NATURAL REGENERATION OF P. RADIATA FOLLOWING THE BALMORAL FOREST FIRE

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Introduction

On 26th to 28th November 1955 an extremely hot forest fire swept through part of Balmoral Forest, destroying *inter alia* some 1,470 acres of 28 and 29 year old *P. radiata*.

This paper describes the attempts which were made to induce regeneration under the burnt stands, and records the results. Mortalities in regeneration were severe. Various investigations were made to determine the cause and extent of seedling mortality; the results are recorded and discussed.

Description of Burnt Stands

The burnt *P. radiata* stands were planted in 1928 and 1929, at a spacing of 8 × 8 ft. They were repeatedly blanked before a reasonable stocking was obtained. At the time of the fire the stocking averaged 450 trees per acre, 6 in. to 18 in. in diameter and 65 ft. to 80 ft. high. The form was generally poor.

The flat alluvial plains site is marginal for *P. radiata*. The soil mantle is thin and overlies compacted and partially cemented river-gravels through which tree roots do not penetrate. The risk of wind-throw is therefore extreme, particularly since the locality is subjected to frequent Fohn-type north-west winds of gale force. Since 1945 there had been sporadic wind-throw throughout all the burnt stands.

The mean annual rainfall at Balmoral, 27.09 in., is fairly evenly distributed throughout the year, but periods of drought are frequent. The north-west winds are commonly associated with high temperatures and low humidities. Evaporation rates are thus high, and during the summer months evaporation tends to exceed precipitation.

Frosts of 10° or more are frequent during winter months and unseasonal frosts occur. The two climatic factors of frost and drought make establishment and re-establishment particularly difficult. In addition the forest carries a high population of rabbits.

As a result of varying intensities of burn it was possible to recognise three categories of fire-damaged stands. They were:

(*a*) Green stands which suffered a ground fire only and in which the trees were still living. Total: 1,022 acres.

(*b*) Brown or scorched stands in which the trees were killed, but the needles not consumed. Total: 498 acres.

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(*c*) Black or completely defoliated stands in which all needles were burnt. Total: 971 acres.

The distinction between the latter two categories was significant as the regeneration problems in each were different.

Salvage operations in the burnt stands (scorched and defoliated only) commenced in December 1955 and continued until April 1957, by which time sapstain had degraded the timber. A total of 916 acres was logged. The logging operations were a complicating factor in regeneration studies, and led to further investigations being undertaken.

Seed Fall

In the dying stages of the fire local staff were too preoccupied with mopping-up operations to devote much time to studies of seed fall. Nevertheless, on 28th and 29th November, i.e. while the ground was still warm, the amount of seed fall was estimated from counts of twenty-five randomly located one square foot quadrats. The counts ranged from zero to seventeen per quadrat, averaging six. The corresponding per acre figure is 263,000.

Three one square yard seed traps were installed on 29th November, two in scorched stands, and one in a defoliated stand. Counts on 8th December (after which little further seed fell) gave 50, 51, and 20 seeds per trap, a weighted average of 140,000 per acre. As birds were already eating seed before 29th November, it can be assumed that the total seed fall was in excess of 400,000 per acre.

Confirmation of this figure is provided from the results of an independent study of vertebrate-fire relationships made soon after the fire by Riney and Batcheler (1958). They reported "One week after the fire, pine seed lying on the surface of the ground in the burned areas ranged between zero and twenty-five per square foot. The average of one hundred stations taken from several parts of the burned areas was twelve per square foot. A conservative estimate would therefore place pine seed on the ground at 522,720 per acre."

Samples of seed were forwarded to the Forest Research Institute early in December for germination tests. The tests showed that 81.2% of the seed was sound, and that 57% germinated after thirty days. From these figures it can be deduced that the average fall of viable seed was in excess of 200,000 per acre, and probably exceeded 300,000.

It is of interest to note that the fall of viable seed was much heavier after the Taupo fires of 1946. Although no counts were made at the time, it is known that in places over 1,000,000 *P. radiata* seeds per acre germinated. (Fenton, 1951.) The Taupo stands were younger (age 17) but the large difference is more probably attributable to the fact that in the much drier Canterbury climate *P. radiata* cones commonly open and shed seed from standing trees, a phenomenon which is rarer in the North Island. In addition, cone production is typically sparser at Balmoral than in more humid areas.

Effects of Birds on Seed

Birds commenced to eat seed as soon as it fell. Redpolls (*Carduelis flammaea*) were the commonest birds in the forest, and it is considered that they took the heaviest toll, both in total and per individual bird. Other birds observed feeding on seed were goldfinches (*Carduelis carduelis*), chaffinches (*Fringilla coelebs*), greenfinches (*Chloris chloris*) and house sparrows (*Passer domesticus*). Riney and Batcheler examined the crops of some thirty-two redpolls, goldfinches, chaffinches, and greenfinches. They found *P. radiata* seed in all.

Previous experience with *P. radiata* fires in Canterbury had been similar. On 27th December 1940, a fire at Eyrewell State Forest burnt some 750 acres of 10–12 year old *P. radiata*. Following an inspection in February 1941, F. W. Foster reported "... no sound seed could be found, all having been eaten by birds" (Foster, 1941). Other forest owners in Canterbury confirmed that their experiences had been identical. (Personal communications, E. A. Cooney and C. M. Williams.) In addition, past observations in clear-felled *P. radiata* areas at Balmoral indicated that birds commonly ate over 90% of all sound seed shed. The previous studies noted that broken seed coats were prevalent, that the only unprotected seed left some months after clear-felling was unsound, and that the only sound seed to be found was the small quantity which had had chance protection from stones, cones, or slash.

From these considerations it was obvious that the chances of natural regeneration at Balmoral would be greatly enhanced if effective steps could be taken to protect the seed. Two methods suggested themselves —scarifying the ground to cover the seed, and spreading poison to reduce the population of birds. Both were tried.

The Scarifying Operation

The decision to conduct a large scale scarifying operation was taken on 29th November, and trials of different implements commenced the next day. The following implements were tested: (1) spike-toothed harrows, (2) lodge-pole harrows, (3) spring-tyne cultivators, (4) tripod and chain harrows, (5) stump-jumper harrows, and (6) tractor-mounted grader blades with scarifiers, all drawn by pneumatic-tyred tractors.

It was found that cut-down stump-jumper harrows were the most suitable; they were not strained or damaged by roots, and they could ride over large boulders or small stumps. In order to lift them over larger boulders they were suspended by chains to an improvised attachment which was in turn fastened to the hydraulic lift of the tractor. The depth of soil penetration was controlled by bolting on short sections of rail, thus varying the weight on the harrows; and to spread the seed more evenly, a length of heavy chain was fastened to the back end of the harrow and dragged behind.

With the best technique worked out to suit the local conditions of stony and debris-covered ground, it then became necessary to consider how the job could be organised. The task was both large and urgent, and was beyond departmental resources of man power and equipment. Accordingly, all available local agricultural contractors were hired and set to work on a contract basis. With this assistance seven tractors were put in the field; they worked sixteen hours per day, for a seven-day week. It was hoped that this tempo of operations would enable the job to be completed in three weeks, i.e. before the Xmas vacation.

It was soon found that progress was delayed by wind-thrown trees preventing the free passage of tractors. To avoid this delay and to enable the scarifying implements to work full time, a gang of Junior Woodsmen was brought from the Training School, Golden Downs, and set to work clearing ahead of the tractors with chain saws. Depending on conditions, one to three Woodsmen were used with each tractor.

Even with this improvement the work did not progress at the required speed. After 809 acres had been covered by scarifying every row, it was decided to restrict the operation to two rows out of three. The faster rate of progress enabled a further 1,213 acres to be scarified by the target date for completion. The total area thus covered was 2,022 acres.* As the scarified band was three feet wide, the actual area scarified was 37.5% of the ground area over 809 acres, and 25% over 1,213 acres.

The operation was done for a cost of under £2 per acre.

Bird Poisoning

On the 12th and 13th December strychnine-coated wheat was distributed by air over the burnt *P. radiata* stands at a rate of five pounds per acre.

The operation was not a success. In the weeks following the poisoning only six dead birds were found – two redpolls, two chaffinches, and two fantails (*Rhipidura fuliginosa*). From their more detailed studies, Riney and Batcheler concluded "There is no evidence to suggest that the poisoned wheat was effective enough on fringillid populations to cause an increase in germination of pine seedlings." The operation, however, did little harm; as birds were noticeably chary of taking pine seed when poisoned wheat was visible, it may have been positively beneficial. The cost (3s. 6d. per acre), was negligible.

Germination

The Balmoral fire ushered in one of the worst summer droughts in Canterbury's history. Heavy rain fell immediately after the fire (107 points on 28th and 29th November) but from November 30th until

*This figure includes over 500 acres of green stands. At this stage the green category could not always be recognised since the green tops were hidden by the scorched foliage on the lower branches. It was only when the scorched needles fell that a true estimate of the area of dead trees could be made; it was much smaller than at first had been thought.

19th March 1956 there was no effective fall. The detailed rainfall figures are given in Table 1.

TABLE 1

RAINFALL DATA—BALMORAL FOREST—1955-56 DROUGHT

	December 1955		January 1956		February 1956		March 1956		Total for drought period
	14th	0.06	6th	0.05	6th	0.15	7th	0.18	
	18th	0.02	9th	0.07	17th	0.16	14th	0.19	
	25th	0.02	15th	0.03	18th	0.01	17th	0.01	
	26th	0.02	22nd	0.05	21st	0.08			
	27th	0.05	25th	0.09	27th	0.10			
			26th	0.21	29th	0.03			
			29th	0.17					
			30th	0.32					
Monthly total		0.17		0.99		0.53		0.38[1]	2.09
Monthly average		2.30		2.06		2.15		0.86[2]	7.37

[1]Total for half month.
[2]Assumed average for half month.

It will be seen that over the three and a half months of the drought the total rainfall was less than one third of normal. Other features of the drought were high temperatures, low humidities, and frequent north-west winds. Under these conditions light falls of rain do not penetrate the ground and are quite ineffective. It is not surprising, therefore, that germination was delayed.

The first seedlings appeared in mid February, presumably as a result of the seventy points which fell between the 26th and 30th January. Even this fall was insufficient to induce germination in any significant quantities and the number of seedlings which emerged was no more than fifty per acre. Germination in quantity did not commence until after the drought broke on 19th March, on which date 1.51 inches of rain fell. Almost immediately profuse germination took place on scarified ground, and scattered seedlings appeared elsewhere. The bulk of the seed germinated by the end of May, although in subsequent months a few more seedlings did appear, particularly in the spring. It is of interest to note there was no month in 1956, even including the winter ones, in which some new seedlings did not emerge. The total germination between March 1956 and July 1957 is estimated at 17,000 seedlings per acre, of which 16,000 per acre had germinated by mid June 1956.

The effects of the scarification were immediately obvious – distinct and regular bands of seedlings on scarified ground and irregular, relatively sparse germination elsewhere. It was noted that seedlings on unscarified ground came mainly from seed which had lodged under stones, stumps, or wind-thrown trees, and which had thus escaped birds. The prevalence of seed-coat fragments on unscarified ground and their absence on scarified gave ample visual evidence both of the activities of birds and of the effectiveness of the scarifying operation.

Assessment of Regeneration

In April 1956 a stocked quadrat survey was carried out in order to assess the extent and distribution of regeneration. The method adopted was to run a line through each burnt compartment and to record the seedlings present on rectangular half-milacre quadrats located every twenty yards along the lines.

Quadrat size and shape were dictated by the width of the scarified bands. Rectangular milacre quadrats would have been 2 ft. 6 in. × 17 ft. 5 in., an unwieldy shape with a disproportionately long margin. Instead paired quarter-milacre quadrats were used, each 2 ft. 6 in. × 4 ft. 3 in. in size. Light wooden frames of these dimensions were constructed and laid down in adjoining positions to mark and count the half-milacre quadrat.

The quadrats were placed more or less alternatively on scarified and on unscarified ground, and the lines were so located that both scorched and defoliated areas were sampled. Just over two miles of line were run, representing 171 quadrats, 64 on scarified ground and 107 on unscarified.

The results obtained gave information both on the average number of seedlings per acre and on the effectiveness of the stocking. An adequate stocking was considered to be one or more seedlings per half-milacre quadrat.

Mean per acre figures were obtained from the weighted average of stockings per acre on scarified and unscarified ground.

The results of this survey were:

	Seedlings per acre	Stocking
Scarified ground	8,000 (± 1,000)	91%
Unscarified ground	2,411 (± 430)	37%
Mean	4,088	53%

A few weeks earlier Riney and Batcheler had made an independent count of seedlings as part of the bird studies they were carrying out. Although the numbers recorded were much smaller, the difference between scarified and unscarified ground was even more marked. Their results for 100 milacre plots were:

Scarified ground	3,920 seedlings per acre
Unscarified ground	760 ,, ,, ,,

Riney and Batcheler also made seedling counts in a small burnt *P. radiata* stand which was entirely unscarified. They found a significant difference between the stocking here and the stocking on unscarified ground in the main area (1,290 as against 760 seedlings per acre). They suggested that the lower stocking on unscarified ground in partially scarified areas was perhaps due to the same bird population per unit of area being forced to feed more intensively than it would in a totally unscarified area. The implication appears to be that had no scarification taken place the mean stocking would have been higher than the 2,411 per acre recorded by the stocked quadrat survey for unscarified ground.

Subsequent stocked quadrat surveys were carried out in July 1956 and June 1957. The results are given in Table 2.

TABLE 2

COMPARISON OF REGENERATION ON SCARIFIED AND UNSCARIFIED GROUND

	July 1956		July 1957	
	Seedlings per acre	Stocking	Seedlings per acre	Stocking
Scarified ground	7,782 (± 600)	73%	5,746 (± 860)	71%
Unscarified ground	2,479 (± 320)	53%	1,590 (± 385)	42%
Mean	4,070	59%	2,837	51%

It will be seen that although the number of seedlings per acre dropped, the significant differences between scarified and unscarified were maintained. Comparison of the mean stocking with that on unscarified ground gives some measure of the effects of scarification. In the final results, the number of seedlings per acre is nearly double, but the increase in stocking itself is only 9%.

Early Seedling Mortality

Damage to seedlings commenced as soon as they emerged, and from visual inspection appeared to be alarming. Birds, particularly greenfinches and house sparrows, were responsible for much of the early damage. Their activities appeared to be as much mischievous as alimentary, the seedlings commonly being either pulled out of the ground or nipped off just above the ground level, and in both cases left uneaten. Damage or destruction appeared to take place equally on scarified and unscarified ground, but it was much more severe in defoliated than in scorched stands. The carpet of fallen needles in the latter areas gave some valuable protection at what was the most vulnerable stage.

Severe damage did, however, take place in scorched stands and was soon found to be caused by the larvae of a noctuid moth, *Ariathisa comma*. Larvae were first recorded on 29th March. Although present throughout all burnt stands it was only under the fallen needles of the scorched stands that the population was large. On these sites counts of over forty per square yard were recorded in April 1956. Damage varied from minor chewing of the cotyledons to complete destruction of the seedlings in the cotyledon stage. On close inspection noctuid damage could be clearly distinguished from that caused by birds.

On 10th May a count was made of damaged or destroyed seedlings on thirty-two randomly located one square yard quadrats. The figures showed:

(*a*) Approximately 8,000 seedlings per acre had already been destroyed by noctuid larvae. This is a weighted average figure for the total burnt area.

(*b*) There was only infinitesimal noctuid damage in the completely defoliated stands.

(*c*) Approximately 4,000 seedlings per acre (again a weighted average) had been destroyed by birds.

(*d*) Bird damage was twice as heavy in completely defoliated as in scorched stands.

It should be stressed that these figures were based on a small sample only; they provide no more than an estimate of the order of damage.

Subsequent Seedling Mortality

(*a*) *Observation Plots*

In order to make more detailed studies of the various agencies responsible for seedling mortality a series of netted and treated plots was established and placed under observation. The plots consisted of 6 ft. × 4 ft. 6 in. quadrats, as follows:

(i) Covered with ½ in. mesh wire-netting 6 in. above ground level to give protection from birds, and treated with insecticide (DDT) to kill noctuid and other larvae.

(ii) Covered with wire netting and left untreated.

(iii) Treated with insecticide and left uncovered.

(iv) Uncovered and untreated (control).

Every seedling in the plots was pegged and recorded (as were new seedlings on emergence) and the plots were inspected at two-weekly intervals.

In May 1956 four sets of the three treatments and the controls were established in scorched stands and one set in a defoliated stand. The plots were sited in areas of dense regeneration. In late June two further sets, intended particularly for the study of frost damage, were established in burnt stands that had been logged since the fire. In no case were any two quadrats in each set of four more than one chain apart. The frames of all netted plots were lifted in September 1956, by which time seedlings were beginning to emerge through the netting.

Observations and records continued for twelve months, i.e. to 26 May 1957. The results are discussed in subsequent paragraphs.

(*b*) *Bird Damage*

By June 1956, damage from birds had almost entirely ceased. There was no evidence of any bird damage on the fourteen unnetted plots under observation from 29 May 1956 to 26 May 1957, although some small amount of further damage may have occurred in the forest.

By June the ground was becoming covered, if sparsely, with pioneer weed species, particularly sorrel (*Rumex acetosella*), flannel-leaf (*Verbascum thapsus*), hawkesbeard (*Crepis capil-*

laris), forget-me-not (*Myosotis discolor*) and mouse-ear chickweed (*Cerastium glomeratum*).

It is possible that birds became less curious about emergent pine seedlings as more foliage developed; but there could well be other explanations connected with feeding and migratory habits which could account for the almost complete cessation of bird damage.

There is some evidence that at this stage the actions of birds were positively beneficial towards regeneration. MacKenzie reported observing a yellow breasted tit (*Petroica macrocephala*) feeding on noctuid larvae; and there is presumptive evidence from the observation plots that birds must have fed on noctuid larvae in large numbers. The latter point is further discussed below.

(*c*) *Noctuid Damage*

Noctuid damage continued in the scorched stands but with decreasing severity. It would appear that the observation plots were installed too late to record the progress of the damage at its peak, just as they were too late to record any bird damage at all.

Counts from the sixteen plots in scorched stands are given in Table 3.

TABLE 3

SEEDLINGS DESTROYED BY NOCTUIDS

	Treated with insecticide			Untreated		
	Total number present	Number destroyed	Percentage destroyed	Total number present	Number destroyed	Percentage destroyed
Protected from birds	90	2	2.2	57	29	51
Unprotected	63	6	10.0	48	13	27
Total	153	8	5.2	105	42	40

The difference between the treated and untreated plots was as expected. What was surprising was that mortality in the untreated unprotected plots (controls) was approximately half that in the untreated plots which had been given protection against birds. The most likely explanation is that birds were responsible for devouring large numbers of noctuid larvae.

Whether for this or for other reasons, the larval population dropped abruptly during May, June, and July. In May, McKenzie, from a sample of eighteen randomly located plots, found an average of seven larvae per square yard, as compared with averages of thirty or forty in April; in August a similar sample gave an average of only three per square yard (McKenzie, 1956). During the winter months the larvae were somewhat inactive and few seedlings were destroyed, but in the spring they grew rapidly and were responsible for another short but considerable wave of mortality. Pupation took place (mainly) in October and since then there has been little sign of noctuid activity. There was no damage at all in 1957, even to the new seedlings which emerged.

Ariathisa comma feeds on a wide range of plants and was undoubtedly responsible for delaying the development of ground vegetation under the scorched stands. In insecticide treated plots, in the absence of noctuids, the thick cover of vegetation stood out in marked and even spectacular contrast to the untreated surrounds.

Ariathisa comma could be found in unburnt stands only after a prolonged search. Under normal circumstances it is not present in large enough numbers to be of significance.

(*d*) *Rabbit Damage*

By Balmoral standards the rabbit population was a light one in the stands under investigation. The numbers were further decreased by the fire.

Only a few seedlings were damaged in the observation plots during 1956. There was no significant difference between the netted and unnetted plots, despite the fact that the frames were not removed from the netted plots until September. In all, mortalities from rabbits amounted to only 4.3% of the total number of seedlings present (weighted average figure for the three categories of scorched, defoliated, and salvaged). Most of the damage took place early in 1957, at which time the ground vegetation was in a dessicated and comparatively unpalatable condition. In May 1957 a good kill was obtained with the poison 1080 (sodium fluoracetate) and in subsequent months the damage noted in the forest was negligible.

Riney and Batcheler expressed the view that the distribution of poisoned wheat may facilitate the re-distribution of rabbits throughout the burnt area. Fortunately their fears proved to be groundless; very little wheat germinated, and in terms of total browse available the quantity was negligible.

(*e*) *Frost Damage*

Fortunately the winter of 1956 was not particularly severe, as the following figures show:

Ground Temperatures (°F.)

	Minimum mean			
	Actual	Average	Extreme minimum	Number of frosts
June 1956	27.9°	26.8°	17°	18
July 1956	28.6°	25.7°	18°	19
August 1956	27.9°	27.6°	22°	20

Neither extreme minima nor numbers of frosts are comparable with some previous records. To quote a few:

	Extreme Minima Screen Temperatures (°F.)	Ground Temperatures (°F.)	Number of Ground Frosts
June 1921	12°	—	26
July 1921	12°	—	30
August 1932	15°	6.5°	24
July 1943	14°	11.0°	26
July 1945	8°	6.0°	27
July 1950	15°	10.0°	25
July 1952	16°	14.5°	26

Nevertheless frost damage was severe. Counts from the total 28 plots are given in Table 4.

TABLE 4

SEEDLINGS DAMAGED BY FROST

	Unnetted plots			Netted plots		
	Total present	Destroyed	Percentage	Total present	Destroyed	Percentage
Defoliated stands	31	9	29.0	38	5	13.2
Scorched stands	111	5	4.5	147	3	2.0
Salvaged stands	63	29	46.0	89	20	22.5

As would be expected mortalities in the netted plots were small, the netting frames giving some protection to seedlings. The weighted average mortality for unnetted plots in all three categories was 35.6%, the equivalent approximately of 1,850 seedlings per acre. Since the plots in the salvaged category were selected in areas of reasonably clear ground, the average mortality in the forest was probably considerably less.

Damage commonly took the form of frost lift, and few deaths from wilting were observed. Rain influenced frost damage; a frost soon after heavy rain resulted in more seedlings being frost lifted than a frost of equal severity occurring after a period of dry weather.

Very fortunately the average 1956 winter was followed by an abnormally warm and wet spring. As a result seedlings which had browned off and partially wilted recovered in a quite remarkable manner. It seems probable that frost damage would have been much greater but for the most favourable conditions in the spring.

In order to study ground temperature conditions, three maximum- and minimum-thermometers were in June placed in sites adjacent to observation plots. In the defoliated and logged stands the thermometers were placed on the surface of the ground in a horizontal position. In the defoliated stand the thermometer was placed in the upper surface of the needle layer.

They provided the following figures:

Extreme Minimum Ground Temperatures (°F.)

	July 1956	August 1956	September 1956
Scorched stands	22°	26°	24°
Defoliated stands	20°	25°	23°
Salvaged stands	20°	22°	20°

As would be expected, ground temperatures were lower in the defoliated than the scorched stands and lower still in the exposed salvaged stands. The scorched stands had some protection from residual needles on the trees, and, probably of greater significance, from a heat-absorbent carpet of needles on the ground. This carpet acted in two ways – ameliorating ground temperatures and physically preventing frost lift. It is likely that the much lower mortalities in the scorched stands are primarily due to the latter effect.

(f) Drought Damage

A short but moderately severe drought occurred in January and February 1957. The relevant climatic figures are:

	Mean Max. Temperature (°F.)		Rainfall (in.)	
	Actual	Average	Actual	Average
January 1957	75.3	73	1.30	2.06
February 1957	77.3	72	1.04	2.15

It was expected that drought losses might be heavy. In fact, they were relatively light. Counts for the three stand categories (unnetted plots only) are given in Table 5.

TABLE 5

SEEDLINGS DESTROYED BY DROUGHT

	Total number present	Number destroyed	Percentage destroyed
Defoliated stands	31	1	3.2%
Scorched stands	111	7	6.3%
Salvaged stands	63	3	4.8%

The weighted average figure for all categories was 4.4%. The difference noted between scorched and defoliated stands is not significant. Observations in the forest suggested that the incidence of drought mortality was much the same in all three categories. Maximum ground surface temperatures (°F.) were as follows:

	January 1957	February 1957
Scorched	107°	109°
Defoliated	118°	125°
Salvaged	129°	135°

As already stated, the needles remaining on the trees and the carpet on the ground together had an ameliorating effect on ground temperatures in scorched stands. The fact that mortalities were not lower in this category suggests that ground temperatures (of the order recorded) were not alone responsible for death by wilting. Rather, lack of soil moisture is more likely to be the main cause.

(*g*) *Other Damaging Agents*

Larvae and adults of *Hylastes ater* were found under the bark of roots and stems of fire-killed trees. Surprisingly, very few seedlings were attacked.

In July 1956 grass grubs (*Costelytra zealandica*) became locally abundant, counts of up to fifty per square yard being recorded. Some damage to seedlings was observed but the grass grubs were not widespread and their total effect on regeneration was negligible. The uneven distribution of grass grubs in isolated dense pockets is probably linked with local variations in soil moisture.

Fungal attack, presumed to be caused by a damping off fungus, was observed in the late autumn and early winter of both 1956 and 1957. In almost every case, however, the seedlings had been previously damaged by noctuid larvae. There was very little mortality which could be attributed to fungal damage alone.

Subsequent Germination

New germination appeared sporadically throughout the winter months of 1956 and with a minor rush in October. In the sixteen scorched plots, 57 seedlings emerged, compared with 201 present at the time of the original count. The dates of emergence of the 57 seedlings were:

June	12
July	1
August	1
September	1
October	36
November	1
January	5
Total	57

The emergence in defoliated and salvaged stands showed similar trends.

Expressed in terms of original stockings, the percentages of new seedlings which appeared were:

Scorched stands	28.4
Defoliated stands	46.8
Salvaged stands	20.6

There is no obvious reason for the significantly greater number of seedlings in defoliated stands. The reverse would perhaps have been expected since there were more chances of a few cones remaining unopened in the scorched than in the defoliated stands.

Examination of the plot figures shows that neither insecticide treatment nor protection from birds had any significant effect on germination. It was not possible on the plots to differentiate clearly between scarified and unscarified ground but from observations in the forest it appeared that later germination came more from the unscarified areas.

Logging Damage

Some damage to seedlings must have occurred during the salvage operations, but its overall effect on stocking was minimised because:

(*a*) Several hundred acres were logged before the main rush of germination in April and May.

(*b*) The logging was selective, only the best trees (some 75 to 100 per acre) being felled. Furthermore, the logging became increasingly selective as sapstain developed in the dead trees; the possibility of damage therefore decreased as salvage operations progressed.

The observation plots do not give any measure of logging damage, as those in the salvaged areas were installed after logging had taken place. There were no plots to record direct logging damage, nor would it have been possible to sample it accurately without a large number of plots.

Analysis of the final quadrat survey results shows a stocking of 3,526 seedlings per acre in unsalvaged areas compared with only 2,497 in salvaged areas, but the difference of over 1,000 seedlings per acre could be attributable as much to frost as to logging damage. As has been seen, frost damage was particularly severe (46% of all seedlings) in the observation plots in salvaged areas. For this reason it is not possible to make any estimate of the number of seedlings destroyed by logging. All that can be said is that whatever the damage may have been, there was still a residual stocking which was adequate in both numbers and distribution.

Combined Results

The stocked quadrat surveys give estimates of seedling populations but they hide the counteracting effects of new germination and mortality. The germination plots measure both germination and mortality but they are too small and too unrepresentative to give valid per acre figures. The two sets of results can be combined only by applying observation plot percentages to actual stocked quadrat survey figures, and then only on the assumption that the trends of mortality and germination in the forest were identical with those in the plots. The assumption may not be justified.

A further difficulty arises from the fact that the proportions of the three stand categories kept changing as salvage operations progressed. In deriving weighted average figures it was thus not possible to use weightings which would be correct for the whole period under review.

All that could be done was to use the weighting most appropriate to each particular set of circumstances. Thus, in the case of noctuid damage the original proportions of scorched and defoliated stands were used, and salvage operations were ignored; noctuid damage was obviously influenced far more by stand category than by subsequent logging activities. In most other cases, the alteration of site factors brought about by logging was of extreme significance, and the weightings given were in accordance with the final areas after salvage had been completed. But whichever method was used there was an inevitable residual error arising from the fact that the proportional areas kept changing and neither the survey nor the plot records could be related to these week-by-week changes.

Despite but in full realisation of these limitations, an attempt was made to apply the observation plot percentages to the stocked-quadrat figure.

The results are:

		Seedlings per acre	Remarks
Stocking as at 29 May 1956		4,079	Mean of April and July surveys
Plus new germination—28.6%		1,167	
Total seedlings present		5,246	
Less Mortalities			
Noctuid	9.2%		Weighted average from control plots
Frost	35.6%		Weighted average from unnetted plots
Drought	4.4%		Weighted average from unnetted plots
Rabbit	4.3%		Weighted average all plots
Unclassified	4.8%		Weighted average all plots
Total	55.3%	3,058	
Calculated stocking at 26 May 1957		2,188	
Actual stocking at June 1957		2,837	

At first sight it would appear that the correspondence is good. One would, however, expect the calculated stocking to exceed the actual stocking since the calculations did not (and could not) take logging damage into account. On the other hand, as already indicated, frost damage for the total burnt area is likely to be overstated. In round figures a general picture does emerge: an average of over 4,000 seedlings in late May 1956, a fresh germination (mainly in the spring) of over 1,000 seedlings, mortality (of which over half was frost) of some 50% and a residual stocking in May 1957 of between 2,000 and 3,000 seedlings per acre.

A further broad summary can be produced. It has been shown that mortalities prior to 27 May 1956 were of the order of 12,000 seedlings per acre. Total germination must therefore have been some

17,000 seedlings per acre. We then have the following comparison:

Number of viable seeds that fell	....	250,000 to 300,000 per acre
„ „ seedlings which germinated	......	17,000 per acre
„ „ „ „ survived	....	2,700 „ „

It will be seen that the chances of any one viable seed becoming an established seedling were approximately one in one hundred. This fact may have some significance in relation to any proposals to restock forests of this nature by the aerial distribution of seed. As always, nature is prodigal, and so must man be if he is to adopt naturalistic methods.

Other Investigations

(*a*) *Effects of Microtopography*

Microtopography appeared to have a marked effect on the development of seedlings, an effect which from previous observations is carried forward for some years.

A small study was undertaken in order to measure the effects of minor elevations and depressions (2 in. or more in height or depth) on survival and growth rates. In December 1956 a count was made of seedlings located on a 6 in. wide 5 chain-long transect, the seedlings being listed under the three headings, elevations, depressions, and level ground. For ease of working, the area selected was one of abnormally dense regeneration. The results were:

	Seedlings per square yard
Elevations	3.1
Depressions	17.0
Level ground	5.1

The difference is most marked. It can be accounted for, in part at least, by the fact that seed tended to be both blown and washed into hollows, and to lodge there.

In order to study survival and growth rates in the critical summer and autumn period, a series of 50 seedlings, 25 in depressions and 25 in elevations, were numbered and recorded. At the time of original measurement, December 1956, the seedlings were all approximately 2½ in. high. In July 1957 the seedlings were remeasured. Mortalities were four on the elevations and one in the depressions. The height differences were:

	Number of seedlings					
	0 in. – 3½ in.	3½ in. – 5½ in.	5½ in. – 7½ in.	7½ in. – 9½ in.	9½ in. – 11½ in.	Dead
Elevations	8	7	3	2	1	4
Depressions	3	5	6	5	5	1

The increased vigour in depressions is significant. Its importance to the present study is the implication that an original dense stocking is desirable at Balmoral so that the chances of enough trees getting a start on the better sites, i.e. in depressions, is enhanced.

(*b*) *Effects of Slash Cover*

On December 1956 investigations were made to determine if slash cover in logged areas was a factor influencing survival. Seedling counts were made on 108 quarter milacre quadrats located in three arbitrarily recognised degrees of cover—light slash, heavy slash, and bare ground. The area chosen for this investigation was logged in December 1955, i.e. before seedlings germinated. Because some needles were still adhering to the branches, the heavy slash category corresponded more or less to the slash from the logging of scorched stands, whereas the light slash quadrats were mainly in completely defoliated stands. The counts gave the following figures:

	Seedlings per acre
Light slash	9,800
Heavy slash	700
Bare ground	2,900

The beneficial effect of light slash is most marked. The cover in the heavy slash category is still lighter than it would be in normal clear-felling operations and the number of seedlings is correspondingly larger. The figures demonstrate clearly that heavy slash is an important inhibiting factor in the development of regeneration.

In order to determine whether slash cover favoured the survival of established seedlings during the summer months, 50 seedlings under light slash and 50 on bare ground were numbered and recorded in December 1956 and inspected at two-weekly intervals. In July 1957 they were remeasured. It was found the mortality was the same – nine seedlings, or 18% in each category. The slash cover therefore did not increase survival rates.

In December the seedlings were all approximately 2½ in. high. In July their heights were:

	Number of Seedlings						
	0 in. – 3½ in.	3½ in. – 5½ in.	5½ in. – 7½ in.	7½ in. – 9½ in.	9½ in. – 11½ in.	11½ in. +	Dead
Bare ground	8	11	11	7	2	2	9
Light slash	2	8	13	8	5	5	9

The increased vigour under light slash is not significant.

(*c*) *Development of Ground Vegetation*

The colonisation of the ground by pioneering herbs and grasses was kept under observation and recorded. The 1956 summer drought prevented early germination but by mid March there was a sparse scattering of sorrel (the first species to appear), hawkesbeard, forget-me-not, and mouse-ear chickweed. There were also a very few wheat seedlings.

A detailed inspection was carried out in July and the vegetation on eighty-five half milacre quadrats was recorded. The above species were more abundant and the following further species appeared: flannel-leaf, geranium (*Pelargonium inodorum*), *Poa linsayi*, thistle (*Cirsium vulgare*), pearlwort (*Sagina apetala*), giant groundsel (*Sencio sylvaticum*), field madder (*Sherardia arvensis*), *Tillaea sieberiana*, *Erophila verna*, *Myosurus novae-zelandiae*, *Cardamine heterophylla*, *Ranunculus* spp., *Epilobium* spp., and an unidentified *Marchantia*. There were also isolated occurrences of *Gypsophila tubulosa*, sandwort (*Arenaria serpyllifolia*), *Aphanes microcarpa*, and suckling clover (*Trifolium dubium*). Sorrel and hawkesbeard were the species most frequently browsed by rabbits, and at this stage constituted their main source of food.

A second quadrat survey was carried out in November. Of the species recorded earlier, *Tillaea sieberiana*, *Myosurus novae-zelandiae*, *Cardamine heterophylla* and *Erophila verna* had now seeded and were sparsely represented. New species occurring in large numbers were fireweed (*Erechtites quadridentata*), cudweed (*Gnaphalium luteo-album*), and hard fern (*Paesia scaberula*). Sorrel was still one of the most abundant species and flannel-leaf was increasing in number of plants, in size of plants, and in proportion of the ground occupied.

Measurements were taken of the green weight of the ground vegetation in the July and November surveys. The results were:

GREEN WEIGHT OF GROUND VEGETATION (Pounds per acre)

	Defoliated stands		Scorched stands		Salvaged stands	
	July	November	July	November	July	November
Herbs & grasses	10	1,091	5	317	27	1,204
P. radiata	0.93	2.65	1.68	3.09	0.91	2.65
Wheat	Nil	Nil	Nil	Nil	Nil	Nil

The marked difference between scorched and defoliated stands could be due to various causes of which the most obvious ones are differential light intensities and the absence of noctuid larvae in the defoliated areas.

Particular features of the vegetation which developed in the first year after the fire were the scarcity of grasses, despite the fact that numerous grass species were present on unburnt fire-breaks; and the almost complete absence of the thistle species which so frequently occupy the ground after fire. Seedlings of the native shrub, kanuka (*Leptospernum ericoides*), which was a predominant feature of the vegetation prior to planting, did not begin to appear until January 1957.

The significance of the ground vegetation in relationship to the regeneration of *P. radiata* is considered to be as follows:

(*a*) The first species to appear in large numbers, sorrel and hawkesbeard, provided an alternative food supply for rabbits at a critical period. In doing this, of course, they also gave the rabbit population an opportunity to increase.

(*b*) All species provided an alternative food supply for noctuid larvae.

(*c*) During the summer months, the vegetation competed with pine seedlings for soil moisture. It had an ameliorating effect on ground temperatures, but as already stated high ground temperatures alone did not appear to be responsible for drought mortality.

(*d*) The vegetation did not suppress pine seedlings in any significant numbers.

Discussions and Conclusions

1. The investigations showed that in Canterbury by far the greater part of all seed shed following crown fires in *P. radiata* is consumed by birds. At Balmoral the actual percentage of available seed eaten was over 90. Bird poisoning was not effective in conserving seed, but ground scarification was.
2. The scarifying operation was responsible for improving the distribution of seedlings by only 9% in terms of stocked quadrat percentages. On the other hand it resulted in a residual stocking of over 2,500 seedlings per acre, nearly double the number it would otherwise have been.

   A high initial density of *P. radiata* is particularly desirable at Balmoral, in order:

   (*a*) To absorb the cumulative mortality due to frost, drought, rabbits, and other causes.

   (*b*) To provide ample choice for the selection of good form trees amongst the inevitably large number of malformed trees which develop on these sites.

   The high stocking will of course necessitate early and drastic thinning. The combined cost of scarifying and thinning at an early age should be less than that of planting at conventional spacings, or even, in order to avoid first thinnings, of planting at wide spacings; and the final crop should be of a much higher quality. From these points of view the scarifying operation can be considered most successful.
3. Large mortalities were caused soon after germination by both birds and noctuid larvae. The sudden build-up of noctuids to epidemic proportions was undoubtedly a fire-induced phenomenon, and deaths from this cause would not normally be large. Bird damage was probably also greater than it would be in normal circumstances. The investigations did, however, suggest that further studies should be made of the effects of birds on the regeneration of unburnt stands.
4. Subsequent deaths were caused mainly by frost, and this despite the fact that the winter was not particularly severe. Frost mortality amounted to over 1,000 seedlings per acre; it is an indication that the site is marginal for *P. radiata*.

5. Wilt death in summer was shown to be unrelated to actual ground temperatures (up to 135°F.). By implication, lack of soil moisture is the critical factor.
6. Microtopography was shown to have a marked effect on the early development of seedlings, as had the amount of slash cover. Light slash provides the optimum conditions for the survival and development of young *P. radiata*.
7. The investigations in general give some valuable but limited results. They were carried out by local staff in the course of other duties, and not by a full time research team. In consequence they were in some respects inadequate, particularly from the viewpoints of sampling size and statistical precision. The results should be interpreted with these limitations in mind. Probably the greatest value of the investigations is the lead it gives to further studies on the factors influencing *P. radiata* regeneration, whether fire induced or not.

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