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BIOLOGICAL CONTROL OF CONIFER SEED DAMAGE BY THE DEER MOUSE (*Peromyscus maniculatus*)

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ABSTRACT: This paper describes the development of a biological technique that successfully controls conifer seed damage by the deer mouse. Eleven experiments have been conducted on three study areas at the University of British Columbia Research Forest, Maple Ridge, B.C. Populations of deer mice have been monitored in all experiments with data from 56,000 trap nights. The technique involves a mixture of conifer seed (Douglas fir) with sunflower seed and oats which is uniformly distributed on logged areas in the late winter-early spring. Survival of conifer seed with these alternate foods was excellent, compared with control Douglas fir by itself, for an 8-week period during this time of year. Populations of seed-eating birds and chipmunks are not present on clearcut areas from late October to early April. In addition, deer mice are at their lowest density during the spring. Thus, the use of alternate foods with Douglas fir seed in a direct-seeding operation at the appropriate time of year will result in successful regeneration of cutover forest lands.

INTRODUCTION

For almost half a century foresters in North America have used direct seeding as a method of regenerating cutover forest lands. Destruction of the seed supply by small mammals and birds has had adverse effects on the success of these reforestation projects. Black (1969), Radwan (1970), and Radvanyi (1973) have provided comprehensive reviews on this subject. The deer mouse (*Peromyscus maniculatus*) is considered to be the most important seed predator in the Pacific Northwest. Chipmunks, microtines, and several species of seed-eating birds have also contributed to the problem by their consumption of conifer seeds (Black, 1969; Radvanyi, 1973; Pank, 1974).

There have been two basic approaches to reducing conifer seed predation by small mammals and birds. Firstly, there are conventional control methods which have mainly involved chemicals and secondly, there is biological control. Conventional control methods have predominated and the following discussion about them is based on reviews by Radwan (1969, 1970). Control, used in the context of this paper, means to control damage.

Since the early 1900's, forest managers in the Pacific Northwest have tried numerous methods for protecting coniferous seeds from rodents and birds. These include mechanical devices, poison baits, and toxicants and repellents applied directly to seeds. Mechanical devices such as screens have been too expensive and not practical for large scale field projects such as reforestation. Poison baits are now considered ineffective because control of rodents is only possible for *very* short periods of time. Elimination of the initial rodent population is incomplete and reinvasion from surrounding areas is often rapid (Gashwiler, 1969; Radwan, 1969; Hooven, 1975). Poisons, either as baits or as toxicants on seeds, are hazardous to nontarget species and the fate of these chemicals in the environment is unknown (see review by Evans, 1974). In addition, the direct application of toxicants and repellents to seeds has often resulted in reduced seed germination (Radwan, 1969, 1970). According to Evans (1974), a substantial change in priorities has taken place, from exclusive reliance on chemicals to research directed towards nonchemical methods of control. There is a trend to phase out persistent pesticides (toxicants and repellents) and replace them with less persistent and less hazardous chemicals. In the meantime, perhaps methods of biological control can be developed which will provide long-term solutions to this reforestation problem.

A broad concept of biological control with respect to insects has been discussed by van den Bosch (1971). This concept involves an attempt to reduce the average density of a pest population by the action of parasites, predators, or diseases. However, biological control can also be more generally defined as a type of control in which the damage caused by the pest is reduced or eliminated by a biological agent or process. This approach has been discussed by Howard (1967) where he includes habitat modification resulting in reduced food and cover, or intentional alteration of the pest's environment resulting in lowered numbers of the pest species. Assuming the pest population does not necessarily have to be reduced, biological control may also refer to the use of preferred (buffer) or alternate foods. This process has shown some success in luring waterfowl away from grain and vegetable crops (Howard, 1967). Flocks of dark-eyed juncos have been easily diverted from fir seed by supplying artificial food at just one place on a cutover (Hagar, 1960). Prunings piled around the base of orchard trees as a buffer food have often minimized damage from meadow voles (Fitzwater, 1962). Browsing of conifer seedlings by deer may be reduced by the availability of alternate and more preferred species of browse (Campbell, 1974).

A biological technique for controlling conifer seed predation in the deer mouse is discussed in this paper with respect to the functional and numerical responses of deer mice to varying densities of Douglas fir seeds. If the upper limits for the number of mice and number of seeds eaten per mouse can be determined, then the use of alternate foods with Douglas fir seeds could result in reduced predation on the conifer seeds. Presumably, the mice develop what might be termed an "olfactory search image" to exploit a food source. Howard and Cole (1967), Howard *et al*. (1968), and Howard and Marsh (1970) have provided evidence for the use of olfaction by deer mice in detecting food. Therefore, by introducing alternate foods of varying palatabilities, densities, and distributions, the predators may switch to a new food source with a resulting increased survival of conifer seeds.

This paper will describe the development of a biological technique for controlling conifer seed predation in deer mice. This method will provide the basis for successful regeneration of cutover forest lands by direct seeding. Eleven experiments were conducted during the course of this project over a 3-year period (1975-77). The success of these experiments was measured in survival of seeds rather than survival and growth of seedlings. This was due to the requirement for several short-term experiments which could be replicated in time and over a number of different areas.

Thus, the following topics will be discussed:

1.) The functional (number of seeds eaten) and numerical (number of animals) responses of deer mice to a wide range of seed densities.

2.) The effects on seed survival and deer mice by the use of alternate foods.

3.) The recommended procedure by which this biological technique should be applied in reforestation projects.

DESCRIPTION OF STUDY AREAS

This project was located in the University of British Columbia Research Forest at Maple Ridge, B.C. (Fig. 1). Field installations (grids and lines) were located in forest and clearcut habitats.

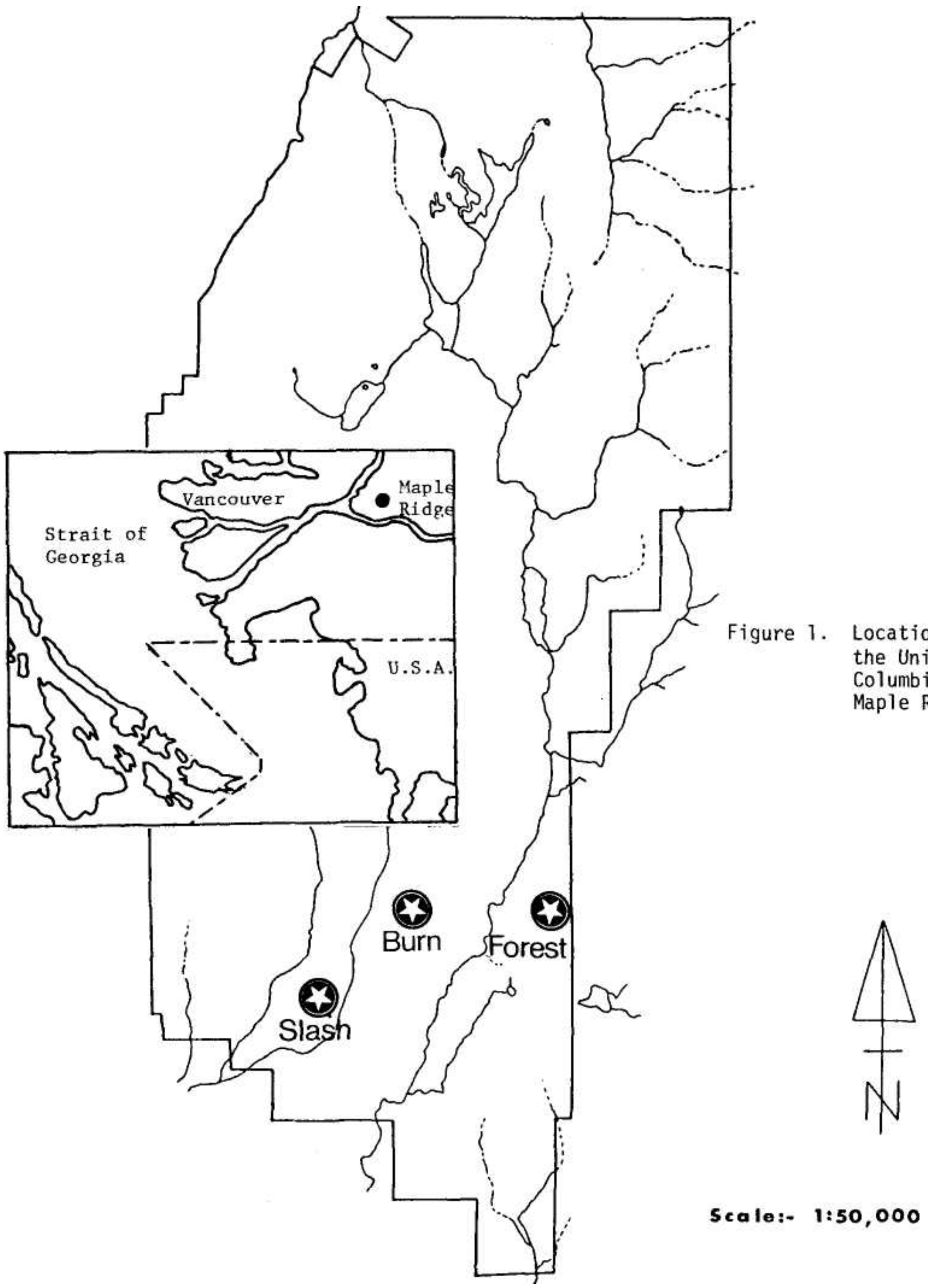

Figure 1. Location of study areas at the University of British Columbia Research Forest, Maple Ridge, B.C.

The forest habitat, in the southeast corner of the Research Forest, consisted of second growth timber following a fire in 1925. Natural regeneration began between 1930 and 1932 and resulted in a forest 43 to 45 years old. It is dominated by western hemlock and western red cedar with some Douglas fir; ground cover vegetation is sparse. Grids A, B, C, D, E, and F were situated in this area and all were on relatively flat terrain.

The clearcut habitat was located in two areas in the southern part of the Research Forest. Grids G, H, I, and J were on an area logged in the fall of 1973 followed by burning in September 1974. The slash burn was uniform in some areas but patchy in others. The main cover was burnt or dead slash with growth of bracken, fireweed, and several other less abundant successional herbs. Grids K and L were on a similar area also logged in the fall of 1973 but not burnt. Cover included dead slash and a similar species composition and dominance pattern to that of the burn. Of these six grids, G was on a 20 degree slope with southwest aspect and all others were on a relatively flat landscape.

Traplines for monitoring chipmunk populations were located along the boundary of the forest and clearcut habitats at the Burn and Slash study areas.

MATERIALS AND METHODS

Deer Mouse Populations

From May to September 1975, April to November 1976, and March to November 1977, twelve 2.07 acre grids (A, B, C, D, E, F, G, H, I, J, K, and L) were livetrapped every two weeks with Longworth live traps. On each checkerboard grid, 49 trap stations were located at fifty foot intervals marked by flagging tape and string (Fig. 2). One live trap was placed within a six foot radius of each station.

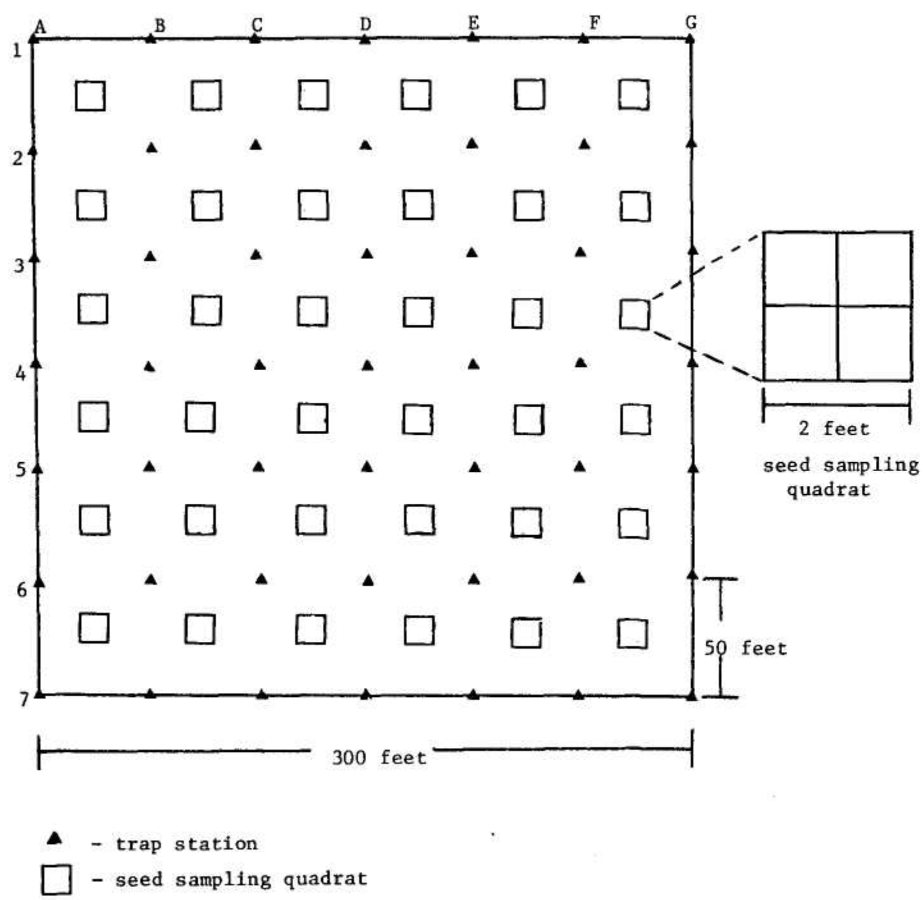

Figure 2. Live-trap grid (2.07 acres) with 49 trap stations (1 trap per station) and location of 36 (4 square feet) seed sampling quadrats.

Traps were baited with peanut butter, Purina lab chow, and Terylene batting was supplied as bedding. Traps were set on day 1, checked on days 2 and 3, and then locked open between trapping periods.

All deer mice captured were weighed on Pesola spring balances, sexed, and ear-tagged with serially numbered fingerling fish tags. The best estimate of population size is minimum number of animals known to be alive (MNA) at each consecutive two week interval (Hilborn *et al.*, 1976). If x number of animals captured at time t are not caught at t+1 but are recaptured at t+2, then those x animals were alive but not censused at t+1 and so should be included in the density estimate for that time.

A control grid in each of the forest and clearcut habitats provided demographic information on the performance of deer mice. The other grids have received various seed treatments in 11 experimental seed trials. All other small mammal species which could be taken by trapping were removed from each of the experimental grids seeded with only Douglas fir seed but no animals were removed from grids seeded with Douglas fir and alternate foods. This allowed precise measurement of the functional and numerical responses of deer mice to increasing density of Douglas fir seeds without interference from other species of small mammals. The forest grids, unlike those on the clearcut, were unaffected by any observed residence or seed predation by birds and therefore, provided reliable responses of deer mice to a range of seed densities.

Chipmunk Populations

From July to November 1976 and March to November 1977, two traplines (Burn and Slash study areas) were livetrapped every two weeks with Sherman live traps. Each line was approximately 3000 feet long with 25 trap stations located at 125 foot intervals. Two traps were placed at each station. The trapping procedure was similar to that for deer mice except traps were set on the morning of day 1, checked the same afternoon, and then the following morning and afternoon of day 2. To avoid interference between lines and grids in the same area, chipmunk lines were usually trapped after completion of the deer mouse trapping period or on alternate weeks.

Populations of Seed-eating Birds

From February to November 1977, populations of seed-eating birds were censused at the Burn study area. During the mornings, usually between 8 to 10 a.m., the number of birds of each species observed on each of the four grids (G, H, I, and J) was recorded. The observer walked the "C" and "E" lines of each grid counting all birds present on that grid. Care was taken not to enumerate an individual bird more than once. This census occurred on one or two days every two weeks and provided information on the number of birds of each species per hectare over the different seasons of the year. Birds were not censused in July and August although the most abundant species were present during these months.

Seed Populations

Each of the experimental live trap grids was systematically divided into 36(50 feet x 50 feet = 2500 square feet) plots. In each plot, a 2 foot x 2 foot quadrat was located in a suitable area for seed sampling and recovery (Fig. 2). A plastic cover was placed over 25 randomly selected quadrats on each grid during experiments with alternate foods in 1976-77. These covers prevented rain from disturbing the seed sampling areas but were propped up to allow mice and any other potential seed predators free access under them. They were placed on the grids at least one week before the first seed experiment began.

Prior to each experiment, seed was weighed and packaged according to the amount desired per square foot of grid (area of grid = 90,000 sq. feet). Several samples of 2500 Douglas fir seeds, 1000 sunflower seeds, and 1000 oats were weighed with the mean value representing that given number of seeds. This value was subsequently used as a multiple to obtain the number of seeds by weight for each of the 36 plots on a grid.

In each of the 25 chosen plots, a known density of seed was placed in one or more of the 4 (one square foot) units in a seed sampling quadrat. Location of individual seeds was marked by wooden toothpicks. The rest of the allotted seed was spread by hand as uniformly as possible over the 2500 square feet of that plot. Care was taken not to accidentally throw more seed into the sampling quadrat during this seed dispersal.

Sampling was then conducted at two week intervals for the next six weeks. Remains of eaten Douglas fir seeds were removed each week for eventual identification of predator. Whole seeds were left in place for sampling in subsequent weeks of that experiment. The difference in estimated number of seeds per acre from these samples at consecutive time intervals provided a measure of conifer seed survival.

To measure potential natural seed-fall during these experiments, one seed-fall trap was placed in a central position on each grid. They were four square feet in area composed of a frame box (1 inch x 3 inch sides). Window screen (14 by 18 mesh) covered the base with three-eighths inch mesh hardware cloth on the top allowing seeds to fall into trap.

RESULTS

Experimental Seeding with Douglas Fir Seed

The responses of numbers of mice to changing seed density for 1975-77 are illustrated in Figure 3. Total numbers (MNA) over a range of seed densities and the controls are shown. These responses represent the first two weeks following each seeding corresponding with the highest rates of consumption

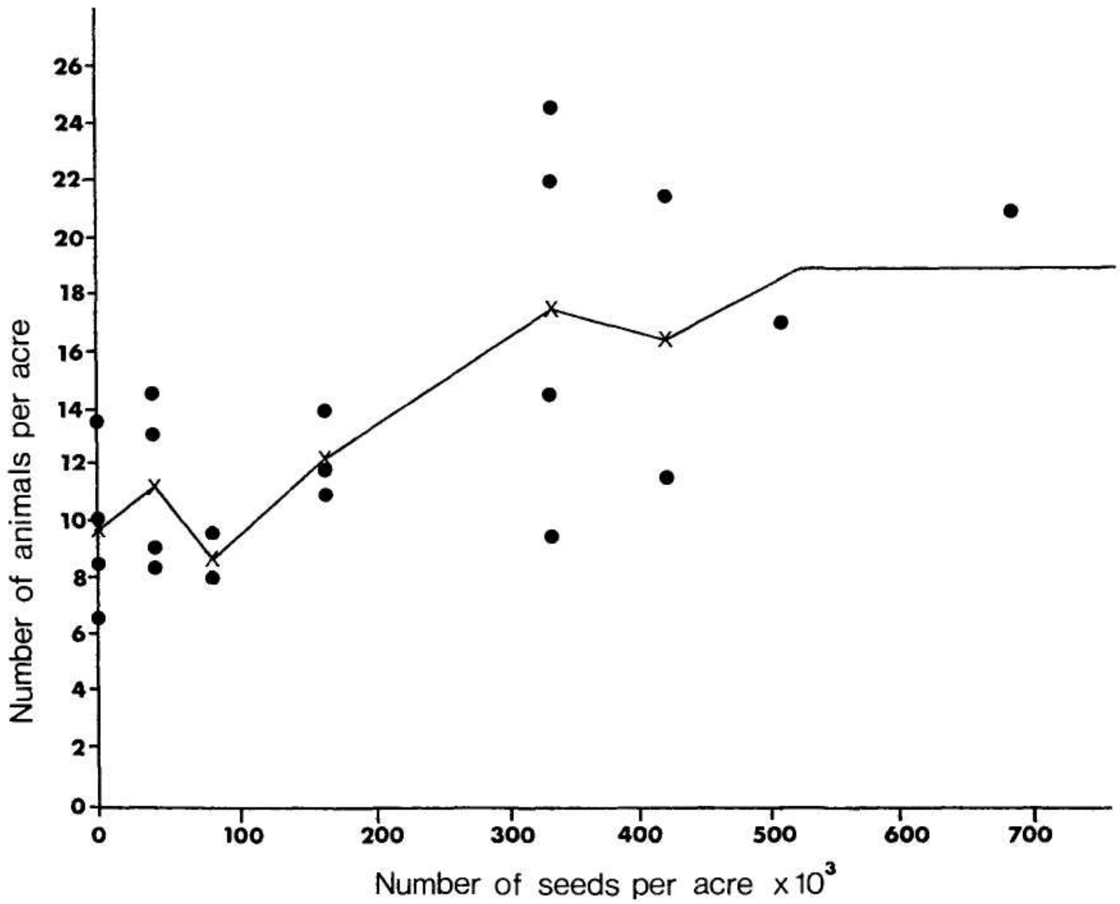

Figure 3. Responses of numbers of mice over a range of Douglas fir seed densities for the study. Each black dot represents the response in density of deer mice (MNA) to the density of seeds on a grid. The line connects the average number of animals at each seed density.

on all grids. There was very little difference in the number of animals at the first 4 seed densities. There was then an increase in density of mice which levelled off at 348,000 seeds/acre.

The number of seeds taken per mouse per day (functional response) is presented in Figure 4. This response has been calculated for the first two weeks following seeding in each experiment. The increase in consumption with seed density started to level off at 174,000 seeds/acre. Consumption increased again at 348,000 seeds/acre and then reached another plateau at a density of 435,000 seeds/acre.

Experimental Seeding with Douglas Fir Seed and Alternate Foods

The results of experimental seeding with Douglas fir and sunflower seed in a uniform distribution on the clearcut in November 1976 are presented in Figure 5. After 2 weeks, there was 50% and 40% respectively, of the Douglas fir seed (with sunflower) remaining compared with control Douglas fir by itself. The same density of sunflower seed was uniformly distributed (sequential seeding) on one of the experimental areas after the second week. Survival of Douglas fir seed at week 4 dropped 10% on the grid with sequential seeding of sunflower which was the same as the decline (50% to 40%) on the other experimental grid. Very little sunflower seed remained on either grid at this time. Thus, it appeared that sequential seeding did not increase survival of Douglas fir beyond that already obtained with the initial seeding of sunflower.

Histograms of percentage survival of Douglas fir seed and sunflower seed in a spring seeding experiment from March to May 1977 are given in Figure 6. At week 2, there was excellent survival of Douglas fir (with sunflower) compared with Douglas fir by itself. Following the sequential seeding, survival of Douglas fir continued to be much higher than the control. However, there appeared to be little difference between the two sets of grids with respect to sequential seeding at week 2. Survival was slightly higher in weeks 6 and 8 on the grids with this second seeding.

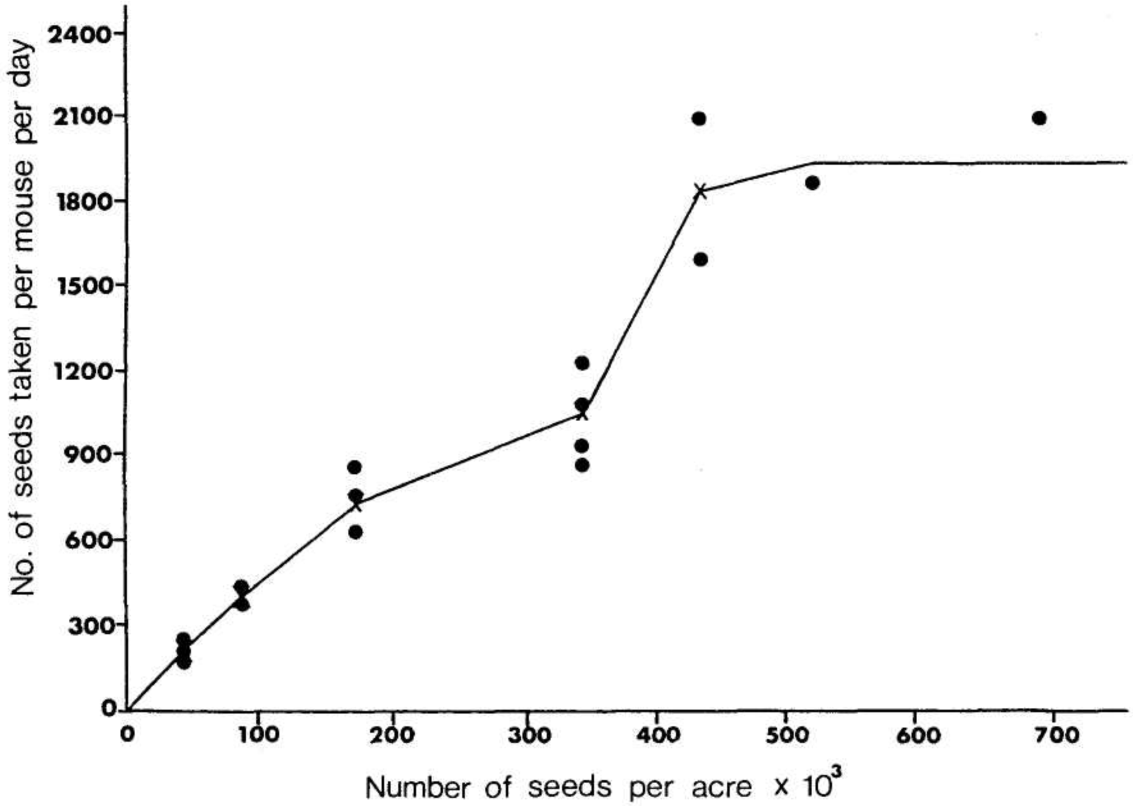

Figure 4. The number of Douglas fir seeds taken per mouse per day (functional response) at changing seed densities. Each black dot represents the response in number of seeds taken per mouse per day to the density of seeds on a grid. The line connects the average response at each seed density.

In summary, this spring seeding experiment resulted in excellent survival of Douglas fir seed at a level at least four times that of the control throughout the 8 weeks. At week 2, there was over 11,000 seeds/acre (seeding at 1/4 pound/acre) available to produce seedlings. Even at the end of the experiment, there was still over 4,000 seeds/acre available to grow into trees on the clearcut.

In an attempt to lower the number of sunflower seeds to be mixed with Douglas fir in a direct seeding operation, experimental seeding was done in June 1977 with ratios of 5:1 and 3:1 sunflower to Douglas fir. The results showed survival to be very poor on all grids at these ratios. Consequently, it appeared that the 7:1 ratio of sunflower to Douglas fir would give the best results for reforestation.

While still using a ratio of 7:1, a mixture of 5 sunflower : 2 oats : 1 Douglas fir was tried in the next experiment in July 1977. By the use of 2 alternate food sources, it was hoped this ratio would at least equal or even improve survival of conifer seed beyond that already obtained. In addition, oats cost less than sunflower seeds, thereby further reducing the cost of this already economic method of reforestation. The 5:2:1 ratio produced slightly better survival of Douglas fir than the 7:1 ratio but all experimental grids showed poorer survival overall relative to the spring (1977) or late fall (1976) seeding experiments. Thus, this same experiment was repeated at a more appropriate time of year in November 1977.

The results of seeding with oats and sunflower in late fall 1977 are shown in Figure 7. There was excellent survival of Douglas fir (with sunflower and oats) at weeks 2 and 4 in both experimental treatments. This was comparable to the results obtained in the spring seeding experiment.

As indicated by seed-fall traps, there appeared to be no natural fall of Douglas fir seeds on any of the grids in either habitat during 1975-77.

Chipmunk Populations

The seasonal variation in density of chipmunks from the Burn trapping area is shown in Figure 8. In 1976, the population was stable during August and September following the increase in number of animals during the initial weeks of trapping. Density began declining in October as animals went into hibernation. Chipmunks reappeared in late March-early April 1977, and were present on the study area until late October. There was no difference between the Burn and Slash trapping areas with respect to seasonal variation in numbers of chipmunks.

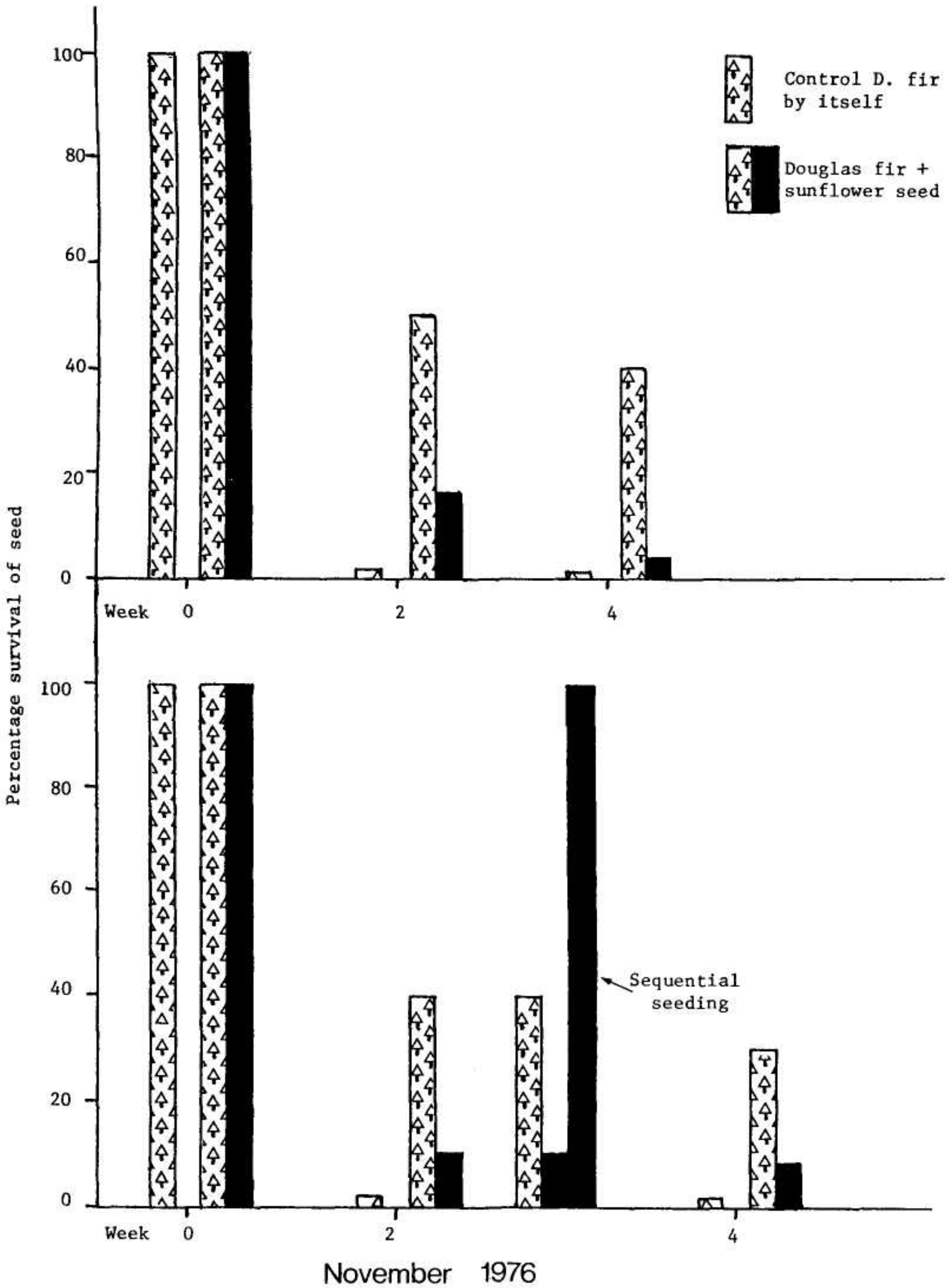

Figure 5. Histograms of percentage survival over time of a mixture of Douglas fir and sunflower seed compared with control Douglas fir by itself. The same proportion (7 sunflower : 1 D. Fir) was used on both clearcut grids in November 1976. The same density of sunflower was again distributed on one grid after the second week (sequential seeding).

Populations of Seed-eating Birds

The six most common species of seed-eating birds and their density per hectare throughout 1977 are shown in Figure 9. The dark-eyed junco was the most abundant species during this study. Most species of these seed-eating birds were absent or at very low densities up to late March when they became more abundant on the clearcut. In late October, these birds again became less numerous probably due to migration to more favorable regions for the winter.

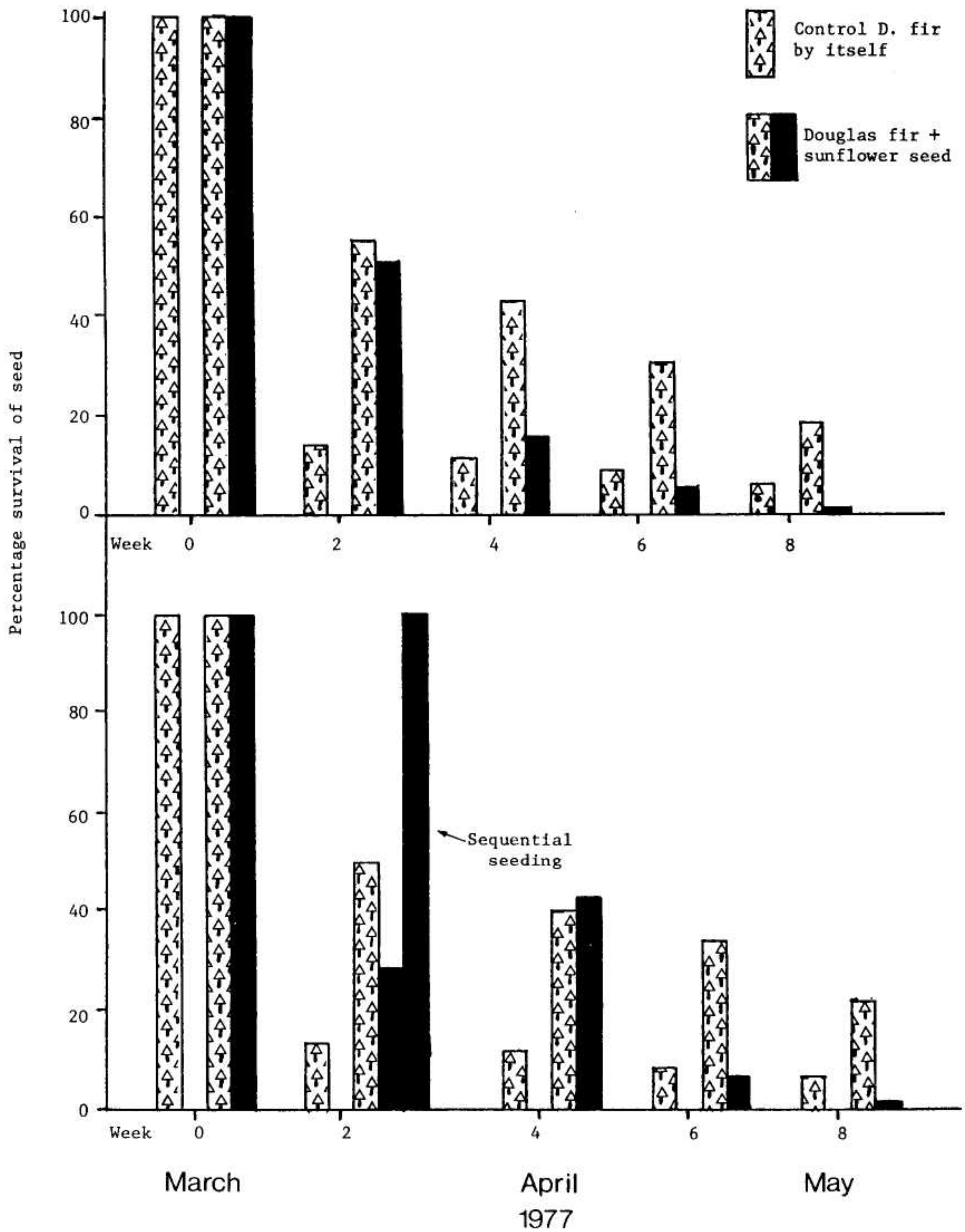

Figure 6. Histograms of percentage survival over time of a mixture of Douglas fir and sunflower seed compared with control Douglas fir by itself. The same proportion (7 sunflower : 1 D. fir) was used on all clearcut grids in this experiment from March to May 1977. The same density of sunflower seed was again distributed on 2 of the 4 grids after the second week (sequential seeding). The values given for each 2-week period are the average survival of seed from 2 experimental grids.

DISCUSSION

The responses of total numbers of animals followed the predicted numerical response of deer mice to increasing seed density. There was not an increase in the number of mice as the range of seed densities increased. There is an upper limit to the total number of mice and consequently, number of new animals, that can live on a given area even when the environment is saturated with food.

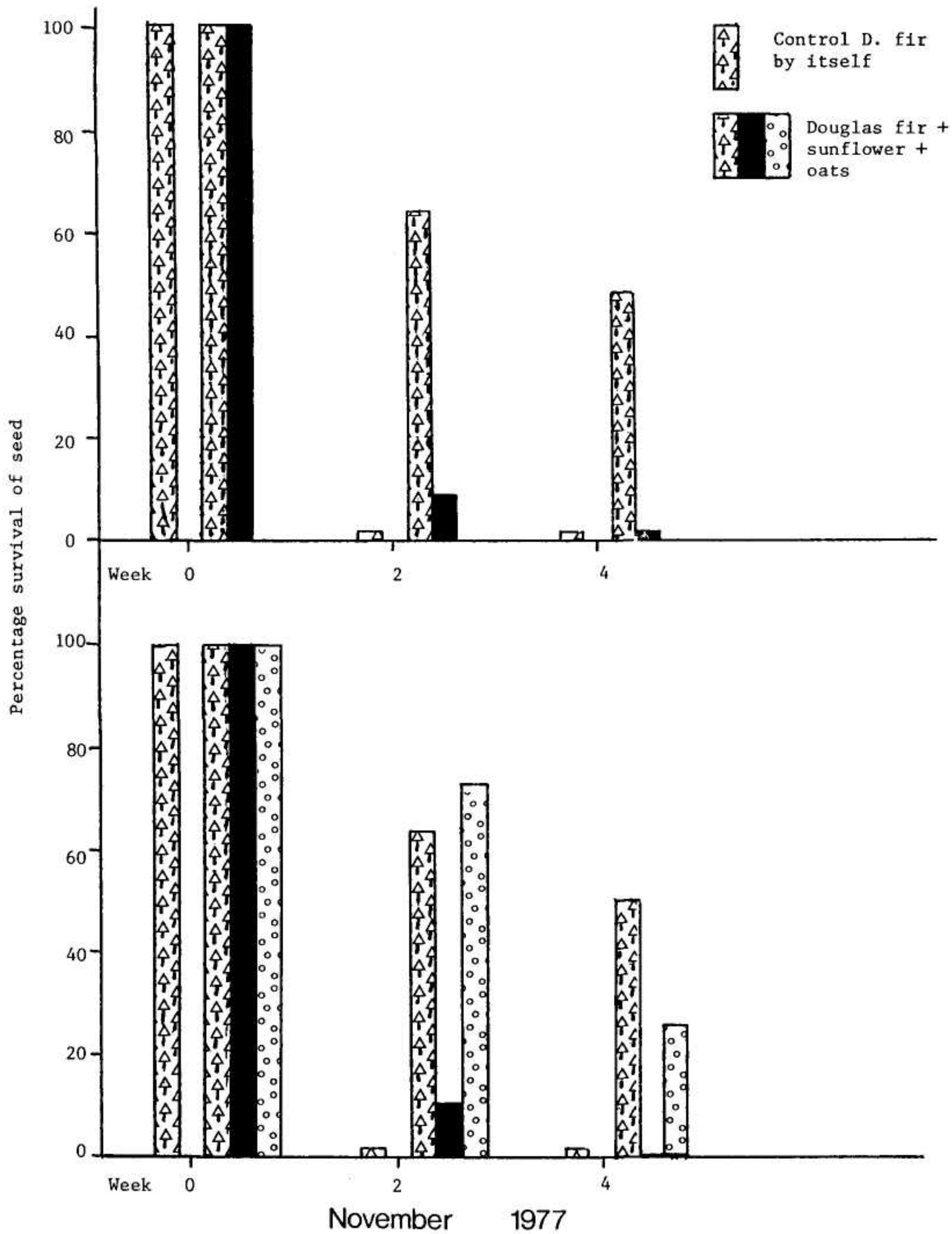

Figure 7. Histograms of percentage survival over time of a mixture of Douglas fir, sunflower seed, and oats compared with control Douglas fir by itself. The same proportion (5 sunflower : 2 oats : 1 D. fir) was used on 2 grids and a 7:1 ratio of sunflower to D. fir was used on a third grid on the clearcut in November 1977. The values given for each 2-week period for the 5:2:1 ratio are the average survival of seed from 2 experimental grids.

Similarly, the number of seeds eaten (functional response) followed the predicted pattern over a wide range of seed densities. It was assumed that those seeds not left as whole seeds or eaten remains were taken either out of the sampling quadrat and eaten, or stored by mice in seed caches. Referring again to Figure 3, the number of seeds taken per mouse per day levelled off at a density of about 174,000 seeds/acre and maintained this response up to approximately 348,000 seeds/acre. Since the numbers of animals stabilized at about 348,000 seeds/acre, it seemed logical to try alternate seed experiments at a combined seed density of about 348,000 seeds/acre (8 seeds/square foot). At this density, the number of mice is no longer increasing and the number of seeds taken per mouse per day has reached an upper limit. The number of seeds taken does not increase again until a higher density of seeds is encountered.

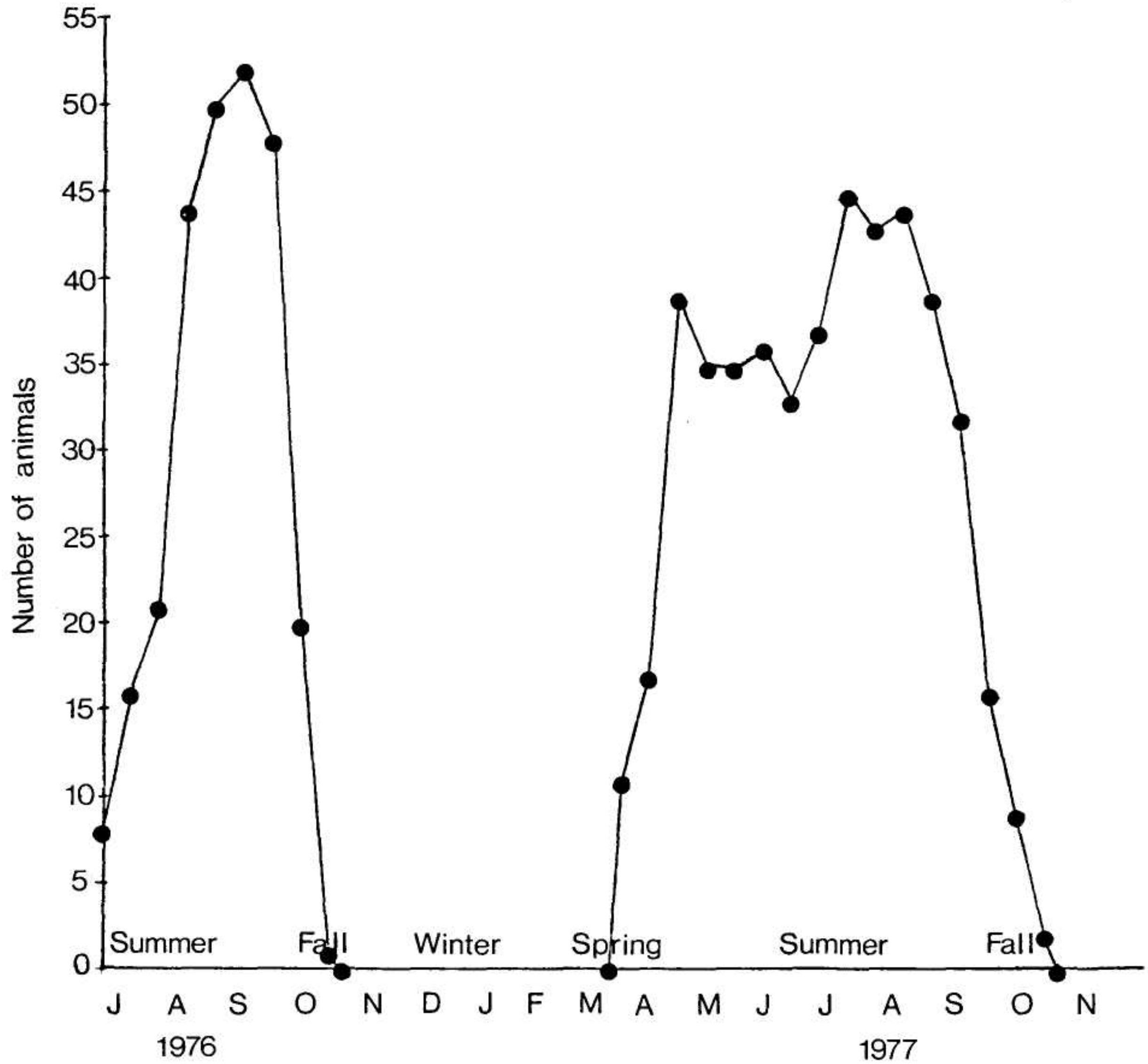

Figure 8. Number of chipmunks on the Burn trap-line for 1976-77. Minimum number known to be alive (MNA) for 25 trap stations covering 3000 feet has been plotted against time.

Populations of deer mice are at peak densities during the fall and are at the lowest point of their annual cycle in the spring (Sadleir, 1965; Healey, 1967; Fordham, 1971; Petticrew and Sadleir, 1974; Fairbairn, 1977; and Sullivan, 1977). Populations of chipmunks and seed-eating birds are present on clearcut areas from April to late October. Therefore, the very best time for seeding with respect to low populations of seed-eating small mammals and birds is in late winter-early spring. According to a review by Waldron (1973), the majority of direct seeding to date, in Canada, has been carried out in the Autumn. Similarly, in the northwest regions of the United States, seeding has been mainly done in the fall (Carmichael, 1957; Lavender, 1958). However, Arnott (1973), in his review of germination and seedling establishment, concluded that seedbed moisture and temperature conditions are likely to be optimum in the spring.

These observations fit in well with the results obtained in my spring 1977 seeding experiment. In addition, seeding experiments in the late fall of 1976-77 also produced valid results on survival of conifer seed which may be applied to spring conditions. Thus, the success of different Douglas fir to sunflower (and oats) ratios is presented in Figure 10. The 7:1 and 5:2:1 ratios produced excellent survival of conifer seed. These results may also be expressed as the potential number of seedlings per acre (assuming, in this case, the cutover area is direct-seeded with 1/4 lb. Douglas fir seed/acre).

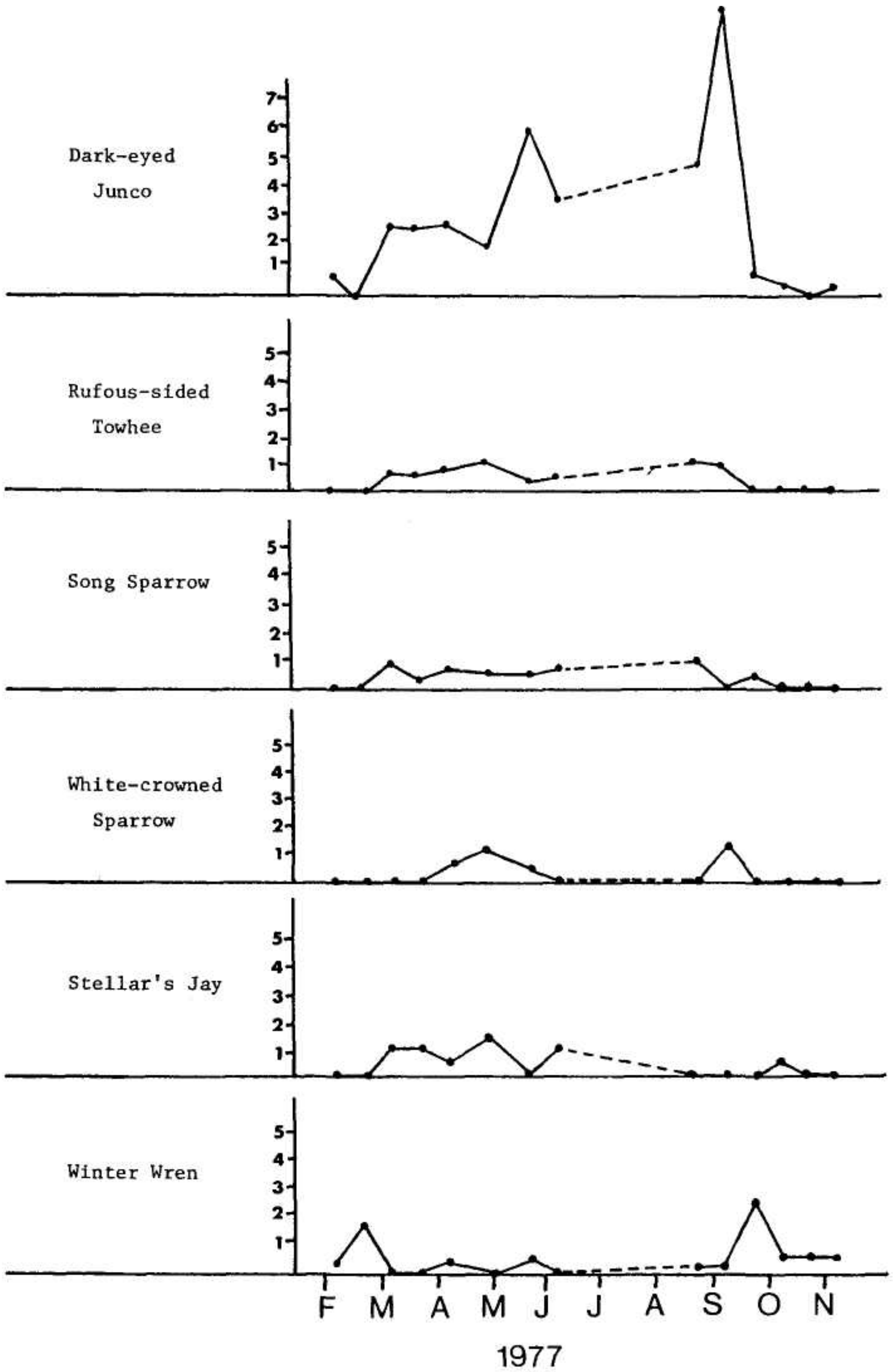

Figure 9. Numbers of the six most common seed-eating bird species on the Burn study area. Each black dot represents the number of birds per hectare (2.5 acres) as an average from 4 different grid areas.

Application in Reforestation Projects

This biological technique for regenerating cutover forest lands should be applied in the early spring (March-April) in the year after an area is logged. The recommended mixture of seed to be aerially seeded over a clearcut is as follows: 1/4 pound Douglas fir seed or other conifer seed to 50 pounds sunflower seed and 6 pounds oats per acre. To obtain maximum effectiveness, the seed must be applied uniformly over the area of the clearcut. In addition, the conifer seed must be stratified for at least three weeks and soaked in growth hormones developed by J. Walters and P. Stovicek of the U.B.C. Research Forest. This procedure should promote seed germination within a 2- to 4-week period

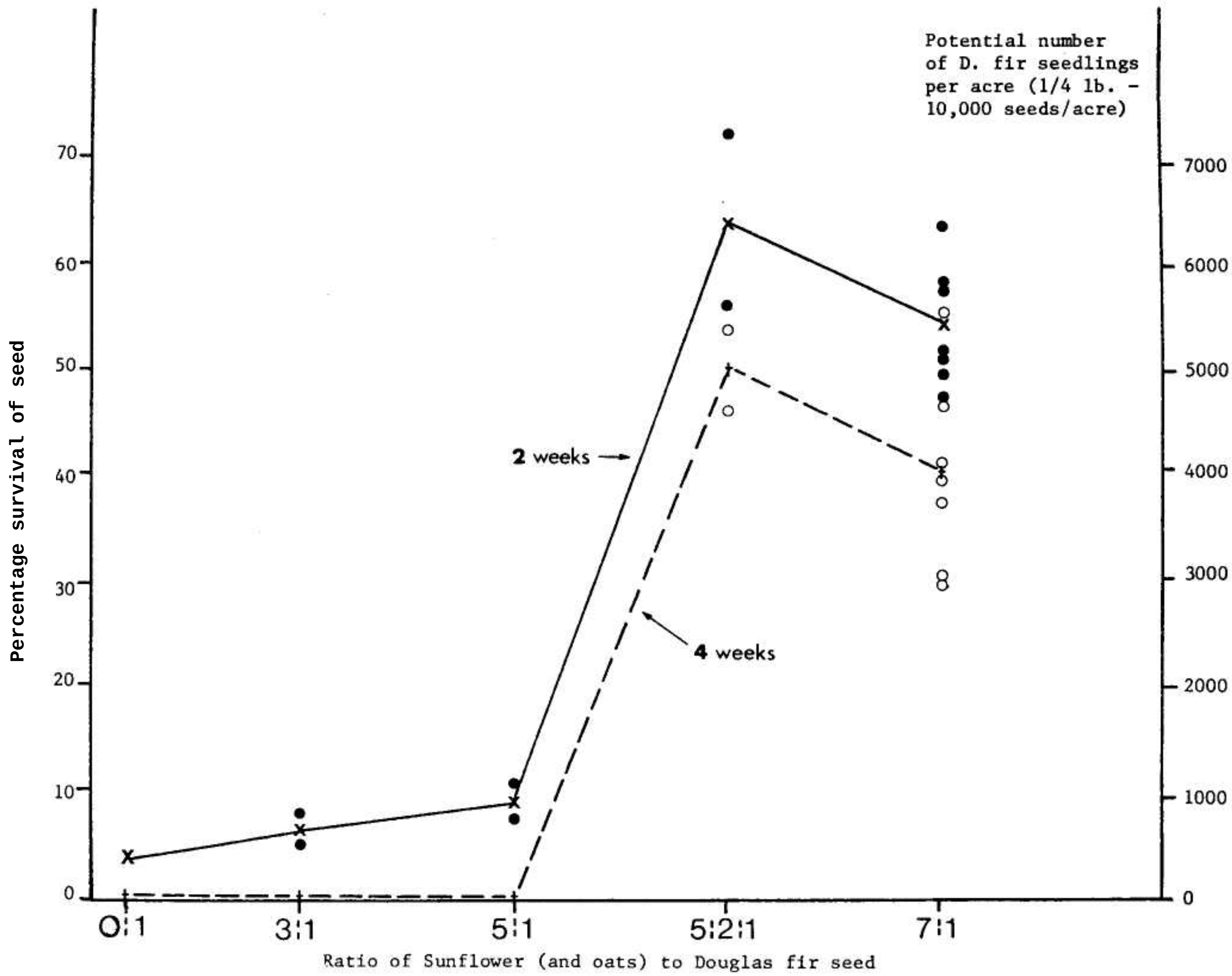

Figure 10. The success of different Douglas fir to sunflower (and oats) ratios after 2 and 4 weeks following seeding. The potential number of seedlings per acre at a seeding density of 1/4 lb. D. fir per acre is also shown. The black dots represent percentage survival of Douglas fir after week 2. The line connects the average value at each ratio. The open circles represent percentage survival after week 4. The dashed line connects the average value at each ratio.

following direct seeding. This time period is well within the average length of time (8 weeks) in which Douglas fir seed showed excellent survival during my spring experiments. The suggested procedure for applying this biological technique in direct-seeding operations is summarized in Figure 11.

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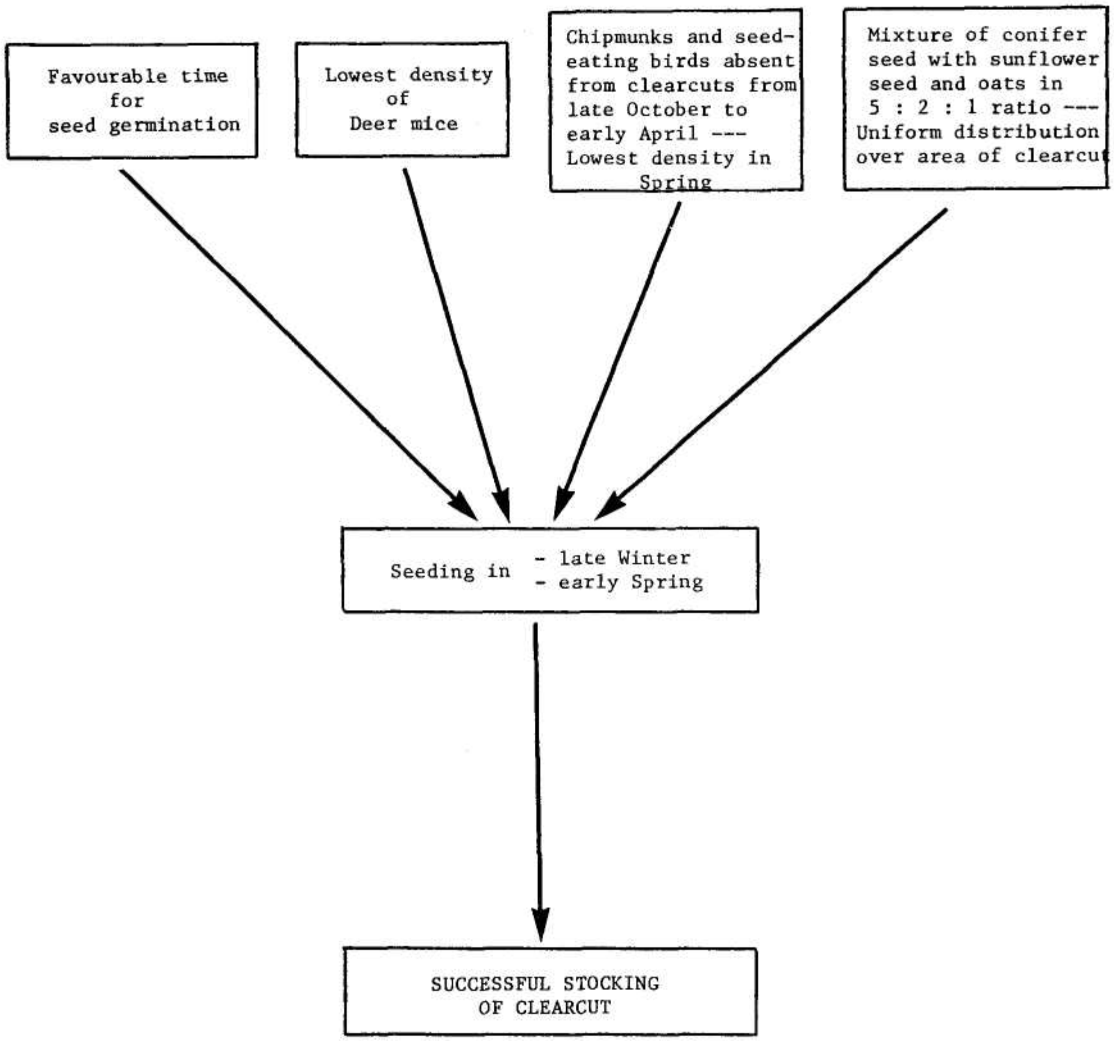

Figure 11. Recommended procedure for successful stocking of a clearcut area by direct seeding with conifer seed and alternate foods.

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