rate of capture differently in the various habitats. These results suggest that the effect of weather change on captures is influenced by population density. Of the four habitats considered broomsedge forb had the lowest density of small mammals, and weather change significantly influenced only captures of male *P. polionotus;* broomsedge vine had the greatest density and weather change was significant for all but female *P. polionotus.*

Detailed consideration of the influence of each type of weather change in each of the four habitats supports the previous analysis shown in Table 1. In the mixed-forb and *Lespedeza* habitats *P. polionotus* captures increased with deteriorating weather. *S. hispidus* acted similarly to *P. polionotus* in the mixed-forb habitat, but in the other habitats captures of cotton rats increased in clearing weather. The interaction between weather change and abundance of animals may reflect competition for available shelter.

The lack of a consistent significant effect of change in weather from night to night on captures of small mammals may be attributed to insufficient data, especially for the night preceding the setting of the line of traps; nevertheless, further information would probably not change the relative importance of the various factors affecting numbers of captures, and, therefore, the conclusion that the type of habitat and the day in the trapping sequence have a greater effect on captures by snap traps than change in weather.

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## Behavioral Changes in an Ant Colony Exposed to Chronic Gamma Irradiation[1]

ABSTRACT: *Changes in the behavior of a colony of ants,* Formica integra, *were investigated in an area experimentally exposed to chronic gamma radiation at Brookhaven National Laboratory. The habits of the colony changed so that ants were no longer exposed to high radiation levels. The ants constructed a covered runway, 12.5 m long, extending away from the radiation source and used exclusively for travel to and from the nest. The ants also abandoned the habit of appearing on the exposed nest stub and banking it with litter.*

[1] Research carried out at Brookhaven National Laboratory under the auspices of the United States Atomic Energy Commission.

## INTRODUCTION

Increased attention has recently been given to the fate of radioactive fallout in natural systems and to potential ecological changes resulting from increased environmental levels of radiation. However, the effects of increased levels of ionizing radiation on natural populations have been largely unstudied. Brower (1964) reported on ants in a wooded area exposed to chronic gamma radiation. He found that ants were absent, for the most part, from shrubs near the source of radiation. He attributed this to a lack of food, since shrubs close to the radiation source were dead and even those further away supported low numbers of insects.

I have found no reports of changes in behavior of natural populations attributable to ionizing radiation, although one of the most intriguing aspects of the effects of radiation on animals is the possibility of behavioral changes elicited by radiation. Certain vertebrate animals apparently can sense radiation, and tend to avoid it. Horne and Brownell (1962) mention that unpublished work has demonstrated a radiation avoidance response in grain beetles irradiated at high intensities. Another report of an insect which shows a definite avoidance response is on the ant. Hug (Brinkman, 1962) discussed this avoidance response of ants and offered a possible explanation. No insect has been shown to demonstrate this avoidance reaction under natural conditions. Ants would be likely subjects for such a field study.

The only report dealing with the sensitivity of ants to direct radiation exposure is that by Cole *et al.* (1959). They reported that for the pharaoh ant, *Monomorium pharaonis* L., the LD/50 in 24 hours for workers was 140,000 roentgens, whereas that for the queen was 190,000R of gamma radiation. The dosages necessary to produce complete mortality within 24 hours was 225,000R for workers and 210,000 for queens. Since these values are high, it would appear that ants, at least the adults, are among the more radioresistant insects.

This paper presents observations of behavioral changes in an ant colony exposed to chronic $\gamma$-radiation. Sincere appreciation is due Dr. George M. Woodwell, Dr. Harvey L. Sweetman, and Dr. Auburn E. Brower for suggesting improvements in the manuscript.

## EXPERIMENTAL AREA AND METHODS

The experimental forest, growing on a sandy glacial outwash plain, is representative of the oak-pitch pine forests of Long Island, New York. The principal species are white oak, scarlet oak, and pitch pine. The understory is characterized by bear oak, and the shrub layer is dominated by ericaceous shrubs.

The experimental forest is circular, with the radiation source at the center. Irradiation was initiated in November 1961; the source, a 9,500c Cesium 137 unit delivering high intensity $\gamma$-radiation is in the irradiating position for 20 hours each day and is in operation on a year-round basis. For four hours daily the source is shielded, making work in the forest possible. The basic design and operation of the installation were described by Woodwell (1963a).

The effects of radiation on vegetation ranged from death, through varying degrees of growth inhibition, to more subtle effects on reproductive capacity; they have been described by Woodwell (1963b). Differences in sensitivity among plant species produced a zonation of vegetation, five zones being clearly distinguishable: a zone of total kill of all higher plants, a sedge zone, a heath-shrub zone, an oak zone, and the oak-pine forest.

OBSERVATIONS

In 1961 an active colony of *Formica integra* Nyl. was observed at the base of a burned pine stump about 1 m tall, 18 m due east of the future site for the source of radiation. The colony appeared normal and the characteristic behavior of this species, as described by Wheeler (1910), was well developed. The pine snag was irregular; all cracks and crevices were filled with small bits of accumulated vegetable detritus, and a considerable mound of this debris was present around the base of the stump (Fig. 1). The workers were busy daily bringing more debris to bank the nest and refill cracks in the snag. Wheeler (1910) mentions that this species also constructs sunken runways, but in this study these were observed initially only where principal travelways crossed open paths.

This colony was observed in subsequent years, following installation and activation of the radiation source, and changes in the general behavior of the colony noted. Unfortunately no "control," in the usual sense, was feasible. However, observations during the same time period on other colonies remote from the radiation source produced no evidence of similar changes. Nor, to the extent observed, did behavior in these other colonies exhibit any marked discrepancies with the description provided by Wheeler.

*1962*.—In 1962 the colony of *F. integra* was again active although now exposed to 10.0R per hour of $\gamma$-radiation for 20 hours each day. Throughout the first half of the summer of 1962, after radiation damage was well developed in the plant community, the ant colony remained normal in appearance and behavior. Workers continued to bring both plant debris and insect food to the nest, although the latter appeared to be reduced in amount. On 21 August, however, it was noticed that the colony was apparently in the process of establishing a secondary colony. The line of march was north and tangential to the circle of radiation damage and was lost among the forest-floor litter at about 60 m from the radiation source. The

Fig. 1.—Photograph of the base of the pine snag containing the nest of *Formica integra* and showing the vegetable debris piled around it by the ants.

new colony was not found, but it appeared not to have any intercourse with the original colony, which maintained itself.

Late in August the colony, though now depleted, was still relatively active. The normal behavior patterns were still observed, although fewer ants were seen on the stump itself. During the month of September activity lessened around the nest and it appeared that the colony was dying out.

*1963*.—In the spring of 1963 the colony was again found to be active with many ants foraging. The nest now had short sunken runways radiating in several directions. These runways had sections which were either open or roofed with plant debris; the longest was about 1 m long. During June the colony appeared as active as when first observed in 1961, but lacked ants working on the snag. During the remainder of the summer an apparent decline in numbers and activity was noted, and it again appeared that the colony might die out. The characteristic of banking the colony with debris seemed to have been abandoned completely during this time. Ants were still present, but not abundant, in September.

*1964*.—Early in June of 1964 the colony was again fairly active but lacked the large numbers associated with a healthy colony. The habit of bringing debris to the colony was lacking, and ants were never observed on the exposed pine snag.

On 1 July the colony seemed to have gained in numbers. However, the ants' behavior seemed unusual. A runway 12.5 m long had been constructed extending from the base of the stump outward at an angle away from the source. This runway was lost at 29 m from the radiation source, and a careful search failed to reveal any subsidiary colony. At 29 m the exposure level was only 3.3R/hour or about one-third of that at the nest. Furthermore, the runway was excavated below the surface of the soil and was covered by ground litter for almost its entire length. Therefore, the level of radiation was lower in this runway than at the surface of the litter layer.

The ants were observed to use this runway exclusively in travel to and from the nest. Even after diligent search around the nest no ants were found away from this trail. If disturbed while on the trail the ants would invariably try to hide under a roofed-over section. A few ants that were removed from the trail and placed nearby either hid in the litter or returned directly to the trail.

During August and early September the ants continued this mode of activity. Activity again declined to some extent but not as noticeably as in previous years. The ants were constantly cleaning and caring for the runway but no new ones were started during this time.

## Discussion

It would be easy to assume that the observed modifications of the habits of *F. integra* were due entirely to a radiation-avoidance response. Indeed they appear to be intimately linked to the radiation and its effects. However, the changes in the community caused by radiation complicate the interpretation. Brower (1964) reported that coincident with the death of vegetation, the herbivorous insects and their parasites and predators were eliminated. Fungivorous forms increased but total insect abundance was much reduced. Therefore, the runway led not only away from the radiation source but also toward a greater abundance of insect food. The path would make it much quicker and easier to reach a supply of food and return to the nest when burdened. Certainly the runway did serve to reduce the exposure level both along its length and in the foraging area at its terminus. The movement of most of the colony in 1962 was probably the result of the decreased food supply rather than a direct radiation effect. Either or both are possible, however.

Another factor which could have been operative was the increase in exposure to sunlight because of the elimination of the tree canopy. However, Wheeler (1910) reported that this species prefers small clearings in open woods so this change should not have affected the ants adversely.

The behavioral change which was most apt to have been caused by direct radiation-avoidance response was the abandonment of the litter-collecting habit. Ants no longer ventured up on the exposed stub to refill the crannies with plant debris. Even the habit of banking the base of the stump was eventually given up. This suggests possible avoidance of exposure to high levels of radiation in this way.

It is not entirely clear why the characteristic habits of the ants in the colony observed changed. The change may have been a direct response to the radiation, or possibly a result of other environmental changes. The absence of ants from the exposed pine stump was the most likely modification of behavior resulting from a radiation-avoidance response. The slow development of the behavioral changes indicates that these developed secondarily as a result of other changes brought about by radiation. If we assume variability among individuals with respect to strength of a radiation-avoidance reaction, or even with respect to other behavior that fortuitously produced differences in extent of exposure, then a selection process for ants which did not expose themselves could have contributed to the observed changes. But ants' high radioresistance makes this unlikely. Even if such selection did occur there was probably no extensively transmitted genetic change in the population during the short period of time involved; if the same queen was present throughout the study period, genetic selection could not occur at all.

The complex behavioral patterns exhibited by ants make any conclusion as to causal factors for the observed changes purely speculative.

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