SPREAD OF EXOTIC CONIFERS ON SOUTH ISLAND RANGELANDS

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ABSTRACT

A number of exotic conifers have spread from plantations into extensively grazed grasslands and scrublands in the South Island. Pinus contorta, Pinus nigra, Pinus radiata *and* Larix decidua *are the species spreading most vigorously. Their spread, which poses some questions about land use, is related to production and wind dispersal of seed, climatic conditions, vegetation cover and management.*

Management options for wildling stands include wood production, prevention of seedling establishment by pasture management, and control of established wildlings by grazing, fire, and felling.

INTRODUCTION

The use of South Island high country and much hill country has been dominated by extensive grazing management for over a hundred years (O'Connor and Kerr, 1978). During that time many alien plants, including conifers, have been introduced to and become naturalised in these areas.

Many conifers are well adapted to a wide range of New Zealand conditions, as evidenced by the widespread establishment of seedlings from self-sown seeds (see Fig. 1). Successful self-establishment was first noted before the turn of the century (Smith, 1903). More recently, and particularly since the late 1940s, there has been an upsurge of wildling establishment beyond planted stands on unimproved rangelands. Beauchamp (1962), for example, documented the spread of *Pinus ponderosa. P. nigra, Larix decidua* and *Pseudotsuga menziesii* on a number of sites in the Mackenzie Basin. His observations and limited plot measurements indicated that almost all of the trees had established in or subsequent to the late 1940s, some 65 years

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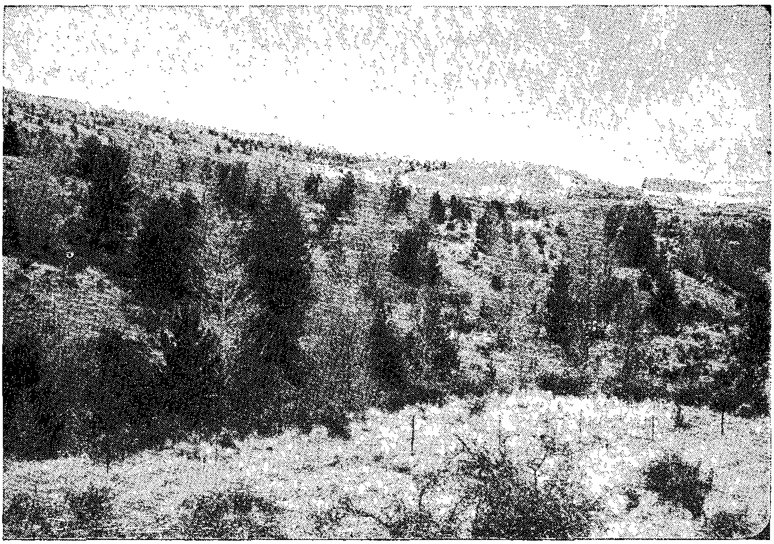

FIG. 1: *Corsican pine* (P. nigra) *and European larch* (Larix decidua) *have spread extensively downwind of parent plantations near Lake Pukaki in the Waitaki Basin. Annual rainfall is 1000-1250 mm. The grassland is unimproved, but, in comparison with many sites of conifer spread, it has an almost-complete canopy.*

after the parent trees were planted. In some areas spread threatens pastoral productivity, scientific and nature conservation, and landscape and amenity values.

SPECIES THAT HAVE SPREAD

Early authors throughout New Zealand recorded the spread of *Cupressus macrocarpa, Pinus radiata, P. pinaster, P. sylvestris* and *P. halepensis* (Smith, 1903; Adams, 1909; Morrison, 1919; Guthrie-Smith, 1921; Thomson, 1922). Watt (1978) noted that the weed potential of *Pinus contorta* had been of concern for at least 20 years.

Table 1 lists present-day occurrences of known major conifer spread in the eastern South Island (Marlborough to Central Southland). Some individual listed records include a number of sites of spread of a species in a locality. This list includes most of the species that have been extensively planted in the region.

C. G. R. Chavasse (*Forest Establishment Report No. 131*, 1979, unpublished report, N.Z. Forest Service) recorded the spread of many exotic trees and woody shrubs, with special reference to their spread into indigenous forest. He included further records of spread of *P. nigra, P. pinaster, P. radiata, P.*

TABLE 1: OBSERVATIONS OF CONIFER SPREAD, EASTERN SOUTH ISLAND

Species	*Reported Occurrences of Spread*
Pinus contorta (lodgepole pine)	13
Pinus halepensis (Aleppo pine)	1
Pinus muricata (muricata pine)	1
Pinus nigra (Corsican pine)	11
Pinus pinaster (maritime pine)	5
Pinus ponderosa (ponderosa pine)	3
Pinus radiata (radiata pine)	12
Pinus sylvestris (Scots pine)	2
Larix decidua (European larch)	16
Pseudotsuga menziesii (Douglas fir)	5
Unstated	4

Source: Records from catchment authorities held on internal files, Water and Soil Division, 1976, 1979.

ponderosa, P. banksiana, L. decidua, Ps. menziesii and *Picea abies* into the grasslands of the eastern South Island. *Larix decidua* and *P. nigra* planted extensively on inland sites, often under legislation introduced in 1857 to encourage the planting of rural lands (Crawford, 1949), have parented the most vigorous and wide ranging invasions in the South Island. *Pinus contorta,* which has caused considerable concern by its spread on the Volcanic Plateau in the North Island, cannot be singled out in the South Island in terms of occurrence of invasion, or the area of land presently affected. However, many plantings of this species are comparatively recent and the situation may change in the future.

SOME CHARACTERISTICS OF WILDLING STANDS

Although most wildling stands cover an area of only several hectares immediately adjacent to the parent stand, on some sites, particularly in exposed situations, trees have colonised large tracts of unimproved rangeland. On the Amuri Range, south-east of Hanmer State Forest in Canterbury, 5000 ha of steep hill country has been invaded by predominantly *P. nigra* wildlings and within this area moderate to high densities of conifers covered 960 ha (Dick, 1976). The extent of the invasion is related to the "cross-wind" width of the seed source and the force of the north-westerly wind as a seed dispersal agent. Further downwind spread has been limited by the improved grasslands of the Waiau

Valley. In the Rakaia Valley, a 10 km long band of predominantly *P. nigra* wildlings has invaded 1500 ha of extensively grazed tussock grasslands south-east of homestead plantings. Trees are scattered throughout the site, but in localised areas they reach high density.

In some areas of the South Island, dense thickets of even-aged seedlings or saplings suggest an infrequent combination of favourable conditions for seed production, dispersal and seedling establishment. On other sites, mixed aged stands, often of widely spaced plants, suggest more frequent conditions favouring seedling establishment.

Sanson (1978) described the interaction of long-distance primary invasion and short-distance secondary establishment of *P. pinaster* spreading into manuka/kanuka scrubland in Abel Tasman National Park. His "outliers" were scattered small colonies of pines, the oldest tree of each being a product of long-range seed dispersal. Each outlier has since parented a cluster of wildlings, with an age gap between parent and oldest progeny of 12-16 years. By this process, tree density throughout the area invaded is likely to increase. We have observed this pattern of spread with other conifers on a range of sites.

FACTORS INFLUENCING SEEDLING ESTABLISHMENT

Climate

Climate has an important influence on conifer flowering, seed set and development, dispersal and germination of seed, and plant establishment (Krugman *et al.*, 1974). Many conifers thrive in a broad range of climates. For example, *P. ponderosa* has self-established prolifically in a 400-600 mm annual rainfall environment in Central Otago (Douglas, 1970), yet it is also sparsely naturalised under a 4000 mm annual rainfall in the Hooker Valley near Mount Cook (Wilson, 1976).

In general, self-sown seedlings may establish in climates to which planted trees of the same species are well adapted, although extreme weather events, particularly frost and drought, will influence the survival of seedlings. Climatic conditions in the lowland and montane altitude zones, below approximately 950 m in the central South Island, are generally favourable for conifer establishment. However, *P. radiata,* a species not well adapted to heavy frosts and snow, is not widespread as a planted or naturalised pine above 700 m. Although climatic conditions in the subalpine and alpine zones above approximately 950 m limit seedling success, *P. contorta* has naturalised at an altitude ing poor seed years, and vice versa, may obscure any seeding cycle. However, the seed of *Pinus* spp. that have spread in the South Island remain viable for at least 7 to 20 years in cool storage (Krugman and Jenkinson, 1974). In a field situation, despite a possibly reduced viability period, and the taking of some seed by birds and small animals, seedlings may be able to establish in significant quantities some years after release.

Seed Dispersal

Wind is the main dispersal vector in the South Island, where seed dispersal distances of several kilometres are common. For example, *P. contorta* wildlings dispersed from Mid Dome plantations in Southland indicate that in most years seedlings establish 4.5 km, and in some years 8 km, downwind from the source (P. D. Chapman, pers. comm.). In Oregon, Gashwiler (1969) found that under normal wind conditions nearly all *Ps. menziesii* seed

Seed Source

Seeding periodicity and seed production influence colonisation. The rate of regeneration is related to the age of first seeding (Table 2). It is well known, for example, that the early age of coning in *P. contorta* enables the species to colonise rapidly (J. D. Hayward and C. J. Wishart, *A Decade of Revegetation Work in Leatham State Forest, Nelson Conservancy,* 1975, unpublished report, N.Z. Forest Service) whereas Weston (1957) noted that the age of coning in *P. ponderosa,* a species that has spread less vigorously, ranges from 20 to 40 years. Trees in open stands, such as some wildling stands, may yield seed at a younger age than those in a closed plantation. Seeding is often erratic and, as Slow (1954) pointed out, peak regeneration years may not follow peak seed years. Good conditions for germination follow-of 1220 m in the Waimakariri Catchment in Canterbury and at Mid Dome in Southland. As far as we are aware, no other species have spread in the subalpine or alpine zones.

Beauchamp (1962) suggested a relationship between the spread of conifers in the Mackenzie Basin in the late 1940s and early 1950s and climate change. Analysis of New Zealand temperature records shows a long-term rise that accelerated from about 1950 (Goulter and Hurnard, 1979). The period from 1950 to 1969, the "green years" of agriculture, provided relatively stable weather conditions, above-average temperatures and favourable precipitation (Salinger, 1979). We can only surmise that this factor may have influenced conifer spread.

TABLE 2: SEED CHARACTERISTICS OF SELECTED CONIFERS

Species	Early Age of Viable Seed Production (yr)	Seed Weight* (seeds/gram)	Comments
L. decidua	11-18	138	Some coning age 6-7 and moderately heavy coning sometimes at age 8. Heavy crop rare but light seeding most years.
Ps. menziesii	18-20	96	Some coning 10 years. One good crop and two to four light crops in 5-7 years. Seed dispersed over short periods.
P. contorta	5-13	200	Serotinous cones may delay seed release 3-4 years. Fair annual seed crops with abundant crops at irregular intervals.
P. nigra (*P. laricio*)	13-21	66	Some coning 8-10 years. Light annual seed crops with heavier crops at 3-8 year intervals. Total seed crop often shed within a week.
P. nigra var. *austriaca*	25-30		
P. pinaster	10-12	28	Some seeding after 5 years. Good seed crops most years, but a proportion of "closed" cones can result in build-up of large seed reservoir.
P. ponderosa	18-24	33	Cone production varies according to provenance.
P. radiata	9-12	36	Moderate seed crop each year, but semi-closed cones open and close depending on atmospheric conditions to regulate seed release.

*NZFS data.
Source: Allsop, 1951; Weston, 1957.

landed within 130 m of the parent stand, but Slow (1954) and Isaac (1940) determined that dispersal of seed of that species was influenced by tree height and prevailing wind conditions. Isaac recorded that seed released from a tree in a 37 km/h wind travelled nearly 1 km. In South Island areas favourable to the establishment of *Ps. menziesii*, evidence can be found of both gliding seed fall resulting in high seedling densities adjacent to parent stands, and widely scattered trees some distance downwind of the parent trees resulting from wind dispersal.

Throughout most of the South Island where conifer spread has occurred, wind gusts reaching or exceeding 63 km/h occur on more than 50 days each year (Tomlinson, 1976) with extreme gusts exceeding 150 km/h (N.Z. Meteorological Service, 1975). These high velocity winds are predominantly north-westerlies which often provide drying conditions necessary for cone opening in *P. radiata, P. pinaster* and some strains of *P. contorta* (Weston, 1957). The marked dispersal of wildlings of many conifers south-east of parent plantings is evidence of the influence of the "nor'-wester".

Seed morphology, including wing dimensions, and weight and size of seed will influence dispersal distance. The seed weight of some conifers is listed in Table 2. It appears significant that *P. contorta,* which is noted for long distance dispersal, has the lightest seed and that *P. pinaster* and *P. ponderosa,* which generally have not spread long distances in a single generation, have the heaviest seed.

Wardrop (*Forest Management Report 1,* 1964 unpublished report, N.Z. Forest Service) noted that the age structure of *P. contorta* spreading eastward from Karioi Forest on the Volcanic Plateau indicated a pattern of dispersal resulting from a single major seedfall about 1951-53, in which seed was carried up to 8 km. Over the following decade, increasing density rather than further spread had occurred. However, by 1975, "infrequent" to "dense" infestations covered 29 700 ha (Hogg and Garrett, 1975) compared with an estimated 10 900 ha in 1963.

Sanson (1978) found that, for *P. pinaster* spread, the age of wildling trees decreased stepwise with increasing distance from the original seed source. Seed dispersal distance was in the order of 100 m and the gaps in age classes tended to agree with the time required for the species to produce viable seed. He calculated an average rate of spread for short-range dispersal into open manuka/kanuka scrubland of 9.1 m per year. Morrison (1919) reported the spread of *P. radiata, P. pinaster, L. decidua* and *P. sylvestris* on the Hanmer Plain area in North Canterbury. Distances of spread for *P. radiata* and *P. pinaster* were similar to those measured by Sanson (1978). Beauchamp (1962) estimated rates of spread of *L. decidua* and *P. nigra* in the Mackenzie Basin of 400 m over a 12-15 year seeding cycle, and predicted a greater rate of spread based on scattered, long distance dispersed outliers.

Other agents may also disperse conifer seed. Guthrie-Smith (1921) suggested sheep could carry seeds lodged in their fleeces.

Thomson (1922), reporting Maxwell, noted that many introduced birds fed on conifer seeds and that they may act as a seed dispersal agent. However, we assume that relatively few seeds would be expelled intact. These modes of dispersal may explain the distribution of many scattered, individual conifers.

Vegetation and Ground Cover

All species, but to a lesser extent *Ps. menziesii,* are "colonisers", establishing most readily in conditions of low competition for light and water, in which they can make fast early growth to overtop surrounding vegetation. Seedling establishment is more prolific in short, open grassland and open scrubland than in tall, closed canopy grassland, scrubland or forest.

Smith (1957) related the vigorous spread of *L. decidua* at Hanmer, Naseby, Tapanui and Queenstown to bare soil (including mining tailings), erosion scars and vegetation depleted by rabbits, and that of *P. contorta* to disturbed grassland. Near Mid Dome in Southland, *P. contorta* has spread more successfully on bare but relatively stable broken rock covered sites than on areas of bare subsoil or well vegetated sites (F. M. Sutherland, pers. comm.). Sanson (1978) related *P. pinaster* establishment in Abel Tasman National Park to open manuka/kanuka scrubland, and recorded poor seedling success in closed canopy scrubland and in forest communities. C. G. R. Chavasse (*Forest Establishment Report No. 131*, 1979, unpublished report, N.Z. Forest Service), noted that, with few exceptions, exotic forest trees had invaded native forest only where it had been severely modified in some way, for example, by grazing, burning, logging, tracking or erosion.

Examining *P. contorta* spread in grassland, Benecke (1967) found that all seedlings planted in improved, ungrazed grassland plots failed within 18 months, and in direct seeding trials, seedlings failed to appear. On unimproved, ungrazed grassland, however, seedling survival rates were high and plants established well from seed. He concluded that unimproved grassland provides a low competition nurse crop favouring seedling success, whereas the competitive stresses in improved grassland, such as oversown and topdressed tussock grassland, markedly reduce seedling success.

Above about 950 m asl seedling establishment on poorly vegetated, eroded soils is poor. This is related to a harsh microclimate, with frost heave and desiccation in the absence of a modifying nurse crop (Wendelken, 1956) and to low fertility soils.

Land Management

Although records of conifer spread extend back to before the turn of the century, there has been a comparatively recent increase in spread by several species (Benecke, 1967). This dates from the late 1940s and early 1950s and Benecke had little doubt that the earlier restriction of spread was a question of grazing pressure.

There has been a gradual decline in sheep numbers on the unimproved high country since the 1880s and O'Connor (1980) noted that, for Vincent and Lake Counties in Otago, the apparent carrying capacity by 1951 was only 10% of what it had been in 1881. He noted that during this period the rangeland suffered severe overstocking and depletion, which persisted until the rabbit plague was overcome in the 1950s (O'Connor and Kerr, 1978). It is significant that the stock numbers reached an all time low during the 1950s, and it appears probable that, after rabbit control, grazing pressure was below a level providing effective conifer seedling control. Benecke (1967) suggested that rabbit control had been a key factor in the spread of conifer seedlings. The dramatic population reduction of the rabbit (*Oryctolagus cuniculus*) throughout the South Island dates from the inception of the killer policy in 1947. Many woody weeds spread in response to the reduced rabbit populations and, for example, the prolific spread of sweet brier throughout many short tussock grasslands (Molloy, 1964) appears to parallel that of conifers. However, Beauchamp (1962) reasoned that neither the control of rabbits nor the level of farm stock grazing were the main factors influencing tree spread. He found that conifers on Motu Ariki Island in Lake Tekapo, a site that had never held rabbits, and apparently no sheep since about 1920, had spread in the same fashion, and at the same time, as trees elsewhere in the Mackenzie Basin.

Restrictions placed by catchment authorities on burning of grasslands since 1945 (McCaskill, 1973) may have reduced the degree of conifer control by fire. An increase in seed production as planted trees matured may also have contributed to increased seedling establishment in the 1950s.

IMPLICATIONS OF CONIFER SPREAD FOR LAND USE

The areas most susceptible to invasion by conifers are the unimproved grassland and open scrublands of the lowland, montane and, in the case of *P. contorta*, the subalpine zones. Indigenous trees are ill-adapted to present-day conditions in much of the eastern South Island, although much of the rangeland is still an environment able to support trees such as exotic conifers (Wardle, 1963). Spread from existing and proposed plantings on to these lands can affect production, erosion control, and scientific, nature conservation and landscape values. O'Connor (1981) suggested that, because of the success of conifers in unimproved grasslands, how the choice is made between forests and improved pastures, and how that choice is averted according to interests of the conservation of New Zealand nature, are the principle landscape planning issues of the tussock grasslands and mountain lands for the next twenty years.

Production

Joyce (1978) noted that the unimproved grasslands of the South Island have been used for relatively inefficient extensive grazing. Tree invasion on to unimproved grazing land may stimulate land occupiers to pursue a more productive form of land use. Where there are no constraints to management, controlled grazing on improved grassland or a grazing-forestry or forestry only enterprise should increase production.

Morrison (1919) proposed using spontaneous reproduction of exotic trees for production forestry. Although wildling stands often have uneven age and spacing compared with a planted forest, and tree form is variable, where access is good and harvesting practicable, this may offer a viable proposition. Management options could include use of the crop "as is" for energy production or for roundwood, or upgrading of the stand to a required merchantable quality. Selection of seed of good provenance for planted stands that may later spread may be a key factor in increasing management options for any future wildling stands.

Erosion Control

Conifers have been planted on a number of sites, particularly on sparsely vegetated, eroded subalpine and montane lands for soil conservation purposes: to reduce flood runoff and stream sediment yields, to stabilise slopes and to control on-site soil loss by the establishment of a vegetation and litter cover.

In a symposium discussion, Holloway questioned the suitability of *P. contorta* for erosion control at Mid Dome (N.Z. Forest Service, 1967). At that time there was little evidence of litter build-up on the bare ground under the pine canopy (first plantings made in 1949-50) and erosion was continuing. More recently, however, A. H. Nordmeyer (pers. comm.) noted considerable litter accumulation under the pine canopy at Mid Dome. The longer term effects of pines on the site are unknown, but we note that, because of run-holder pressure, wildlings spreading on to adjacent grasslands have been manually cleared.

Pinus contorta has been planted for erosion control in Leatham State Forest in Marlborough. The condition of the catchments was of considerable concern and remedial treatment was considered to be of high priority. The revegetation programme planned to capitalise on the success of the species on harsh sites, and on the early production of easily disseminated seed, which in turn would lead to colonisation of untreated eroded sites (J. D. Hayward and C. J. Wishart, *A Decade of Revegetation Work in Leatham State Forest, Nelson Conservancy,* 1975, unpublished report, N.Z. Forest Service). However, there is concern that, despite physical barriers, trees may spread on to adjacent uneroded sites beyond the project area, where they are not wanted (Simpson, 1980).

Recognising the problem of spread, the Soil Conservation and Rivers Control Council in 1977 adopted a policy for the use of *P. contorta* by catchment authorities. The Council placed no general restriction on its use for erosion control purposes, but the policy recommended that it not be planted where satisfactory alternative species are available or where its spread is likely to affect adjacent land, unless its planting can otherwise be justified. Although there is widespread acceptance of the role of tree establishment for soil and water conservation purposes, we found a lack of quantitative evidence to demonstrate that tree establishment has any advantage, or otherwise, over grassland enhancement in meeting erosion control objectives in the South Island mountain lands.

The authors of the *Review of Mountainland Revegetation* (N.Z. Forest Service Report, 1982, unpublished) evaluated the need for active mountain land revegetation based on condition and trend vegetation survey data. They suggested that, in areas with an annual rainfall above 2000 mm, revegetation will not generally be necessary. However, mountain land areas with an annual rainfall below 2000 mm may require active revegetation on presently eroded land to avoid further deterioration of on-site soil and vegetation resources. They also noted that objectives of maintaining or improving the on-site soil resource and productivity have tended to replace the objectives of protection from flooding and prevention or reduction of supply of coarse debris to major rivers, which had motivated the mountain land revegetation efforts up to the mid-1970s.

Because of the implications of spread, the need for, the practicality of and the expected benefits from exotic tree establishment for erosion control should be investigated, even in low rainfall terrain. We note that studies of the effects of trees planted on a number of sites since the 1950s, particularly in terms of soil stability, soil development and catchment responses, could be undertaken to obtain the quantitative data so far lacking to clarify some of these issues.

Scientific and Nature Conservation Values

Wardle (1978) considered that "there is a clear obligation to protect the native plants, animals and natural communities of the New Zealand high country for their intrinsic worth, for our own enjoyment and for the world at large". There is concern that in specific instances conifer invasion may threaten important indigenous ecosystems. For example, Molloy and Simpson (1980) observed that aggressive exotic plants, such as broom, wattles, eucalypts, as well as pines, are encroaching on to *Pachystegia* habitats in Marlborough.

Landscape and Amenity Values

The presence of pines in the high country is an affront to many people (Simpson, 1980), yet exotic grasses, herbs and shrubs that are much more firmly established in the tussock grasslands appear to be of less concern. Many wildling stands do not bear the harsh outline and uniformity of planted stands and they can enhance landscape and recreation values. We believe, for example, the planted and wildling stands of *P. nigra, P. contorta* and *L. decidua* adjacent to Lake Tekapo are a haven from the might of the Mackenzie Basin "nor'-wester", and thus enhance recreation values, and arguably the landscape.

CONTROL OF CONIFER SPREAD

Means of control of unwanted conifers which have met with varying success include grazing, fire, felling and chemicals. With most methods, follow-up treatment to control subsequent regrowth and regeneration is required.

Grazing

Benecke (1967) showed that in unimproved grassland *P. contorta* seedling survival was clearly influenced by grazing pressure. In an ungrazed plot the seedling survival rate was 94% after 27 months. Where subjected to a grazing pressure of 0.6 sheep/

ha or greater in a controlled grazing plot situation, seedling survival was reduced to 20% over the same period and the health of a high percentage of surviving seedlings was poor. He recorded similar results in a free-range grazing situation (0.6-1.2 sheep/ha).

The Cockayne plots at Cromwell provide further evidence of control of conifers by grazing (Douglas, 1970) (Table 3). In 1920, *P. ponderosa, P. nigra,* and *P. radiata* were planted in fenced enclosures. Although it is likely that some trees had been producing seed for many years before 1954, seedling success, with the exception of those on plot 10, was low between 1930 and 1956 when the plots were open to grazing. After re-fencing in 1956, seedling success increased markedly in the plots. Douglas noted that the only seedlings able to survive outside the plots were those restricted to rock crevices out of the reach of browsing animals (See Fig. 2). However, it is interesting to note the high numbers of seedlings in and adjacent to plots 9 and 10, which had not been excluded from grazing for some years, in 1984. An assessment of the age structure of these conifers may help to clarify trends in tree establishment.

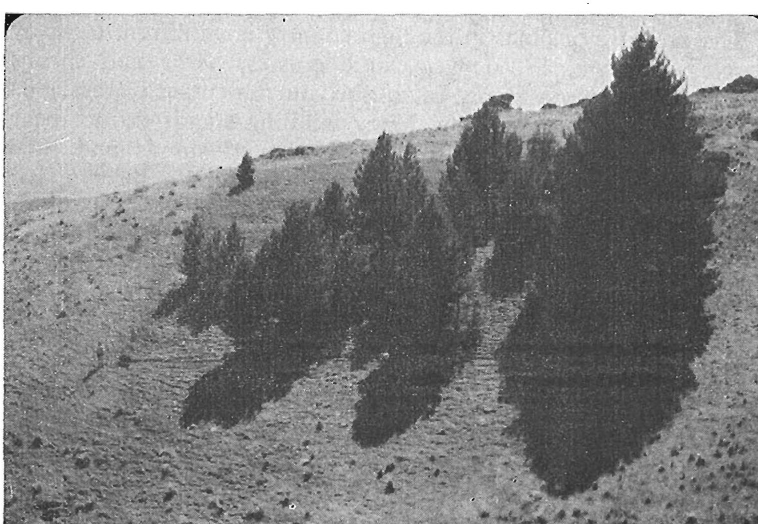

FIG. 2: *In 1984, 54 wildling trees and seedlings of* P. nigra *were counted inside Cockayne Plot 11, in a semi-arid environment in Central Otago. Only 1 seedling was counted outside the exclosure fence. See Table 3 in this paper for further details of the Cockayne Plots, and Douglas (1970) for photographs of plot 11 taken in 1949 and 1967 (B. J. Wills photo).*

TABLE 3: *PINUS* SEEDLING ESTABLISHMENT ON THE COCKAYNE PLOTS, CROMWELL

Plot	*Alt. (m)*	*Aspect*	*Species*	*No. of Planted Trees Counted* 1967	*Total No. of Wildlings inside each Plot, by year* 1954	1956	1963	1967	1984	
5	460	NW	*P. ponderosa*, *P. nigra*	3	2	4	20	21	24	
6	520	S	*P. radiata*, *P. nigra*	2			1	2	1	
8	610	N	*P. radiata*, *P. nigra*	2			19	26	60	(20*)
9	610	S	*P. ponderosa*, *P. nigra*	6	1		6	12	17	(464*)
10	700	N&S	*P. ponderosa*	4	9	25	80	165	236	(178*)
11	750	S	*P. nigra*	2		1	17	25	54	(1*)

*Conservative counts of wildlings outside of but adjacent to the plots. The source of some wildlings outside plots 9 and 10 is unclear. Inside plots 1, 3, 3A (established 1948) and 13, at altitudes ranging from 320 to 365 m asl, 3, 2, 2 and 14 conifers, probably *P. radiata*, respectively, including the original planted trees, were counted in 1984. A small number of seedlings were observed outside plots 3 and 13. No results for these plots were presented by Douglas (1970).

Plot management: Trees planted 1920-21. Plots ungrazed, then opened for full grazing 1930-35. In 1936 the plots were refenced to keep out sheep, rabbits and hares, but opened each winter on a controlled sheep grazing basis. In 1956 the plots were fully refenced to exclude all stock, but by 1967 deterioration in the fencing had allowed some grazing by rabbits and hares. In 1984, the fences on plots 5 and 8 were sheep-proof but rabbits and hares were not excluded. Fences on other plots permitted access by sheep.

Sources: Douglas, 1970; B. J. Wills, pers. comm.

However, control of trees on extensively grazed rangelands is not a simple case of stocking rate, since the grazing intensity throughout the rangeland may vary widely. O'Connor (1978) noted that grazing follows seasonally available pasturage and dispersed grazing tends to be selective. Therefore, grazing patterns may not coincide with seedling establishment areas.

Although there is abundant evidence that grazing animals eat many conifer seedlings, sometimes preferentially, our own field observations and those of Beauchamp (1962) indicated that *P. nigra* seedlings are infrequently browsed. Intensive stock management, such as mob stocking, may be necessary to control conifer seedlings in some situations, such as a mass seedling establishment following a heavy seedfall. It it important to graze the seedlings while still small if palatability decreases as they grow. Goats, with their preferences for a high-fibre diet, may assist with conifer control, as has been the case with other woody weeds (Radcliffe, 1984).

Much land, especially the tussock grasslands in low rainfall districts, or at mid or high altitudes, or sites of very low fertility soils may be incapable of sustaining the grazing pressures required to effect conifer control (O'Connor, 1981).

Fire

Variables of terrain, fuel density and weather mean that control by fire is rarely as complete as could be desired. In addition, some conifers are highly adapted to recolonisation after fire. Closed cones in *P. radiata, P. pinaster* and *P. contorta* can be induced to open by the drying heat of a fire, releasing a cast seed supply. Fenton (1951) discussed the natural regeneration following fire in a 14- to 18-year-old stand of *P. radiata* and *P. pinaster* north of Taupo. Three years after the fire he recorded seedling densities of over 1 million per hectare in and adjacent to the burned stand. In Canterbury, seed densities of over 1 million per hectare were recorded underneath a burned *P. radiata* canopy after the Balmoral Forest fire (Riney and Batcheler, 1959). In spring 1978, short tussock grassland hill country on the Amuri Range, Canterbury, was burnt to control spreading conifers, chiefly *P. nigra.* Before the fire, North Canterbury Catchment Board staff counted 191 conifers on a 20×20 m plot, ranging from seedlings to saplings 1-2 m high, and including a single seed-bearing tree. During the burn, all but 3 conifers were incinerated. No new seedlings were found in the regenerating grassland in the first year after the fire, but in successive years from December 1980 to 1983, 34, 57, 96 and 335 seedlings and small plants were counted (D. C. Wethey, pers. comm.). On a second plot which had reverted to bracken after the fire, no emergent conifers had been observed. The site has been set-stocked for most of the period since the fire. The 460 ha block carried 400 merino wethers until December 1980 and then 80 heifers, with no sheep, in 1981. In 1982 it carried 115 cows, and no sheep, from April to November only, and 90 cows from July to August only in 1983. No specific follow-up control of conifers has been attempted on the plot. However, elsewhere on the Amuri Range, fire followed by pasture improvement and close stock control appears to be controlling unwanted conifer regeneration.

Fire following crushing has in many instances given effective control of *P. contorta* on the Waiouru Military Reserve in the North Island, with little subsequent regeneration (Hogg and Garrett, 1975). Without previous crushing and drying and intense heat, burns gave poor control with widespread seed germination and regrowth. Many areas which had simply been burned required follow-up control of regrowth by cutting or slashing.

Soil erosion hazards may in some situations limit control by fire.

Felling

On drying, felled cone-bearing trees often release viable seed. Hand or rotary slashing of *P. contorta* on the Volcanic Plateau was frequently followed by regrowth from uncut lower branches (Davenhill and Preest, 1974) but Hogg and Garrett (1975) and J. W. Garrett (pers. comm.) noted that effective control of young trees by rotary or hand slashing could be achieved. On the Volcanic Plateau, hand cutting and pulling was employed on class VIII land, on land with poor vehicle access, or where burning was undesirable, and on areas of scattered trees.

Chemicals

Davenhill and Preest (1974) reported mixed success with "total kill" herbicides applied tree by tree to *P. contorta*. Use is only likely to be economically justifiable in the case of smaller, widely scattered trees. Broadcast application of herbicides able to destroy infestations of young trees is likely to result in the elimination of all vegetation for some years (D. S. Preest, pers. comm.) and for that reason use cannot be justified. From chemical trials carried out on the Volcanic Plateau it was concluded that, with the present state of knowledge, chemical control was not suitable for widespread use (Hogg and Garrett, 1975; J. W. Garrett, pers. comm.). We believe that further efforts could be made to select or develop chemicals suitable for conifer control.

CONCLUSION

The colonisation of low producing, unimproved grassland and scrubland in the South Island by exotic conifer species indicates that conifers are well adapted to this environment. These sites are clearly able to support a forest, and production forestry may often be a land use option. Where this is not desirable, rangeland improvement and enhanced grazing control will usually provide adequate conifer seedling control. However, there may be many situations where both these options are impracticable or undesirable. Any conifer plantings on, or adjacent to, extensively managed grasslands may spread and the consequences of this tree establishment for production, and scientific, nature conservation, and landscape and amenity values should be carefully considered.

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