). In all other Conservancies it was either unknown or not considered a potential pest. At about this time, climbing spindle berry was listed, along with other species, as unsuitable for garden planting because of its known weediness (Forest Friendly scheme; Craw 1994).

The DOC weed inventory in the Bay of Plenty Conservancy reported no infestations of climbing spindle berry on DOC-managed land (Beadel 1990). However, there were many infestations known on Regional Council-managed land; about 50 infestations by 1999 (R. Mallison & P. Cashmore pers. comms.).

4.2.3 Elsewhere in the world

Climbing spindle berry was introduced into North America before 1879 and has been widely planted for decorative purposes because of its brightly coloured dried fruits. The relative lack of insect pests and diseases on the species in North America also made it attractive to horticulturists (McNab & Meeker 1987). It was first collected as a naturalised plant in 1912 (Patterson 1973). It is now naturalised in 21 states from Maine to Georgia: all of New England, west to the Great Plains and up into Ontario, and south to most of the Atlantic coastal states (Dreyer et al. 1987; Westbrooks 1998). It is not known in the wild on the Pacific coast of North America.

4.3 HABITAT

4.3.1 Climatic requirements

In Japan and Korea, climbing spindle berry grows from the lowlands to the mountains, from 100 to 1400 m a.s.l. (Hou 1955; Ohwi 1965). The agro-climatic analogues constructed by Nuttonson (1947) for China–North America and Japan–North America suggest that climbing spindle berry can tolerate a very wide range of climates (Patterson 1974). Its potential range in North America extends from Nova Scotia to North Carolina.

In New Zealand, climbing spindle berry currently grows from sea level to 540 m a.s.l., the latter record coming from near Tokaanu in the central North Island (Appendix 1). This distribution extends over 3 of the 15 climate districts of New Zealand (Tomlison 1976). These areas cover a wide range of winter temperatures, but they all have warm summers and seldom suffer from serious droughts. Overall, the winter climates in these areas are milder than those reported from North America.

4.3.2 Substrate

Few soil types are given in the North American studies, but climbing spindle berry has been recorded with medium frequency on drought-prone soils derived from sandstone, deep silty soils derived from weathered granites and horneblende-gneiss, and flood plain soils in valleys (Robertson et al. 1994). These authors also found that soils under climbing spindle berry were slightly acidic (pH range 5.6–6.5) with a wide range of mean nutrient concentrations (ppm): Ca 1919, Mg 163, K 145, P 7.4 (Robertson et al. 1994).

In New Zealand, climbing spindle berry grows mostly on substrates derived from sedimentary and metamorphic rock types, but because it is concentrated in the central North Island, most soils have a large component of volcanic material. The most vigorous stands are found on colluvium or alluvium. It appears to tolerate wet soils, but these are probably only seasonally waterlogged. It is less common on excessively drained and drought-prone sandy or stony soil. However, the scarcity of climbing spindle berry on some substrates may just be a result of its relatively recent spread, i.e. it may well spread to other substrates.

4.3.3 Plant communities

In North America, climbing spindle berry is widely associated with marginal communities such as roadsides and thickets, as well as established woodlands. A study comparing several weeds along a successional gradient showed climbing spindle berry was equally common from recent riparian vegetation, through old fields and thickets, to woodland and forest. It was more common in mixed mesophytic forest than in mixed oak forest where crown density was higher (Robertson et al. 1994). It also has some capacity to colonise unstable dune areas (Dreyer 1994).

In New Zealand, we found climbing spindle berry mainly occurs in early successional shrubland and young forest (Appendix 1). In forest or scrub up to 6 m tall, it forms patches in the canopy some distance from the margins. Scrub and shrubland (4–6 m tall) may be completely smothered, i.e. up to 90% canopy cover over an area of 0.2 ha (Fig. 4). Climbing spindle berry also occurs on 'wasteland', as an understorey in open conifer forest, and in cut-over vegetation (Appendix 1). Its habitat range may well broaden in the future, particularly if climbing spindle berry penetrates into established forests via canopy gaps.

In the North Island areas, the native species we found most frequently associated with climbing spindle berry in woody vegetation, in rank order, were: fivefinger (*Pseudopanax arboreus*), mahoe (*Melicytus ramiflorus*), karamu (*Coprosma robusta*), bracken (*Pteridium esculentum*), kohuhu (*Pittosporum tenuifolium*), fuchsia (*Fuchsia excorticata*) and kanuka (*Kunzea ericoides*). Other weed species are relatively uncommon, the most frequent weeds at the same sites being: blackberry (*Rubus* spp.), barberry (*Berberis glaucocarpa*), gorse (*Ulex europaeus*), broom (*Cytisus scoparius*), and Himalayan honeysuckle (*Leycesteria formosa*). It occasionally grows in association with willows (*Salix* spp.). In combination, these species suggest colonisation of early secondary vegetation on zonal soils of medium fertility and drainage, with an occasional occurrence on poorly drained soils (Appendix 1). This could change in the future as climbing spindle berry spreads more widely.

Our literature search found no information about the interaction of climbing spindle berry with herbivorous animals, nor on the influence of grazing on its population dynamics. It is known to be relatively free of insect pests and diseases in North America, adding to its attractiveness to horticulturalists there (McNab & Meeker 1987). However climbing spindle berry plants grown in a glass house in Auckland became badly infested with scale insects (J. Sullivan pers. comm.).

Figure 4. *Celastrus orbiculatus* covering regenerating scrub, Lake Taupo.

4.4 MORPHOLOGY AND GROWTH

4.4.1 Morphology

In North America, climbing spindle berry produces long stems up to 10 cm in diameter that twine around the host and may reach a height of 18 m where it can form a dense canopy cover (Hutchison 1992). The species cannot twine around stems greater than 15 cm in diameter, but it can climb into the canopy over tall trees with large boles by twining around smaller diameter hanging branches and other lianes. Lateral underground runners branch and shoot regularly, and produce roots at the nodes. Alternatively, in high light environments and in the presence of low scrubby vegetation such as blackberry, it may climb unsupported using its own stems to form a curtain of vegetation. Climbing spindle berry stem densities are much higher in these environments than in forest (Robertson et al. 1994).

Climbing spindle berry grows in a similar manner in New Zealand, where the main stems of a plant are commonly 5–6 cm in diameter, with stems up to 14.0 cm in diameter recorded in Taranaki. In the presence of supporting foliage, climbing spindle berry can reach 15 m in height in New Zealand (Fig 4, Appendix 1). Individual plants may spread to cover as much as 170 m^2. During our site visits, stems from throughout its geographic range were cut at 0.5–1.0 m above ground level. Many stems had 5–10 growth rings and, on the assumption these are annular, the vines were 10–12 years old (Fig. 5). The largest number of visible rings on a vine was 32 (Clova Bay, Marlborough Sounds; Appendix 1). One vine at Rotorua had a rotten centre, and allowing for this, we estimated it could have been between 25 and 30 years old.

4.4.2 Perennation

Climbing spindle berry shoots are dormant under the cold winter conditions of northeastern North America and old leaves may be shed under extreme cold. In

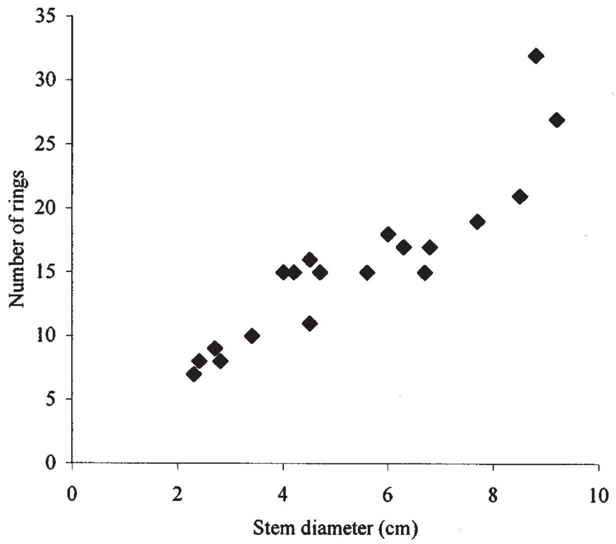


Figure 5. Relationship between stem diameter and stem age for *Celastrus orbiculatus* in New Zealand.

North Carolina, plants break dormancy in April (Patterson 1974). Annual linear shoot growth often exceeds 3 m (Patterson 1974).

Paul Cashmore (DOC Bay of Plenty Conservancy) and Nick Singers (DOC Tongariro/Taupo Conservancy) made monthly notes on the phenology of climbing spindle berry around Rotorua and Turangi respectively during 1999 and 2000. These observations showed vines lose their leaves by late July and August, and produce new leaves by early October, so any period of complete dormancy is very short (P. Cashmore & N. Singers pers. comms.).

4.5 PHYSIOLOGY

Climbing spindle berry has considerable capacity to acclimate its photosynthetic activity to available irradiance during growth. Plants grown at low irradiance had the highest CO_2 uptake (i.e. photosynthetic activity) and the lowest light compensation points (Patterson 1975). These results may explain our field observation that climbing spindle berry seedlings can survive under the shade of parent plants. Patterson (1975) also showed that plants were able to adjust to increased light levels after periods of low light by rapidly increasing photosynthesis, 1.6–1.9 fold. These responses may indicate that climbing spindle berry has a competitive advantage over some species because of its adaptability to a wide range of light environments. This pattern is typical of other invasive vines in New Zealand (Baars & Kelly 1996). However, the sort of habitats climbing spindle berry occupies, in both North America and New Zealand, suggest it is less shade-tolerant than Japanese honeysuckle (*Lonicera japonica*) (Patterson 1975; Williams & Timmins 1999).

Specific conductivity and root pressure in climbing spindle berry, and a native North American grape vine (*Vitis riparia*), have been compared experimentally (Tibbets & Ewers 1998). (Root pressure is implicated as vital to the recovery of xylem function in wide vessels following winter freezes.) The two species responded differently to environmental constraints at different times of the year, but there was nothing to suggest root pressure was a factor in the invasive success of climbing spindle berry. Further details of photosynthesis and water relations can be found in Clement et al. (1991) and Siccama et al. (1976).

4.6 PHENOLOGY AND REPRODUCTION

4.6.1 Phenology

Climbing spindle berry is fully deciduous and dormant during the winter in North America. It flowers in spring, the fruits ripen in summer, and capsules open in late summer or autumn and then persist on the vines for much of the winter. The species follows a similar pattern in New Zealand. Fruit appear in early summer and ripen over summer, leaves turn yellow in late summer and drop by July; all the fruit has fallen by late August in the Rotorua area (P. Cashmore pers. comm.). There is some variation in the timing of leaves turning yellow throughout New Zealand, and even within one site (field obs PAW, SMT; P. Cashmore & N. Singers pers. comms.).

4.6.2 Floral biology

Climbing spindle berry produces small greenish flowers that usually become unisexual by abortion of male or female organs, thus making the plants functionally dioecious (Brizicky 1964). Vines may occasionally develop both unisexual and perfect flowers and become polygamodioecious (Gleason & Cronquist 1991). Monoecious plants have occasionally been reported (Hou 1955).

Ample, viable pollen is produced at most sites in North America (Dreyer et al. 1987) and this dehisces approximately 24 h after the flowers open (Pooler et al. 2002).

Fruit was seen on plants at all sites observed during the April 1999 field trip with the exception of a large bush near Tokaanu. However, we were not able to study the floral biology of these individuals.

Hymenopterous insects, particularly bees, are the main known pollinators in North America (Brizicky 1964). These insects are abundant in New Zealand so we presume that pollination is not limited. In North America, pollen viability ranged from 57% to 74% at three sites with climbing spindle berry *sensu stricta* but was lower at a site where there may have been hybridising with American bittersweet (Dreyer et al. 1987).

Cymes of fruit are commonly 0.5–1.0 m long, with several auxillary branchlets about 10 cm long. A typical spray examined in the Rotorua area during this study had 375 fruit and thus a conspicuous fruit display.

4.6.3 Seed ecology

The mean number of climbing spindle berry seeds per fruit in four North American populations ranged from 2.5 to 4.1. Mean seed weight was 1.022 g but ranged from 0.790 g to 1.186 g and the lightest seeds were found in the fruit with the most seed (Patterson 1974). Our sample of 20 fruit from Rotorua had a mean (± SD) of 3.0 ± 1.2 seeds per fruit. By contrast, a sample of 225 fruits from Waikato had a mean (± SD) of 2.1 ± 1.0 seeds per fruit (Sullivan & Stephens 2002).

Whole fruit fall close to the parent plant, but fruit may be eaten by birds and thus seeds dispersed long-distance. Many bird species disperse climbing spindle berry seeds in North America, particularly in winter (Dreyer 1994). We found no direct observations of seed dispersal in New Zealand, but the fruit are of a size that could be readily eaten by several small passerines, particularly blackbirds (*Turdus merula*) and silver eyes (*Zosterops lateralis*)(Williams & Karl 1996).

Climbing spindle berry seeds germinate best after cold stratification. Patterson (1974) stratified seeds at 5°C during the day and 0°C at night for 90 days. There was no germination at temperatures of 11°C in the day and 2°C at night. Highest germination or percentages rates (95%) occurred with temperatures of 24°C by day and 13°C by night; 55% in light and 70% in dark. A mean of 71% germination was obtained under low light (125 foot-candles[1]; Dreyer et al. 1987). A series of trials examining seedling emergence from a soil mix, found emergence was greatest under medium temperatures (30°C by day, 19°C at night) with medium to low light levels (Dreyer et al. 1987). In New Zealand, a germination trial in Auckland found 11–14% germination of unstratified seed (planted in July, germination in early September) (Sullivan & Stephens 2002).

Dreyer (1994) reports a probable seed bank in the United States of about 6 years. High germination percentages reported for climbing spindle berry plus its high germination under low light conditions (often a cause of dormancy) are consistent with no reports of a long term seed bank. Seedlings can survive low light levels, but they grow most rapidly in moderate to full light (Patterson 1974; Sullivan & Stephens 2002).

4.7 POPULATION DYNAMICS

In North America seedlings appear in the spring following seed production and, combined with older seedlings, they may reach a density of 60/m^2, but their density declines over summer, probably due to drought (Patterson 1974).

A 2.48 ha area of upland oak forest in the Appalachians had densities of 831 climbing spindle berry seedlings/ha (< 1.5 cm dbh) and 27 saplings/ha (> 1.5 cm dbh) prior to milling (McNab & Meeker 1987). After the oak overstorey was removed, the climbing spindle berry covered 'most of the canopy' within 7 years (McNab & Meeker 1987). In a similar situation, climbing spindle berry increased in cover from 5% to 100% over a 600 m^2 area of low vegetation in five years, largely from root sprouts (Patterson 1974). Other authors have reported substantial climbing spindle berry seedling regeneration following control (Dreyer 1994).

Seedlings are uncommon in the wild in New Zealand. After control operations, the flush of what appears to be new seedlings is mostly resprouts from roots. At one study site near Taupo, where a shrub canopy of predominantly kanuka covered free-draining friable alluvium, we found seedlings present at densities of < 1/m^2. This observation, combined with the age structure of the climbing

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[1] A *foot-candle* is a lumen per square foot, and a lumen is a measure of 'brightness' of which the SI unit is *luminous flux*.

spindle berry populations we examined, plus the stand structure of the invaded native canopy vegetation, suggest that climbing spindle berry seedlings establish under moderate shade in New Zealand, primarily in the early stages of vegetation succession, then grow up more or less simultaneously with the supporting native trees (Fig.4).

4.8 ECOLOGICAL IMPACTS

4.8.1 North America

Climbing spindle berry stems are typical of climbing vines because they twine around other plants and kill them by restricting the flow of nutrients and water (Lutz 1943). Once they have reached the canopy they grow over the crowns of the host and completely smother them. This eventually leads to canopy collapse. In eastern North America, several habitat types are threatened, the most vulnerable being upland meadows, thickets and young forests, both natural and managed (Dreyer 1994; Fike & Niering 1999). This leads to a simplified forest structure and lower floristic diversity, with a particular reduction in spring ephemerals (Hutchison 1992).

Climbing spindle berry also has a detrimental impact on threatened species. It can invade open habitats that are refugia for threatened plant species dependent on open sites (Langdon 1993). It has spread into the nesting areas of rare shore birds in sand country (Dreyer 1994).

Pure populations of the native North American bittersweet are potentially threatened by interspecific hybridisation with the introduced species (Dreyer 1994; Pooler et al. 2002). *C.orbiculatus* × *C. scandens* hybrids produced seed with less dormancy than the native seeds (Pooler et al. 2002), but it may be significant that hybrids produced flowers, but no fruit, in their fourth year (White & Bowden 1947).

4.8.2 New Zealand

The infestations of climbing spindle berry in New Zealand are still relatively light, so we have yet to see the full extent of its physical impacts. Where climbing spindle berry gets into the canopy, it can smother native forest trees. Based on its current distribution, the most vulnerable communities appear to be open scrub, shrublands, early successional forest, and the margins of mature forests, particularly those on alluvial or colluvial sites. By contrast, true wetland habitats, which Japanese honeysuckle can invade (Williams et al. 2001), don't seem to be particularly vulnerable to climbing spindle berry invasion.

DOC Conservancy staff's perception of the impact of climbing spindle berry in New Zealand is summarised by Conservancy below, from highest impact (4) to lowest impact (0); modified from categories used in Owen (1997). The information was gleaned from the authors' discussions with DOC weed staff in 1999/2000:

(4) Known to be affecting conservation sites: Tongariro/Taupo.

(3) Naturalised, not yet affecting conservation sites, but impact likely in the future: Northland, Waikato, Bay of Plenty, Wanganui, Nelson/Marlborough.

(2) Naturalised, but effects not identified.

(1) Not naturalised yet but considered to have potential for impact if arrives: Wellington, Otago, Southland.

(0) Not considered to have potential for impacts: Auckland, Hawke's Bay/East Coast, West Coast, Canterbury.

These rankings of climbing spindle berry's present distribtion concur with our own opportunistic observations made in 1999 and 2000, primarily from roadsides. Together, they indicate that climbing spindle berry is common only in the Central North Island conservancies, from Turangi to Rotorua and to a lesser extent in the King Country. Otherwise it occurs only as very localised infestations.

Climbing spindle berry appears to be at an early stage of invasion in New Zealand. The existing plants and patches are often closely associated with small settlements and even individual farmhouses. These include existing and abandoned gardens. This distribution pattern is consistent with a plant that is initially distributed by humans, with occasional secondary spread, principally by birds and possibly by other animals. This secondary dispersal is slow, as evidenced by the infrequency of seedlings, just as described for Japanese honeysuckle (Williams & Timmins 1999). Once established, individual patches develop primarily by spreading over the scrub or forest canopy. Judging from the age of the oldest vines, climbing spindle berry may have begun to invade native vegetation about 30 years ago. Its pattern of distribution suggests that there are large areas of habitat suitable for climbing spindle berry which are currently not infested, simply because it has not arrived there yet.

Many weed species probably have a short-term impact because they are only part of early secondary succession (Williams 1997). This may apply to climbing spindle berry at some sites; for example, it may disappear from regenerating forest on stable slopes near Rotorua in 30 years because it does not appear to grow up to the top of a mature forest canopy. However, even in stable sites, climbing spindle berry may have a longer-term impact if it can establish in tree fall gaps—a possibility given its successful germination in low light (see Section 4.6.3). Other communities such as the unstable, flood-prone kanuka forests on the banks of the Tongariro River appear particularly vulnerable, even in the long term, because of their fragmented nature and high edge : area ratio.

Based on our literature review and personal observations, we conclude that climbing spindle berry occupies only a fraction of the areas suitable for it in New Zealand, and that it will continue to spread over wide areas of central New Zealand.

4.9 WEED MANAGEMENT

Climbing spindle berry is recognised as a threat and is being controlled in each of the six Conservancies in which it has been found to date. Tongariro/Taupo Conservancy has a formal weed-led control programme for climbing spindle berry. At the start the aim was to eradicate climbing spindle berry. But once the programme started in 1999 several more infestations were found, although most were small, easily controlled and two had no fruit set (N. Singers pers.

comm.). A further challenge is that climbing spindle berry has been more difficult to control than anticipated. Control is very labour-intensive and it is difficult to find all the vines at a site—obviously any vines that miss treatment continue to grow. The current aim of the programme is to contain the spread of the weed within the Conservancy. This is likely to be achieved in 2003 (N. Singers pers. comm.). Subsequent eradication may be possible by 2008–2013.

Since control started in Tongariro/Taupo Conservancy in 1999 and the full extent of the problem was realised, the cost of controlling climbing spindle berry has escalated. Initially, a total of NZ$11 500 was allocated to the weed-led control programme. Subsequently, more hours and dollars have been allocated. In the 2000/01 financial year alone approximately 1400 staff hours and $5 500 in operating costs were allocated. In the 2001/02 and 02/03 years a total of $23 800 was allocated to treat four major sites. This approach of tackling just two sites each year, and treating them thoroughly, is likely to prove more successful than the past approach where staff efforts were spread too thinly (N. Singers pers. comm.). DOC staff have convinced the major adjoining landowner, Lake Forest Trust, of the threat of climbing spindle berry to forestry and this group is controlling the weed with support from DOC in surveying and monitoring. In Environment Waikato's Regional Pest Management Strategy 2002–2007, climbing spindle berry has been classified for eradication (Environment Waikato 2002). These different threads of support make the weed-led programme in Tongariro/Taupo all the more viable.

In all the conservancies we examined, and where it was possible to separate it out from other weed control work, the cost of climbing spindle berry control represented a very small percentage of the total conservancy weed control budget, e.g. Bay of Plenty (9%), Tongariro/Taupo (0.02%) (DOC unpub. conservancy budget figures). This reflects the scale of other weed problems in these conservancies, and the relatively low infestation rate of climbing spindle berry, at the moment. The latter makes vigilance the more important because where climbing spindle berry is still rare, the opportunity still exists for eradication if new infestations are found and controlled early.

4.9.1 Physical methods

Monthly mowing will eventually exclude climbing spindle berry but if mowing occurs only two or three times a year, the plant responds by suckering (Dreyer 1988). In our 1999 survey we saw cut stems that had resprouted at Lake Tarawera, near Rotorua (site 5, Appendix 1). Grubbing suffers from the same problem—any portions of the root system not removed may resprout. Grubbing is really suitable only for small initial populations in environmentally sensitive areas where herbicides cannot be used.

4.9.2 Herbicides

In a control trial in England (Dreyer 1988), the dense, low patches of climbing spindle berry were cut to the ground early in the growing season and allowed to regrow. One month later, the climbing spindle berry regrowth was sprayed with a 1–2 %[2] solution of triclopyr using a backpack sprayer. This gave a 100% root kill of climbing spindle berry with minimal damage to non-target vegetation. Because triclopyr does not kill monocotyledonous plants, grass and

TABLE 1. CHEMICAL CONTROL METHODS USED AGAINST CLIMBING SPINDLE BERRY BY FOUR DOC CONSERVANCIES AND TWO LOCAL AUTHORITIES.
The information, for the most part unpublished, was supplied by personal communication to SMT by the relevant DOC Weed Technical Support Officer or Regional Council Biosecurity Officer. Results of a control trial conducted by HortResearch (Ward & Henzell 2003) are also included.

AGENCY	CHEMICAL[1]	APPLICATION METHOD	SEASON OF CONTROL OPERATION	COMMENTS[2]	SOURCE OF INFORMATION
DOC					
Northland Conservancy	20% triclopyr + picloram in diesel; (or 20% metsulfuron)	Stump painting	Spring	Poor kill rate and a lot of regrowth from vines; perhaps spring is the wrong season for control	Tony McCluggage pers. comm.
Northland Conservancy	5 g metsulfuron in 2 L water + 20 mL surfactant; (or triclopyr + picloram)	Stump painting	Autumn	Good kill of root system; suggests that Autumn is a preferable season for control. Stumping works well for large vines with their large root masses but for small plants it is difficult to paint the small cut surfaces	Tony McCluggage pers. comm.
Northland Conservancy	1% triclopyr + picloram with 0.0 2% surfactant	Foliar spray	Spring	Appeared to be the best chemical for foliar spraying; foliar spraying better than stumping for small plants	Tony McCluggage pers. comm.
Northland Conservancy	2 g metsulfuron in 10 L water	Foliar spraying	Spring	Apparently not as effective as triclopyr + picloram	Tony McCluggage pers. comm.
Northland Conservancy	0.7% triclopyr + picloram; or 2 g metsulfuron in 10 L water	Foliar spraying	Spring	Not as effective as triclopyr + picloram alone	Tony McCluggage pers. comm.
Tongariro/Taupo Conservancy	2% triclopyr + 0.5% Boost™	Foliar spraying	Autumn	Used when climbing spindle berry is spreading over other weeds; some regrowth from underground runners observed at Motuapa; overall a 95% kill rate	Nick Singers pers. comm.
Tongariro/Taupo Conservancy	2% glyphosate + Pulse™	Foliar spraying	Autumn		Nick Singers pers. comm.
Tongariro/Taupo Conservancy	5% picloram in gel	Cut stems and apply gel	Autumn	95% kill rate; difficult to find all the stems; those not treated continue to grow	Nick Singers pers. comm.
Tongariro/Taupo Conservancy	25% triclopyr	Apply mixture to freshly cut stems	Autumn	Cutting is preferable to foliar spraying under a canopy	Nick Singers pers. comm.

Tongariro/Taupo Conservancy	25–50% glyphosate	Apply mixture to freshly cut stems	Autumn		Nick Singers pers. comm.
Tongariro/Taupo Conservancy	18% glyphosate	Foliar spray	Autumn	After 6 weeks climbing spindle berry on top killed but vines under bracken still alive; non-target kill of native species	Nick Singers pers. comm.
Bay of Plenty Conservancy	Triclopyr 4 mL/L water + penetrant	Gun and hose	Autumn	Control at Kaharoa showed good results	Paul Cashmore pers. comm.
Bay of Plenty Conservancy	Triclopyr 6 mL/L water	Knapsack			Paul Cashmore pers. comm.
Bay of Plenty Conservancy	20% glyphosate	Cut and paint		Regrowth of young shoots from root zone, but not from cut stems	Paul Cashmore pers. comm.
Bay of Plenty Conservancy	10% clopyralid	Cut and paint		Regrowth of young shoots from root zone, but not from cut stems	Paul Cashmore pers. comm.
Bay of Plenty Conservancy	Metsulfuron 25gm/L water	Cut and paint		Minimal regrowth 1 year after trial	Paul Cashmore pers. comm.
Bay of Plenty Conservancy	10% triclopyr	Cut and paint		Minimal regrowth 1 year after trial	Paul Cashmore pers. comm.
Wanganui Conservancy	2% glyphosate	Cut stems, spray regrowth	Winter/spring	No regrowth observed 6 months after treatment	Mike Andrews pers. comm.
Environment Bay of Plenty	Triclopyr 4mL/L water + penetrant	Gun and hose	Autumn	This treatment seems to show the most promise; best results if applied at the end of the growing season when plants are in full leaf (March, April)	Richard Mallison pers. comm.
	1 part triclopyr :4 parts water	Cut stem, treat stump		Apply over the top and sides of freshly cut stumps	Richard Mallison pers. comm.
HortResearch	5% picloram in gel	Cut stem, apply gel immediately	Autumn	All treated stems died but only 40–50% of vines were treated; hard to find all the stems	Ward & Henzell (2003)
	1% picloram in gel	Cut stem, apply gel to stump	Autumn	100% of treated stems died	Ward & Henzell (2003)
	1% metsulfuron-methyl in gel	Cut stem, apply gel	Autumn	100% of treated stems died	Ward & Henzell (2003)
	10% glyphosate in gel	Cut stem, apply gel	Autumn	90.0% of treated stems died	Ward & Henzell (2003)
		Cut stem, no herbicide	Autumn	7.7% cut stems died	Ward & Henzell (2003)
Rotorua District Council	Glyphosate /metsulfuron / dicamba mix			Variable results; could be ineffective mix or inadequate coverage	Richard Mallison pers. comm.

1 All percentages refer to the percentage of active ingredient in the herbicide solution for commercially available chemical products.

2 For the most part, comments on the success or otherwise of the different control methods are based on visual observation; only where a percentage kill rate is given, are the comments based on a more formal trial.

sedge species remained providing good soil cover and dominating the site up to a year after treatment (Dreyer 1988). The same study found foliar applications of glyphosate and amitrole were ineffective in killing the roots of climbing spindle berry. Foliar applications of a mixture of 2,4-D and triclopyr in mid-spring however effectively reduced the population of climbing spindle berry (Hutchison 1992).

Where large vines climb high into trees, cutting the vines 5 cm above the ground and treating the vine stump surface immediately with herbicide (e.g. 25% glyphosate or 25% triclopyr)[2] is a usual procedure for woody vines. Hutchison (1992) recommended using this method with 100% glyphosate[2] [Roundup] but no data concerning the effectiveness of this technique were reported. Similarly, where vines are established within or around non-target plants the cut and paint method is preferable. For large populations, a foliar application of herbicide is recommended, e.g. 2% glyphosate[2] or 2% triclopyr[2].

Various control methods have been tried to date in New Zealand. These are summarised in Table 1, with comments on their relative success/failure. Best practice for DOC has yet to be determined. Nevertheless, the New Zealand experience closely follows the international accounts above. Cutting and painting the vines, with picloram (50 g kg^{-1} picloram acid salt as a potassium salt) or glyphosate, without frilling, leads to initial success. The subsequent regrowth is usually sprayed with triclopyr, which gives good results (M. Andrews pers. comm.). At a site near Timaru Stream, New Plymouth, where all the stems had been cut and the regrowth sprayed with 2% glyphosate[2], we found no re-growth 6 months after treatment.

The chemical lopper system developed by HortResearch—a device for cutting weed vines and applying a herbicidal gel to the cut stem in the one action (Ward & Henzell 1999)—was trialed on climbing spindle berry (Ward et al. 1999). Gels with various active ingredients were trialed by HortResearch including 1% and 5% picloram[2], 5% metsulfuron-methyl[2] and 10% glyphosate[2] (Ward & Henzell 2003). All were effective on climbing spindle berry. Because the actual device proved too fiddly to use on climbing spindle berry, the technique used is to cut stems with a pruning saw and then dispense the herbicide gel using a brush bottle.

As 5% picloram[2] proved the most successful across a range of species, a water soluble herbicidal gel with 5% picloram[2] (as a potassium salt) was registered with the New Zealand Pesticide Board in 2000 under the brand name Vigilant™®. It was registered for use on four weed species including climbing spindle berry (Ward & Henzell 2003). In a trial in the Parikarangaranga Recreation Reserve, Motuoapa, the Vigilant gel achieved a 100% kill rate against all treated climbing spindle berry stems (Ward & Henzell 2003). However, a major problem with any cutting method is the difficulty of finding all the stems. In the trial, only 40–50% of the vines were cut in the first pass. Furthermore, only 7.7% of the stems that were cut, but not painted with gel, died. Regrowth from these underground root suckers can apparently continue for years after initial control. Because climbing spindle berry is easy to spot in autumn when it has yellow foliage, this is a good time for control operations.

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[2] All percentages for chemicals refer to the percentage of active ingredient in the herbicide solution for commercially available chemical products.

4.9.3 Biological control

No information is available on the potential of biological control to manage climbing spindle berry infestations—as it has not been the subject of a biocontrol investigation in New Zealand, or anywhere else in the world (L. Hayes pers. comm.). However, since there are no native or commercial plant species in this family, biocontrol could be considered as an option if the species ever becomes common enough on conservation land to warrant the investment.

4.9.4 Future control strategy

As climbing spindle berry still has a very limited distribution throughout most of New Zealand, there is the potential to eradicate any new infestation that is found in a new catchment or Conservancy as soon as it appears, i.e. a weed-led control programme. In the Rotorua area, the relative abundance of climbing spindle berry probably dictates a different (site-led) approach.

5. Conclusions

Climbing spindle berry has been relatively unknown as a weed in New Zealand, particularly in comparison with many other weedy vines. At the time of field work for this account (1999) it was still at only the early stage of invasion. In the Rotorua area and on the eastern side of Lake Taupo the populations have developed a critical mass in the wild and can be expected to steadily increase. Our study indicates that climbing spindle berry currently appears to be primarily associated with early successional vegetation and thus it can be expected to persist on forest edges and in vegetation that is subject to disturbance. In contrast, vegetation that is tall and stable may be more resilient to invasion, and such incursions of climbing spindle berry as occur, may not persist. However, as with most weed invasions, the damage caused is difficult to define and the full impact on conservation land has yet to become apparent. Fortunately, effective chemical control methods are available. In parts of New Zealand the opportunity still exists to eradicate this species, but this will require vigilance to spot new infestations early, taking immediate control action against new infestations, and the co-operation of all relevant landowners.

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Appendix 1

SITE CHARACTERISTICS OF CLIMBING SPINDLE BERRY *CELASTRUS ORBICULASTUS* STANDS IN NEW ZEALAND[1]

NO.	LOCALITY	GRID REF.[2]	ALTITUDE (m a.s.l.)	SUBSTRATE & VEGETATION	MAIN PLANT SPECIES, INCLUDING OTHER WEEDS	*CELASTRUS ORBICULATUS* COVER (%)[3] AREA (ha)	HEIGHT MEAN (m) MAX. (m)	PHENOLOGY DATE OF OBS. dd/mm/yy	STAND DYNAMICS	PROGNOSIS FOR SITE
1	Onerahi, Whangarei	Q 07 348 037	20	Glauconitic sandstone Shrubland	*Weinmannia racemosa, Kunzea ericoides, Myrsine australis, Ulex europaeus*	- 0.8	- 6	- 16/04/99	Resprouts and seedlings present	
2	McLaren Falls, Bay of Plenty	U14 783 730	100	Hill slope Regenerating forest	*Aristotelia fruticosa, Melicytus ramiflorus, Podocarpus halli*	- 0.2	- -	No fruit 3/05/99	Old vines and regrowth	Under control
3	Lake Okareka, Rotorua	U16 032 316	360	Volcanic colluvium, toe-slope Scrub	*Pseudopanax arboreus, Ulex europaeus, Pteridium esculentum, Rubus fruticosus*	10 0.40	4 8	Abundant fruit, most not open 28/04/99	Spreading by suckers	Will continue to expand
4	Lake Tarawera, Rotorua	U16 073 318	300	Volcanic alluvium near water Forest	*Salix* spp., *Prunus* sp.	50 1.5	4 8	Abundant fruit, few open 28/04/99	Spreading vigorously, no seedlings seen	Will continue to expand
5	Lake Tarawera, Rotorua	U16 072 291	300	Volcanic bluff and toe-slope Scrub	*Pseudopanax arboreus, Cyathea medullaris, Fuchsia excorticata, Pteridium esculentum*	60 0.8	5 8	Some fruit, few open 28/04/99	Re-sprouted from a cut made 2 years ago	Lateral spread likely
6	Lake Tarawera, Rotorua	U16 071 283	300	Volcanic alluvium near water Woodland, scrub	*Coprosma robusta, Melicytus ramiflorus, Pseudopanax arboreus, Pteridium esculentum*	20 0.2	2 8	Few fruits 28/04/99	Scattered plants originating from lake margin open area	Spread likely because very difficult to control here
7	Whakarewarewa Forest, Rotorua	U16 965 315	320	Hillslope of pumice soils Forest margin	*Pinus radiata, Pittosporum tenuifolium, Dicksonia squarrosa*	20 0.2	4 7	Few fruits 28/04/99	Solitary plant	Source site for spread into the forest

8	Mt. Ngongataha, Rotorua	U16 921 378	500	Hill slope volcanic material Tall scrub	*Coprosma robusta, Melicytus ramiflorus, Berberis glaucocarpa, Cyathea medullaris*	5 1.0	6 8	Scattered fruit 28/04/99	Scattered plants over wide area	Existing plants will expand slowly
9	Huka Falls, Taupo	U18 788 792	380	Roadside bluffs and debris slopes, volcanic material Scrub	*Pseudopanax arboreus, Myrsine australis, Leycesteria formosa, Blechnum* sp.	50 25.0	6 9	Scattered fruit 29/04/99	Extensively scattered along forest edge	Existing plants will expand slowly
10	Huka Falls, Taupo	U18 786 787	380	Roadside bluffs and debris slopes, volcanic material Scrub	*Pinus radiata, Pseudopanax arboreus, Myrsine australis, Leycesteria formosa, Cytisus scoparius*	40 12.5	4 12.5	Scattered fruit 29/04/99	Extensive cover, several scattered plants	Will spread into adjacent broken vegetation
11	Motuoapa, Taupo	T19 590 480	400	Rhyolite talus slope Vineland-scrub	*Rubus fruticosus, Cytisus scoparius, Pteridium esculentum, Pittosporum tenuifolium, Pseudopanax arboreus, Cotoneaster* spp.	2–3	2–5	Yellow fruit, not open 26/04/99	New plants and some regrowth after control	Will need intensive control
12	Motuoapa, Taupo	T19 593 483	400	Rhyolite talus slope Tree/shrubland	*Pseudopanax arboreus, Melicytus ramiflorus, Pittosporum tenuifolium, Podocarpus hallii*	5 0.2	5–6 10	Fruit yellow, not open 26/04/99	New plants and some regrowth after control plus seedlings	Will need intensive control otherwise will spread extensively
13	Hinemai-aia, Taupo	U18 715 568	380	Lakeside alluvium Shrub/vineland	*Kunzea ericoides, Pseudopanax arboreus, Rubus fruticosus*	35 0.1	2 10	Sparse fruit, not open 26/04/99	A few, well established	Spreading
14	Hautepe, Taupo	T19 714 564	380	Lakeside volcanic alluvium Scrub/fernland	*Kunzea ericoides, Coprosma robusta, Pseudopanax arboreus, Pteridium esculentum*	10 0.5	4 6	Scattered fruit 29/04/99	Several large plants and seedlings	Treated but still expanding
15	Tokaanu, Turangi	T19 477 486	540	Hillslope, volcanic colluvium Shrub/vineland	*Rubus fruticosus, Pteridium esculentum, Pittosporum tenuifolium, Acer pseudoplatanus, Cornus capitata*	50	4	Male (?) plant, no fruit 27/04/99	Probably only one plant	Spread reliant on existing plant
16	Piopio, King Country	R17 813 987	170	Toe-slope near stream Scrub	*Berberis glaucocarpa, Coprosma* spp., *Coriaria arborea*, also *Plectranthus* sp.	90	4	Sparse fruit, not open 27/04/99	An extensive continuous patch along 8 km of road	Spreading
17	Paemako, Awakino	R17 802 992	170	Mudstone colluvium adjacent to river Scrub	*Melicytus ramiflorus, Cyathea dealbata, Fuchsia excorticata, Coprosma* spp.	10 0.1	2 4	Sparse fruit, few open 27/04/99	Probably a single plant —no outliers	Reliant on existing plant

APPENDIX 1 continued

NO.	LOCALITY	GRID REF.[2]	ALTITUDE (m a.s.l.)	SUBSTRATE & VEGETATION	MAIN PLANT SPECIES, INCLUDING OTHER WEEDS	*CELASTRUS ORBICULATUS* COVER (%)[3] AREA (ha	HEIGHT MEAN (m) MAX. (m)	PHENOLOGY DATE OF OBS. dd/mm/yy	STAND DYNAMICS	PROGNOSIS FOR SITE
18	Ahititi, Taranaki	Q18 489 609	5	Mudstone colluvium adjacent to river Shrubland	*Melicytus ramiflorus*, *Hoheria* spp., *Fuchsia excorticata*	50 0.2	3 6	Sparse, unripe fruit 27/04/99	Scattered plants No seedlings	An outlier population; spreading
19	Timaru Stream, Taranaki	P20 897 274	80	Hill slope Regenerating forest	*Dysoxylum spectabile*, *Melicytus ramiflorus*, *Fuchsia excorticata*	< 0.5 1.0	4 1	No fruit or flowers 09/03/00	A few vines on the forest margins	Limited expansion at site
20	Manunui Recreational Reserve, Taumaranui	S18 105 553	190	Low river terrace Intact, tall podocarp forest	*Dacrycarpus dacrydioides*, *Prumnopitys taxifolia*, *Podocarpus totara*	40 0.1	0.5 1	No fruit 27/04/99	Vine sprawling across forest floor	Vines will ascend shrubs and trees
21	Kawhatau River, Mangaweka	T22 578 527	500	High river terrace Unkempt old garden	*Chamaecyparis lawsoniana*, *Clematis montana*, *Euonymus europaeus*	80	3	Fruit common 01/05/99	Old vines and regrowth from a single plant	Much potential to spread from garden to adjacent native forest
22	Clova Bay, Marlborough Sounds	P27 970 097	10	Alluvium Shrubland, abandoned garden	*Melicytus ramiflorus*, *Berberis glaucocarpa*, *Carpodetus serratus*	10 0.4	3 6	Fruit common 20/05/99	Old vines and seedlings	Limited expansion at site

1 Most of these sites were visited, and site details recorded, during the authors' field trip in April 1999. Subsequently, information on a few further sites was contributed by DOC Weed Technical Support Officers.

2 Grid reference for the climbing spindle berry infestation.

3 Percentage canopy cover of climbing spindle berry across the infested area at a site, subjectively assessed.