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ABSTRACT: For almost a half century now repeated failures in direct seeding operations on cutover forest lands in North America had been largely blamed on the unproven destruction of the seed supply by small mammals. In 1960, the Canadian Wildlife Service undertook a research project to ascertain the possible fate of white spruce seeds placed into the natural environment and the influence which small mammal populations may have upon such a seed supply. By equipping each seed with a microscopic radio-transmitter (radio isotopes), the seeds could be left in the field for up to one year and then recovered intact or as seed coat fragments to provide data on seed fate. Recovery success on 21,800 white spruce seeds in ten years of study has been 90%. Recoveries indicate near 50% of spring sown seeds could be destroyed by small mammals within 17 weeks in some years despite the fact that these seeds had been previously treated with the widely accepted protective coating of aluminum powder-endrin-arasan-1atex. Late winter seeding reduced losses to small mammals by 2/3. No direct relationship between numbers of small mammals present and the number of seeds destroyed could be demonstrated.

A critical examination of seed treatment procedures widely used has led to the development of a new seed coating formulation employing a potent rodent repellent, R-55- Under laboratory conditions, the new coating yielded improved germination and a high degree of protection against small mammals. The new coating treatment received limited field testing during 1969 and is currently undergoing refinement and more extensive laboratory and field testing in Alberta.

For almost half a century foresters in North America have turned repeatedly and hopefully to direct seeding for an economical and rapid method of regenerating cutover forest lands. Many such attempts have ended in only mediocre success or disastrous failure and in most instances the failures have been blamed upon the suspected but unproven destruction of the seed supply by small mammals. Scientific journals abound with references depicting the destructive capabilities of small mammal species. For example, Hooven (1958) calculated that a small mammal population of only two animals per acre, each consuming only 300 Douglas-fir seeds per night, can, within a matter of 35 nights, destroy the amount of seed of that species which foresters broadcast onto an area to start the next crop of trees.

In 1960 the Canadian Wildlife Service was requested to undertake a study to determine the influence of small mammal populations on regeneration of white spruce [Picea glauca (Moench) Voss var. albertiana (S. Brown) Sarg.] in western Alberta. This study, still under way, has been carried out on cutover forest lands of North Western Pulp and Power Ltd. situated at Hinton, Alberta, approximately 180 miles west of Edmonton and in the Clearwater Forest area near Rocky Mountain House, approximately 170 miles southwest of Edmonton. In both of these areas repeated broadcast seeding operations at the rate of one pound of treated white spruce seed per acre i.e. placement of an average of 220,000 seeds per acre - had not yielded the required 300 to A00 trees per acre being sought. What was happening to all those seeds? Our primary objective was to answer this one question. As I shall be reviewing 10 years of work, I will be hitting only the highlights of the methods and results of our study. Radvanyi 1966, 1970a, 1970b, 1971.

Our initial approach involved an extensive program of live trapping and tagging to determine what small mammal species could be present on typical cutover areas, how the population might vary throughout the year, how it may vary from year to year, what size home range might be covered by individuals of each species, and by stomach content examinations, to determine whether or not they were actually consuming coniferous seeds. A total of 1291 individual small mammals were handled in 4,295 captures and recaptures during the 1961 summer field season. Similar small mammal studies have been conducted during each subsequent year with the result that in the past 10 years we have now handled 5,598 individual small mammals in a total of 15,723 captures and recaptures.

In 1962, while continuing the small mammal studies we introduced to Canadian forestry research the radiotracer technique developed by Lawrence and Rediske (1959) in their studies on fate of Douglas-fir seeds. The method calls for placing, in essence, miniature radiotransmitters (radio isotopes) onto individual seeds, the signals from which would then enable the researcher to relocate the seed at any time in the field and to recover the seed for examination at the end of the field study. While Douglas-fir seeds measure 6.0 - 7.0 mm in length, a whole seed of white spruce measures between 2.5 and 3-0 mm in length. As will be seen in the slides, many of the recovered seed fragments represent only 1/2 to 1/4, or even less, of the original seed coat. We were thus looking for very small needles in the big brushpiles of the cutover areas. The radiotracer technique as used here, as far as I have been able to ascertain, had not been used in Canada before and nowhere had it been used on seeds as small as those of white spruce. Our initial experiment involved the placement into the field of 2,000 radiotagged spruce seeds in June 1962. Each seed carried a Scandium 46 tag of approximately 3 µ Ci strength. The seeds could be detected from 18-24 inches distance using a portable scintillometer and could be pinpointed to the diameter of a 25-cent piece. Recoveries made in September of 1962 yielded just under 91 percent of the tagged seeds placed in the field.

By far the larger portion of broadcast seeding operations by our one pulp mill and the forestry service were being carried out during the last week of May and early June. Yet seed trap data indicated the peak of natural seed fall occurred in mid-September. Why then, were seeding operations being carried out in late spring and how would the fate of seeds differ if placed into the natural environment at other periods of the year? The initial spring seed fate study was followed by two over winter studies, a second spring seeding operation during a year of a considerably lower small mammal population and then a combined winter and spring seeding operation. Tagged seeds were left in the field from 4 months to a full year before recovery. For the longer duration studies, seeds were tagged using $Zinc_{65}$ and $Cobalt_{60}$ radio isotopes. Recovered radiotagged seeds, or fragments, were microscopically examined, and compared with seeds of known fate obtained from feeding trials involving small mammals of each species known to occur on the study areas. What has this game of cat and mouse and brushpile searching shown?

First of all, the small mammal studies combined with the radiotagging procedures have provided some of the first statistical evaluations of what has been happening to white spruce and lodgepole pine seeds in the natural environment. Over the 10 year period we have now set out 21,800 white spruce seeds. Our recovery success on these seeds has averaged 90.0 percent. They have shown that in some years small mammals -- principally white-footed mice (Peromyscus maniculatus), redbacked voles (Clethrionomys gapperi), meadow voles (Microtus pennsylvanicus),chipmunks (Eutamias amoenus) and also the classically accepted insectivores - the shrews (Sorex cinereus) can destroy within 3 1/2 to 4 months 50 percent of treated white spruce seeds sown in late spring. In our earlier studies only 1/3 as many seeds were destroyed and 5 to 7 times as many seeds germinated following winter seeding. Finally, the number of seeds destroyed did not appear directly related to the number of small mammals present. In the two spring seeding trials referred to, and carried out 4 years apart, small mammal numbers differed by 44%; yet the percentage of seeds destroyed during these two years differed by only 1.2%, (49.3 and 50.5%) respectively. Nor do I believe small mammal populations ever become low enough under natural conditions to permit successful regeneration by direct seeding methods using the then current seed treatment procedures.

Populations of seed eating small mammals on newly harvested white spruce cutover areas consisted generally of 3 - 4 animals per acre in the first spring following cutting. Fall populations on the same area usually rose to 8 - 10 animals per acre. By autumn of the second year following cutting, with increasing amounts of grass vegetation, populations reach 12 - 15 animals per acre. By the 5th - 6th year as many as 18 animals per acre can occur. Their numbers decline somewhat in subsequent years. If two animals per acre can take care of the artificial seed supply, then what are the chances of seed survival when dense grass vegetation takes over the area and small mammal populations reach 8 - 9 times this number. Laboratory tests indicate a single Peromyscus can consume in excess of 400 non-treated Douglas-fir seeds nightly, if available, or 1000 lodgepole pine seeds, or 2000 white spruce seeds or 2100 black spruce seeds. While these numbers may not be directly applicable to field conditions, still their keen sense of smell enable mice to detect a large portion of the seed supply in their habitat.

All our studies and conclusions arrived at to this point had been based on studies of seeds treated with the aluminum powder-endrin-arasan-latex coating used by foresters throughout North America for the past 18-20 years. The seed fate studies indicated the coating treatment being used so indiscriminately was not providing the degree of protection foresters had hoped for - at least not in Alberta and under our Canadian climatic conditions,

Figure 1. Placing of individual radiotagged white spruce seeds into the field in winter. Temperature -27°F.

Figure 2. Locating tagged seeds in a brushpile using a sensitive portable scintillometer.

Figure 3. Checking a germinated radiotagged white spruce seed.

Figure 4. Dense grass vegetation sometimes made it difficult to find even the seed plots.

Figure 5. Radiotagged seeds placed on the surface sometimes end up far below.

Figure 6. Tagged seed are at times far removed from their original location.

Largely through dissatisfaction with the measure of protection being accorded to coniferous seeds by the aluminum powder-endrin-arasan-latex treatment as revealed by the radiotagging studies, we extended our original 5 year project and began in 1968 to look more critically at seed coating treatments and possible ways of improving them. In the course of over 200 experiments conducted over the following two years, in which more than 25 coating ingredients or treatments were tried, singly or in combination, we ended up by discarding entirely the aluminum powder, the endrin, the arasan, and modified the form of the adhesive. In their place, dull black graphite powder replaced the bright, shiny aluminum powder. As you will see in the slides to follow, this change alone improved germination of white spruce seeds in a germinator by over 24% compared to seeds coated with aluminum powder. An effective rodent repellent (tertiary-butylsulfeny1dimethyldithio-carbamate, better known as R-55) replaced both the endrin and arasan. Germination of treated white spruce seed was further improved by changing the pH of the latex from the 9.6 level as supplied by the manufacturer and being used by almost every forester to pH 4.8 - or in other words taking the seeds from a highly alkaline microenvironment and placing them into a slightly acidic one. Lutz and Chandler 1946, Baker 1950, Spurr 1950, 1962, Jarvis, Steneker, Waldron and Lees 1966, had all contended that coniferous trees germinate better in a slightly acid medium than in an alkaline one. Yet foresters continued placing seeds within a highly alkaline coating.

Laboratory testing of the new seed coating procedure commenced in 1969. White spruce seeds treated with 4:1 weight ratios of R-55: graphite and acidified Dow latex 512, yielded over 60% germination while seeds coated with the aluminum powder-endrin-arasan-latex formulation barely reached 50% germination (Control 88%). To test the effectiveness of R-55 as a rodent repellent periodic feeding tests were conducted in which non-treated and treated white spruce seeds were made available to captive Peromyscus. In our earlier experiments the seeds were placed in separate food containers on the floor of the cage. In later tests however, it was feared that concentrating the strong pungent odour of R-55 on 1000 seeds into the confines of a small feeding dish may have been biasing the feeding reactions of the test animals. Our feeding trials now call for scattering treated and non-treated seeds onto the floor of a small empty office and allowing the test animal full freedom to pick and choose from more widely separated seeds of either treatment. Generally 1000 treated and 2000 non-treated seeds are used daily for one animal and the test is run for five consecutive days. No animal is used in more than one feeding test. The ratio:

$$\frac{\%\ \text{non-treated seeds destroyed} - \%\ \text{treated seeds destroyed}}{\%\ \text{non-treated seeds destroyed}}$$

was used to calculate the percentage effectiveness of the treatment. This is a modification of the formula suggested by Besser and Welch (1959). Feeding experiments on freshly treated spruce seeds indicated the new coating was better than 90% effective in preventing seed destruction by Peromyscus under laboratory conditions. To be useful in the field, however, the coating must continue to accord protection following prolonged exposure to climatic and edaphic factors. A weathering test was set up in which treated seeds were exposed to direct sunlight, heat, rain and periodic chilling. Feeding trials were then conducted on the weathered seeds at approximately bimonthly intervals. A marked reduction in percentage effectiveness of treatment was noted after 4) days exposure. This proved to be due to excessive handling of the seeds and the subsequent rubbing off of the coating materials. A second weathering test on both treated and non-treated seeds was run in a manner that only those seeds being used in feeding experiments were brought into the laboratory at one time. The rest remained exposed to the elements. In this second weathering test, after 12 feeding trials and 244 days of exposure of the seeds to the elements from November to July, the percent effectiveness of the R-55 graphite coating was still better than 95%.

To the present only limited field trials have been carried out on the new seed coating treatment. In the first of these our aim was to compare germination of white spruce seeds following winter placement vs spring placement and using the aluminum powder-endrin-arasan-latex coating vs the R-55/graphite-1atex treatment. Aluminum coated seeds were placed out into deep snow in January 1969 but at that time the new coating procedure had not yet been developed far enough to warrant field trial. Seeds bearing both treatments were placed out, however, in June 1969. Germination of spring placed aluminum coated seeds was 37%; similarly treated winter placed seeds gave 40.2% germination. The difference was not statistically significant. Germination of the R-55/graphite treated seeds, however, was 52% - which is highly significant, statistically speaking. Percentage of seeds destroyed in the three lots did not differ significantly suggesting that under these field conditions the amount of the new coating staying on the seeds may have a greater beneficial effect on germination than on actual protection of the seeds.

Publication of the development of the new coating treatment for coniferous seeds in The Forestry Chronicle (Radvanyi 1970) has brought considerable response from foresters all across North America and abroad, particularly with the recent ban on further use of endrin in forestry practices. Many questions were raised for which we do not have answers.

For example, most frequently asked was the question of how much of the coating ingredients are needed to treat say 20 lbs. of Douglas-fir seed, or lodgepole pine seed. We did not know as in all our developmental work we were treating only 1000 spruce seeds or less at a time. We had not calculated the amounts needed to treat larger amounts of white spruce seeds, let alone other species. The questions were very valid ones and we are seeking answers for them. Many more questions have also arisen. In all our repellent testing feeding trials, only white-footed mice were used as test animals. How effective is the coating treatment in repelling chipmunks, meadow voles, shrews, birds, insects? We do not know. What effect has the R-55 treatment on germination of seed which for some reason or another end up back in storage for possibly months? This aspect is being investigated. How applicable is the treatment or formulation on other seed species? Laboratory studies indicate the R-55/graphite treatment can improve germination and serve as an effective repellent against our most common seed eater, Peromyscus. Our most recent field trials indicate that while in the development of the coating procedure we had replaced three of the four coating ingredients being used, we now need to examine more closely that fourth ingredient - the adhesive being used to retain the protective agents on the seed. At the present this is a weak link in the application of the R-55 treatment when applied to field conditions and we hope to pursue that particular aspect further. Here too, more tests are needed. Personally, I would not anticipate one formulation will be applicable to all seed species. I would assume that an R-55/graphite latex formulation will have to be developed for each seed species. Above all, I would wish to avoid the pitfall which appears to me occurred with the aluminum powder treatment wherein foresters everywhere accepted it unquestioningly assuming that if it worked elsewhere, it will work for us here.

We do not regard the formulation we had suggested as being either final or entirely satisfactory. We are still conducting experiments trying to improve our techniques and results. I would estimate at least two more years of laboratory and five years of field testing should yet be done before aerial broadcast seeding on a large scale using the new treatment will enable foresters to begin to reduce the thousands and thousands of acres of backlog requiring artificial regeneration. With spiralling labor costs, the ever increasing demands being made on our forest resources, which do have limits, by a world population which has not set its own limits, more and more will it become imperative that cutover forest lands be successfully made productive lands shortly after harvesting. I believe direct seeding using an effective coating treatment combined with proper seedbed preparation and timing of seeding can be made to work and more economically than other reforestation methods but more research is needed in perfecting the techniques. I do not believe Canadian or American forestry can continue much longer to comfort itself under the illusion that our forests are unlimited and we have no real urgency to cope with regeneration problems - for to do so will surely place us all, and soon, beside the sage who, in speaking of our forested lands is said to have remarked "I looked around me and there it was... gone!"

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