FIRST-YEAR LOSSES OF *PINUS MUGO* SEED AND SEEDLINGS ON AN EXPOSED HIGH-COUNTRY SUBSOIL

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ABSTRACT

Major first-year seed and seedling losses resulting from the direct sowing of pine seed on to an exposed subsoil at 850 m altitude were attributed to birds (100% in unprotected plots), failure of emerging radicle to penetrate the subsoil (15%), insect attack (15%), and frost heave (44%). Losses of lesser significance were caused by mice.

Techniques for minimising losses are discussed. Coating seeds with repellents and fungicides could reduce losses due to birds and fungi, but effective repellents for mice and insects are not yet available.

By sowing earlier in the winter, seed burial should be more complete by spring. This would decrease losses to birds and assist the seedling radicle to penetrate the soil.

Cover is essential to protect seedlings from frost heave. The most practical way of providing cover is by sowing a sward of grasses and legumes.

INTRODUCTION

In addition to its role in re-establishing production forests (Jackson, 1975), the direct sowing of woody species has also been recognised as a possible cheap and practical method for revegetating eroded mountain lands (New Zealand references include Faulkner *et al.*, 1972; Hayward and Wishart, 1975; Slow, 1970). Ledgard (1976) has discussed the initial research in this field in the South Island high country where three main stages in the establishment of seedlings were recognised: germination, establishment during the first growing season, and survival thereafter, particularly during the first winter. On eroded sites survivals rarely exceeded 1%.

Major seed losses in the field due to a variety of small mammals, birds and insects have been studied by a number of workers (Hedderwick, 1967, 1969; Jackson, 1975; Lawrence and Rediske, 1962; Radvanyi, 1966, 1974). In these studies, destruction of seed by birds and small mammals (particularly rodents) has been the main cause of loss, although regular use of the bird repellent Arasan 42S since the 1950s seems to have effectively reduced the bird hazard (Jackson, 1975).

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On bare subsoil sites, common in the high country, seedlings usually do not survive through to their second spring (Ledgard, 1976). Frost heave during the first winter and subsequent desiccation of the seedling is recognised as a major cause of loss. Frost heaving (*or frost lifting*) results from the successive freezing at or just below the soil surface of moisture drawn upwards by capillary action. The severity of a heave depends primarily upon the amount of water available and the nature of the temperature fluctuations around 0°C (Graber, 1971). The fine-textured high-country subsoils are particularly susceptible to frost heaving when exposed.

This paper outlines a trial in which *Pinus mugo* seeds, sown directly on to an exposed subsoil, were observed regularly from spring, through summer and into mid-winter. The work was conducted in the Craigieburn Range, North Canterbury, an area which typifies the eroded mountain lands of the South Island. The dominant climatic patterns and geography of the region are described by Morris (1965).

The trial described here is treated more fully in the unpublished report of Ledgard (1978).

METHODS

The plot sites chosen were small exposed subsoil areas situated on a relatively flat terrace at 850 m altitude in the Broken River basin, North Canterbury. Surrounding and partly sheltering these bare areas was a grazed indigenous and exotic grass sward, dominated by hard tussock (*Festuca novae-zelandiae*), *silver tussock* (*Poa laevis*), and browntop (*Agrostis tenuis*), through which was growing a scattered scrub cover of 1 to 1.5 m high *Cassinia vauvilliersii* and matagouri (*Discaria toumatou*). The plots were flat, smooth, and relatively uniform. A few small rock fragments were visible on the surface.

The following three types of plot (Fig. 1), each 50 cm^2 in area, were established:

(1) Control: Completely open.

(2) Mouseproof: These were surrounded by a circular, 15 cm high, green, tin wall with small (5 mm diameter) drainage holes around the base.

(3) Birdproof: These were enclosed by a wire cage covered in bird netting, but were still accessible to mice.

Each plot was replicated 10 times.

The ringed mouseproof plots were soon found to give protection against birds as well. This type of exclosure also prevented seed from being windblown out of the plot, although rain did cause the accumulation of seed at the plot

FIG. 1: *The mouseproof (right) and birdproof (left) plots pictured on the trial area.*

margins, where some burial then occurred. Seed was wind-blown from the other two plots, and hence an accurate tally of seed losses was hard to keep. For these reasons, results have been calculated from the ringed mouseproof plots only.

In spring (4 October), 50 unstratified *Pinus mugo* seeds were placed into each plot. The seed (FRES 74/177) originated from a stand in the Craigieburn Range, had a laboratory germination of over 90%, and numbered 130 seeds/g. In order to aid relocation the seed was sown in 5 rows of 10, with small stones to mark the ends of each row. Although frost, wind, and rain readily moved the seeds, all except those which were either buried or blown out of the plots were relocated during the observations.

Initially, observations were made daily. After 8 to 10 weeks, when seedlings appeared established, observations were reduced to approximately once a fortnight. The trial was terminated at the end of July when frost heave had killed the majority of surviving seedlings.

Climate data were obtained from the nearby Craigieburn Forest weather station situated about 1 km away at a similar altitude.

Pinus mugo seeds are 3 to 4 mm long, and only practice made them readily discernible on the soil surface. For this reason the number of observers was kept to a minimum. The author and one other made 85% of the observations.

RESULTS

The major factors affecting seed and seedling survival from October 1976 to July 1977 are shown in Table 1 and Fig. 2.

Open Plots

Within a day of sowing, 10% of the seed had disappeared. After 7 days only 2 seeds of the original 500 sown could be located.

Birds were considered the main cause of loss. Fragments of seed crushed in the characteristic manner (Lawrence and Rediske, 1962) were found daily within and around the plots. Some seed was without doubt buried, but subsequent observations suggested that this seed was soon located by birds as no eventual germination was ever recorded.

Most damage from birds seemed to occur in the early mornings. At this time of day several birds capable of destroying seed were noted in the vicinity of the plots. Of these the commonest and most probable seed eaters were chaffinches, redpolls, yellow-hammers, greenfinches, and goldfinches. The open nature of the country made it difficult to observe the birds actually eating the seed, despite the fact that they were often seen on the ground and in the scrub in the immediate vicinity.

Enclosed Plots

From the pattern illustrated in Fig. 2, three main stages can be recognised: seed burial and germination (to mid-November), seedling establishment (to the end of April), and

TABLE 1: THE MAJOR FACTORS AFFECTING SURVIVAL OF SEED AND SEEDLINGS ON EXPOSED SUBSOIL AT 850 m ALTITUDE

Factors Affecting Seed and Seedling Numbers	*Percentage of Seed and Seedlings affected* — *Protected Plots*	*Unprotected Plots*
Birds (seed)	0	100 (loss)
Burial (seed)	30 (loss)	—
Insects (seed)	4 (loss)	—
Desiccation of seedlings during early establishment	15 (loss)	—
Emergence of seedlings from buried seed	10 (gain)	—
Insect clippings (seedlings)	15 (loss)	—
Frost heave (seedlings)	44 (loss)	—
Total loss (%)	98 after 300 days	100 after 7 days

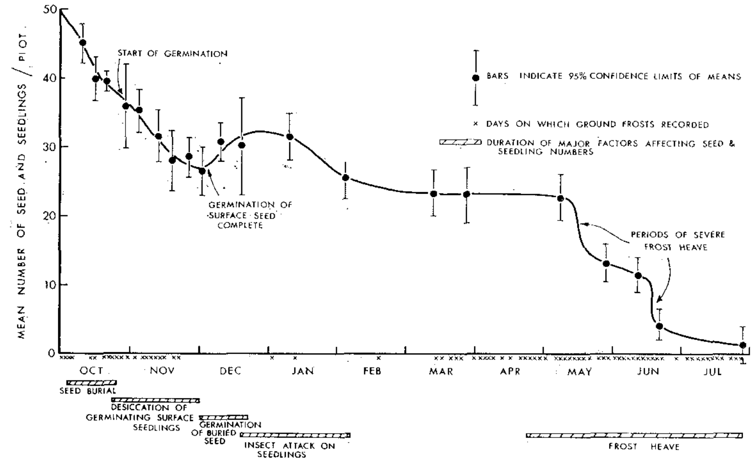

FIG. 2: *Losses of* Pinus mugo *seed and seedlings on bare subsoil at 850 m in plots protected from birds and mice.*

seedling survival over winter (from May to July). The characteristics of, and the losses occurring within, each of these stages are described below.

1. *Seed burial and germination*: During this first stage seed numbers declined continuously, mainly through the action of wind, rain, and frost heave which caused a number of seeds to become buried.

By the end of October (4 weeks after sowing), approximately 150 seeds (30%) were missing and presumed buried (as suggested by later emergence), while 18 (3.6%) were found to have been attacked by chewing insects. Wetas (in this case *Hemideina maori*) appeared responsible for damaging the majority of these seeds, their pattern of damage being characterised by the obvious crushing of up to two-thirds of the seed.

In the plots caged to prevent bird entry, insects and mice had freer access, but damage to sound ungerminated seed was not common and occurred to a significant level in only one plot. During one night (27 October 1976, when 1 cm of snow fell), all 34 seeds in this plot were eaten. The scale and type of damage indicated mice to be responsible (E. B. Spurr, pers. comm.). This was the only seed damage attributable to mice.

Rain fell regularly in the initial weeks of the trial and there was adequate moisture for germination. Observations of seed on the soil surface indicated that field germination differed little from the laboratory figure of over 90%.

2. *Seedling establishment*: From early November until early December nearly all undamaged surface seeds (approximately 70% of total seeds sown) were observed to germinate.

Observations at this time showed that emerging radicles had considerable difficulty in penetrating the soil surface. Even after successful initial penetration, frost heave and wind-blown rain were very effective in exposing radicles inserted up to 1 cm into the subsoil. Table 1 shows 15% of seedlings died because of desiccation promoted by this cause.

By mid-December approximately 60% of the seed sown had become established as seedlings. In the 2 to 3 weeks prior to this, recently germinated seedlings were observed emerging from the ground, presumably from seed buried in the first weeks of the trial. It was these seedlings which contributed to the small rise of approximately 10% in seedling numbers illustrated in Fig. 2.

Damage to established seedlings was confined to the period from mid-December to the end of January. The seedlings involved were mostly those which had emerged during the first half of December from the seed buried early in the trial. These delicate seedlings had their stems broken or clipped either at the root collar (the majority) or just below the needle collar. Twenty-four severed shoots were found in the plots during two observations made on 2 January and 1 February. A close inspection of the stem area around the break indicated that insects were most likely to blame. At this time the green manuka beetle (*Pyronota festiva*) was in flight and several were found in and around the plots. As the beetle is capable of this type of damage (Miller, 1971), and as the damage ceased at the same time as the beetle disappeared, it seems likely that *P. festiva* was involved with the clipping of seedlings during December-January.

3. *Seedling survival over winter*: By the end of April, 44% of the original seed sown approximately 7 months previously was present in seedling form. From this time on, frosts were occurring and were responsible for all further seedling mortality.

By the end of June, after two particularly severe periods of frost heave in mid-May and mid-June, an overall total of only 46 seedlings remained. At the last count on 27 July this figure was down to 14, *i.e.*, 2.3% of total seed sown. Of these, 10 were growing near the plot perimeter and appeared to be slightly protected from frost by the surrounding tin wall.

In the less protected caged plots only one seedling could be found. In the area of the trial, frost heave was still occurring regularly.

DISCUSSION

Past attempts at direct seeding of woody plants on to eroded high-country soils have met with limited success. Ledgard (1974) described a trial involving the direct seeding of *Alnus viridis, Pinus contorta,* and *P. mugo* on to depleted high-country sites, in which survivals of 0.03, 0.5, and 0.4%, respectively, of the seed sown were recorded after 2 years. It is likely that the main reasons for the low success rate were similar to those outlined in this trial, *i.e.*, destruction of seed before germination, failure of the seedlings' radicles to penetrate the substrate, insect attack during establishment, and winter frost heave after establishment.

In this, as in other small-plot trials, the incidence of seed loss has probably been increased through having quantities of seed concentrated in small areas. Once found by seed eaters, such areas can be quickly eaten out. Where seed is spread over a large area these problems should not be so acute.

Seed Losses prior to Germination

Birds: In this study, seeds sown in unprotected plots on exposed subsoil were all taken by birds within 7 days of sowing. The seed was given no chance to become effectively buried from sight despite soil movement caused by rain, wind, and frost soon after sowing. It should be possible, however, to minimise the destruction caused by birds by:

(1) Pelleting with proven bird repellents such as Arasan 42S.

(2) Sowing in winter before the spring flocks of finches and other seed-eating birds arrive and when soil movement is more frequent. In this way most seed should be buried by spring. Seed should not be sown too early, as premature germination induced by warmer spells of winter will lead to subsequent frosting of young seedlings (Ledgard, 1976).

Mice: In the high country the only small mammal capable of destroying significant quantities of seed is the mouse (*Mus musculus*), which has been recorded in the area since the middle of the last century (Wodzicki, 1950). In this study, mouse damage was never identified beyond all doubt, but seed damage of a type and scale closely resembling that caused by a captive mouse (E. B. Spurr, pers. comm.) was recorded in one birdproof plot.

Elsewhere in New Zealand mice have presented a more serious problem. In the Richmond mountains behind Nelson, J. D. Hayward (pers. comm.) recorded seed losses to mice reaching 90%, with an average loss over a range of vegetated and bare sites of 54%. Despite these losses (identified by the type of damage to seed), only 2 mice were caught from a total of 250 trapnights, and attempts to observe mice by spot-lighting at night were similarly unsuccessful. In general, it appears that mice damage occurs sporadically and is often localised, symptomatic of low numbers of mice eating large quantities of seed.

In both forest and grassland, mouse populations fluctuate markedly from season to season, dependent probably on natural seedfall of indigenous species such as snowgrass (*Chionochloa* sp.) and beech (*Nothofagus* sp.) (Wodzicki, 1950; King, in press). If this is the case it may be unwise to direct-sow woody species in the period after a good seed year of local native species. Seed destruction would also be diminished by the abovementioned practice of mid-winter sowings to make use of natural soil movement to bury the seed.

The effectiveness of a variety of rodent repellents and poisons has been tested by many workers, but results are not promising (Schubert *et al.,* 1970).

Insects: It has proved hard to identify exactly which insects damage seed. Spurr (pers. comm.) has noted the following potential seed-eaters amongst a variety of invertebrates caught in traps located in the area surrounding the seed trials: ants (*Chelaner antarcticus*), wetas (two spp., including *Hemideina maori*), and a weevil; but the patterns and extent of damage caused by each are as yet uncertain. In order to identify more accurately the involvement of invertebrates, further work using captive specimens is required.

From comparison with seed eaten by a captive weta (Spurr, pers. comm.), it appeared that most of the damage caused by insects in the first 4 weeks of this trial (only 3.6% of all seed sown) could be attributed to wetas. Ants were noted on a few occasions to be present in or near partially eaten seed, but it is unlikely that they were responsible for any primary damage.

Of the seeds which were initially buried, a number were noted to reappear with small incisions through the testa into the endosperm. This damage appears to have been caused by underground soil organisms, and resulted in the eventual death of the seed. From Table 1 it can be seen that the number of buried seeds which re-emerged as seedlings in December was only one-third of the number initially buried. It seems, therefore, that either further seed was destroyed underground, probably by soil-dwelling invertebrates, or that some seed had yet to germinate. The situation concerning delayed germination of *P. mugo* seeds is uncertain. Field studies have shown it does occur for at least two seasons after sowing (Davis, 1977), but the percentage of seed involved is not expected to be high.

Usually where insect damage is expected, attempts are made to protect the seeds by pretreating them with an insecticide. Arasan-endrin mixtures have been used extensively as a multipurpose repellent in the United States since the mid-1950s but while there has been general agreement that this mixture is effective as a fungicide and bird repellent, it does not prevent seed from being eaten by insects or rodents (Jackson, 1975; Hedderwick, 1967).

Seedling Losses after Germination

Desiccation: The inability of emerging radicles to quickly penetrate the substrate was a significant cause of loss after germination. Such problems with surface-sown seed are not uncommon (Dowling *et al.*, 1970). The answer seems to lie in a more rapid burial of seed, which would eventuate if seed were sown earlier in the winter when winter soil movement is more pronounced.

Insects: Once the radicles had established in the soil, clipping of young shoots by insects destroyed a number of seedlings. The green manuka beetle and the weta appear to be responsible. Birds will also clip young seedlings (G. W. Hedderwick, pers. comm.), but in this trial they were not responsible as damage occurred within the birdproof plots. Practical control of this sort of damage in any oversown area would be difficult, although the level of damage should not normally be high.

Frost heave: This accounted for virtually all seedlings which had survived through to the first winter and is a problem which on exposed surfaces would be difficult to counter.

Present indications are that, in the South Island high country, woody seedlings sown on bare subsoil can be practically protected from frost heave only by either:

(1) A "permanent" covering of snow for most of the winter months, or

(2) By sowing into a herbaceous cover of fast-growing exotic grasses and legumes topdressed with liberal rates of fertiliser.

Both these aspects of frost-heave protection are more fully discussed by Ledgard (1976) and Davis (1977).

Trial Method

The type of observation trial described here has many drawbacks, the major one being that once a seed is lost from sight it is unlikely to be relocated and its fate must be left to conjecture. In studies in the Northern Hemisphere where rodents are a serious problem, up to 50% of some seed lots under observation have had to be simply recorded as "missing" (Lawrence and Rediske, 1962). The astuteness of observers also varies and must influence the significance of final figures. However, in this study where seed and seedlings could not be removed from the plot margins, and where the ground was bare throughout the growing season, it was possible to note the causes of loss fairly accurately and, from the patterns which resulted, partial control measures can be formulated. However, where similar direct-seeding trials are extended on to vegetated or stony surfaces, or into areas where the type of destruction by animals is more varied, a means is needed to recover invisible seeds. In these circumstances the radio-tagging procedure developed by Lawrence and Rediske (1959, 1962) cannot at present be bettered.

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