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RESPONSE OF A FOREST ECOTONE TO IONIZING RADIATION

Summary Report

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Abstract

Compositional and structural characteristics of three forest types, including aspen dominated, maple-birch dominated, and an intervening ecotone, were studied before and after irradiation in northern Wisconsin. Preirradiation findings are reported in papers by Murphy and Sharitz (1974) and Murphy, Sharitz, and Murphy (1974).

Irradiation occurred during the summer of 1972. By the summer of 1973, the density of viable tree seedlings at 10 m from the radiation source was substantially reduced in all three areas relative to the preirradiation densities of 1971. Re-establishment of tree seedlings has thus far been prevented by the vigorous development of ground vegetation at 10 m. At 20 m, the density of seedlings in the three areas increased during the period between 1971 and 1973 in response to the partially opened canopy. The overall density of seedlings of _Populus tremuloides_ and _Acer rubrum_ increased markedly in the three areas and _P. tremuloides_ invaded some areas in which it had not been found prior to irradiation. By 1974 many of the seedlings at 20 m had reached the sapling size-class. Viable trees greater than 2.5 cm dbh were eliminated at 10 m in all three areas by June of 1974 and were reduced in density at 20 m.

Leaf litter production was reduced by up to 94% at 10 m and 64% at 20 m during the period between 1971 and 1973 in the irradiated areas. The reduction was greatest in the aspen area. Leaf litter reduction in the ecotone and maple-birch areas was less severe, averaging 56% at 10 m and 27% at 20 m. The rate and compositional characteristics of succession in the ecotone relative to aspen and maple-birch forest types is presently under study.

Background

The investigations described herein and in the two appended reprints were begun in 1971 in cooperation with the Radiobiology of Northern Forest Communities Project of the Institute of Forest Genetics at Rhinelander, Wisconsin. The scope of the study remains as described in the original proposal. The study seeks to determine the immediate and long-term effects of ionizing radiation on the populations of tree species in an ecotone, or transition zone, linking aspen and maple-birch forest types in the Enterprise Radiation Forest near Rhinelander. Ecotones constitute a spatially significant portion of northern forests due to lumbering and associated disturbances which have tended to create a mosaic of relatively distinct successional forest types with abrupt boundaries.

Permanent transects concentric to the radiation source were established at 10, 20, 30, 40 and 50 m from the source in the preirradiation study (see Murphy and Sharitz, 1974, appended) and these same transect plots have been used to document radiation effects and the subsequent characteristics of succession of tree species in the experimental areas. Three control areas, well-removed from the radiation area, were also sampled. The immediate effects of radiation have now been documented but additional information will be required to adequately evaluate the characteristics of recovery, or succession, in the three areas. An evaluation of the rates and characteristics of recovery is essential for a meaningful assessment of the overall impact of radiation.

Oral presentations of preliminary findings were made at two conferences during 1973 (the Annual Meeting of the Michigan Academy of Science and the Annual Meeting of the American Institute of Biological Science) and at one conference in 1975 (The Fourth National Symposium on Radioecology).

The total budget for this project has been: 1972-73, $1725.00; 1973-74, $2135.00; 1974-75, $2360.00.

Preirradiation Studies

The collection and analysis of preirradiation data as described in the original proposal has been completed. The results of this work are summarized in two papers that were published in the AEC volume entitled The Enterprise, Wisconsin, Radiation Forest (TID-26113). Reprints of the two papers are appended to this report. The papers describe the floristic (tree species) composition of the seedling, sapling, and canopy strata at 10, 20, 30, 40, and 50 m from the radiation source prior to exposure. Estimates of forest structural features including tree species diversity, leaf area index, and leaf litter production for tree species along a gradient of distance from the radiation source are also presented in these papers. These data are intended to serve as a base-line for evaluating radiation effects and forest recovery.

Postirradiation Studies

Using the permanent transects established in the preirradiation study, preliminary data concerning the response of the aspen, ecotone, and maple-birch areas to irradiation were collected during the summer and fall of 1972, 1973, and 1974. Additional data were collected in June of 1975 and one additional sampling trip is scheduled for the present contract period. The collection and analysis of postirradiation data has not, therefore, been completed at this time. The following sections review the data concerning changes in tree species composition and changes in patterns of leaf litter production through June, 1975.

Changes in the Tree Flora

Figures 1-3 show the year-to-year changes in density of populations of tree species, by size class and distance from the radiation source, in the aspen, ecotone, maple-birch, and control areas. Irradiation occurred during the growing season of 1972. The data for 1972 were collected while irradiation was still occurring and mortality was not fully expressed at that time.

Average cumulative radiation doses, calculated from the data of Brad Salmonson, are shown below.

Distance from radiation source	Cumulative dose
10 m	58.0×10^3 R
20	11.5×10^2
30	4.2×10^2
40	2.4×10^2
50	1.4×10^2

Seedlings. Figure 1 shows annual changes in the density of tree seedlings (less than 30 cm in height) for the period 1971-75. In some cases, small root sprouts may have been categorized as seedlings.

In the aspen and ecotone controls, the density of seedlings increased slightly over the years 1971-75 but in the maple-birch control the density declined slightly. Apparently, some year-to-year variation in the density of seedlings is "normal". In all instances, the average density was less than one seedling per meter square.

In the irradiated areas there was little evidence of any radiation-induced changes in seedling densities by late September of 1972 while irradiation was

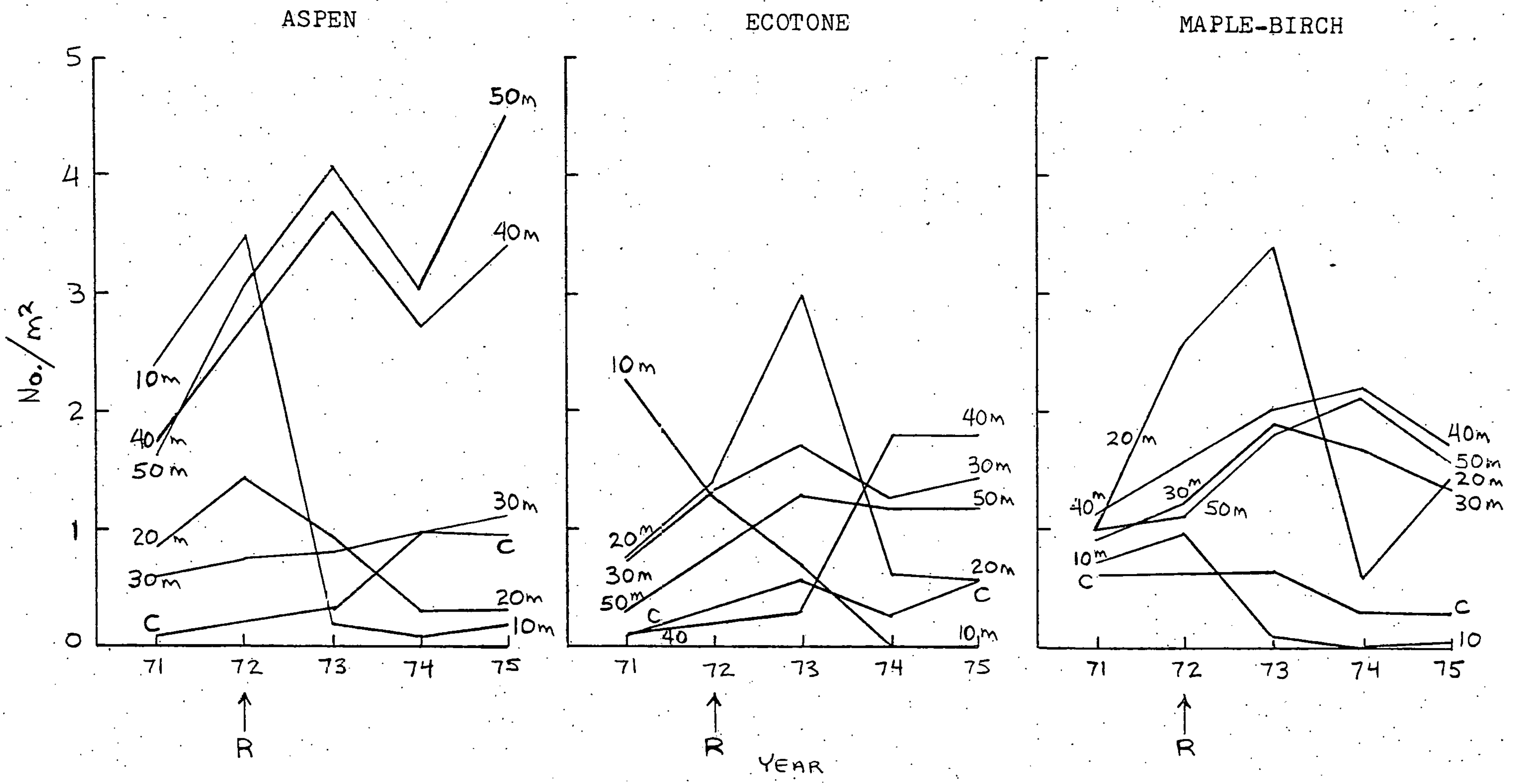

Figure 1. Density of tree seedlings in the aspen, ecotone, maple-birch, and control forest areas. Distance from the radiation source is indicated in meters (m); C represents the control area. Irradiation (R) occurred in 1972.

still occurring. At most sampling distances, even 10 m, overall seedling density increased between 1971 and 1972, largely due to *Acer rubrum*. The exception is the ecotone at 10 m where seedling density declined from 2.3 to 1.3/m^2 between 1971 and 1972. Most of this decline was due to a 69% reduction in the density of *Abies balsamea*. Even in the maple-birch area, where seedling density at 10 m increased by 39% between 1971 and 1972, the density of *A. balsamea* decreased by 46%. In the aspen area *A. balsamea* seedlings were partially shielded by rocks and stumps and actually increased in density by 29% between 1971 and 1972. *A. balsamea* is the only seedling species that strongly suggests a radiation effect as early as September, 1972. The high radiosensitivity of this species and its elimination by radiation at 10 m was predicted (Murphy and Sharitz, 1974) based on its large interphase chromosome volume (Zavitkovski *et al.*, 1974).

By June of 1973 the effects of irradiation at 10 m were apparent in the three forest types due to a marked decline in the density of seedlings relative to 1972. Seedling density had declined by 94% in the aspen area, 46% in the ecotone, and 90% in the maple-birch area. These figures give the impression that ecotone seedling populations were less influenced than those of the other two areas. Actually, all except one of the seedlings present in the ecotone at 10 m in 1972 were eliminated by 1973 but six new seedlings (possibly root sprouts) of *Populus tremuloides* appeared in 1973, partially compensating for the 1972-73 decline in overall seedling density. Several *A. rubrum* seedlings survived from 1972 to 1973 at 10 m in each of the three areas, as did two *Quercus rubra* seedlings in the maple-birch area. Such exceptional instances of survival at 10 m appeared to be related to partial shielding by micro-relief. By July of 1974 seedling density had declined still further at 10 m in all three areas and, in fact, only in the aspen area were there any viable seedlings, and even there only 2.9% of the number present in 1972. By June of 1975 tree seedlings were still absent at 10 m in the ecotone while a very slight increase in seedling density was observed in the aspen and maple-birch areas.

The apparent low rate of re-establishment of seedlings at 10 m can be attributed to the development of very dense and vigorous ground vegetation in this area, presumably in response to increased light under the opened forest canopy. The ground vegetation, composed of light-demanding shrubs and herbs, completely covers the inner irradiated area.

At 20 m the effects of irradiation on seedling densities were much less pronounced than at 10 m. In the aspen area, seedling density at 20 m peaked in 1972 due largely to _A. rubrum_ and _Prunus serotina_. In the ecotone and maple-birch areas the density of seedlings at 20 m peaked in 1973 because of the establishment of _P. tremuloides_, even though most other seedling populations declined. The reason for these peaks in 1972 and 1973, followed by sharp declines, seems clear. The peaks are associated with a thinning of the forest canopy at 20 m and the proximity of the relatively undistrubed forest seed source. Figures 4-6 (to be discussed later in this report) show leaf litter production over the 1971-74 period and indicate that foliage proudction dropped markedly in 1972 in the aspen area at 20 m whereas in the ecotone and maple-birch areas a marked decline occurred one year later in 1973. The consequent increase in light penetration at 20 m, while not enough to stimulate the development of successional vegetation to the extent observed at 10 m, was sufficient to stimulate the development of more shade-tolerant _P. tremuloides_ seedlings and root sprouts. The decline in density of tree seedlings that followed the peaks in the ecotone and maple-birch areas was not due to mortality, but rather to the rapid growth of the _P. tremuloides_ seedlings which put them into the sapling size class (30-100 cm in height) by 1974. In the aspen area, seedlings of A. rubrum and P. serotina were partially replaced in 1973 by seedlings of P. tremuloides which grew into the sapling category by 1974.

Figure 1 indicates that at 30 m and beyond there is no evidence of a radiation effect on the density of tree seedlings. A possible exception is the elimination by 1973 of seedlings of A. balsamea (original density, $1.3/m^2$) at 30 m in the aspen area. The sharp increase (130%) in seedling density between 1971 and 1973 at 40 and 50 m in the aspen area can be attributed to an increase in abundance of A. rubrum, Acer saccharum, and P. tremuloides but the reason for the increase in population densities is not known.

Summarizing the seedling data, at 10 m tree seedling density was substantially reduced (46 to 94%) by 1973 in all three areas. While the seedlings were probably dead by the end of the 1972 growing season, the reductions in population densities were not apparent until the summer of 1973. Competition from ground vegetation that developed under the opened canopy subsequent to irradiation has thus far prevented re-establishment of tree seedlings at 10 m. At 20 m, while most seedling populations were reduced, the establishment and growth of P. tremuloides was stimulated due to the thinned, but not entirely opened, forest canopy resulting in a great increased in the number of saplings by 1974 in all three areas. P. tremuloides appears to be the most successful tree colonizer in all three areas at 20 m. Prior to 1973, P. tremuloides was absent from all transects in the maple-birch area but by 1973 it had established in every transect, most densely at 20 m. There was no evidence of radiation-induced changes in seedling densities at sampling distances beyond 20 m.

Saplings. Figure 2 shows annual changes in the density of tree saplings (30-100 cm in height) for the period 1971-75.

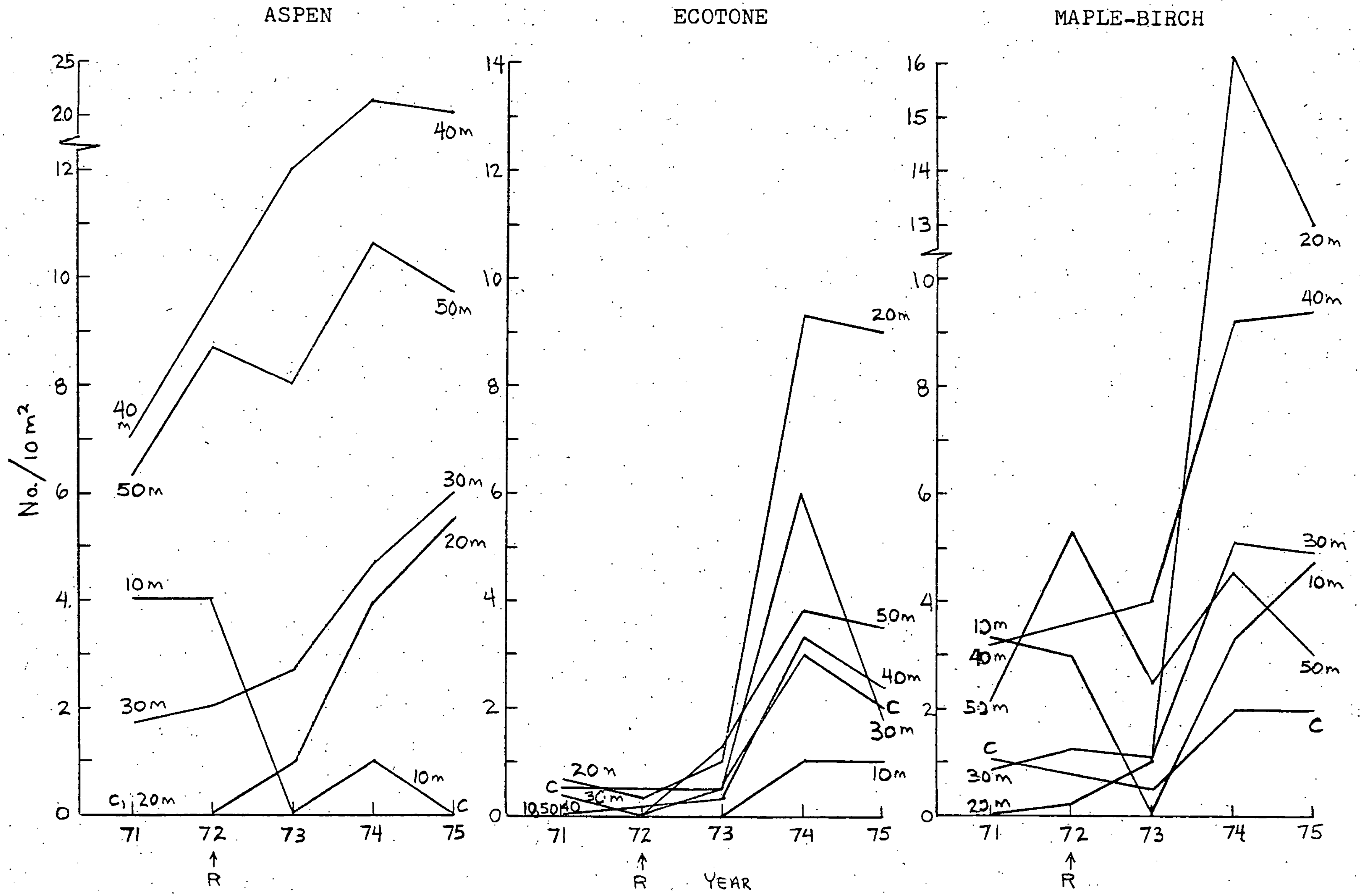

Figure 2. Density of tree saplings in the aspen, ecotone, maple-birch, and control forest areas. Distance from the radiation source is indicated in meters (m); C represents the control area. Irradiation occurred in 1972.

The density of saplings decreased from 4/10 m^2 in the aspen area and 3/10 m^2 in the maple-birch area, in 1972, to zero in both areas in 1973. In the ecotone there were no saplings at 10 m prior to irradiation. Many of the saplings present in subsequent years at 10 m were rapidly growing sprouts.

As previously discussed, the density of saplings at 20 m rose sharply in all three areas after 1973, reflecting the thinned canopy and accelerated growth of seedlings. The rise in sapling densities is matched by a fall in seedling densities representing change in size class.

An increase in sapling density was not limited to the 20 m transect. At 30, 40 and 50 m, sapling density increased in all three areas over the 1971-75 period, as it did in the ecotone and maple-birch control areas. The species primarily responsible for the increase were *P. tremuloides*, *A. saccharum*, and *A. rubrum*. The reason for these increases in areas where the canopy was not generally thinned by radiation is not apparent. In most cases the increases in sapling density were not as great as at 20 m.

Trees. Figure 3 shows annual changes in the density of trees (more than 2.5 cm, dbh) for the period 1971-75.

The density of viable trees at 10 m was strongly affected by radiation in all three areas. All trees in the aspen and maple-birch areas were dead by 1974. The one tree in the ecotone at 10 m, an *A. balsamea*, was dead by September of 1972.

The data suggest a less pronounced decline in the number of viable trees at 20 m between 1972 and 1975 in all three areas, 71%, 59%, and 40% for the aspen, ecotone, and maple-birch areas, respectively. *A. saccharum*, *A. rubrum*, and *P. tremuloides* were the most abundant trees in the sampling plots at 20 m prior to irradiation. Of these, the most radioresistant species was *A. saccharum*,

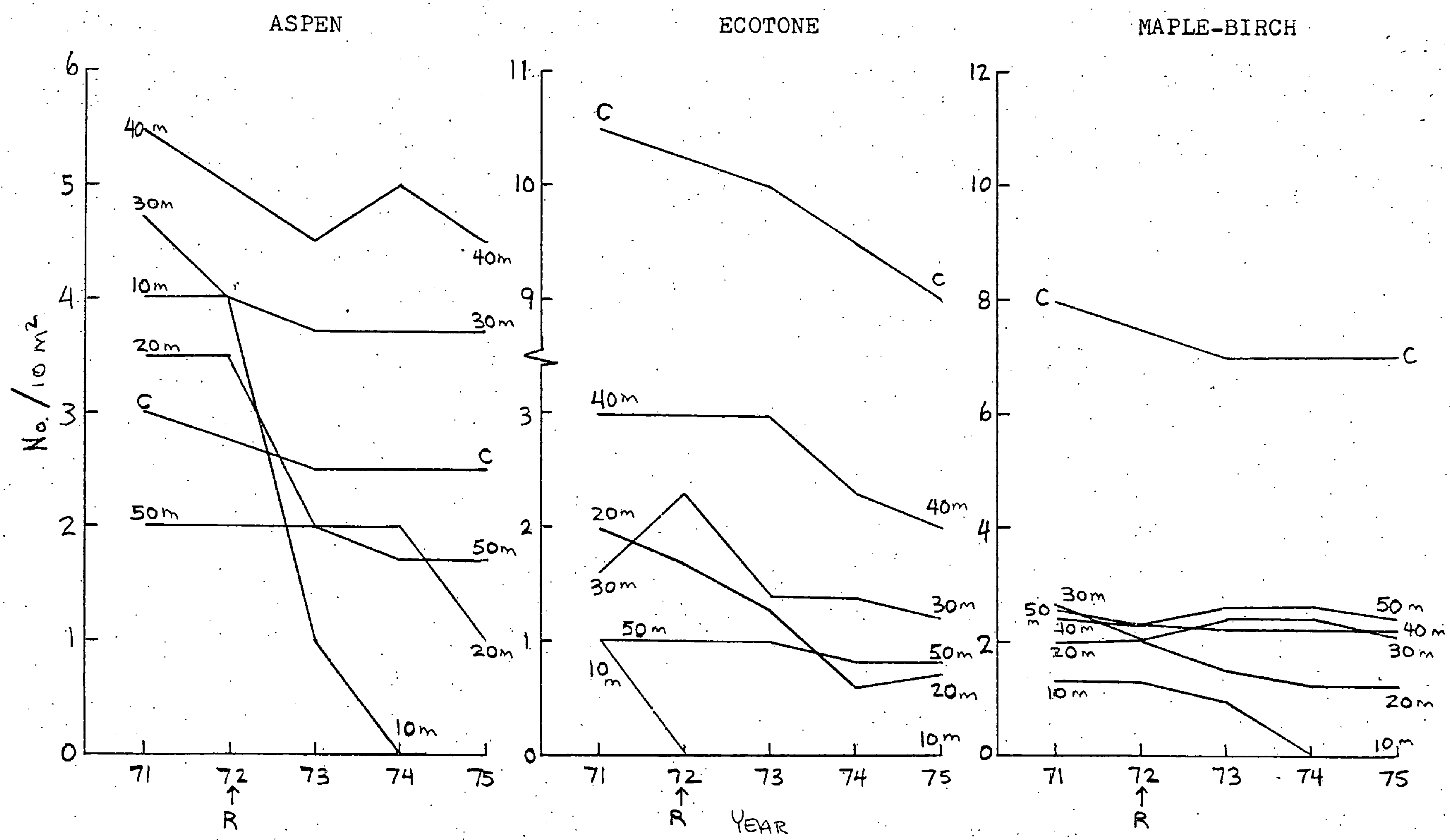

Figure 3. Density of trees (more than 2.5 cm dbh) in the aspen, ecotone, maple-birch, and control forest areas. Distance from the radiation source is indicated in meters (m); C represents the control area. Irradiation occurred in 1972.

the density of which was unchanged at 20 m from the radiation source. The maple-birch area had the highest relative density of this species. The densities of A. rubrum and P. tremuloides, both having larger interphase chromosome volumes than that of A. saccharum, declined in density after 1972. These species were more abundant in the aspen and ecotone areas.

At sampling distances beyond 20 m, there is no evidence of a decline in tree density assoicated with irradiation. The three control areas showed slight declines in the density of trees, as did a number of more distant transects in the irradiated area, but the declines are small and can probably be attributed to normal rates of mortality in the successional forest.

Leaf Litter Production

One of the appended reprints (Murphy, Shartiz and Murphy, 1974) reports on preirradiation rates of leaf litter production in the experimental areas and, more specifically, the contribution by individual tree species to total leaf litter production. Leaf litter samples were collected in late October or early November each year as described in the appended reprint. We found a direct relation between the relative basal area for a given species and its relative leaf litter production (biomass basis). We also found that it was possible to estimate forest diversity patterns by determining the diversity of leaves produced. We therefore intend to utilize data on leaf litter collected subsequent to irradiation to estimate and interpret changes in the composition of the forest canopy as well as changes in leaf area index. The data for individual tree species are currently being analyzed. The data for 1975 have not yet been collected. Changes in total leaf litter production in response to irradiation are summarized in Figures 4-6.

Aspen area. Figure 4 shows annual leaf litter production at each sampling distance in the aspen area over the period 1971-74. Note that even in the control area, leaf litter production fluctuates from year-to-year. For example, it increased by 36% between 1973 and 1974. We must, therefore, assume that some year-to-year variation in foliage production is to be expected.

At 10 m in the irradiated aspen area, leaf litter production fell by 94% between 1971 and 1973, one year following irradiation. In 1974, leaf litter production increased six-fold but was still only 41% of the preirradiation level. In 1971, the major leaf litter component at 10 m was P. tremuloides, accounting for 40% of total leaf litter by weight, but in 1974 P. tremuloides produced only 12% of the total and Rubus sp. produced 69% of the total leaf litter. Rubus sp. is a shrub that has responded vigorously to the open condition within the 10 m area; its leaf litter was not even present in samples prior to 1974.

At 20 m, the large decrease (44%) in total leaf litter production between 1971 and 1972 was due primarily to a 43% decrease in the production of P. tremuloides leaf litter and a 55% decrease in the production of Q. rubra leaf litter. Other species also decreased in production of leaf litter and, in fact, P. tremuloides and Q. rubra contributed about the same proportion of the total leaf litter in 1972 as they did in 1971. The overall decrease between 1971 and 1972 was probably not entirely due to rradiation because at 10 m the effects of irradiation on leaf litter production was not apparent until 1973.

Between 1972 and 1973 leaf litter production at 20 m declined another 32%, putting it 62% below the 1971 preirradiation level. This decline was primarily due to a drop of 90% in leaf litter production by Q. rubra and 55% by P. tremuloides, relative to 1972.

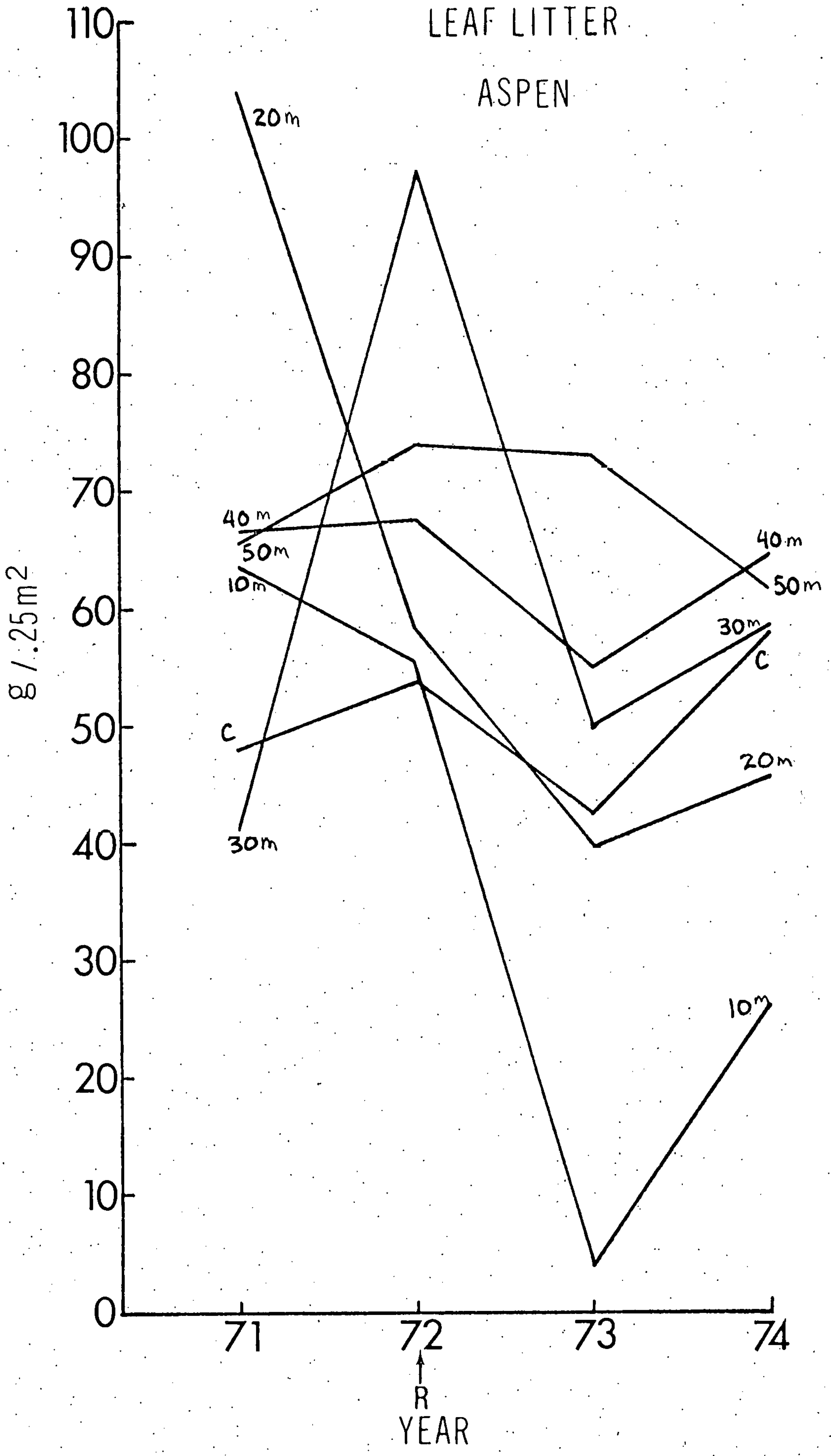

Figure 4. Annual leaf litter production (air-dry wt.) in the aspen forest type. Distance from the radiation source is indicated in meters (m); C represents the control. Irradiation (R) occurred in 1972.

In 1974, leaf litter production at 20 m increased by 15%, largely due to increased litter production by Q. rubra, P. tremuloides and Corylus cornuta (beaked hazel). Leaf litter production by C. cornuta has been increasing at 20 m each year from 1971 through 1974.

While strong year-to-year variations occurred, there is no clear evidence of a radiation-induced change in leaf litter production at sampling distances beyond 20 m (Figure 4).

Ecotone. Figure 5 shows annual leaf litter production at each sampling distance in the ecotone over the period 1971-74. As in the aspen control area, the ecotone control shows strong fluctuations in year-to-year foliage production. Between 1973 and 1974 leaf litter production increased by 85% in the control, largely due to increased litter production by P. tremuloides, P. grandidentata, and Q. rubra.

At 10 m in the irradiated area, leaf litter production increased between 1971 and 1972 but then declined by 74% between 1972 and 1973, apparently in response to irradiation. All tree species showed reduced leaf litter production. Most woody species at 10 m showed little or no increase in leaf litter production between 1973 and 1974 but the sudden appearance of Rubus sp. in the litter, accounting for up to 60% of the total leaf litter weight, increased overall leaf litter weight by 26% between 1973 and 1974.

At 20 m, leaf litter production declined by 33% between 1972 and 1973, largely due to a reduction in P. tremuloides and Betula papyrifera litter. Between 1973 and 1974 leaf litter production dropped by another 6%, primarily because of the virtual disappearance of leaves of B. papyrifera which had comprised 25 to 30% of total leaf litter weight prior to 1974.

Again, there is no clear evidence of a decline in leaf litter production,

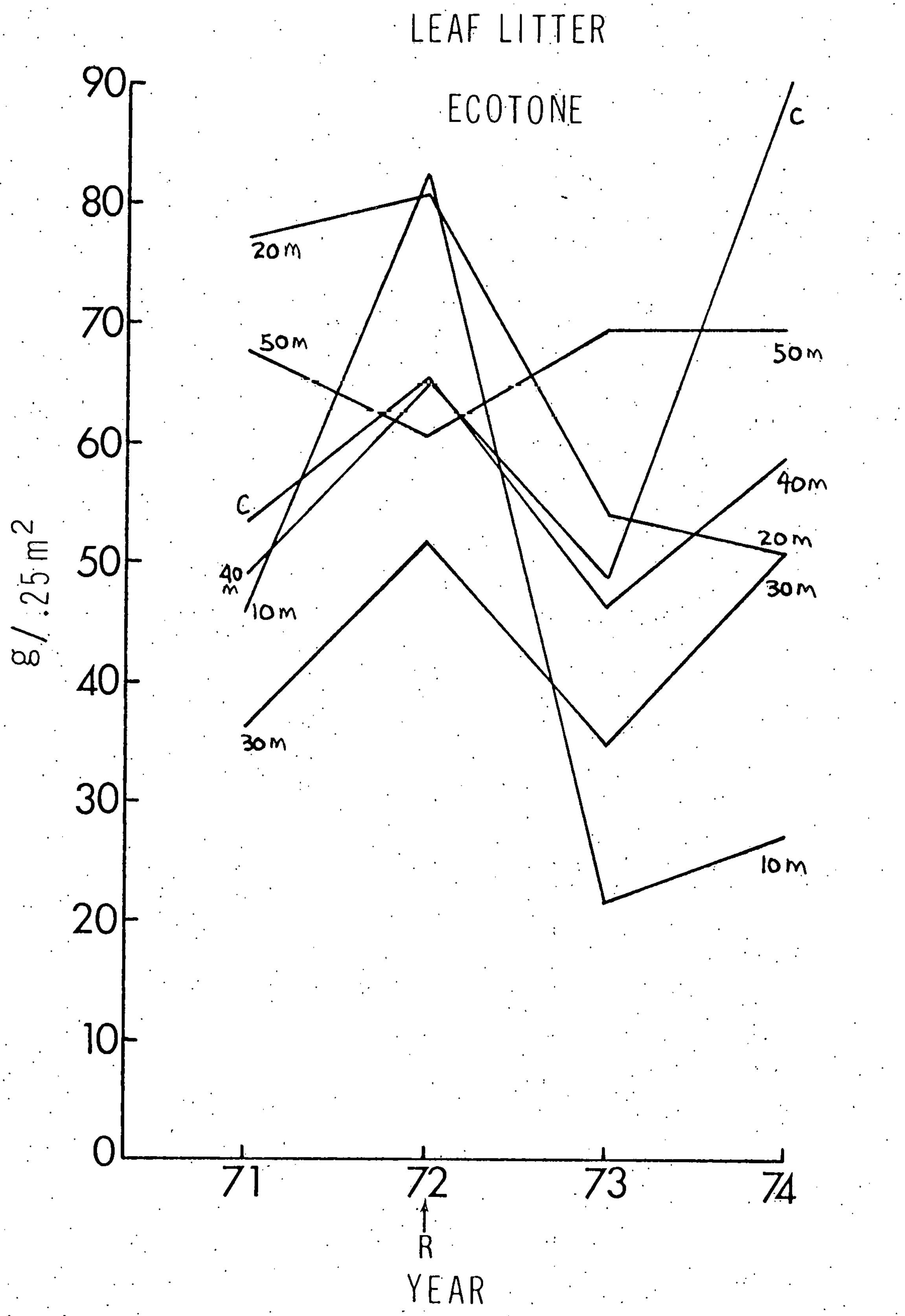

Figure 5. Annual leaf litter production (air-dry wt.) in the ecotone. Distance from the radiation source is indicated in meters (m); C represents the control. Irradiation (R) occurred in 1972.

due to irradiation, at sampling distances beyond 20 m. There are, however, strong year-to-year fluctuations at all sampling distances, including, as previously discussed, the control area. Note that at most sampling distances in the irradiated area, and in the control area, leaf litter production declined at least slightly between 1972 and 1973. This is apparent in the other forest types as well and suggests there may have been meterologic factors acting in combination with irradiation to reduce foliage production at 10 and 20 m.

Maple-birch. Figure 6 shows annual leaf litter production at each sampling distance in the maple-birch area over the period 1971-74. As in the other forest areas, leaf litter production varies from year-to-year in the control area as well as in the irradiated areas at all distances from the radiation source.

At 10 m, leaf litter production decreased by 68% between 1972 and 1973. Most of the tree species present contributed to the decrease, particularly *A. rubrum*, *P. tremuloides*, and *B. papyrifera* which declined by 99%, 63%, and 68%, respectively. Interestingly, the amount of *A. saccharum* leaf litter in the samples did not decline. This is probably due to the proximity of living *A. saccharum* trees at 20 m, as discussed earlier.

The further reduction in leaf litter production at 10 m between 1973 and 1974 was due mainly to the near elimination of leaf litter of *Betula papyrifera*; this species contributed only 1.6 g / 0.25 m^2 in 1974 whereas in 1972 it produced 50.6 g/0.25 m^2. In 1974, *Rubus* sp., previously absent, comprised 12% of the leaf litter at 10 m.

At 20 m, leaf litter production declined by 21% between 1972 and 1973, and an additional 27% between 1973 and 1974. Most of the overall reduction between 1972 and 1974 was due to an 84% reduction in *P. tremuloides* and a 95% reduction

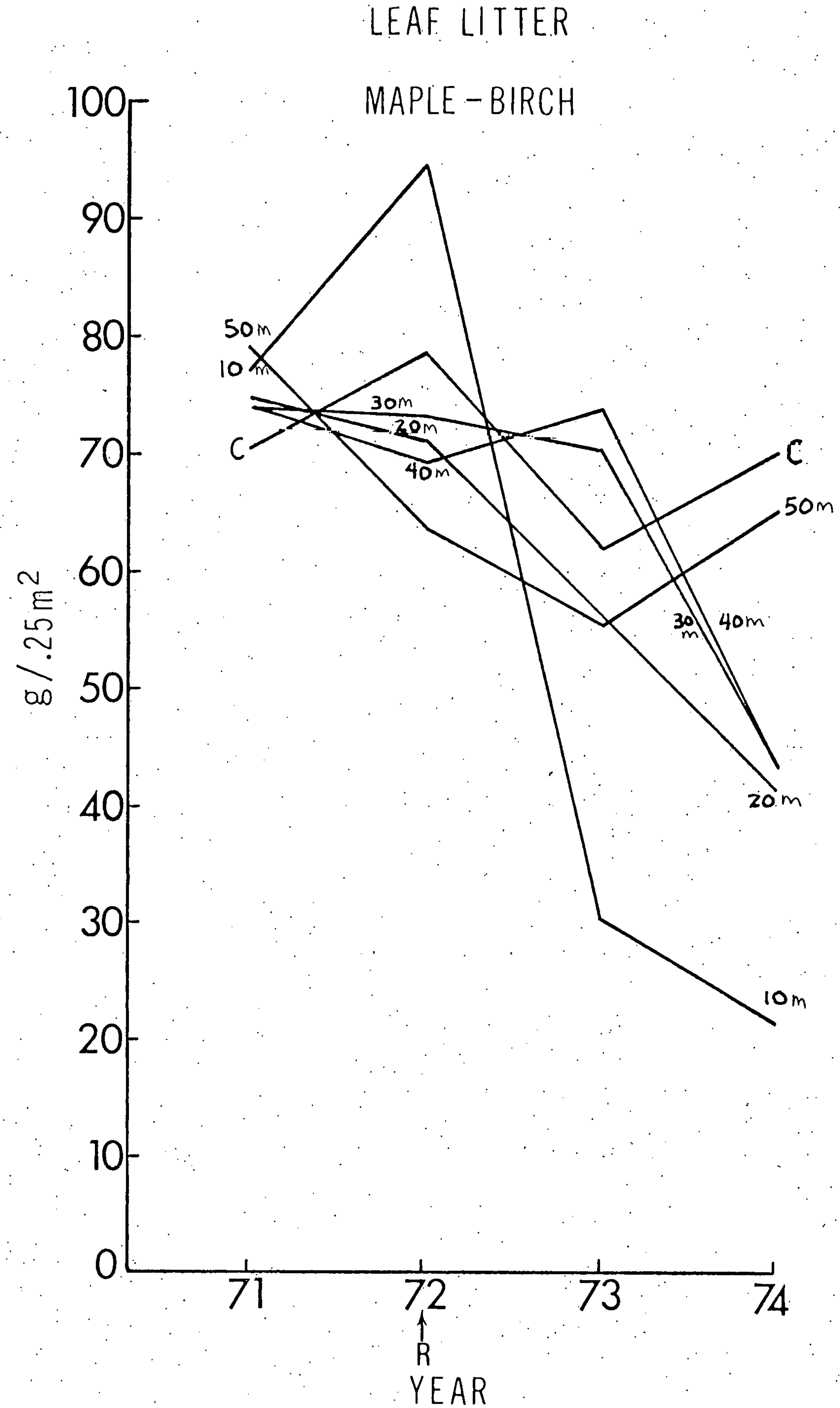

Figure 6. Annual leaf litter production (air-dry wt.) in the maple-birch forest type. Distance from the radiation source is indicated in meters (m); C represents the control. Irradiation (R) occurred in 1972.

in B. papyrifera.

At 30 and 40 m, leaf litter production varied relatively little between 1971 and 1973 but fell by about 40% between 1973 and 1974. In view of the fact that leaf litter production at 30 and 40 m in 1973, one year following irradiation, was "normal" (relative to 1971) it seems unlikely that the decline between 1973 and 1974 at 30 and 40 m was caused by irradiation.

At 50 m, leaf litter production declined by 29% between 1971 and 1973 and then in 1974 rose to within 18% of the 1971 preirradiation level.

Summary

Comparison of Radiation Response in the Three Forest Types

Except where they were protected by micro-relief tree seedlings at 10 m from the radiation source were killed by irradiation in all three areas. *A. balsamea* appeared to be the most radiosensitive species and was eliminated even at 30 m in the aspen area. In all areas, competition from successional ground vegetation prevented re-establishment of seedlings under the opened canopy at 10 m. At 20 m, most seedling populations were about equally reduced in density in the three areas between 1972 and 1973 but the establishment of *P. tremuloides* in all three areas caused peaks in seedling densities subsequent to irradiation. *P. tremuloides* invaded plots in the ecotone and maple-birch areas where it had not previously been found and by 1974 had grown into the sapling size category in all three areas. This increase in populations of *P. tremuloides* at 20 m is attributed to the thinned forest canopy at that distance from the radiation source.

Tree mortality was 100% at 10 m in all three areas but at 20 m mortality was most severe in the aspen area (71%) and least severe in the maple-birch area (40%). The ecotone showed an intermediate level of mortality (59%) at 20 m. The reason for these differences is that *A. saccharum* was not killed at 20 m and this species had the highest relative density in the maple-birch area. *P. tremuloides*, however, was more radiosensitive and was most abundant in the aspen and ecotone areas.

The aspen area showed the quickest and greatest reduction in production of leaf litter in response to irradiation, 94% at 10 m and 62% at 20 m. At 30 m the production of leaf litter in 1973 in the aspen area was actually 22% higher than in 1971. The ecotone and maple-birch areas showed similar levels of reduction in leaf litter production, averaging 56% at 10 m and 27% at 20m. Since all trees at 10 m were dead by 1974, it is assumed that some of the leaf litter, that not contributed by _Rubus_ sp. and other shrubs, was blown in from the less disturbed forest.

In general, based on the data analyzed to date, it appears that the aspen area was most changed, initially, by irradiation. It showed the greatest loss of mature trees and its canopy was, therefore, most drastically opened. But _P. tremuloides_, the dominant tree in the aspen area, is also the dominant successional tree species in all three areas where irradiation thinned the canopy. This species will likely, therefore, become a more abundant component of the ecotone and maple-birch areas where radiation damage occurred whereas there seems to be no tendency for dominants from the ecotone or maple-birch area to increase their presence in the aspen area. The aspen area should, therefore, most quickly regain its original appearance in the radiation damaged area. In most respects the ecotone shows properties, and responses to irradiation, intermediate to the aspen and maple-birch areas.

Future Sampling

As previously indicated, one additional sampling trip is scheduled for 1975. We are interested in continuing observations on the influence of the opened forest canopy on the rate and compositional characteristics of succession, especially the interaction between ground vegetation and tree seedlings. We also wish to determine the rate at which leaf litter production and leaf area index returns to original preirradiation levels. We hope to continue these observations over a period of several years. The overall impact of the radiation stress will obviously depend upon the rate at which forest succession proceeds in the damaged areas. Information on succession in disturbed northern forest types is virtually non-existant.

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APPENDIX