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Responses of a Grassland Arthropod Community to Simulated Radioactive Fallout[1]

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Responses of an arthropod community to beta and gamma radiation from ^{137}Cs-tagged simulated fallout and the interaction of radiation with other environment parameters are being investigated in a unique experimental facility at Oak Ridge National Laboratory. Lithium fluoride microdosimeters attached to the thorax and abdomen of insects in a fallout field indicate that closely related organisms may receive significantly different doses owing to differences in habitat or behavior. Significant differences in variation between control and contaminated communities appeared in summer 1970 ($P \leq 0.05$), disappeared in autumn 1970, and reappeared in summer 1971 ($P \leq 0.01$). Population densities of four arthropod taxa had been significantly ($P \leq 0.05$) reduced by summer 1970. By summer 1971, three of these taxa had recovered to control levels, but four additional taxa underwent significant ($P \leq 0.05$) reductions in population density. This number of affected populations is not statistically significant. No significant increase in dissimilarity in taxa composition between the contaminated and control areas was evident. Consequently, the threshold for long-term effects of fallout radiation on taxa comprising the arthropod community appears to be above the 2.4–13.0 rads/day exposure over the 3-year period.

INTRODUCTION

The proliferation of nuclear technology and the use of controlled nuclear fission as a modern energy source have increased the need for radiological guidelines. Such information is fundamental for radiological assessments, as well as for environmental impact analyses of reactor site selection and for projects involving excavation by nuclear explosion. Further, additional quantities of low-level waste from reactor operation and high-level waste from spent nuclear piles must be anticipated, monitored, and controlled (*1*). The addition of small quantities of radioactivity from civilian nuclear sources to the biosphere requires sophisticated studies of dose–effect relationships for chronic,

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[3] Operated by the Union Carbide Corporation for the U. S. Atomic Energy Commission.

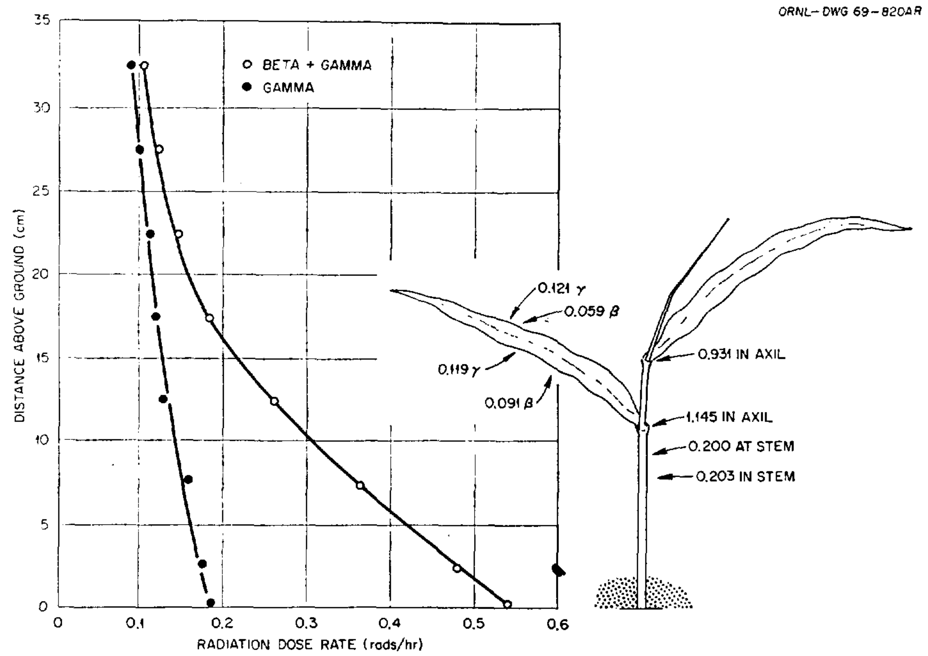

FIG. 1. Distance above ground plotted against gamma and beta + gamma radiation dose rates 11 weeks after the July 1968 application of fallout simulant (8 weeks after the August 1968 application). The profile was prepared for the middle of the contaminated enclosure. Distance between the two dose-rate lines represents the beta radiation dose rate. *N* for each point is 2. Beta, gamma, and the combined dose rates observed for a typical fescue plant are also presented.

low-level exposures. Arthropod population responses to an *in situ* radiation source are evaluated in this paper for dose rates which are at least an order of magnitude lower than those observed from preexisting experiments.

Early assessments of radiation effects on ecosystems consisted of extrapolations from laboratory studies on single organisms or populations. Acute doses of gamma radiation were used to establish relative sensitivities of different species.[4] Little information was gained on effects of chronic irradiation on population parameters, e.g., fecundity and longevity. Beta radiation effects received even less attention since satisfactory systems for measuring beta radiation dose have only recently become available.

Modes of environmental contamination with radionuclides may be either acute or chronic and the scope of a contaminating event may range from highly localized to global. Several studies have involved gamma irradiation of communities and ecosystems: eastern U. S. field and forest (*2*), tropical rain forest in Puerto Rico (3), Nevada (U. S.) desert (*4*), and southern U. S. old field and forest (*5*). Platt (*6*) and his co-workers have observed effects of mixed fast neutrons and gamma radiation on a southern U. S. forest.

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[4] L. L. Eberhardt, Some ecological aspects of nuclear war. TAB-R-7. Battelle Memorial Institute, Richland, WA, 1967.

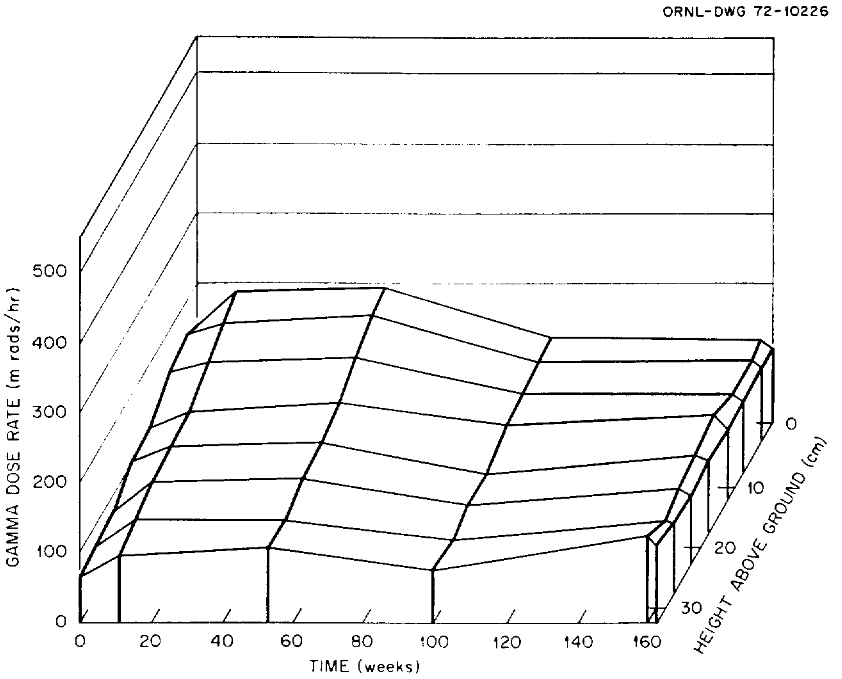

FIG. 2. Gamma radiation dose rate plotted against height above ground and time after July 1969 application of fallout simulant. Data were compiled from vertical profiles of shielded dosimeters in the middle of the contaminated enclosure. N for each point is 2. The apparent rise in dose rates between weeks 1 and 11 resulted from the second application of fallout simulant in August, 3 weeks after the July application.

The studies mentioned above unfortunately paid little attention to invertebrate animals and radiation effects which alter or upset the functional role of these organisms. A long-term project has been initiated at Oak Ridge National Laboratory specifically to examine responses of an ecosystem—plants, vertebrates, and invertebrates—to mixed beta and gamma radiation from simulated fallout. A managed grassland ecosystem was selected for the initial experimental system, since grasslands cover very large areas of this country and are extremely important as pastures for grazing animals. This paper covers the first 3 years of observation on community structure and population dynamics of arthropods.

MATERIALS AND METHODS

Effects of simulated radioactive fallout on an *in situ* arthropod community were studied at the 0800 Ecology Research Area of Oak Ridge National Laboratory. The 5-acre field is dominated by Ky-31 tall fescue, *Festuca arundinacea* Schreb (*7*). Herbaceous and litter arthropods of the area have been most recently studied by Van Hook (*8*). Three sites, 100 m², were established for sampling the arthropod community: a primary control site fenced with sheet metal, a similar site for application of the fallout simulant, and a field area which

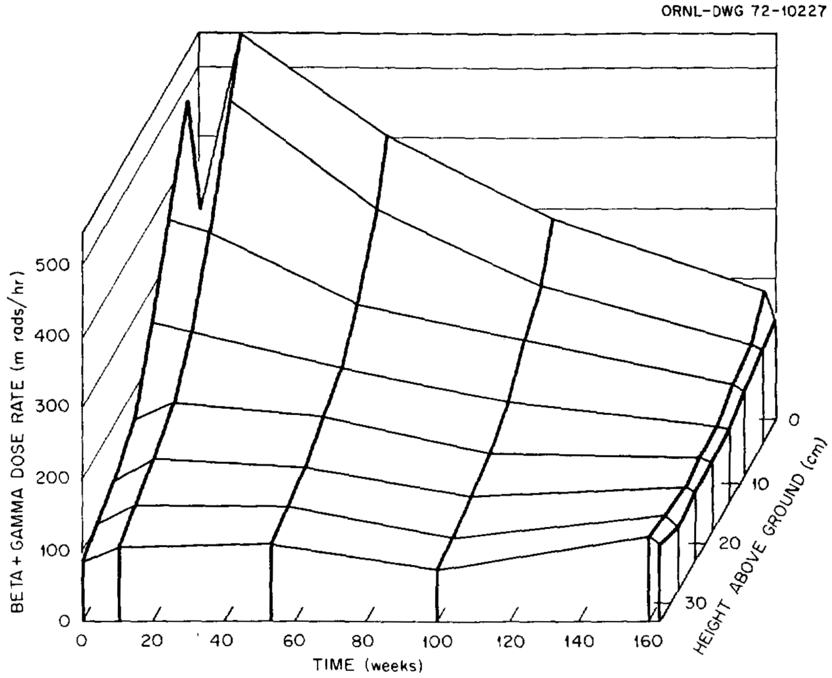

FIG. 3. Beta + gamma radiation dose rate plotted against height above ground and time after July 1968 application of fallout simulant. Data were compiled from vertical profiles of unshielded dosimeters in the middle of the contaminated enclosure. The apparent rise in dose rates between weeks 1 and 11 after the July sanding resulted from the second application of fallout simulant in August, 3 weeks after the July application.

served as a secondary control. The field subplot area was used for comparison with the uncontaminated enclosure to detect possible effects of fencing. A total of 2.44 Ci of ^{137}Cs adsorbed on silica sand grains[5] was applied (*9*) to the field enclosure set aside for contamination. The first application in July 1968 was followed 3 weeks later in August by a second and final loading. The primary control enclosure was loaded with an equivalent amount of unlabeled sand. Sampling of the arthropod community was initiated 4 months prior to application of the simulant and continued twice a month during the first year and monthly thereafter. Seventy-five arthropod taxa were sorted from samples collected in each site with 26 pitfall traps 12.2 cm deep by 6.7 cm diameter, five soil cores 5.0 cm long by 4.4 cm diameter (*10*), and one biocoenometer (cylindrical nylon tent) 0.25 m^2 by 1.0 m high (*11*).

Beta and gamma radiation dose rates in microhabitats of the contaminated enclosure were determined using LiF microdosimeters (Harshaw Chemical Co., TLD-100). These dosimeters are mechanically rugged, available in several geometries and sizes, essentially energy-independent for beta and gamma radia-

[5] W. B. Lane, Fallout simulant development: temperature effects on the sorption reactions of cesium on feldspar, clay and quartz. MU-6014. Stanford Research Institute, Menlo Park, CA, 1967.

tion, and measure doses as low as 5 mrads. Extruded crystals 0.5 mm diameter by 6.0 mm long were suspended at several heights above ground in the middle of the contaminated enclosure during the first week after July application of simulated fallout. Similar dosimetric profiles were prepared 11, 52, 98, 160, and 163 weeks later to monitor changes in beta and gamma dose rates through vertical distance and time. Profiles were developed at four additional points in the enclosure during week 11 after July application to estimate evenness of dose rate distribution across the pen. Total beta+gamma dose rate was determined with unshielded dosimeters; other dosimeters were enclosed in 2-mm-thick nylon capsules to shield out the beta but not the gamma radiation. Extruded crystals also placed in and on grass stems and leaves, and cleaved crystals 1 mm^3 were attached to insects with silicone rubber during week 8 after August application of the fallout simulant.

RESULTS

Beta and Gamma Radiation Dosimetry

Soil, litter, and grass-inhabiting components of the arthropod community received significantly different beta- and gamma-radiation doses owing to changes in vertical distribution of fallout simulant and to the short range of ^{137}Cs beta particles. A typical radiation profile for the middle of the contaminated enclosure 11 weeks after July application of fallout simulant (Fig. 1) illustrates the vertical distribution of dose rates. Gamma radiation dose rates were obtained directly from shielded dosimeters; beta dose rates were calculated by substracting gamma from beta+gamma (unshielded dosimeters) dose rates. Beta radiation makes an important contribution to the total dose rate at the 0- to 10-cm level. Profiles at five points in the enclosure during week 11 after July application of simulant revealed no significant difference in beta- or gamma-radiation dose rates. Radiation profile data for a 3-year period are summarized in Figs. 2 and 3. The dramatic increase in gamma and beta+gamma dose rates between weeks 1 and 11 resulted from a second application of fallout simulant during August. After week 11, the more rapid decline in beta-radiation dose rates, as compared to gamma-radiation dose rates, is attributed to differential shielding of beta particles as the simulant was incorporated into upper layers of soil. Grasshoppers (*Melanoplus* sp.) and caged crickets (*Acheta domesticus*) carrying cleaved crystals of LiF (*12*) provided realistic estimates of doses received by these insects as they moved through various dose rate levels. Differences between dose rates to thorax and abdomen of the same insect were not significant, but there was a significant difference ($P \leq 0.01$) between total exposures of living grasshoppers (thorax 0.09, abdomen 0.10 rads/hr) and ground-dwelling crickets (thorax 0.22, abdomen 0.31 rads/hr.)

Community Analysis

Numbers of individuals of each arthropod taxon collected during 39 sampling periods were subjected to a three-way analysis of variance (*13*) to detect significant changes in structure of the communities and to determine whether more extensive analyses were appropriate. The analysis of variance was repeated for a number of different time periods. If an arthropod taxon was absent from all samples during the time period covered by an analysis, data for the taxon were not included in the analysis. Variations among sites, taxa, and sampling dates was calculated using seven sampling dates (April 1–June 25, 1968) before application of fallout simulant. An F test indicated significant differences among dates [$P(6, 1472) \leq 0.01$] and taxa [$P(73, 1472) \leq 0.01$] but not between communities from experimental and control sites. Differences among sampling dates would be expected because of seasonal responses of the arthropod community, and differences among taxa would be expected because the taxa normally occur in varying population densities. Further analysis of all 39 sampling dates (April 1, 1968 to August 17, 1971) confirmed the difference among dates [$P(38, 9008) \leq 0.01$] and taxa [$P(77, 9008) \leq 0.01$]. Since the three field sites originally possessed comparable arthropod species compositions, subsequent differences in community structure cannot be attributed to pretreatment variabilities.

When sampling dates were sequentially deleted from the beginning toward the end of the study and the analysis of variance repeated after each deletion, a seasonally cyclic pattern of variance between all sites emerged. Comparison of site variance by F test indicated greatest variance for summer samples, least for winter samples. Variance between the primary control and contaminated communities was greater—but not statistically significant—during the first summer of treatment by fallout simulant (1969) than before application of fallout. By August 1969, the soil component of the arthropod community had received 1.76 krads gamma and 2.99 krads beta radiation; the litter component, 1.56 krads gamma and 2.66 krads beta; and the grass component, 0.84–1.42 krads gamma and 0.18–1.61 krads beta. Variances between control and contaminated communities reached a level of statistical difference [$P(2, 2507) \leq 0.05$] during the second summer (1970) when accumulated doses had nearly doubled. This variance declined in the ensuing autumn and winter, but reappeared [$P(2, 207) \leq 0.01$] during the third summer (1971).

Calculation of an index of taxa composition dissimilarity (*14*) for each sampling period and site pair combination has verified the seasonal cycle in community composition (Fig. 4) pointed to by analysis of variance. The number of individuals of each arthropod taxon collected from a site on each sampling period was transformed by Eq. 1 and used to calculate, in euclidean hyperspace, the species composition distance, d, between each pair of sites (primary control/secondary control, primary control/contaminated, and secondary control/contaminated) by Eqs. 2 and 3.

$$X = \log(y + 1), \tag{1}$$

$$d_{ij}^2 = (X_{1,i} - X_{1,j})^2 + (X_{2,i} - X_{2,j})^2 \cdots + (X_{75,i} - X_{75,j})^2, \tag{2}$$

$$d_{ij} = (d_{ij}^2)^{\frac{1}{2}}, \tag{3}$$

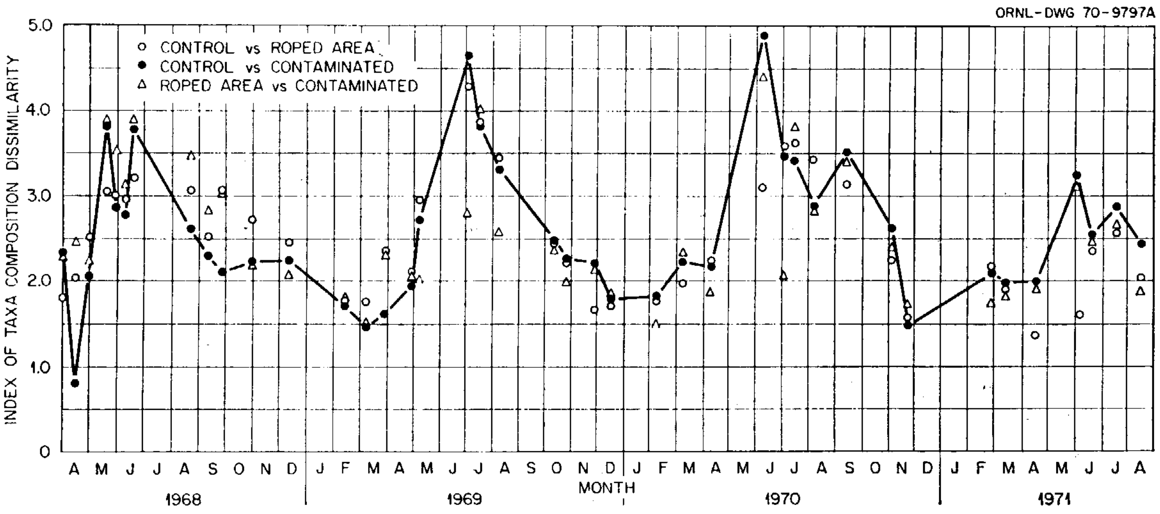

FIG. 4. Index of taxa composition dissimilarity for the primary control/secondary control (○), for the primary control/contaminated community (●), and for the secondary control/contaminated community (△) plotted against each sampling date. The effects of changes in taxa composition in the enclosures is superimposed on a seasonal cycle with minima of taxa composition dissimilarity in winter and maxima in summer. Natural variation in community structure obscures effects of fallout simulant. Dissimilarity was greatest for primary control/contaminated communities during summer 1969, 1970, and 1971.

where

y = number of each taxon collected from each site,
d_{ij} = taxa composition distance between sites i and j,
$X_{1,i}$ = value of taxon 1 for site i,
$X_{1,j}$ = value of taxon 1 for site j, $\cdots$
$X_{75,i}$ = value of taxon 75 for site i, and
$X_{75,j}$ = value of taxon 75 for site j.

The lower the value of d, the greater the similarity between communities; the higher the value of d, the lesser is the similarity between communities. This technique is relatively sensitive for detecting changes in community composition and is of great value for summarizing large amounts of data.[6]

Results of the analysis (Fig. 4) showed no significant or consistent change in similarity between communities of the contaminated enclosure and either the primary control or secondary control during the summer of 1969. According to this analysis, community composition was not affected by a year's exposure to the radiation. When values of dissimilarity between these communities were plotted against time, seasonal cycles became evident. Minima of dissimilarity for all combinations of communities were reached during winter months, and maxima occurred in the summer. During winter fewer taxa were active, and inactive taxa would not contribute to an index of dissimilarity. A larger number of active taxa during the summer led to a greater possible dissimilarity between sites. The temporal maxima of dissimilarity between primary control and contaminated communities in the summer of 1969 were followed closely by that between primary and secondary controls. In the second (1970) and third (1971) summers, however, the primary control/contaminated communities and the secondary control/contaminated communities were more dissimilar than the primary control/secondary control communities. Generally lower dissimilarity values for 1971 as compared to 1970 may have resulted from smaller collections for 1971.

An analysis of population data is summarized in Table I and Appendix I. Mean numbers of each arthropod taxon collected per trap at each site on each date were plotted against time and site. Graphs were compared visually, and any apparent differences between control and contaminated populations were tested for statistical significance by Student's t (*15*). In 1969 there were no significant differences between any populations of control and contaminated areas. In comparison with populations in the primary control enclosure during summer 1970, four arthropod taxa—the leafhopper *Kolla bifida*, the carabid ground beetles, the phalacrid shining flower beetles, and the simuliid black flies—in the contaminated enclosure evidenced statistically significant ($P \leq 0.05$) reductions in seasonal population density maxima. During summer 1971, all taxa affected in 1970 except *K. bifida* recovered to control levels, while four addi-

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[6] G. M. Woodwell, Radiation and the patterns of nature. BNL-924. Brookhaven National Laboratory, Upton, L. I., NY, 1965.

TABLE I

CONTAMINATED ARTHROPOD POPULATIONS WITH RESPONSES SIGNIFICANTLY DIFFERENT FROM CONTROL POPULATIONS AFTER 3 YEARS OF BETA AND GAMMA IRRADIATION

Taxa[a]	*Responses*[b]
Carabidae (ground beetles)	Density was 84% less in contaminated pen than in control pen [P (5) ≤ 0.01] in summer 1970. Density was not significantly different in summer 1971.
Phalacridae (shining flower beetles)	Density in contaminated pen was 76% less than control pen [P (6) ≤ 0.05] in summer 1970. In summer 1971, density of contaminated population was comparable to control.
Simuliidae (black flies or buffalo gnats)	Density was 34% less in contaminated pen than in control pen [P (6) ≤ 0.05] in summer 1970. In summer 1971, density of contaminated population was comparable to control.
Kolla bifida (leafhopper)	Density was 12% in contaminated pen than in control [P (6) ≤ 0.05] in summer 1970 and 80% less during summer 1971 [P (6) ≤ 0.5].
Poduridae (springtails)	Density in contaminated pen was 18% less than control pen [P (6) ≤ 0.05] in summer 1971.
Sminthuridae (springtails)	Density in contaminated pen was 38% less than control pen [P (5) ≤ 0.05] in summer 1971.
Aphididae (aphids, plant lice)	Disappeared from contaminated pen during summer 1971 [P (6) ≤ 0.05]
Trombiculidae (harvest mites)	Density declined 72% in contaminated pen [P (5) ≤ 0.05] in summer 1971.

[a] Classification follows Borror and DeLong (*18*).

[b] Data are available from the International Biological Program Eastern Deciduous Forest Biome Information Center, Oak Ridge National Laboratory, Oak Ridge, TN.

tional taxa—the aphidid plant lice, the trombiculid harvest mites, the podurid springtails, and the sminthurid springtails—were significantly reduced in density. Arthropod taxa included in this analysis but lacking a significant change in population density between control and contaminated enclosures are listed in Appendix I. At the 5% level of probability, one would expect to find significant differences for four out of 75 arthropod taxa merely by chance. Therefore, these numbers of arthropod taxa showing seasonal differences in population density in the contaminated enclosure are not considered to be statistically significant at the community level of organization.

DISCUSSION

Sound ecological dosimetry that is directly applicable to a specific experimental situation forms the keystone of research on effects of radiation on natural systems. Grasshoppers and crickets are closely related taxonomically, but they occupy different microhabitats. Crickets dwell primarily on and in litter, where, in this instance they were exposed to more beta radiation. Grasshoppers dwell higher on blades of grass at a greater distance from the fallout, most of which was located in the litter and on the ground surface by week 8 after contamination. Thus, any attempt to predict ecological responses to radiation based on differential radiation sensitivities of species should also deal with the problem of differential radiation exposures.

Based on differential radiation sensitivities and exposures from mixed beta and gamma radiation, responses of the arthropod community were relatively slight in comparison with what might have been predicted from laboratory studies including sensitive egg and juvenile stages (*12*, *16*, *17*). For example, Styron (*17*) reported that acute sublethal doses of either ^{90}Sr–^{90}Y beta or ^{60}Co gamma radiation could seriously affect the survival of springtail (Collembola) populations by acting on their fertility rates (number of eggs surviving). Adult *Sinella curviseta* had an $LD_{50(30)}$ of 14.9 krads gamma or 30.0 krads beta radiation; their eggs, an LD_{50} of 1.4 krads gamma or 1.5 krads beta radiation. Sensitivity of fertility rates of another springtail, *Folsomia* sp., to chronic sublethal dose rates of beta radiation also has been studied (*12*). Although adults had an $LD_{50(30)}$ of 174.5 rads/hr (total dose in 30 days of 125.6 krads), fertility rates were significantly reduced ($P \leq 0.05$) by the lowest dose rate used, 3.3 rads/hr. Dose rates as high as 1.145 rads/hr (combined beta and gamma) have been recorded in the present study in leaf axils of fescue in the contaminated enclosure (Fig. 1). Except for such highly localized pockets of simulant, however, dose rates in the enclosure ranged from 0.10 rads/hr in standing grass to 0.54 rads/hr in litter. By August 17 of the third summer the soil component of the arthropod community had received 10.46 krads of beta+gamma radiation (4.43 krads of gamma alone), the litter component received 8.61 krads of beta+gamma (3.99 krads of gamma), and the grass component received 2.59–6.41 krads of beta+gamma (2.38–3.63 krads of gamma). The apparent sensitivity of fertility rates of *Sinella* and *Folsomia* to sublethal doses and dose rates of beta and gamma radiation in laboratory studies suggests that a chronic exposure to 0.10–0.54 rads/hr should significantly affect fertility rates of a number of arthropod taxa over a 3-year period.

Analyses of community responses in this study revealed no lasting change in community structure. The multiple analysis of variance test and the analysis of taxa composition dissimilarity between communities pointed only to temporal differences during the second and third summers of exposure. The transient differences between primary control and contaminated communities occurred during summer periods of maximum reproduction and growth. At these levels of chronic radiation exposure, natural fluctuations in population dynamics would be expected to obscure any radiation effects should they occur. Thus, the threshold for effects of mixed beta and gamma radiation from fallout on community structure must be above the 2.4–13.0 rads/day delivered over 3 years. A likely explanation for this degree of radiation effect in a field situation lies in homeostatic mechanisms that enable the community to respond to radiation stress in much the same manner as to other environmental stresses (*6*).

Population responses in this study were variable. Four taxa had significantly reduced population density maxima in the contaminated enclosure during the second summer (1970), but three of the four recovered by the third summer (1971). It was also in the third summer that four additional taxa were reduced in density. All of the eight taxa that showed significant reductions in population density are small arthropods (<10 mm long), and five are closely associated with soil and litter at some stage in their life cycle. Beta-radiation dose rates were highest from accumulated fallout in litter and soil. The 1.18-MeV beta of ^{137}Cs has a mean range of 3.50 mm in soft tissue and could deliver a significant dose to small insects.

The plant lice Aphididae in this study are small (≤ 4 mm long), soft-bodied insects that are usually found sucking sap from stems and leaves of plants. They overwinter in the egg stage, and these eggs hatch in the spring into females that reproduce parthenogenetically and give birth to live young. In the latter part of the season, a bisexual generation arises, mates, and lays eggs which overwinter (*18*). The size and soft bodies of these insects would provide little shielding of internal organs from external beta radiation, and eggs overwintering in the soil would receive large doses of beta and gamma radiation. The leafhopper *Kolla bifida* rarely exceeds 6 mm length. Similar to aphids, they feed principally on sap from leaves of plants. They have a single generation a year and overwinter in the egg stage. Their size and overwintering eggs also could result in greater effectiveness of beta radiation.

Poduridae are minute springtails (Collembola) that occur on soil and litter. Sminthuridae are small, oval-bodied springtails that frequent vegetation. Both types of springtails may feed on decaying plant material, fungi, arthropod feces, and other materials. Eggs of springtails are quite delicate and are essentially unshielded against external beta radiation (*12*, *18*).

The harvest mites Trombiculidae are small and as adults feed on small arthropods and arthropod eggs. These mites lay their eggs in and around vegetation and overwinter in the egg stage. Close association with soil and litter could contribute to significant radiation doses from fallout.

Declines and subsequent recovery in three arthropod taxa are difficult to explain. Carabidae, or ground beetles, are commonly found in the litter. Adults and larvae are predaceous on other insects, and the larvae occur in burrows in the soil. Adults likely receive some shielding from beta radiation from their exoskeleton, but larvae are essentially unshielded. As permanent residents of the soil and litter they could accumulate large doses of radiation from fallout. Phalacridae, or shining flower beetles, are small (1–3 mm long) and would have received insignificant internal doses from beta radiation since adults are common on flowers of composites and larvae develop in the heads of these flowers. They have little association with soil and litter and the bulk of the fallout. Simuliidae are small black flies or buffalo gnats. The females are bloodsucking. Adults are most frequently encountered near streams where the larvae occur, but the adults may occur at considerable distances from streams. There is insufficient information at this time to determine the cause or causes of the decline in population density and subsequent recovery of these three taxa.

Continued monitoring of the experimental site should produce a clearer understanding of relationships between the affected populations and the community as a whole, and the effects of beta and gamma radiation. Another advantage of the study will be the possibility of considering genetic as well as somatic effects of radiation by analyzing population growth forms and densities each year and correlating these population parameters with environmental parameters such as temperature and rainfall. The rate of accumulation of genetic defects in natural populations merits more intensive study. The far-reaching, but subtle, genetic responses of populations are among the most difficult factors to extrapolate from short-term laboratory or field studies.

This research is the first long-term field study on effects of mixed beta and gamma radiation on a terrestrial arthropod community. It has established the existence of a radiation threshold for significant changes in community structure. This threshold occurs at or above 2.4–13.0 rads/day (chronic for 3 years) due to the absence of a lasting significant difference in variation and in dissimilarity between control and contaminated communities. We have identified several arthropod taxa that merit more detailed study of their sensitivity to beta and gamma radiation, and we have demonstrated differential radiation exposures for closely related arthropod taxa which is an important consideration in hazards analyses and postattack scenarios.

ACKNOWLEDGMENTS

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APPENDIX I: ALPHABETICAL LISTING OF CONTAMINATED ARTHROPOD POPULATIONS WITH RESPONSES NOT SIGNIFICANTLY DIFFERENT FROM CONTROL POPULATIONS AFTER 3 YEARS OF BETA AND GAMMA IRRADIATION

Acrididae (short-horned grasshoppers)
Acylophorus sp. (rove beetles)
Agelenidae (grass and funnel-web spiders)
Agromyzidae (leaf-miner flies)
Araneida (spiders)
Arctosa littoralis (burrowing wolf spider)
Bostrichidae (branch and twig borers)
Cantharidae larvae (soldier beetles)
Cercopidae (spittlebugs)
Chalcididae (chalcidid wasps)
Chalcidoidea (chalcid wasps)
Chilopoda (centipedes)
Chironomidae (midges)
Chrysomelidae (leaf beetles)
Coccinellidae (ladybird beetles)
Coleoptera (beetles)
Collembola (springtails)
Ctenizidae (trapdoor spiders)
Culicidae (mosquitoes)
Curculionidae (weevils)
Diplopoda (millipedes)
Diptera (flies)

Drosophilidae (fruit flies)
Elateridae (click-beetles)
Empididae (dance flies)
Entomobrya sp. (springtails)
Entomobrya griseolivata (springtail)
Formicidae (ants)
Gryllinae (field crickets)
Hahniidae (hahniid spiders)
Halictidae (halictid bees)
Halticus sp. (leaf bug)
Harpalus sp. (ground beetle)
Hemiptera (bugs)
Histeridae (hister beetles)
Hymenoptera (ants, wasps, bees)
Ichneumonidea (ichneumon wasps)
Julida (millipedes)
Lycosa punctata (large-bodied wolf spider)
Lycosa rabida (large-bodied wolf spider)
Lycosidae (wolf spiders)
Lygaeidae (seed bugs, chinch bugs)
Melandryidae (false darkling beetles)
Melanoplus sp. (spur-throated grasshopper)
Mesostigmata (gamasid mites)
Milichiidae (= Phyllomyzidae) (milichiid flies)
Miridae (plant bugs)
Mycetophilidae (fungus gnats)
Onychiurus armata (springtail)
Oribatei (oribatid mites)
Orthoptera (grasshoppers, crickets, mantids)
Paederus littorarius (rove beetle)
Pardosa milvina (thin-legged wolf spider)
Pipunculidae (big-headed flies)
Pteromalidae (pteromalid wasps)
Pteronemobius sp. (field crickets)
Reduviidae (assassin bugs)
Rhagionidae (snipe flies)
Scelionidae (scelionid wasps)
Staphylinidae (rove beetles)
Stilicus angularis (rove beetle)
Tephritidae (= Trumpaneidae) (fruit flies)
Tetranychidae (spider mites)
Theridiidae (comb-footed spiders)
Thysanoptera (thrips)
Thripidae (common thrips)
Unidentified larvae

REFERENCES

1. D. E. Reichle, P. B. Dunaway, and D. J. Nelson, Turnover and concentration of radionuclides in food chains. *Nuclear Safety* **11**, 43–55 (1970).

2. G. M. Woodwell, Effects of ionizing radiation on ecological systems. In *Ecological Effects of Nuclear War* (G. M. Woodwell, Ed.), pp. 20–38. Brookhaven National Laboratory, Upton, L. I., New York, Publ. 917, 1965.

3. H. T. Odum and R. F. Pigeon (Eds.), *A Tropical Rain Forest. A Study of Irradiation and Ecology at El Verde, Puerto Rico.* Nat. Tech. Info. Service, Springfield, VA, 1970.

4. N. R. French, Radiation and animal population: problem, progress and projections. *Health Phys.* **11**, 1557–1568 (1965).

5. C. D. Monk, Effects of short term irradiation of an old field. *Radiat. Bot.* **6**, 329–335 (1966).

6. R. B. Platt, Ionizing radiation and homeostasis of ecosystems. In *Ecological Effects of Nuclear War* (G. M. Woodwell, Ed.), pp. 39–60. Brookhaven National Laboratory, Upton, L. I., New York, Publ. 917, 1965.

7. R. W. Pohl, The grasses of Iowa. *Iowa State J. Sci.* **40**, 341–566 (1966).

8. R. I. Van Hook, Jr., Energy and nutrient dynamics of spiders and orthrptera populations in a grassland ecosystem. *Ecol. Monogr.* **41**, 1–26 (1971).

9. R. C. Dahlman, S. I. Auerbach, and P. B. Dunaway, Behavior of ^{137}Cs tagged particles in a fescue meadow. In *Environmental Contamination by Radioactive Materials*, pp. 153–165. International Atomic Energy Agency, Vienna, 1969.

10. S. I. Auerbach and D. A. Crossley, Jr., A sampling device for soil micro-arthropods. *Acarologia* **2**, 279–285 (1960).

11. A. L. Turnbull and C. F. Nicholls, A "quick-trap" for area sampling of arthropods in grassland communities. *J. Econ. Entomol.* **59**, 1100–1104 (1966).

12. C. E. Styron and G. J. Dodson, Responses of some grassland arthropods to ionizing radiation. In *Survival of Food Crops and Livestock in the Event of Nuclear War* (D. W. Bensen and A. H. Sparrow, Eds.) pp. 509–520, A.E.C. Symposium Series 24, 1971. (Available as CONF-700909, National Technical Information Service, U. S. Department of Commerce.)

13. F. E. Croxton, *Elementary Statistics with Applications in Medicine and the Biological Sciences*, pp. 295–310. Dover, New York, 1953.

14. R. R. Sokal and P. H. A. Sneath, *Principles of Numerical Taxonomy*, pp. 176–180. Freeman, San Francisco, 1963.

15. R. G. D. Steel and J. H. Torrie, *Principles and Procedures of Statistics with Special Reference to the Biological Sciences*, p. 72. McGraw-Hill, New York, 1960.

16. R. V. O'Neill and C. E. Styron, Applications of compartment modeling techniques to Collembola population studies. *Amer. Midland Natur.* **83**, 489–495 (1970).

17. C. E. Styron, Effects of beta and gamma radiation on a population of springtails, *Sinella curviseta* (Collembola). *Radiat. Res.* **48**, 53–62 (1971).

18. D. J. Borror and D. M. DeLong, *An Introduction to the Study of Insects*, 3rd edition. Holt, Rinehart and Winston, New York, 1971.