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RESPONSES OF A GRASSLAND ARTHROPOD COMMUNITY TO CHRONIC BETA AND GAMMA RADIATION[1]

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Abstract. A long-term project was initiated in 1968 at Oak Ridge National Laboratory to assess effects of mixed beta and gamma radiation from simulated fallout on a grassland ecosystem. Beta and gamma radiation dose rates in microhabitats of the experimentally contaminated enclosure were measured with LiF thermoluminescent microdosimeters. Extensive statistical analyses of data on numbers of individuals collected for each of 76 arthropod and 2 molluscan taxa have identified no lasting significant changes in similarity or species diversity of experimental versus control communities as the result of the long-term irradiation at low dose rates. Natural fluctuations in community dynamics obscured any possible radiation effects. Thus, the apparent threshold for mixed beta and gamma radiation inducing changes in community structure must be above the exposure rate range of 2.3 to 13 rad/day delivered during the 5 yr of observation. Establishing such a threshold is of importance in assessing the impact of communities subjected to chronic, low level environmental exposure to ionizing radiation.

Key words: Arthropod; insect; radiation effects; beta; gamma; chronic; threshold.

INTRODUCTION

Our expanding nuclear technology and the attendant possibilities for environmental contamination with low levels of long lived radionuclides have established a need for information on possible environmental consequences of such contamination. Efforts to project effects of low levels of ionizing radiation on natural systems have suffered from several deficiencies. Estimates of radiation effects on ecosystems (Eberhardt 1967) have customarily been based on extrapolations from laboratory studies on single organisms and populations. In these studies acute doses of gamma radiation were used to establish relative sensitivities of different species. Beta radiation effects received very little attention, since satisfactory systems for beta radiation dosimetry were not available. Bigot et al. (1973) describe the difficulties in extrapolating from laboratory experiments to natural systems, and further suggest that observations on responses of natural ecosystems to chronic low level irradiation should extend over several growing seasons or longer to monitor the possibility of long term genetic effects.

In 1968 and 1969 studies were begun in France, Russia and the United States on long-term effects of radiation on terrestrial arthropod communities. A point source (1200 Ci of ^{137}Cs) was installed in a mediterranean type forest in France to study responses of entomofauna, microfauna and microflora (Tchernia 1971, Le Masne and Bonavita-Cougourdan 1972, Rougon and Rougon 1970, Bigot et al. 1973). In Russia some aspects of the effects of in situ radioactive sources on the meso- and microfauna, terrestrial and soil invertebrates and on leaf-eating insects have been studied for a wheat field contaminated with ^{239}Pu (Krivolutskii and Fedorova 1973) and a birch-pine forest contaminated with ^{90}Sr (Krivolutskii et al. 1972).

In 1968 a long-term project was initiated in east Tennessee at Oak Ridge National Laboratory specifically to assess responses of an ecosystem—plants, vertebrates and invertebrates—to mixed gamma and beta radiation from simulated fallout. A managed grassland ecosystem was selected for the initial experimental system, since grasslands cover a very large area of this country and are important bases of agronomic food chains. This paper covers the first 5 yr of observation on the numbers of 76 arthropod and 2 molluscan taxa collected in control and experimental sites with pitfall traps, soil cores and biocoenometers. The question of establishing a threshold for effects of ionizing radiation at the community level of organization is also considered.

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Human Subjects Project

MATERIALS AND METHODS

The research area consists of a 2 ha field dominated by Ky-31 tall fescue, *Festuca arundinacea* Schreb. Herbaceous and litter arthropods of the field have previously been studied by Van Hook (1971). Within the research area three plots 10 x 10 m were chosen and designated as follows: 1) contaminated fenced enclosure, which received 2.44 Ci ^{137}Cs by application of tagged silica sand grains (Lane 1967, Dahlman et al. 1969, Styron and Dodson 1971,1973); 2) primary fenced control, which received a similar application of untagged silica sand grains; and 3) secondary unfenced control, which received no sand. Sampling of the arthropod communities was initiated four months prior to the treatment by means of pitfall traps, soil cores, and biocoenometers (Styron and Dodson 1973). Samples were taken twice a month from each plot through the first year and monthly thereafter. The basic observation was the number of animals of each of 76 arthropod and 2 molluscan taxa (Styron and Dodson 1973) collected in each trap of a plot on a particular date.

Beta and gamma radiation dose rates in microhabitats of the contaminated enclosure were determined using LiF thermoluminescent microdosimeters (Harshaw Chemical Co., TLD-100) suspended at several heights above ground in the middle of the enclosure (Styron and Dodson 1973). Dosimeters with and without beta radiation shields were exposed during the first week after contamination, the eleventh week, and annually thereafter to monitor changes in beta and gamma radiation dose rates through time and vertical distance.

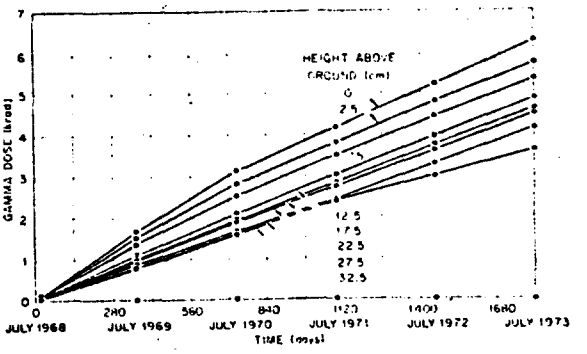

Fig. 1. Accumulated gamma radiation doses at several heights above ground plotted on time. Data points are estimated doses for each anniversary.

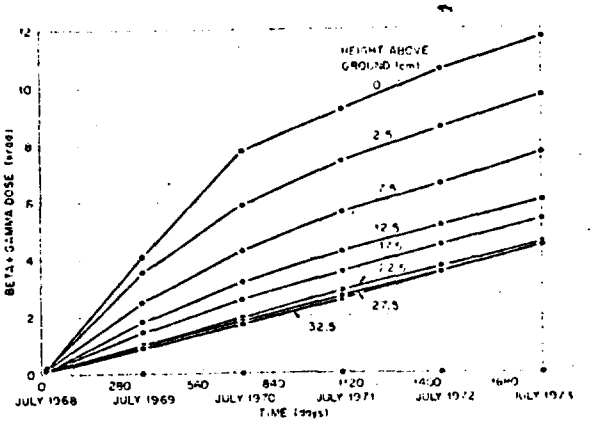

Fig. 2. Accumulated beta + gamma radiation doses at several heights above ground plotted on time. Data points are estimated doses for each anniversary.

RESULTS

Beta and Gamma Radiation Dosimetry

Radiation dose rates ranged from 2.3 to 13 rad/day. The high of 13 rad/day was recorded during the first week after contamination and consisted of the combined beta and gamma dose rates. The combined dose rate gradually declined over a 2 yr period to 2.3 rad/yr as the fallout simulant was incorporated into soil, shielding the beta component. Radiation doses accumulated at each height above ground over the 5 yr are presented in Figs. 1 and 2. Soil, litter, and grass-inhabiting components of the arthropod community have 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. Beta radiation made an important contribution to the total doses accumulated at the 0 and 7.5 cm levels during the first 2 yr. Grasshoppers (*Melanoplus* sp.) and crickets (*Acheta domesticus*) carrying cleaved crystals of LiF (Styron and Dodson 1971) provided estimates of integrated 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 doses of living grasshoppers (thorax 0.09, abdomen 0.10 rad/hr) and ground-dwelling crickets (thorax 0.22, abdomen 0.31 rad/hr).

Community Analysis

Data on the arthropod community have been evaluated in a number of ways in order to obtain as much information as possible and to fully examine the null hypothesis of no radiation effect. Analyses of the first 3 yr data (Styron and Dodson 1973) for

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78 taxa identified no statistically significant difference between control and contaminated arthropod communities in terms of the species present and their densities. In subsequent analyses using data for 5 yr, it was necessary to aggregate the taxa because many of the 78 taxa were not observed during a majority of the experiment in all three communities. The number of taxa was operationally reduced (1) by grouping them trophically—herbivore, carnivore, omnivore in the soil, litter, or grass; (2) by using first 20 and then 10 major taxonomic categories; and (3) by considering 5 resident macroarthropod categories (Table 1).

The first segment of data analysis involved a two-way analysis of variance using the total number of animals of each taxonomic group collected in an enclosure on a particular sampling day, where the factors were the 3 treatments and the collection dates. The analysis was repeated for each of the major taxonomic groupings in Table 1. Further, the analysis was performed on the logarithm of the observed number of animals [x = lox (X + 1)] collected at a particular time in a particular plot to ensure normality, and each of the following comparisons was tested: (1) contaminated enclosure versus uncontaminated enclosure (or primary control), (2) contaminated enclosure versus secondary control (or fenced plot), and (3) uncontaminated enclosure versus secondary control. The objective of this analysis was to single out those taxa that indicate a time-dependent treatment effect. Several combinations of collection dates were used in this procedure.

TABLE 1. Taxon groupings used in analyses.

20 taxon grouping	10 taxon grouping	5 taxon grouping
Springtails	Springtails	Bugs
Grasshoppers	Grasshoppers	Beetles
Bugs	Bugs	Ants, Bees, Wasps
Beetles	Beetles	Aphids
Ants, Bees, Wasps	Ants, Bees, Wasps	Spiders
Flies	Flies	
Aphids	Aphids	
Leafhoppers	Leafhoppers	
Spiders	Spiders	
Mites	Mites	
Diplopoda		
Julida		
Chilopoda		
Thysanoptera		
Thripidae		
Coccinellidae		
Rhagionidae		
Unidentified Larvae		
Slug		
Snail		

After the analysis of the complete data set, observations from collection dates were successively omitted starting with collection date 1, then collection dates 1 and 2, etc., until only the 10 most recent collection dates were left. From the calculated F values for each taxon in this analysis of variance, a plot was made of the number of time periods deleted versus the probability of not exceeding the observed F. A second analysis of variance started with the first seven collection dates, which were before the contamination dates until the complete data set was obtained. Calculated values were plotted as the number of time periods accumulated versus the probability of not exceeding the observed F. Finally, a moving-year analysis was performed on the similar collection of two-way tables for each taxon, but only a year's data was used in each analysis. That is, a two-way table to be analyzed for a significant treatment effect would be made up by using 1 yr data starting from collection date 1, then the next two-way table would start with collection date 2 and use 1 yr data from that date, etc. For each taxon a plot was made of the number of days between the first collection date used and collection date 1 in each two-way analysis of variance versus the probability of not exceeding the calculated F value. Because of natural yearly fluctuation in the number of animals present, all three types of analysis of variance were repeated using the arc sine transformation on the proportion of animals collected which were of a given taxon in a particular experimental site on a particular date. An investigation of plots resulting from these analyses of variance showed no significant difference between experimental and control arthropod communities.

The second segment of investigation into the arthropod community data involved calculation of diversity and similarity indices. In the preceding analyses of variance the basic observation was the total number of animals from a particular taxonomic group at a particular site on a particular date, i.e., all of the animals from the 26 pitfall traps (20 for secondary control), 5 soil cores, and the biocoenometer samples were pooled. This pooling could cover a possible source of differentiation between control and treated sites. Therefore, observations from the three sample types (pitfall traps, soil cores, and biocoenometer) were separated during subsequent analyses. Further, only the contaminated enclosure and primary uncontaminated control were included in the analyses since the secondary control plot differed in the number of pitfall traps.

The diversity indices considered were Shannon's

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index of diversity $\bar{H}$ (Shannon and Weaver 1949), Simpson's index of diversity (Simpson 1949), and the reciprocal of Simpson's index. Similarity measures included x^2, $\int$, C_λ, and τ (Van Belle and Ahmad 1974). In this analysis all indices were calculated and plotted for each collection date. The calculations were also done separately for the three sample types (pitfall traps, soil cores and biocoenometer) and taxon groupings (Table 1). Examples of plots generated in this analysis are given in Figs. 3 and 4. From an examination of the plots of diversity, it appears that all three indices follow a similar pattern over the entire experimental period, which implies that they measure the same phenomena. Plots of the four similarity measures also follow similar patterns. For the diversity indices as well as similarity measures there appeared to be no measurable divergence in pattern between the primary control and contaminated enclosures, i.e., there is no observed difference in arthropod community diversity or similarity that can be attributed to the radiation treatment over a 5-yr period.

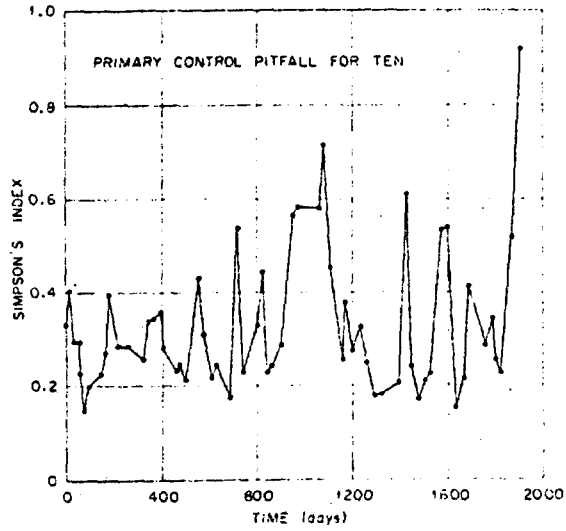

Fig. 3. Simpson's index of diversity plotted on time for pitfall trap samples of the primary fenced control enclosure, using the 10 taxon grouping.

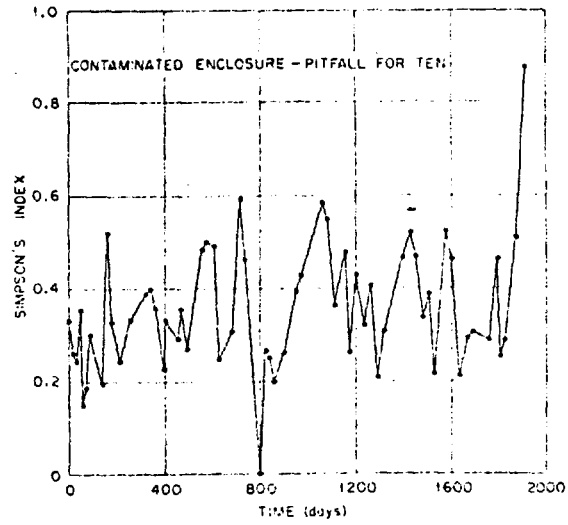

Fig. 4. Simpson's index of diversity plotted on time for pitfall trap samples of the contaminated fenced enclosure, using the 10 taxon grouping.

DISCUSSION

Bigot et al. (1973) in France have reported that chronic gamma-irradiation of a forest ecosystem resulted in a significant effect on the entomofauna and microflora. A demographic explosion of Psoques was observed after 3 yr, and this was accompanied by disappearance of Collembola in the zone nearest the irradiator. Study sites were established at several distances from the point source and dose rates along the experimental gradient ranged from 1.4 to 14 rad/hr. Even the lowest dose rate is considerably above the range of dose rates—95 to 540 mrad/hr—generated by simulated fallout in this study. The differences in radiation dose rates as well as in ecosystem types are undoubtedly the most important factors in accounting for the difference in results from these experiments.

In contrast to the experiments of Bigot et al. (1973) which appear to demonstrate an effect of chronic irradiation at various dose rates ≥ 1.4 rad/hr, the present study using simulated fallout has established the existence of a threshold for radiation effects on structure of an arthropod community. This threshold occurs at or above the dose rate range 2.3 to 13 rad/day (chronic for 5 yr) due to the absence of a significant difference in variance, diversity, or similarity of control and contaminated communities. The work of Bigot et al. (1973) by demonstrating an effect on terrestrial insects at 34 rad/day and work presented here indicating no effect at 2.3 to 13 rad/day suggest that the range of 2.3 to 34 rad/day warrants further intensive study in setting more precise limits for a threshold for chronic irradiation of natural ecosystems and the potential chronic radiation effects on arthropod communities.

In earlier analyses of data from the study of grassland arthropods (Styron and Dodson 1973) several individual taxa (Carabidae, Phalacridae, Simuliidae, *Kolla bifida*, Poduridae, Sminthuridae, Aphidae, and Trombiculidae) of the community evidenced significant reductions in numbers in the contaminated enclosure during summer, followed by re-

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covery. For any given year the number of affected taxa was not above what might be expected by chance at the $P \leq 0.05$ level. Significant differences ($P \leq 0.05$) between control and contaminated communities were identified by analysis of variance for the second and third summers, but recovery was observed following each of these summer periods. It is suggested that during summer months (1) periods of maximum reproduction occur and radiation effects are most likely to be seen during this radiosensitive stage (Styron 1971,1973) and (2) elevated temperatures, lowered moisture, and other factors in microhabitats may act synergistically during summer months to lower environmental carrying capacity to a point at which increased stress from ionizing radiation (Platt 1965) may become evident. Further analyses of these and subsequent data will evaluate seasonal variations in community dynamics via mean value functions and a study of their relation to microclimate in view of the above implications.

Arthropod responses over a 5-yr period (1968-1973) to an in situ radiation source have been evaluated for dose rates which are at least an order-of-magnitude lower than those from preexisting experiments. It is important to note also that these levels of radiation exceed by approximately four orders-of-magnitude the stipulated acceptable levels from routine releases from nuclear power reactors (reference limit 5 mrem/yr per proposed Appendix I, Title 10 CFR). The absence of a lasting significant effect that can be attributed to ionizing radiation suggests that environmental exposure from civilian sources are not likely to produce effects on the density and diversity of grassland arthropod communities.

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