Commercial in Confidence
Client Report No. 12054
Output No. 40507

Overview of Scotch Broom (*Cytisus scoparius*) Ecology and Past and Present Management Practices in Commercial Forestry

By K.J.B. Potter & D.J. Kriticos

THE JOINT FORCES OF CSIRO & SCION

ensis

Commercial in Confidence

Client Report No. 12054

Overview of Scotch Broom (*Cytisus scoparius*) Ecology and Past and Present Management Practices in Commercial Forestry

By K.J.B. Potter & D.J. Kriticos

Date: April 2007
Client: New Zealand Site Management Cooperative

CSIRO scion

THE JOINT FORCES OF CSIRO & SCION

CLIENT REPORT No: 12054

EXECUTIVE SUMMARY

Scotch broom is an extremely aggressive weed of Temperate and Mediterranean climatic origins. In its exotic range it threatens open grasslands on both productive and conservation lands, large areas of wasteland, roadsides, riverbeds and plantations forests. In Australia and New Zealand, Scotch broom has not reached its maximum potential distribution. The ability of Scotch broom to impact on plantation tree survival and growth drives the need for improved management techniques. Furthermore concern exists as infestation severity increases over multiple rotations due to large seed-banks and forest certification requires reduced chemical use.

Objective

The objective of this overview was to summarise the literature relating to the biology and ecology of Scotch broom (*Cytisus scoparius* (L.) Link), previous and current herbicide treatments and Scotch broom management regimes. It also aimed to identify knowledge gaps and to develop recommendations to direct future Scotch broom research needs.

Key Results

Scotch broom has the potential to survive over a broad altitudinal range, on a range of soil types and topography. Shading of plantation trees by Scotch broom can lead to tree death and reduced growth rates. Herbicide treatments for Scotch broom control in New Zealand have varied over time, closely mirroring the fluctuations in herbicide availability, cost and knowledge of their effectiveness and toxicity. Similarly, Scotch broom management regimes have adjusted under the effect of the same drivers, with a general shift away from mechanical site-preparation and burning regimes to the use of aerial pre-plant and release herbicide applications. The most common aerial pre-plant treatment currently used is a glyphosate plus metsulfuron mixture, and herbicide release mixtures are divided broadly into two groups; clopyralid plus picloram and/or triclopyr mixtures and terbuthylazine plus hexazinone mixtures. Current management regimes incorporate at least one aerial release operation with some companies applying up to three in some locations. Other non-chemical components to broom management regimes include cultivation and mechanical site preparation, cover crops, grazing and biological control. Recommendations on the direction of future Scotch broom research incorporate studies of reduced herbicide rates, mycoherbicides, dispersal mechanisms, stand hygiene, broom ecology and population dynamics and the impact of weed competition on wood quality.

Application of Results

The literature review will assist in directing future research into Scotch broom management in New Zealand. The data, in conjunction with the results of the industry survey (Potter, 2007) provide the background information needed to develop new projects focusing on national approaches to broom management in forests.

Further Work

It is recommended that the information gathered by this review, including the key management questions and recommendations on future Scotch broom research needs, be used to guide the direction of a new Forest Site Management Cooperative Project and to support the next application for funding from the Foundation for Research Science and Technology. Specific sections of the research programme should also be flagged as appropriate for student or postgraduate projects.

CLIENT REPORT No: 12054

OVERVIEW OF SCOTCH BROOM (*CYTISUS SCOPARIUS*) ECOLOGY AND PAST AND PRESENT MANAGEMENT PRACTICES IN COMMERCIAL FORESTRY

By K.J.B. Potter & D.J. Kriticos
April 2007

TABLE OF CONTENTS

Information for Ensis abstracting:

Output number	40507
Weed species worked on	Scotch broom (*Cytisus scoparius*)
Key words	Weed, biology, ecology, management regime, herbicide, New Zealand

INTRODUCTION

This overview summarises knowledge relating to the management of Scotch broom (*Cytisus scoparius* (L.) Link) within the commercial forestry industry, both internationally and within New Zealand. It focuses on what is known of its biology and ecology, particularly in exotic habitats, as well as previous and current herbicide treatments and management regimes. This information is then used, in conjunction with the results of an industry survey (Potter, 2007), to identify knowledge gaps and develop recommendations on future Scotch broom research needs.

Scotch broom, was selected as the target of this report as it was considered by members of the New Zealand Site Management Cooperative to be either a significant weed problem within the forest estate, or likely to become a problem in the near future. In New Zealand, Scotch broom is widespread and abundant over large areas of the country, invading open grasslands on both production and conservation lands, large areas of wasteland, roadsides, river beds, and plantation forests (Syrett, 1989; Syrett *et al.*, 1999). Scotch broom has the ability to grow and set seed over a wide altitudinal range (Syrett, 1986), on land of varied topography (Syrett, 1989) and grows all year round under adequate moisture and mild temperature conditions (Richardson & Davenhill, 1996a; Williams, 1981).

In commercial forestry plantations, Scotch broom often appears as a dense mat of seedlings after cutover and/or site preparation for forest planting. If allowed to establish, and not managed appropriately, Scotch broom can reach a height of 1 m in a few months, competing strongly with plantation seedlings. In the short term, Scotch broom competition can lead to mortality of plantation seedlings and in the longer term cause considerable ‘opportunity’ costs if trees take longer to reach harvestable size or yield is reduced (Barton (nee Frohlich) *et al.*, 2003).

PART 1. Current Knowledge of Scotch Broom Biology and Ecology

Common names and affiliations

Common names for *Cytisus scoparius* include Scotch broom, Scot's broom, English broom and common broom and its taxonomy and affiliations are listed below.

Family: Fabaceae Lindl., nom. Cons. (1836)
Subfamily: Papilionideae (after Isley and Polhill)
Tribe: Genistaea (Adans.) Benth.
Subtribe: Cytisus-Genista (after Bisby 1981)
Genus: *Cytisus* Link (Sarothamnus Wimmer syn.)
Species: *scoparius* L.

Distribution

Scotch broom is widely distributed throughout the temperate and Mediterranean climatic zones (Figure 1). It is native to western and central Europe, North Africa and Western Asia (Holm *et al.*, 1979; Hosking, Smith & Sheppard, 1996; Luken & Thieret, 1997; Wheeler *et al.*, 1987). Its native geographical range extends from southern Sweden in the north to southern Spain and the Azores, and from Ireland in the west to Central Ukraine (Cubas, Tahira & Pardo, 2001; Hosking, 1995; Tutin *et al.*, 1968). The southern distribution of Scotch broom in its native range is limited by drought while the northern range is limited by winter cold or winter drought (Hegi, 1926; von Walter, 1968; Wardle, 1971). Scotch broom commonly grows at higher cooler altitudes in the more southerly parts of this range.

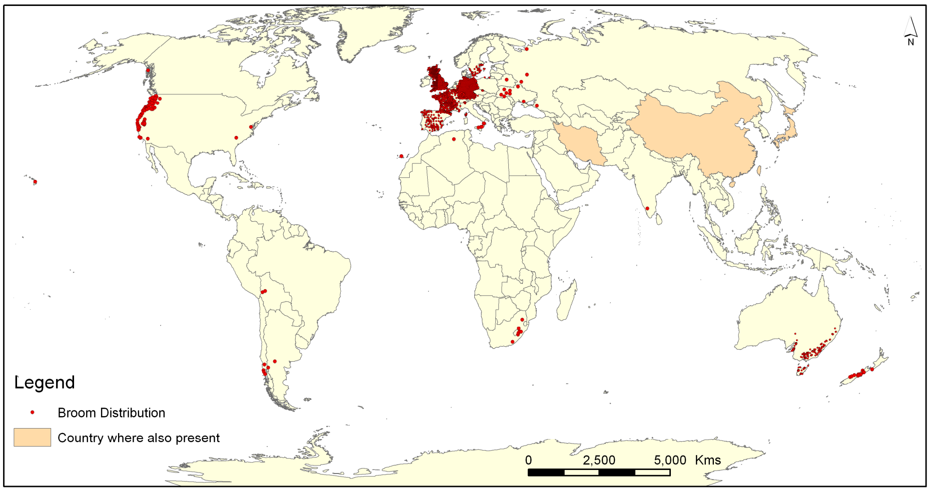


Figure 1: World distribution of Scotch broom.

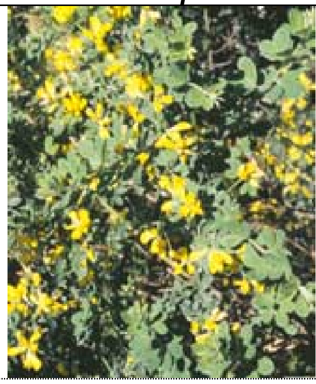
Scotch broom is a weed in five continents, and even within its native range can reach an abundance that requires management, particularly within forestry and grazing systems (Hosking, Smith & Sheppard, 1998; Rousseau & Loiseau, 1982). It is considered an introduced weed in New Zealand (Williams, 1981), Australia (Downey & Smith, 2000; Parsons & Cuthbertson, 1992), South Africa, Canada, Chile, Iran (Smith 2000), eastern and western United States of America including Hawaii (Bossard, 1991; Holm *et al.*, 1979; Hosking *et al.*, 1996; Luken *et al.*, 1997), southern South America, the Canary Islands and parts of Asia including India (Smith, Sheppard & Hosking, 2000), Japan (Dobashi, 1995; Nemoto *et al.*, 1993; Smith *et al.*, 2000) and China (Fowler *et al.*, 1996). It is recorded as a particular threat to commercial forestry operations in New Zealand, Australia, the USA and Canada (Peterson & Prasad, 1998; Prasad & Peterson, 1997; Zielke *et al.*, 1992).

Description

Scotch broom is a deciduous, leguminous shrub with erect, semi-woody branches. The small and sparse leaves are trifoliate with the central leaflet longer than the other outer two leaflets. Stems and branches are photosynthetic, five angled, mostly hairless and bear sunken stomata beneath a thick epidermal wax (Richardson *et al.*, 1996a). Scotch broom has a deep tap root system, and while branched roots do not produce new shoots, plants can sprout from the stump if damaged or cut above the crown. According to Zielke *et al.* (1992), this sprouting potential declines as Scotch broom ages with little or no sprouting in stems of 20 years of age if cut in late spring. Symptoms of decline in Scotch broom include an increase in the ratio of woody to green plant material, a thinning of stems, decreasing pod production and stem collapse from a previously erect form to become prostrate (often accentuated by heavy snow falls or wind). Eventually old plants die and topple over.

It is important to note that there is a second weedy broom species in New Zealand. This is commonly known as Montpellier (or Cape) broom, *Genista monspessullana* (L.) L. Johnson and the key distinguishing features between Scotch and Montpellier broom are listed in Table 1.

Table 1: Distinguishing features between Scotch and Montpellier Scotch broom[a]

	Cytisus scoparius	***Genista monspessullana***
Photo		
Common names	Scotch (or Scot's) broom	Montpellier (or Cape) broom
Stems	usually 5-angled (+/- star-shaped in x-section)	8-10-ridged (round in x-section)
Leaves	compound, leaflets 3, sometimes single on new twigs, deciduous	compound, leaflets 3, usually dense, evergreen
Flowers	single or paired in leaf axils	4-10 in head-like clusters at ends of short auxiliary branchlets
Petals	yellow or partially to entirely dark red	yellow
Calyx	2-lipped, top lip minutely toothed, Glabrous	2-lipped, top lip 2-lobed to near middle, lower lip shallow (1-)3-lobed, pubescent
Pods	Flattened glabrous with margins densely lined with long hairs 2-5 cm long, ~ 1 cm wide	Slightly flattened densely covered with long hairs 1-3 cm long, ~ 0.5 cm wide

[a] Source: www.cdfa.ca.gov/phpps/ips/weedinfo/brooms.htm

Habitat

Soil and nutrient conditions

Scotch broom can survive on a wide range of soils, parent materials and nutrient regimes, and in New Zealand, appears to grow especially vigorously on fresh alluvium and recent soils which are well supplied with inorganic phosphorus (Syrett, 1989; Williams, 1981). Scotch broom can however tolerate strongly acid soils and those with very low levels of native inorganic phosphorus. In a garden plot trial in the Mt. Lofty Ranges, Australia, Fogarty and Facelli (1999) concluded that the increased growth of Scotch broom in higher nutrient soils indicated that it was a fast growing species adapted to fertile soil. In a New Zealand study by Williams (1981), where Scotch broom was grown in pots of field collected soil from Lincoln, Waimakariri and Cragieburn, total plant dry weight of Scotch broom followed the order of their Olsen Phosphorus levels but not Truog Phosphorus levels, demonstrating the dependence of Scotch broom on iron and aluminium bound phosphorus. Scotch broom is also an efficient nitrogen fixer due to its *Rhizobium* nodulated root system. It can fix nitrogen at soil temperatures between 4 - 30℃ (Wheeler *et al.*, 1979) and is capable of fixing up to 200 kg/ha (Gadgil, 1983).

Water relations

Soil moisture may be a key factor influencing Scotch broom seed germination and seedling survival. Sheppard *et al*. (2002) noted that seedling emergence at an Australian site appeared to be linked to significant rainfall and daytime temperatures of at least 15℃ with flushes of germi nation following dry periods, particularly drought. Once established, Scotch broom is well suited to habitats with seasonal moisture stress, although it remains susceptible to periods of severe, extended drought (Williams, 1983). In New Zealand, Scotch broom has been observed to grow with apparently equal vigour on sites with 760mm and 1300mm rainfall annually (Stevens & Hughes, 1973). Scotch broom displays a number of key adaptations to surviving in a dry environment including a deep taproot, a reduced leaf surface area, photosynthetically active stems bearing sunken stomata beneath a thick epidermal wax covering and the ability to abscise its leaves when necessary (Zielke *et al.*, 1992).

Light relations and impact on growth habit

Young Scotch broom plants can tolerate a wide range of light regimes, are moderately shade tolerant (Zielke *et al.*, 1992) and show a wide range of growth habits (Richardson *et al.*, 1996a; Williams, 1981). Under glasshouse conditions it was found that under full light, vertical growth of young Scotch broom plants was relatively slow with strong development of lateral shoots arising from the first node (Williams, 1981). Under this light scenario, almost half the total weight of the plant was contained within the extensively nodulated root system. In the field, this growth habit was reflected in open environments where young plants were almost prostrate, with no single leading shoot.

At a 70% reduction in light in the glasshouse, Williams (1981) found that young plants were almost three times as tall as those under full light with no lateral branches and a poorly developed and a weekly nodulated root system. In the field, this growth habit was recorded in shaded plants (Zielke *et al.*, 1992) with Richardson and Davenhill (1996a) reporting that plants exposed to low light conditions often only have a single upright leader, and have a greater rate of height growth. The ability for greater height growth under shaded conditions probably contributes to the success of Scotch broom in a wide range of habitats such as cutovers, river beds and grasslands where it faces competition during establishment from herbaceous plants and assists in its ability to tolerate herbaceous competition caused by cover-crops (Richardson *et al.*, 1996a; Zielke *et al.*, 1992). Under heavily shaded conditions such as those experienced below dense Scotch broom stands however, high seedling mortality has been recorded in the field (Hosking *et al.*, 1998; Paynter *et al.*, 1998).

Temperature relations

Scotch broom has the ability to grow and set seed over a wide altitudinal range (Syrett, 1986) and according to Stevens and Hughes (1973), Scotch broom has the ability to grow vigorously up to 1200m in New Zealand. In a study of the phenology of Scotch broom reproductive stages at different sites in New Zealand, Harman (1999) found that Scotch broom phenology varied considerably between sites and slightly between years and proposed that this variation was due to variation in temperature between sites. Support for this hypothesis can be gained from observations by Williams (1981) who found that the appearance of the reproductive stages of Scotch broom was delayed at higher altitude sites.

Other comments relating to temperature relations include the observation of Wheeler *et al.* (1987) that frost did not appear to impact on plants in Oregon and Scotland while Williams (1981) reports Scotch broom to have a low tolerance to frost in Canterbury, New Zealand.

Reproduction, growth and development

Flowering and pollination

Scotch broom reaches maturity and begins to flower at around 2-5 years of age (Sheppard *et al.*, 2002; Smith & Harlen, 1991). In an Australian study by Sheppard *et al.* (2002), for example, 1.3% of plants flowered as 2 year olds, 10.9% as 3 year olds, 80% as 4 year olds and 8% as 5 year olds, in Washington USA, plants began reproducing in their 3rd or 4th year (Parker, 2001) and in British Columbia, at 2-3 years of age (Zielke *et al.*, 1992). Flowering age can be influenced by factors such as grazing, disturbance and grass competition with grazing and grass competition increasing the age at flowering by at least 1 year while disturbance decreased age at flowering by at least 1 year (Sheppard, Hodge & Paynter, 2000).

Scotch broom flowers can be found on plants at any time of the year in warmer climates, though most flowering occurs from October to December in Australia (Blood, 2001) and New Zealand (Williams, 1981). Flowers excrete no nectar and in order for pollination to occur, an insect visitor must be large enough to push the fused keel down and split the petals, releasing the style and anthers, which then spring up to contact the back of the pollinator in an explosive motion (Parker, 1997). Once a flower has been ‘tripped’ in this way it does not return to its original configuration. This tripping mechanism appears to act to prohibit self-pollination (Parker, 1996, , 1997) and also makes it easy to identify flowers that have been visited by an appropriate pollinator (Suzuki, 2000). Pollinators maximise the probability of out-crossing by visiting only about 6 flowers per plant and only 2-3 plants within a local area (Parker, 1997). Scotch broom flowers are pollinated predominantly by honey bees and bumblebees (Meyer, 2003) and in Washington, USA, reproduction was found to be strongly pollinator limited with the frequency of visitation by pollinators varying among individuals and among sites (Parker, 1997). Sheppard *et al.* (2002) also found evidence of pollinator limitation at an Australian site where Scotch broom flowered prolifically, but only a relatively small proportion of flowers (30%) developed fruit and set viable seed. Similarly, Suzuki (2000) attributed the low average fruit production per flower of Scotch broom growing in a shady habitat in Japan to a shortage of pollinator visits. It was proposed that this shortage was due to pollinators preferring sunny open places during spring rather than shady places where the air temperature was low. Suzuki (2000) was also unable to find any evidence that patch size or size of Scotch broom plant influenced pollinator limitation as has been shown in other plant species.

While evidence exists that Scotch broom may be pollinator limited at some locations, the reproductive capacity of an individual also varies widely depending on environmental conditions. For example, two year old plants grown over a range of sites in New Zealand produced vastly different numbers of seed (Williams, 1981). Even within a site, seed production can be strongly dependent on plant size (Parker, 2000) and can also vary by an order of magnitude between years (Waloff & Richards, 1977). In the forestry context, pollinator limitation is unlikely to be relevant as even low pollination success (e.g. 30% of flowers) would produce a contribution to the seed-bank greatly in excess of the minimum required for stand replacement.

Seed production and dispersal

Seed production is the only means of Scotch broom reproduction (Sheppard *et al.*, 2002). Scotch broom seed pods are 4-5 cm long and upon maturing turn from green to dark brown/black with brown hairs along the margins. At one site in British Columbia, Zielke *et al.* (1992) recorded that a single Scotch broom plant could produce 2000-3500 seed pods per bush. Pods twist as they dry and dehisce, flinging 6-18 yellow seeds from the parent plant in summer to early autumn (December to early March) in Australia and New Zealand (Blood, 2001; Hosking *et al.*, 1998; Williams, 1981). Ballistic dispersal generally occurs over 15-20 days for an individual bush with the timing dependent on the position of the pods and relative warmth of air layers (Waloff *et al.*, 1977; Williams, 1981). Most Scotch broom seed is deposited within the parent canopy (Allen, Williams & Lee, 1995) or falls within 1 m of the parent plant. Some can however be flung up to 5 m from the parent plant. Dry pods containing seeds can also be blown short distances by wind and some secondary local dispersal may be achieved by ants in some countries (Bossard, 1990b). Longer distance dispersal is via mud on vehicles, machinery, footwear, sand and gravel from quarrying operations, the bed load of rivers and streams (Williams, 1981) and internally by animals such as horses and pigs.

Scotch broom seed-banks

Scotch broom seed dormancy, in combination with seed production that is generally greatly in excess of the minimum necessary for stand replacement (Bossard & Rejmanek, 1994; Smith *et al.*, 2000) often leads to an accumulation of large seed-banks beneath Scotch broom stands (Paynter *et al.*, 1996). Seed-bank density under mature Scotch broom stands is highly variable and seed-bank sizes, driven by seed rain, reflects the growing conditions at a site (Sheppard *et al.*, 2002). In Australia, seed-banks exceeding 50,000 seeds/m^2 are not uncommon and such large seed-banks indicate that the population is unlikely to be seed limited (Paynter *et al.*, 1996). Seeds can remain viable in the soil seed-bank for between 30 (Zielke *et al.*, 1992) and 80 years (Fowler, Cross & Shaw, 1993). Studies by Smith and Harlen (1991) in New South Wales, Australia found that 80% of seeds buried in nylon mesh bags at a depth of 5cm were still alive and dormant after 45 months and Sheppard *et al.* (2002) recorded a seed-bank annual decay rate of about 40% (including germination) in disturbed mature Scotch broom subplots (i.e. no seed rain) during the first 4 years of disturbance.

Germination and seedling survival

Scotch broom seed are 2-3 mm in diameter and have an impermeable seed coat which prohibits water uptake and can delay germination for months or years (Bossard, 1993; Harper, 1977; Smith *et al.*, 1991). Scotch broom seed germination can occur at any time during the year when conditions are favourable (Downey *et al.*, 2000). At an Australian site, Sheppard *et al.* (2000) observed seedling emergence in all months of the year, with flushes of germination following dry periods, particularly droughts. At some Australian and New Zealand locations, Scotch broom seedling germination and establishment can occur under mature Scotch broom plants (Sheppard *et al.*, 2002) while at others, Scotch broom shading curbs regeneration by both broom and native flora until the original plants progressively senesce and die to the point the canopy is opened.

In order for germination to occur, it is proposed that adequate water and heat are required, the seed coat needs to be ruptured and disturbance is required to remove intra- and inter-specific competition (www.cdfa.ca.gov, 2006). The relative importance of these variables is unclear and appears to vary between the native and exotic range of the weed.

Laboratory based germination trials by Fogarty and Facelli (1999) found that the time taken for 70% germination of scarified Scotch broom seed was 5 days in a growth cabinet (12 h day at 25 ℃ and 12 h night at 12 ℃). Bossard (1993) showed that Scotch broom seed dormancy could be broken by treatment with high temperatures (Harper, 1977). This “induced” dormancy mechanism prevented seeds from germinating under unfavourable conditions and allowed them to benefit from favourable conditions when they occur

(Paynter *et al.*, 1998). Other experimental trials found that germination could be stimulated by nicking or sanding the seed coat, by treating with sulfuric acid, by applying dry heat for 1 minute at 130 ℃ or 15 min at 70 ℃ or by pouring boiling water over seeds and leaving them to cool to room temperature (Smith *et al.*, 1991). Bossard (1990a) showed that alternate immersion in liquid nitrogen and boiling water could stimulate germination without killing the seeds. Seeds heated to temperatures above 150 ℃ for 2 minutes were killed, seeds heated to 100 ℃ for 1 min appeared to be more susceptible to fungal pathogens (www.cdfa.ca.gov, 2006) and Parker (2001) gained a positive but insignificant effect of burning on seed germination.

A seed's position in the soil profile probably influences its likelihood of germination. In New Zealand, Scotch broom seed can generally be found in the top 5-6 cm of soil and occasionally as deep as 15 cm (Partridge, 1989; Williams, 1981). Seedlings have been observed to emerge from soil depths of 8 cm with optimal emergence from 2 cm (www.cdfa.ca.gov, 2006). While seeds lower in the soil profile can escape predation and may survive for many years or decades (Turner, 1934), they require a major disturbance to both bring them close enough to the soil surface to germinate and to reduce competing vegetation to levels that allow seedling establishment (Paynter *et al.*, 1998). Studies by Richardson and Davenhill (1996a) and Williams (1981) concluded that seeds buried to a depth greater than 10 cm were unlikely to survive.

In the field, germination can be stimulated by soil or vegetation disturbance including commercial forestry operations, fire, cultivation, slashing, herbicide application, roadworks or animal digging (Downey, 2000; Partridge, 1989; Paynter, Downey & Sheppard, 2003; Paynter *et al.*, 1998; Robertson, Morgan & White, 1999; Williams, 1983; Zielke *et al.*, 1992). Another stimulant to germination is travel in the bed load of rivers and streams where scouring in the stream bed damages the hard seed coat preparing the seed for germination when it washes up onto the bank (Richardson *et al.*, 1996a).

Many trials have examined the impact of disturbance on Scotch broom seed germination and seedling survival with the treatment impact usually attributed to scarification of the seed coat and/or the removal of intra- and/or interspecific competition. In an Australian trial, ground disturbance in the form of cultivation was found to significantly increase Scotch broom establishment and seedling survival compared to plots where competing vegetation was removed by cutting, to simulate natural Scotch broom mortality, leaving the soil undisturbed (Sheppard *et al.*, 2002). In contrast, Parker (2001) found that cultivation did not increase germination rates of Scotch broom at three Australian sites, and in California, Bossard (1991) found that Scotch broom germination at one site decreased when the soil was disturbed. It can be hypothesised that the variation in responses may be due to site factors such as moisture conditions at the site at the time of treatment application and the competing vegetation community, i.e. the removal of the surrounding vegetation could increase the levels of drought stress experienced by seedlings due to soil temperature variations resulting from direct sunlight and radiative cooling increasing seedling mortality (Moodie, 1985; Parker, 2001; Smith *et al.*, 2000). Similarly, sites dominated by strongly competitive plant species such as turf forming grasses might display a negative impact on Scotch broom seed germination and survival (Bellingham & Coomes, 2003; Parker, 2001).

Lifespan and growth

It is not clear from the literature whether there is significant variation in Scotch broom lifespan and maximum height between the native and exotic range (Paynter *et al.*, 2003; Paynter *et al.*, 1998; Rees & Paynter, 1997; Sheppard *et al.*, 2002). Plants have however, been recorded to live greater than 20 years and reach up to 5 - 6 m high under some Australian and New Zealand conditions (Fowler *et al.*, 1996; Sheppard *et al.*, 2002; Smith *et al.*, 1991). At Barrington Tops in Australia, Smith *et al.* (1991) estimated the maximum age of Scotch broom at the site to be at least 23, and probably more than 27 years.

Height growth of Scotch broom can be rapid, particularly in the first few years (Richardson *et al.*, 1998; Zielke *et al.*, 1992). Scotch broom stem diameter and height have been found to be significantly correlated with plant age; however there was considerable variation in size for any given age (Paynter *et al.*, 2003; Richardson *et al.*, 1998). Records of Scotch broom growth in New Zealand and Australia include plants growing to 1 m in height in the first year and to 4 m within a few more years (Wilson, 1994), reaching 2.5 m in height and 2 cm in basal diameter after only 2 years (Williams, 1981) and at another site, achieving heights of more than 2 m after 4 years with stems > 6 m long and a foliage projective cover averaging about 40% (Downey *et al.*, 2000). Models of broom height growth developed by Kimberley and Richardson (2001) in New Zealand estimated plants to reach approximately 1 m in height after 12 months and almost 3 m in 2.5 years. This study also noted a marked seasonal pattern of growth. In another New Zealand study, Richardson *et al.* (1998) reports that growth rates differed by region, and site within region, and that asymptotes of maximum height growth varied by region with maximum heights ranging between 2.5 - 4.5 m at approximately 9 years of age.

Scotch broom invasion

Scotch broom is an outstandingly successful invader of Mediterranean (Fogarty *et al.*, 1999) and Temperate ecosystems. However, successful invasion of resident plant communities depends both on the attributes of the invaders as well as on aspects of the environment and the communities that make them susceptible to invasion (Bellingham *et al.*, 2003). Under some circumstances, resident herbivores can retard invasion (Bellingham *et al.*, 2003) and conditions that make invasion possible can be variable in time (Johnstone, 1986).

According to Smith *et al.* (2000), Scotch broom stand expansion is not rapid under conditions of low disturbance with 0.5 m per year recorded at Barrington Tops in Australia. Disturbance such as fire, herbicide treatment or physical disturbance however, accelerate the process by increasing rates of seed germination and seedling establishment, leading to both denser (Moodie, 1985) and larger populations (Robertson *et al.*, 1999) than prior to the disturbance. Studies in the Mt. Lofty Ranges near Adelaide, South Australia recorded Scotch broom invading native woodlands after disturbance such as fire as well as establishing in undisturbed open woodlands (Fogarty *et al.*, 1999). Scotch broom also has the ability to invade vegetation without a major disturbance event (Sheppard *et al.*, 2002) with seedlings found in open microsites such as along animal tracks and beside fallen timber (Dep. Primary Industries, 2002).

Scotch broom stand expansion can occur through two types of dispersal process (Figure 2). A population can expand its contiguous area by an incremental process of repeated short-distance dispersal. It can also expand using jump dispersal where an individual (leading to a population) becomes established at a distance from the parent populations after a (relatively) long distance dispersal event with a gap of uncolonised space remaining (at least temporarily) between the parent and daughter populations (Smith *et al.*, 2000).

Ballistic (short-distance) dispersal of Scotch broom seed has been studied in detail by Hinz (1992). As most Scotch broom seeds are deposited within the parent canopy, and seed rain declines significantly with distance from the Scotch broom stand edge, an abrupt advancing front is created (Allen *et al.*, 1995). This dispersal mechanism probably contributes little to stand expansion. Plants dispersing through secondary jump mechanisms (i.e. those dispersed via means other than explosive dehiscence from the parent plant) are the primary influence on the rate of Scotch broom spread and should be prioritised for weed control (Allen *et al.*, 1995; Mack, 1985). Calculations by Allen *et al.* (1995) indicate that eradication of younger isolated bushes before they seed could prevent the seed-bank from developing, and failure to detect and eradicate bushes in their 2nd or 3rd year would result by the 3rd or 4th year in a 16 fold increase in the area infected by Scotch broom seeds and the establishment of a substantial soil seed-bank.

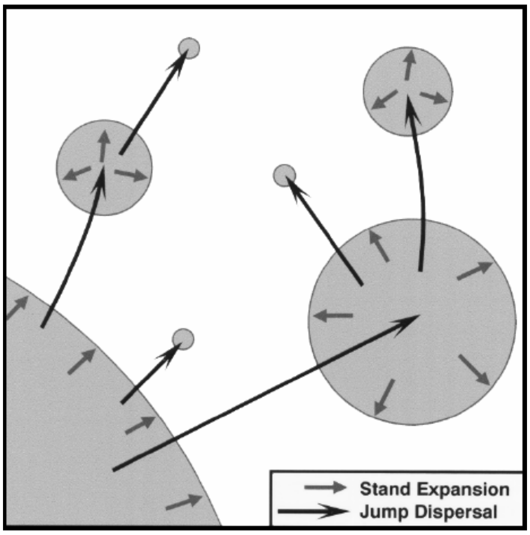


Figure 2: Conceptual model of the processes of range expansion in an invading species such as Scotch broom (after Smith *et al.*, 2000)

Natural enemies and biological control

The relative absence of phytophagous fauna on Scotch broom in New Zealand is in marked contrast to the numbers of insects found on the plant in its native range of Europe (Waloff, 1968) and in North America where it has been introduced (Waloff, 1966) as measured by both diversity of species and numbers of insects (Syrett, 1993). In England for example, up to 35 species of insect have been recorded breeding on Scotch broom, together with their 70 parasitoids and 60 arthropod predators. This is particularly true in the case of the pods and seeds, which support a number of species in Britain (Waloff, 1968) but are apparently free from attack in New Zealand.

The importance of insect herbivores in the population dynamics of Scotch broom was demonstrated in a large scale insecticide-check experiment operated at Silwood Park in the UK from 1966-1977 (Waloff *et al.*, 1977). This trial showed that unsprayed Scotch broom had higher numbers of most insect herbivores, did not attain full height growth and had higher rates of mortality than Scotch broom regularly sprayed with insecticide. Seed production by the unsprayed bushes, over the average 10 year life span, was also reduced by 75% compared with the sprayed Scotch broom.

Several arthropods have been investigated as classical biological control agents for Scotch broom in New Zealand. Two species, the Scotch broom seed beetle (*Bruchidius villosus)* and sap sucking Scotch broom psylid (*Arytainilla spartiophila* Hemiptera: Psyllidae) have already been intentionally introduced (Syrett *et al.*, 1999) and one species, the Scotch broom twig miner (*Leucoptera spartifoliella* Lepidoptera:Lyonetiidae), has arrived by unknown means.

The Canterbury Scotch broom Group has recently gained permission from the Environmental Risk Management Authority to release three more agents for the biological control of Scotch broom: the broom gall mite (*Aceria genistae,* Eriophyidae), the broom moth (*Agonopterix assimilella,* Lepidoptera, Oecophoridae) which feeds on foliage and the broom leaf beetle (*Gonioctina olivacea,* Coleoptera, Chrysomelidae).

Plant pathogens can also be used as biological control agents utilising either the classical or mycoherbicide strategy (Te Beest, Yang & Cisar, 1992). Fungi applied as mycoherbicides are applied inundatively as a suspension of inoculum, and act in a similar way to a chemical herbicide, primarily damaging susceptible plants that are directly treated (Johnston, Parkes & Broadhurst, 1995). The fungi, *Fusarium tumidum*, *Pleiochaeta setosa* and *Chondrostereum purpureum* (Johnston, Parkes & Broadhurst, 1995), all naturally occurring pathogens of Scotch broom in New Zealand, have been evaluated as potential mycoherbicides.

Preliminary studies in the early 1990's found that spores and mycelial fragments of the fungus, *P. setosa* could infect and kill young Scotch broom seedlings and reduce the growth of larger plants (Ray & Dick, 1992). These studies, however, also found that it was difficult to maintain sporulating cultures and that *P. setosa* was unlikely to be a vigorous enough pathogen to warrant efforts towards formulation development (M. Dick pers. comm. 2007).

Fusarium tumidum is capable of infecting and causing disease on Scotch broom and other plants within the same tribe (Barton nee Frohlich *et al.*, 2003). *Chondrostereum purpureum* is a wound-infecting generalist pathogen that attacks a wide variety of woody plants including Scotch broom, and has been developed into a mycoherbicide formulation in some countries (Wall, 1996).

Recent research with *C. purpureum* and *F. tumidum* has examined the potential for these pathogens to be used as mycoherbicides applied to gorse (*Ulex europaeus*) regenerating after decapitation. The expectation being that the fungi would work equally well on Scotch broom (J. Barton pers. comm. 2007). Both fungi were found to independently reduce the density of regenerative shoots on the decapitated gorse stems by 39-63%. No evidence of synergism between the two fungi was found (Bourdot *et al*., 2006). Further research into a formulation of *F. tumidum* that will protect its conidia from desiccation without causing damage to non-target plants is still required. Similarly, an inoculation method for *C. purpureum* that will enable it to damage or kill entire plants is still needed (Bourdot *et al.*, 2006). Furthermore, in order for mycoherbicides to be useful in a forestry context, a mechanical delivery system would need to be devised and tested.

Sheep and other vertebrates have also been shown to control Scotch broom invasions at some sites (Bossard *et al.*, 1994; Rousseau *et al.*, 1982) and under some circumstances cessation of grazing has led to rapid Scotch broom recruitment, increased Scotch broom seedling survival (possibly by reducing competition with grasses (Sheppard *et al.*, 2000)) and increased plant growth (Williams, 1983). At later stages of invasion, when Scotch broom forms a closed canopy, however, vertebrate grazing appears to have little effect on Scotch broom seedling survival (Paynter *et al.*, 1998).

PART 2. Past and Present Management Practices for Scotch broom Control in New Zealand

History of herbicide treatments and management regimes

In New Zealand, herbicide treatments for Scotch broom control have varied over time, closely mirroring the fluctuations in herbicide availability, cost and knowledge of their effectiveness and toxicity. Gous (2003) provides an excellent general overview of the use of agrichemicals to control competing vegetation within the New Zealand forestry industry. He discusses the herbicides used in both forest establishment and silvicultural practices from 1970 – 2003 and comments on the drivers of change.

Successful plantation establishment depends on tree seedling survival. In most cases high mortality and growth losses occur where no weed control is undertaken (Gous, 2003). Prior to the 1970's, herbicides were not commonly used for site preparation, with manual and mechanical weed control used in conjunction with prescribed fire (Table 2). However, this had its own problems (Preest, 1966) with high machinery costs, problems with working in difficult terrain and environmental concerns such as high levels of erosion. With the increased availability of herbicides during the 1970's, site preparation protocols changed. A pre-plant spray application was introduced into the regime, aimed at desiccating the weedy vegetation in preparation for the prescribed burn (Table 2). Applications of 2,4,5-T and 2,4,5-T + picloram were commonly used on sites infested with Scotch broom. The use of desiccating spray applications led to more effective burns due to the large amount of dead standing vegetation though the herbicides used were of relatively high mammalian toxicity and were applied at high rates (Gous, 2003).

Aerial herbicide operations became more common during the 1970's. These operations became known as "release" sprays, as they released the crop trees from the strong competitive effects of weed competition. Aerial herbicide applications were becoming more cost-effective, with little of the forest owners' labour involved, limited capital locked up in equipment, the ability to cover large areas in a short time and application to difficult terrain less off a concern (Preest, 1966). There remained however many difficulties with a dependence on the weather, which in many cases restricted the season of treatment, and there was significant unexplained variation in release success. There were difficulties in selecting effective herbicide mixtures and the time of maximum weed susceptibility often coincided with the time of least crop tolerance leading to tree damage or negative growth impacts. The application of herbicides to areas not requiring release and an inability to use hormone type herbicides in some areas due to damage to neighbouring crops also troubled the industry (Preest, 1966).

From 1980-1990, many new herbicides including triazines and glyphosate became available, replacing the more toxic products such as the hormone-based 2,4-D and 2,4,5-T. The use of prescribed fire became less common for site preparation and aerial application became a more affordable option. Research emphasis during the 1980's and 1990's tended to focus on lowering application rates and improving the efficiency of herbicides using adjuvants. With the added pressure on the forestry industry, from environmental certification authorities (such as the Forest Stewardship Council (FSC)) and other sources, to reduce chemical use, spot release became an important tool and an alternative to blanket aerial applications. Dose response trials were also used to minimise the use of herbicides and models of weed-tree competition helped define the level of weed control needed to ensure maximum tree growth.

CLIENT REPORT No: 12054

Table 2: Examples of Management regimes used for Scotch broom control in New Zealand.

Year	Treatment circumstances	Sequence of treatments					
Pre1970[a]	Prior to herbicides becoming readily available and cost effective	Mechanical control	Burn				
1975[b]	Scotch broom mixed with bracken or gorse	Pre-burn spray	Burn	Release spray			
1975[b]	Grazing country reverted to Scotch broom	Pre-burn spray	Burn	Crush & rip	Pre-plant spray	Release spray	Optional 2nd release
1975[b]	Turangi	Roller crush	Burn	Giant disc and harrow	Release spray	Optional 2nd release	
1975[b]	Light scrub, Scotch broom and bracken	Burn	Disked	Release spray			
1975[b]	Mixed gorse, Scotch broom and bracken	Burn	Root rake	Release spray			
1975[b]	Scotch broom and gorse	Burn	V-blade	Pre-plant spray	Release spray		
1975[b]	Seedlings and young growth up to 1m	Pre-burn spray	Burn	Release spray			
1982[c]	Balneaves – experimental trial	Pre-burn spray	Roller crush	Burn	Release spray	2nd Release	
1996[d]	Richardson and Davenhill	Pre-plant spray	Crush stems and woody debris	Pre or post plant residual herbicide	Release spray		
1997[e]	Mature Scotch broom infested site	Pre-plant spray	Crush	Burn	Release spray		
1997[e]	Seedlings on cutovers	Pre-plant spray	Release spray				
2006[f]	Potter survey results	Optional root rake & roller crush	Pre-plant spray	Optional spot release	Release spray	Optional 2/3rd release	

[a] Gous (2003), [b] Chavasse (1975), [c] Balneaves (1982), [d] Richardson and Davenhill (2006), [e] Davenhill *et al.* (1997), [f] Potter (2007)

Current herbicide use and management regimes

There are two distinct phases of forestry operation where vegetation management using chemical control is implemented, the pre-plant or site preparation phase and the post-plant or competition release phase. These two management phases tend to utilise different groups of herbicides as vegetation management tools, primarily due to differences in the purpose of the application, the weed complex present and the time of application within the schedule of commercial forestry operations.

Gous (2003) provides an overview of many of the agrichemicals utilised currently and in the past for both the site preparation and release phases where Scotch broom infestations are present (see glyphosate, hexazinone, terbulthylazine, picloram and triclopyr). Two other commonly used herbicides used in Scotch broom management regimes not discussed by Gous (2003) are metsulfuron and clopyralid. Metsulfuron (often marketed as Escort) is a non-selective, highly active, yet relatively slow acting compound commonly used as a pre-plant control for weeds such as gorse, Scotch broom and blackberry in New Zealand. It has a residual effect and is taken up through both the foliage and root system of plants. In New Zealand, metsulfuron is suitable for aerial or vehicle application in summer, autumn and winter. Clopyralid (often marketed as Versatil) is currently used by some New Zealand companies (often in a mixture with other herbicides) in release operations for the control of weeds such as gorse, Scotch broom and tree lupin. It is absorbed by the foliage and persists in the soil for between 2 and 14 months depending on soil type, climate, and other factors (Tanphiphat & Burrill, 1987). It is suitable for application in both *Pinus radiata* and eucalypt plantations in year 1 or 2. It is applied either with a knapsack or aerially in late spring-early summer and it is recommended that it be applied when woody weeds have abundant new growth.

In a recent survey of New Zealand forestry companies, all forest managers interviewed used an aerial application of glyphosate plus metsulfuron with 0.4-0.5% organosilicon surfactant for site preparation on Scotch broom infested sites. Glyphosate rates varied between 2160 – 4500 g ai/ha while metsulfuron rates varied between 36 -167 g ai/ha (Table 3 and Potter, 2007). Glyphosate is a non-selective, non-residual, systemic herbicide and is the component of the mixture responsible for weed knockdown. The metsulfuron component has a residual effect with a half-life in soil of 14 to 180 days (mean = 30 days). Most companies implemented a withholding period of approximately 2 months prior to tree planting.

The forest industry survey also found that post-plant / release applications on Scotch broom infested sites were applied both as a land based spot-release and as an aerial application. Chemicals commonly used for spot-release included Terbuthylazine (500 g ai/L) + Tordon Brushkiller (picloram 100 g ai/L

+ triclopyr 300 g ai/L), Valzine (terbuthylazine 425 g ai/L + hexazinone 75 g ai/L) and Forest Mix granules (67 g ai/kg hexazinone + 150 g ai/kg atrazine). Spot-release was reported to provide approximately 12 month residual control and spot size was approximately 1.5-2 m in diameter.

Table 3: Common glyphosate plus metsulfuron site preparation mixtures for Scotch broom infested sites in New Zealand

Glyphosate			**Metsulfuron***		
g ai/kg	**Rate**	**g ai/ha**	**g ai/kg**	**Rate**	**g ai/ha**
360	10 L/ha	3600	600	0.2 kg/ha	120
360	12 L/ha	4320	600	0.2 kg/ha	120
360	3-9 L/ha	1080-3240	600	0.08-0.33 kg/ha	50-200
450	7-10 L/ha	3150-4500	600	0.25 kg/ha	150
450	5.8 L/ha	2958	600	0.06 kg/ha	36
510	4.33 L/ha	2208.3	600	0.28 kg/ha	167
510	6.6 L/ha	2970	600	0.06 kg/ha	36
510	5.0 L/ha	2550	200	0.5 kg/ha	100
510	6 L/ha	3060	200	0.3 kg/ha	60
510	6.33 L/ha	3228.3	600	0.28 kg/ha	167
680	5 kg/ha	3400	200	0.56 kg/ha	112

* Escort = 600 ga.i./kg metsulfuron methyl, Answer = 200 gai/kg metsulfuron methyl

The majority of interviewees employed at least one aerial release operation within their Scotch broom management regime (Potter, 2007). Chemical mixtures and rates used for aerial release on Scotch broom infested sites varied between forest managers (Table 4) but could be divided broadly into two groups; clopyralid plus picloram and/or triclopyr (either alone or pre-mixed as Tordon Brushkiller) mixtures and terbuthylazine plus hexazinone mixtures.

In the case of the clopyralid plus picloram and/or triclopyr mixes, both picloram and triclopyr are selective herbicides that kill woody and some broad leaf weeds. Both are absorbed by the foliage and roots, with picloram providing a soil residual action for 7 to 14 months while triclopyr has a half-life of only 46 days depending on soil and climate conditions. Picloram and/or triclopyr products have the ability to cause twisting of *Pinus radiata* trunks so careful assessment must be made of the rate applied, weather conditions and tree age prior to application. Neither clopyralid, picloram nor triclopyr significantly affect members of the Poaceae (grasses).

Both terbuthylazine and hexazinone are semi-selective, residual herbicides primarily absorbed through the roots but also through foliage. The terbuthylazine component provides both pre- and post emergent control of a wide range of annual and perennial grasses and some broadleaf weeds. It has a half-life of 1-2 months. Hexazinone also controls woody and herbaceous species and in combination with terbuthylazine, increases activity on the broadleaf species. Hexazinone has a half-life in soils of between 1 - 6 months.

Table 4: Aerial Release mixtures and rates used for Scotch broom infested sites

Mix no.	Chemical 1	Chemical 2
1	**Clopyralid 300 g ai/L (Versatill)**	**Triclopyr 300 g ai/L + Picloram 100 g ai/L (Tordon Brushkiller)**
	2.5 L/ha = 750 g ai/ha	0.5 L/ha = Triclopyr 150 g ai/ha + Picloram 50 g ai/ha
	4.5 L/ha = 1350 g ai/ha	0.5 L/ha = Triclopyr 150 g ai/ha + Picloram 50 g ai/ha
	5.0 L/ha = 1500 g ai/ha	0.5 L/ha = Triclopyr 150 g ai/ha + Picloram 50 g ai/ha
	5-5.8 L/ha = 500-1740 g ai/ha	0.58 L/ha = Triclopyr 174 g ai/ha + Picloram 50-58 g ai/ha
2	**Clopyralid 300 g ai/L (Versatil)**	**Triclopyr 600 g ai/L (Grazon)**
	4.2 L/ha = 1260 g ai/ha	0.6 L/ha = 360 g ai/ha
	5.0 L/ha = 1500 g ai/ha	0.5 L/ha = 300 g ai/ha
	5.0 L/ha = 1500 g ai/ha	0.6 L/ha = 360 g ai/ha
3	**Clopyralid 225 g ai/L + Picloram 150 g ai/L (Radiate)**	
	2-2.5 L/ha = Clopyralid 450-562.5 g ai/ha + Picloram 300-375 g ai/ha	
4	**Terbuthylazine 500 g ai/L**	**Hexazinone 750 g ai/kg (Velpar DF)**
	12 L/ha = 6000 g ai/ha	2.5 L/ha = 1875 g ai/ha
	15 L/ha = 7500 g ai/ha	1.5-2.0 L/ha = 1125-1500 g ai/ha
5	**Terbuthylazine 425g ai/L + Hexazinone 75 g ai/L (Valzine)**	
	20 L/ha = Terbuthylazine 8500 g ai/ha + Hexazinone 1500 g ai/L	
6	**Terbuthylazine 435 g ai/L + Hexazinone 65 g ai/L**	**Triclopyr 300 g ai/L + Picloram 100 g ai/L (Tordon Brushkiller)**
	17 L/ha = Terbuthylazine 7395 g ai/ha + Hexazinone 1105 g ai/ha	0.5 L/ha = Triclopyr 150 g ai/ha + Picloram 50 g ai/ha + Rapid Plus surfactant (no oxyflurofen)

Application of herbicide to Scotch broom is most effective during periods of active growth, up to the time seed pods turn brown and according to Richardson and Davenhill (1996a) there is likely to be some lessening of effectiveness when plants are in heavy flower or suffering drought stress. It is recommended therefore that particular attention be paid to targeting Scotch broom when it is actively growing to gain greatest chemical uptake.

Other important components of current Scotch broom management regimes highlighted during the industry survey were the use of cultivation and mechanical site preparation operations, cover crops and biological control (Potter, 2007). While in some locations in New Zealand, extensive cultivation and mechanical site preparation operations have been largely phased out (Table 2), some forest managers continue to consider it critical to successful tree establishment. Cultivation and mechanical site preparation such as root raking and gravity roller crushing are generally implemented to improve poor soil structure and drainage, with the added benefit of stimulating weed seed germination. In some cases, forest managers believed that the increased weed seed germination followed by a pre-plant herbicide application significantly depleted the weed seed-bank, reducing the number and/or cost of chemical release operations later in the Scotch broom management regime.

The use of grass and legume cover crops (with and without grazing) is another weed control option utilised by some forest managers. The primary advantage being that the cover crops limit the availability of resources (e.g. space, light and water) to weeds germinating on the site. However, the scheduling of cover crop sowing in relation to tree planting and weed seed germination appears critical to success, and can be difficult to achieve. In some areas, the sowing of a cover crop can also cause trees to suffer more severe damage from frost and insect herbivores (Herman & Davidson, 2000; (Richardson *et al.*, 1996b).

Biological control is a valuable non-chemical weed control technique although its long establishment time and the need for agents to be introduced for individual weed species has so far limited its application in vegetation management in the forestry sector. Multiple insect biological control agents have been introduced into New Zealand for Scotch broom control (see section on biological control above) but a quantitative advantage to the industry is yet to be seen.

PART 3. Key Management Questions and Recommendations on Future Scotch broom Research

The combined knowledge gained from the literature review, industry survey (Potter, 2007) and consultation with New Zealand Forest Site Management Cooperative (Appendix 1) provides a basis for the identification of knowledge gaps and the development of recommendations on future Scotch broom research.

Control Technologies

Site preparation failures

Interviewees revealed that in some instances, forest companies fail to gain control of Scotch broom with a single pre-plant herbicide application. These sites often require a second pre-plant application and in the worst cases, may need to be replanted with tree seedlings. Each site preparation failure has multiple costs. It significantly increases the amount of herbicide needed, requires a replant and extends the payback period for the rotation. A better understanding of the frequency and nature of site preparation failures may clarify the extent to which this problem can be addressed through research. Possible causes of these failures include resource allocation, scheduling difficulties or operator error.

Reduced Herbicide Application Rates

In areas that are not prone to severe cold or dry periods, Scotch broom may not “harden off”. In these areas, there may be an opportunity to reduce herbicide application rates while still achieving reliable and sufficient control.

Mycoherbicide

If, in the future, *Chondrostereum purpureum* and / or *Fusarium tumidum* are registered as mycoherbicides for woody weeds such as Scotch broom, research into a mechanical delivery system would be required for the effective deployment of these treatments in a forestry situation.

Dispersal and Stand Hygiene

Scotch broom dispersal is a key factor in its dynamics and impact due to its highly persistent seed-bank. Ballistic dispersal mechanisms limit how far it can invade into an intact vegetation stand in the absence of disturbance. Long distance transport mechanisms such as humans, animals or machine movement however, can lead to the movement of seeds further into the forest stand. These seeds provide a source for seedling establishment inside the stand following a natural disturbance, thinning or harvest operation.

By better understanding the dispersal process, the value of controlling populations of Scotch broom and other woody weeds inhabiting the lighter periphery of the forest stands may be gauged. Similarly, a greater understanding of the importance of machinery hygiene in slowing the spread of weeds between and within stands might also be valuable.

Ecology and Population Dynamics

In the presence of pollinators, and reduced presence of natural enemies, Scotch broom rapidly develops a supersaturated seed-bank. A physiological development model that includes an understanding of the relationship between the environment and the onset of reproductive maturity (i.e., the length of the juvenile period) could assist managers by informing them of the window in which they should seek to kill broom prior to it contributing to the seed-bank.

By understanding the growth rate of Scotch broom and *Pinus radiata*, in relation to soil moisture and temperature, it would be possible to create a model that would indicate the likely 2 species competitive outcome for a given environment and different planting dates. This should allow forest managers to plan their operations with more confidence. It should also be possible to extend the knowledge in VMAN, translating it into a process-based environment so that herbicide treatment events can be included.

Weed Competition and Wood Quality

Weed competition has been shown to improve some desirable wood qualities such as modulus of elasticity. The recent trend toward valuing wood quality more highly over wood quantity suggests that there may be some value in tolerating higher levels of weed competition within an establishing stand than previously accepted. However, by allowing higher levels of weed presence in a stand, there is likely to be a trade-off with tree growth and an increased risk of planting failure. While we have gained some understanding of how weed competition impacts on wood quality, it is not clear how this competition effect interacts with environment (climate and nutrition).

The forest management regime required to optimise wood quality while reducing planting failure or delaying the return on investment, would need to satisfy multiple criteria. It may be possible to analyse the PSP dataset in an attempt to gain an understanding of the trade-offs involved. Another option is to use a computer based self-learning system. Forestry companies could upload their operations and the outcomes of the operations confidentially onto a computerised system. The data could then be mined to indicate the optimal solutions for a given set of criteria and assumptions about the differential prices of different grade wood products etc. This would form the basis for a decision-support system. The advantage of such a system is that being self-learning, it is self-correcting. Therefore, if companies implement techniques that are risky (as indicated by treatment failures), then the system will indicate that this is not a good set of techniques to use for that location.

RECOMMENDATIONS AND CONCLUSIONS

The literature review should assist in directing future research into Scotch broom management in New Zealand and the areas of interest for future research identified by this report should be the focus of future funding applications. It is also recommended that the information gathered by this review including the key management questions and recommendations on future Scotch broom research needs be used to guide the direction of a new Forest Site Management Cooperative Project and to support the next application for funding from the Foundation for Research Science and Technology. Specific sections of the research programme should also be flagged as appropriate for student or postgraduate projects.

ACKNOWLEDGEMENTS

The author would like to gratefully acknowledge the support of the New Zealand Site Management Cooperative and the Foundation for Research, Science and Technology in funding this review. Thanks also go to Brian Richardson and Darren Kriticos for their comments on earlier versions of this document.

REFERENCES

Allen, R.B., Williams, P.A., & Lee, W.G. (1995) Seed bank accumulation of broom (*Cytisus scoparius*) in South island. In Proceedings of the 48th New Zealand Plant Protection Conference, pp. 276-280.

Balneaves, J.M. (1982) A multiple spray regime for broom control in forestry operations. In Proceedings of the 35th New Zealand Weed and Pest Control Conference (ed M.J. Hartley), pp. 157-161, Palmerston North, New Zealand.

Barton (nee Frohlich), J., Gianotti, A.F., Morin, L., & Webster, R.A. (2003) Exploring the host range of *Fusarium tumidum*, a candidate bioherbicide for gorse and broom. *Australasian Plant Pathology*, **32**, 203-211.

Bellingham, P.J. & Coomes, D.A. (2003) Grazing and community structure as determinants of invasion success by Scotch broom in a New Zealand montane shrubland. *Diversity and Distributions*, **9**, 19-28.

Blood, K. (2001) *Environmental weeds: a field guide for South Eastern Australia* Jeffam & Associates, CRC for Weed Management Systems.

Bossard, C.C. (1990a) *Secrets of an ecological interloper: Ecological studies on* Cytisus scoparius *in California*. PhD, University of California, Davis, USA.

Bossard, C.C. (1990b) Tracing of ant-dispersed seeds: a new technique. *Ecology (Tempe)*, **70**, 2370-2371.

Bossard, C.C. (1991) The role of habitat disturbance, seed predation and ant dispersal on establishment of the exotic shrub *Cytisus scoparius* in California. *The American Midland Naturalist*, **126**, 1-13.

Bossard, C.C. (1993) Seed germination in the exotic shrub *Cytisus scoparius* (Scotch broom) in California. *Madrono*, **40**, 47-61.

Bossard, C.C. & Rejmanek, M. (1994) Herbivory, growth, seed production, and respouting of an exotic invasive shrub *Cytisus scoparius*. *Biological Conservation*, **67**, 193-200.

Bourdot, G.W., Barton, J., Hurrell, G.A., Gianotti, A.F., & Saville, D.J. (2006) *Chondrostereum purpureum* and *Fusarium tumidum* independently reduce regrowth in gorse (*Ulex europaeus*). *Biocontrol Science and Technology*, **16**, 307-327.

Chavasse, C.G.R. (1975) The Use of Herbicides in Forestry in New Zealand. In FRI Symposium No. 18. Forest Research Institute, Rotorua.

Cubas, P., Tahira, H., & Pardo, C. (2001) Karyological and taxonomic notes on Cytisus Desf. Sect. Spartopsis Durmort. and Sect. Alburnoides DC. (Gensiteae, Leguminosae) from the Iberian Peninsula and Morocco. *Botanical Journal of the Linnean Society*, **135**, 43-50.

Davenhill, N.A., Ray, J.W., & Vanner, A.L., eds. (1997) *Forest Weed Control Manual: a guide to herbicide use in forests*, 2nd edn. Vol. No. 180, FRI Bulletin, pp 136. New Zealand Forest Research Institute Limited, Rotorua, New Zealand.

Department of Primary Industries, Water and Environment. (2002). Service Sheet: Broom - Montpellier broom (*Genista monspessulana* L.), English broom (*Cytisus scoparius* (L.) Link). Agdex 647.
Dobashi, Y. (1995) The Scotch broom. *World of Plants*, **5**, 7-10.
Downey, P.O. (2000) The impact of fire on Scotch broom (*Cytisus scoparius*) seed banks: implications for management. *Plant Protection Quarterly*, **15**, 178-183.
Downey, P.O. & Smith, J.M.B. (2000) Demography of the invasive shrub Scotch broom (*Cytisus scoparius* (L.) Link) at Barrington Tops, NSW: insights for management. *Austral Ecology*, **25**, 477-485.
Fogarty, G. & Facelli, J.M. (1999) Growth and competition of *Cytisus scoparius*, an invasive shrub, and Australian native shrubs. *Plant Ecology*, **144**, 27-35.
Fowler, S.V., Cross, A.E., & Shaw, R.H. (1993). Report on weed work for New Zealand, 1993. International Institute of Biological Control, Ascot, UK.
Fowler, S.V., Harman, H.M., Memmott, J., Paynter, Q., Shaw, R., Sheppard, A.W., Syrett, P., Moran, V.C., & Hoffmann, J.H. (1996) Comparing the population dynamics of broom, *Cytisus scoparius*, as a native plant in the United Kingdom and France and as an invasive alien weed in Australia and New Zealand. In Proceedings of the 9th International Symposium on Biological Control of Weeds, pp. 19-26 South Africa.
Gadgil, R.L. (1983). Biological nitrogen fixation in forestry research and practice in Australia and New Zealand. In *Biological nitrogen fixation in forest ecosystems: foundations and applications* (eds J.C. Gordon & C.T. Wheeler). Martinus Nijhoff/Dr W. Junk Publishers, The Hague, Netherlands.
Gous, S. (2003). Overview of the use of agri-chemicals and alternatives to control competing vegetation in forestry. Contract Report for the NZ Site Management Cooperative, Forest Research, Rotorua, New Zealand.
Harman, H.M. (1999) The effect of variability in the phenology of the reproductive stages of scotch broom (*Cytisus scoparius*) on the synchronization of the life stages of broom seed beetle (*Bruchidius villosus*) in New Zealand. *Biological Control*, **15**, 228-234.
Harper, J.L. (1977) *Population Biology of Plants* Academic Press, London, UK.
Hegi, G. (1926) *Illustrated flora of Central Europe* Carl Hanser, Munich.
Herman, T. & Davidson, M. (2000) Introduction and establishment of *Microplitis croceipes*, a larval parasitoid of *Heliothis* in North Island pine forests. *New Zealand Plant Protection* **53**, 328-333.
Hinz, H.L. (1992) *Studies on the two seed-feeding beetles* Apion fuscirostre *F. (Coleoptera: Apionidae) and* Bruchidius villosus *F. (Coleoptera: Brucidae): potential biological control agents for broom (*Cytisus scoparius*)*. MSc thesis, University of London, U.K.

Holm, L., Pancho, J.V., Hergerger, J.P., & Plucknett, D.L. (1979) *A Geographical Atlas of World Weeds* Wiley-InterScience, New York, USA.

Hosking, J.R. (1995) The impact of seed- and pod-feeding insects on *Cytisus scoparius*. In Proceedings of the 8th International Symposium on Biological Control of Weeds (eds E.S. Delfosse & R.R. Scott), pp. 45-51. DSIR/CSIRO, Melbourne, Lincoln University, Canterbury, New Zealand.

Hosking, J.R., Smith, J.M.B., & Sheppard, A.W. (1996) The biology of Australian weeds. 28. *Cytisus scoparius* (L.) Link subsp. scoparius. *Plant Protection Quarterly*, **11**, 102-108.

Hosking, J.R., Smith, J.M.B., & Sheppard, A.W. (1998). *Cytisus scoparius* (L.) Link subsp. scoparius. In *The Biology of Australian Weeds* (eds F.D. Panetta, R.H. Groves & R.C.H. Shepherd), Vol. Vol. 2, pp. 77-88. R.G. & F.J. Richardson Publishers, Melbourne, Australia.

Johnston, P.R., Parkes, S.L., & Broadhurst, P.G. (1995) Fungi associated with gorse and broom in New Zealand. *Australian Plant Pathology*, **24**, 157-167.

Johnstone, I.M. (1986) Plant invasion windows: a time-based classification of invasion potential. *Biological Reviews*, **61**, 369-394.

Kimberley, M.O. & Richardson, B. (2001) Modelling the growth and interactions of young *Pinus radiata* with some important weed species. *New Zealand Journal of Forestry Science*, **31**, 235-246.

Luken, J.O. & Thieret, J.W., eds. (1997) *Assessment and Management of Plant Invasions*. Springer, New York, USA.

Mack, R.N. (1985). Invading plants: their potential contribution to population biology. In *Studies on Plant Demography* (ed J. White), pp. 127-142. Academic Press, London, U.K.

Meyer, S.A. (2003). *Cytisus scoparius* (L.) Link. In *Woody plant seed manual* (eds F.T. Bonner & R.G. Nisley), pp. 4. U.S. Department of Agriculture, Forest Service, Washington, D.C., USA.

Moodie, J.C. (1985). An evaluation of control techniques for broom (*Cytisus scoparius*) on Barrington Tops. University of New England, Armidale, Australia.

Nemoto, N., Nakagoshi, N., Horie, H., & Nishimura, N. (1993) Allelopathic potential of broom (*Sarothamnus scoparius*) dominating post-fire stands in south west Japan. In Proceedings of the 10th Australian Weeds Conference and 14th Asian Pacific Weed Science Society Conference, pp. 333-338.

Parker, I.M. (1996) *Ecological factors affecting rates of population growth and spread in* Cytisus scoparius*, an invasive exotic shrub.* Dissertation, University of Seattle, Washington, USA.

Parker, I.M. (1997) Polinator limitation of *Cytisus scoparius* (Scotch broom), an invasive exotic shrub. *Ecology*, **78**, 1457-1470.

Parker, I.M. (2000) Invasion dynamics of *Cytisus scoparius*: a matrix model approach. *Ecological Applications*, **10**, 726-743.

Parker, I.M. (2001) Safe site and seed limitation in *Cytisus scoparius* (Scotch broom): invasibility, disturbance, and the role of cryptograms in a glacial outwash prairie. *Biological Invasions*, **3**, 323-332.

Parsons, W.T. & Cuthbertson, M. (1992) *Noxious Weeds of Australia* Inkata Press, Melbourne, Australia.

Partridge, T.R. (1989) Soil seed banks of secondary vegetation on the Port Hills and Banks Peninsula, Canterbury, New Zealand, and their role in succession. *New Zealand Journal of Botany*, **27**, 421-436.

Paynter, Q., Downey, P.O., & Sheppard, A.W. (2003) Age structure and growth of the woody legume weed *Cytisus scoparius* in native and exotic habitats: implications for control. *Journal of Applied Ecology*, **40**, 470-480.

Paynter, Q., Fowler, S.V., Hinz, H.L., Memmott, J., Shaw, R., Sheppard, A.W., Syrett, P., Moran, V.C., & Hoffmann, J.H. (1996) Are seed-feeding insects of use for the biological control of broom? In Proceedings of the 9th International Symposium on Biological Control of Weeds, pp. 495-501, South Africa.

Paynter, Q., Fowler, S.V., Memmott, J., & Sheppard, A.W. (1998) Factors affecting the establishment of *Cytisus scoparius* in southern France: implications for managing both native and exotic populations. *Journal of Applied Ecology*, **35**, 582-595.

Peterson, D.J. & Prasad, R. (1998) The Biology of Canadian weeds. 109. *Cytisus scoparius* (L.) Link. *Canadian Journal of Plant Science*, **78**, 497-504.

Potter, K.J.B. (2007). Report on a survey conducted for the New Zealand Forest Site Management Cooperative on Scotch broom management in New Zealand Rep. No. Report No. 12176. Ensis, Hobart, Tasmania.

Prasad, R. & Peterson, D.J. (1997) Mechanisms of invasiveness of the exotic weed, Scotch broom (*Cytisus scoparius* (L.) Link) in British Columbia. In Proceedings of the Expert Committee on Weeds Annual Meeting, pp. 197-198, Victoria, British Columbia (Abstr.).

Preest, D.S. (1966) Chemical weed control in young conifer plantations. In Proceedings of the New Zealand Weed and Pest Control Conference (ed L.J. Matthews), pp. 145-151. Otago Museum, Dunedin

Ray, J.W. & Dick, M.A. (1992). *Pleiochaeta setosa* - a mycoherbicide for the control of broom. Forest Research, Rotorua.

Rees, M. & Paynter, Q. (1997) Biological control of Scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. *Journal of Applied Ecology*, **34**, 1203-1221.

Richardson, B., Coker, G., Gous, S., & Kimberley, M.O. (1998). Light attenuation and canopy characteristics of important forest weed species. Forest Research, Rotorua, New Zealand.

Richardson, B. & Davenhill, N. (1996a). Control of Scotch Broom (*Cytisus scoparius*). New Zealand Forest Research Institue, Rotorua, New Zealand.

Richardson, B., Davenhill, N., Coker, G., Ray, J.W., Vanner, A.L., & Kimberley, M.O. (1996b) Optimising spot weed control: first approximation of the most cost-effective spot size. . *New Zealand Journal of Forestry Science* **26**, 265-275.

Robertson, D.C., Morgan, J.W., & White, M. (1999) Use of presecribed fire to enhance control of English Broom (*Cytisus scoparius*) invading a subalpine snowgum woodland in Victoria. *Plant Protection Quarterly*, **14**, 51-56.

Rousseau, S. & Loiseau, P. (1982) Structure et cycle de developpement des peuplements a *Cytisus scoparius* L. Dans la chaine des Puys. *Acta Ecological - Ecologia Applicata*, **3**, 155-168.

Sheppard, A.W., Hodge, P., & Paynter, Q. (2000) Factors affecting broom regeneration in Australia and their management implications. *Plant Protection Quarterly*, **15**, 156-161.

Sheppard, A.W., Hodge, P., Paynter, Q., & Rees, M. (2002) Factors affecting invasion and persistence of broom *Cytisus scoparius* in Australia. *Journal of Applied Ecology*, **39**, 721-734.

Smith, J.M.B. & Harlen, R.L. (1991) Preliminary observations on the seed dynamics of broom (*Cytisus scoparius*) at Barrington Tops, New South Wales. *Plant Protection Quarterly*, **6**, 73-78.

Smith, J.M.B., Sheppard, A.W., & Hosking, J.R. (2000) An introduction to the biogeography and ecology of broom (*Cytisus scoparius*) in Australia. *Broom management*, **15**, 140-144.

Stevens, E.J. & Hughes, J.G. (1973) *Distribution of sweet brier, broom and ragwort on Molesworth Station* Special publication, Tussock Grasslands and Mountain Lands Institute, New Zealand.

Suzuki, N. (2000) Pollinator limitation and resource limitation of seed production in the Scotch broom, *Cytisus scoparius* (Leguminosae). *Plant Species Biology*, **15**, 187-193.

Syrett, P. (1986). Assessment of the impact of introduction of broom seed feeding insects into New Zealand. Landcare Research, Lincoln.

Syrett, P. (1989). *Cytisus scoparius* (L.) Link, broom (Fabaceae). In *A review of biological control of invertebrate pests and weeds in New Zealand 1874-1987* (eds P.J. Cameron, R.L. Hill, J. Bain & W.P. Thomas), Vol. No. 10, pp. 347-349. CAB International, Wallingford, Oxon, UK.

Syrett, P. (1993). The suitability of *Pirapion immune* Kirby (Coleoptera: Curculionidae), a potential agent for biological control of *Cytisus scoparius* (L.) Link (broom) in New Zealand. Landcare Research, Lincoln, New Zealand.

Syrett, P., Fowler, S.V., Coombs, E.M., Hosking, J.R., Markin, G.P., Paynter, Q.E., & Sheppard, A.W. (1999) The potential for biological control of Scotch broom (*Cytisus scoparius*) (Fabaceae) and related weedy species. *Biocontrol News and Information*, **20**, 17n-34n.

Tanphiphat, K. & Burrill, L.C. (1987) Persistence of clopyralid in soil. In Proceedings of the Western Society of Weed Science, Vol. 40, pp. 75.

Te Beest, D.O., Yang, X.B., & Cisar, C.R. (1992) The status of biological control of weeds with fungal pathogens. *Annual Review of Phytopathology*, **30**, 637-657.

Turner, J.H. (1934) The viability of seeds. *Bulletin of Miscellaneous Information, Kew*, **6**, 257-269.

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M., & Webb, D.A. (1968) *Flora Europaea* Cambridge University Press, Cambridge, U.K.

von Walter, H. (1968) *Die vegetation der erde in okophysiologischer betrachtung* Jena, Gustav Fischer Verlag.

Wall, R.E. (1996). Pathogenicity of the bioherbicide fungus *Chondrostereum purpureum* to some Trees and Shrubs of Southern Vancouver Island. Pacific Forestry Centre, Canadian Forest Service, British Columbia.

Waloff, N. (1966) Scotch broom (*Sarothamnus scoparius* (L.) Wimmer) and its insect fauna introduced into the Pacific north-west of America. *Journal of Applied Ecology*, **3**, 293-311.

Waloff, N. (1968) Studies on the insect fauna of Scotch broom *Sarothamnus scoparius* (L.) Wimmer. *Advances in Ecological Research*, **5**, 87-208.

Waloff, N. & Richards, O.W. (1977) The effect of insect fauna on the growth, mortality and natality of broom, *Sarothamnus scoparius*. *Journal of Applied Ecology*, **14**, 787-798.

Wardle, P. (1971) An explanation for alpine timberline. *New Zealand Journal of Botany*, **9**, 371-402.

Wheeler, C.T., Helgerson, O.T., Perry, D.A., & Gordon, J.C. (1987) Nitrogen fixation and biomass accumulation in plant communities dominated by *Cytisus scoparius* L. in Oregon and Scotland. *Journal of Applied Ecology*, **24**, 231-7.

Wheeler, C.T., Perry, D.A., Helgerson, O.T., & Gordon, J.T. (1979) Winter fixation of nitrogen in Scotch Broom (*Cytisus scoparius*) L.) *New Phytologist*, **82**, 697-701.

Williams, P.A. (1981) Aspects of the ecology of broom (*Cytisus scoparius*) in Canterbury, New Zealand. *New Zealand Journal of Botany*, **19**, 31-43.

Williams, P.A. (1983) Secondary vegetation succession on the Port Hills, Banks Peninsula, Canterbury, New Zealand. *New Zealand Journal of Botany* **21**, 237-247.

Wilson, H.D. (1994) Regeneration of native forest on Hinewai Reserve, Banks Peninsula. *New Zealand Journal of Botany*, **32**, 373-383.

Zielke, K., Boateng, J., Caldicott, N., & Williams, H. (1992) *Broom and Gorse: A Forestry Perspective Problem Analysis* British Columbia Ministry of Forests, Queen's Printer, Victoria, BC.

Appendix 1 – Potential Research Questions Regarding the Ecology and Management of Scotch Broom

The following research topics and questions were identified during the interview and literature review process. They have not been prioritised or evaluated in terms of their potential to provide practical solutions to management questions.

1. Scotch Broom Biology and Ecology

1.1 Relationship between flowering, seed set and seed viability over time

- Measure the viability of seed within the seed-bank in stands of varying age.
- The literature suggests that shading and drought decrease flowering and/or Scotch broom seed set. A greater understanding of this relationship might explain some regional and local variation in seed-banks.
- What is the input to the seed-bank over time? Is there a particular season or age when the plant is most productive at producing seed?
- Some foresters noted that Scotch broom does not have many opportunities to flower and set seed within a forest stand due to pre-plant and release herbicide operations and subsequent canopy closure.
- If a Scotch broom slashing pre-plant treatment was applied, until what seed pod developmental stage would this be beneficial so that seed development is completely halted rather than leaving pods on the forest floor to dehisce and disperse their seeds.

Management outcomes:

- ❖ If plants that are not exposed to herbicide treatments and shading (e.g. those on roadsides) are the primary source of Scotch broom seed, the targeting of flowering plants on the outskirts of stands may be a highly effective means of Scotch broom containment and management.
- ❖ Due to the large seed set and slow seed-bank decay rate in Scotch broom infestations, the identification and/or development of management options to reduce or stop seed set would be valuable.
- ❖ It may be necessary to modify management regimes that allow Scotch broom within plantation blocks to reach seeding age. Appropriate management of these infestations prior to seeding could have a massive impact on the accumulation of the Scotch broom seed-bank. While this may not provide immediate, short-term benefits it is likely to have long-term benefits for future rotations, particularly if developed in conjunction with a germination stimulant treatment.

1.2 Waves of seed germination and germination stimulants

- A greater understanding of germination stimulants would be advantageous as evidence in the literature is either laboratory-based or based largely on subjective evidence.
- How critical is physical scarification of the seed coat for germination?
- Within the forestry setting, what is the relative importance of competing vegetation (for space/nutrients/light), temperature and moisture conditions for Scotch broom seed germination?
- How many and what type of annual site-preparation operations would stimulate 99% germination of the seed-bank?
- Exploration of management options that trigger a greater proportion of seeds within the seed-bank to germinate at the one time would enable a single pre-plant operation to destroy a larger proportion of the seed-bank.
- By understanding germination stimulants, managers could better schedule the sowing of cover crops to compete effectively with weeds on the site. For example, what soil temperatures does Scotch broom need to germinate? Grass seed germinates at 7℃. an d gorse at 10℃.

Management outcomes:

❖ Germination stimulant treatments may involve a repeat disturbance regime or the application of smoke water products etc. If they could be used effectively, managers maybe able to apply a pre-plant treatment that kills a larger proportion of the seed-bank.

❖ Germination stimulants would assist companies to schedule the sowing of cover crops.

❖ If a treatment was developed that involved the stimulation of germination of the Scotch broom seed-bank, it would be critical for the site to receive follow-up management probably in the form of herbicide application otherwise an even greater Scotch broom infestation would be created.

❖ Explore the strategy utilized in the native range that inhibits Scotch broom seed germination and seedling survival by slashing Scotch broom stands without cultivation to conserve competing ground flora. This approach however may not be appropriate in the exotic range (e.g. New Zealand) as Scotch broom stands are often so dense and long-lived that there is very little competing vegetation surviving below the canopy to compete with emerging seedlings following stand removal. A slashing strategy may only be appropriate in New Zealand in conjunction with a cover crop to provide a source of competing vegetation.

1.3 Variation in plant morphology at different sites

- What is driving the plant morphology at different sites and does it have any impact on herbicide uptake and efficacy? E.g. Single stem, above-ground multi-stem and below ground multi-stem. From the literature, it is likely plant morphology is influenced by shading and disturbance.
- What is the structure of the Scotch broom population being treated with the pre-plant application? Are the plants all newly germinated seedlings or are there also plants that have re-sprouted following the mechanical site preparation operations?

Management outcomes:

- ❖ Understanding the different Scotch broom growth patterns and Scotch broom population structure at a site may allow us to improve herbicide uptake and efficacy.

2. Competition Relationships

2.1 Impact of intra-specific competition on seedling survival

- Intra-specific competition may need to be explored if a management strategy that stimulated massive seed germination was implemented.
- The impact of the time of germination (seedling cohort) and seed location within the soil profile could be affected by different management practices and could impact on seeding survival.

2.2 Competition between Scotch broom and crop tree

- Is it important to understand how different Scotch broom densities impact on tree growth?
- Previous work has focused on competition between Scotch broom and the crop tree leading to reduced tree growth. Should we be looking closer at how the competition is causing tree mortality, i.e. what resources are limiting?
- What is the relative growth rate of trees and Scotch broom at different sites in New Zealand?
- What is the impact of the time of release operations, both within a season and year since planting, on management regimes?
- Can certain herbicide applications be eliminated from the regime by better timing of other applications?

Management outcomes:

- ❖ As the timing (both within a season and year since planting) of release operations appear to be controlled by when the weed and tree begin to compete, a greater understanding of the relative growth rate of trees and Scotch broom at different sites in New Zealand may indicate when it is critical to intervene and manage the Scotch broom problem.

2.3 Succession

- In some cases, the decision whether to manage Scotch broom or not is influenced by what other weeds are at the site i.e. is there the potential for something of greater or lesser threat to the forestry operation to germinate from the local seed-bank with its removal?
- How does the presence of Scotch broom alter the soil environment? What impact will this have on successive competing vegetation and/or future tree rotations? Will the changes to the soil environment due to the prior presence of Scotch broom have a different impact depending on the plantation tree species planted in the next rotation?
- May need to look at models of secondary succession

Management outcomes:

- ❖ Provide a basis to deciding whether Scotch broom management at a certain time and location is likely to lead to a beneficial or detrimental change in the competing understory community and/or the suitability of the soil environment for future rotations.

3. Herbicide treatments

- Almost all companies were confident that the chemical brews they were using for Scotch broom control worked and they were generally able to explain the cause of any failures, eg. weather, operator error etc.
- However, companies still aimed to reduce chemical use to adhere to FSC and to reduce dollars spent.
- How does the susceptibility of Scotch broom to herbicide change a) during its life span and b) within a season?
- How does the time of herbicide application (within a season and year since planting) affect tree health, form and wood quality?
- What is the impact of plant physiology at the time of herbicide application on the efficacy of application? i.e. what is the impact of the plants physiological state and local weather conditions on efficacy.
- Some indication that lower rates are successful in areas where weeds do not harden off due to high rainfall (i.e. west coast of NZ).

Management outcomes:

- ❖ May provide opportunities to reduce chemical rates or remove an application from the spray regime.
- ❖ Improve efficacy of herbicide applications

4. Other notes of interest

- Foresters have a keen interest in biological control and myco-herbicides as potential Scotch broom control options.
- How and why do different herbicides and rates affect individual trees in different ways, i.e. some trees within a stand suffer from herbicide application more than others.

- Continued interest in alternative site-preparation options; both chemical and mechanical, to reduce weed problems. For example, some forest managers have tried creating mounds that turn the soil 180° upside down and put the seed-bank on the bottom of the pile. This makes it difficult for the Scotch broom seed to germinate.
- Could improvements in hygiene policies significantly reduce seed spread? Would these be operationally viable?
- It was noted that Scotch broom produces alkaloids are potentially toxic to stock and may also influence invertebrate browsers.