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LANDSCAPE INVESTIGATIONS USING CÆSIUM-137

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RADIOACTIVE tracers offer almost unexplored opportunities for investigating ecological processes in the landscape. Nutrient and trace-element cycling in ecosystems, delineation of food-chains, or any other ecological process which involves the transfer of material between two components of an ecosystem, are subject areas where radioactive tracers may be useful. Perhaps even more important, tracers provide the ecologist with a tool for tagging the entire biota of a community. By so doing the ecologist is in a position to estimate the interactions between the components of a community.

Although field investigations using radioactive tracers are not unique, in that they have been used for examining insect behaviour and dispersion patterns, uptake of fertilizer, limnological and stream phenomena, investigations in which tracer quantities of long-lived radioisotopes were used on a relatively large scale in field experiments hitherto have not been attempted in the U.S.A. The purpose of this article is to describe such an experiment which our group designed and initiated in May 1962, in which a forest ecosystem was tagged with cæsium-137, the half-life of which is approximately 30 years. This experiment has these general objectives: to determine the

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cycles and rates of cycling of cæsium and related elements in a mesic forest ecosystem, to measure cæsium transfer between components of an ecosystem and apply these results to a theoretical model of element circulation developed by one of us[1], and to derive information useful for predicting the fate of problem radionuclides in those ecosystems which potentially may have a large capacity for storage in biological materials.

The forest is situated within the U.S. Atomic Energy Commission Reservation at Oak Ridge, Tennessee. The experimental site is one of several sinkholes in an isolated part of the Reservation. Although these sinkholes are underlain by dolomitic limestone, they have no surface drainage and contain a deep (> 25 ft.) fill of colluvial (Emory) soils which would sorb the cæsium before it could reach ground-water. The forest is dominated by second-growth yellow (tulip) poplar (*Liriodendron tulipi-*

Fig. 1. Radioisotope tagging of a forest. Trough of malleable sealing compound is formed around tree trunk and covered with aluminium foil. Slits are cut into inner bark at 1-in. intervals around the trunk. As soon as translocation is evident, radioisotope tag, previously diluted with tap-water, is poured into trough as shown. Second man from left is adding diluent continuously as man on right adds the radioisotope

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fera L.). Second growth stands which are almost pure *Liriodendron* are not uncommon in the forests of the Appalachian region[2]. The sinkhole habitat then, in addition to having advantages of isolation and protection, is relatively discrete so there is a high probability of tagging the entire biota. Moreover, the sinkhole has a deep rich soil and woody vegetation which will serve as a contrast with a previous investigation[3] on the behaviour of cæsium-134 in white oak (*Quercus alba* L.) growing on less productive shale and dolomite sites.

A 20 m × 25 m portion of the forest was selected for tagging. This plot was subdivided into 5 m × 5 m squares. Vegetation was mapped and understory sampled in nested plots in each square. The thirty largest *Liriodendron* in the plot, ranging in size from 1·8 to 14·2 in. diameter at breast height (4·5 ft.), were tagged. In addition, two redbud (*Cercis canadensis* L.) and one tree each of red maple (*Acer rubrum* L.), red oak (*Quercus rubra* L.) and flowering dogwood (*Cornus florida* L.) were tagged to check for possible interspecific differences in translocation among minor understory species.

The quantity of radioisotope required was derived empirically from inoculation of single trees during the previous three years. Various species were inoculated with differing quantities and kinds of radioisotopes to determine the levels needed to facilitate subsequent sampling and analyses. Ideally, the quantity desired per leaf during the growing season should be sufficient to minimize counting time (1–2 min). The quantity per tree ranged from 0·4 mc. to 94·2 mc., adding to a total of about 467 mc. for the entire stand. Previous weighing of cut trees in the same vicinity provided regression estimates of tree mass (bole plus branches) as a power function of diameter *D*. Quantity of cæsium assigned per tree was made approximately proportional to tree mass by the following formula:

$$\text{millicuries of cæsium-137} = 0{\cdot}133\ D^{2.46}$$

Utilization of such a large quantity of long-lived radioisotope in the field required careful handling and special procedures in order to avoid unnecessary exposure of personnel or accidental contamination during the tagging operation. First the inoculum for each tree was bottled separately in a hot cell at the laboratory. Each small (15 ml.) vial containing a single inoculum was then placed in a cylindrical lead shield for transport to the field site.

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Only the quantity needed for one day's operations was transported to the site. The shields were carried in compartmented trays which were fastened to the bed of the transport truck. At the field site each lot of radioisotope was diluted to a volume of approximately 100 ml. with tap-water. The dilution process required four men. One handled the isotope vial with long tongs, the second handled the diluent container, while the third monitored and timed the operation. A fourth man stood by with absorbent paper to wipe the lips of the vials and also to wipe any contamination should there be a spill.

The method of inoculation resulted from three years of testing of various techniques[4–7] and ensured uniform translocation and distribution in the canopy. First a 4–12 in. wide ring of outer bark, usually at breast height, was smoothed by means of a stripping knife. Then a trough of malleable sealing compound ('Permagum') and aluminium foil (Fig. 1) was constructed around the trunk. After this was complete the trough was filled with water, and slits were chiselled through the inner bark (cuts 0·25–0·5 in. deep) at intervals 1–2 in. apart around the trunk, the interval depending on trunk diameter. As soon as translocation was evident (while the water in the trough moved rapidly into the trunk) the isotope solution was poured into the trough (Fig. 1).

Again, because of safety considerations a team of four men was used in the pouring operation. One poured the isotope, moving around the trunk to distribute the solution evenly in the trough, a second followed holding a plastic bag underneath to catch any spill while a third continued to add diluent solution at a rate equal to the quantity being absorbed by the tree. A fourth man monitored the operation with an ionization chamber ('Cutie pie') and timed it. Diluent (tap-water) was added as long as the tree absorbed the solution rapidly. When the rate of intake slowed, additions ceased. For a large tree (10 in. diameter) about 6 l. of water was required before this point was reached. After the last of the water was absorbed the trough was sealed by filling with additional sealing compound. By using six men and alternating functions the entire tagging operation was completed in less than 4 days and no individual received more than 5 per cent of his permissible weekly radiation exposure.

A rather elaborate sampling programme is required in any large field investigation and this experiment is no exception. Fig. 2 illustrates many of the sampling techniques which are being used. Prior to tagging, a tower of scaffolding was erected which provided several levels of working areas up to 35 ft. above the ground. This

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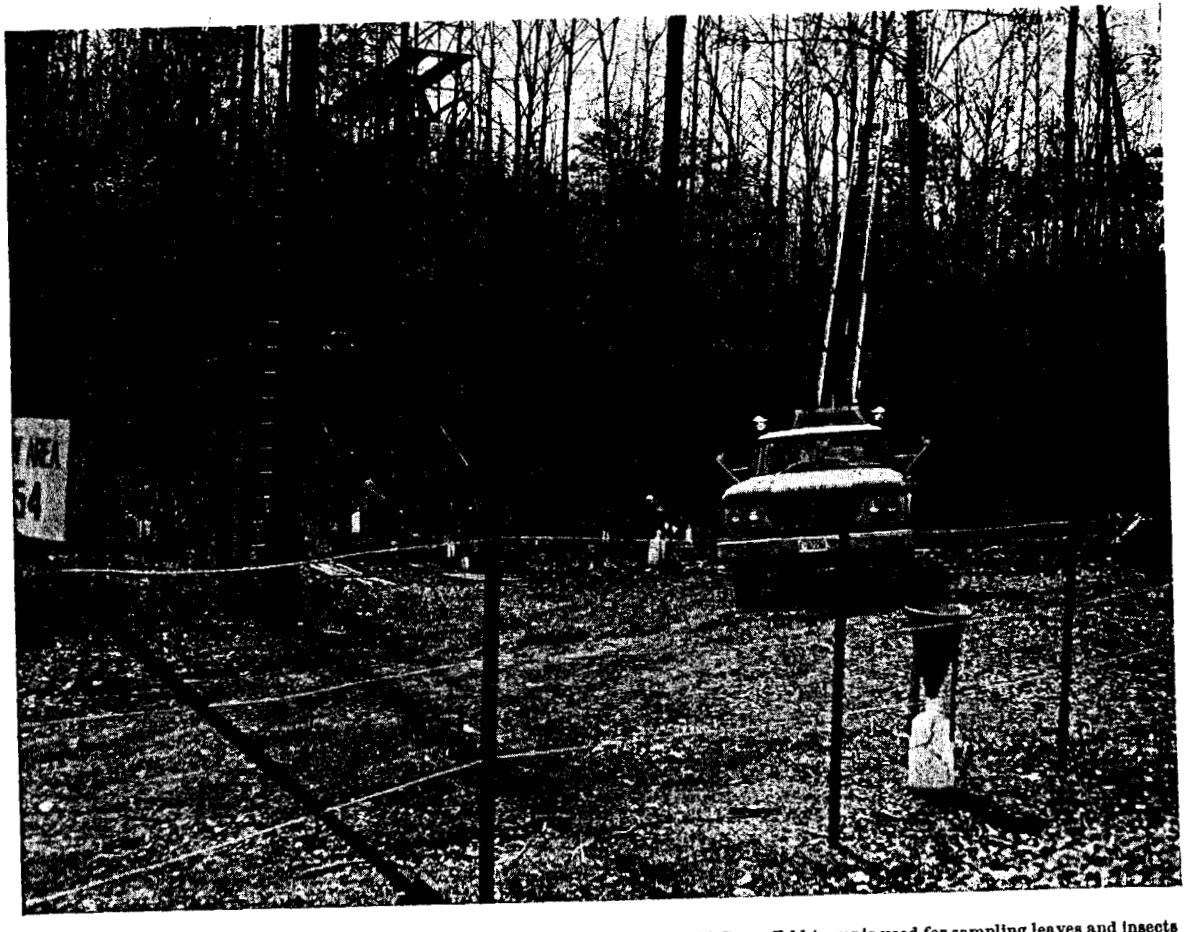

Fig. 2. Early spring aspect of radioactive cæsium-137 tagged *Liriodendron* forest. 35-ft. scaffold tower is used for sampling leaves and insects [illegible] Polyethylene carboys attached to troughs collect rain stem flow. Bushel baskets serve as leaf-fall collectors

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tower enabled the staff to sample readily and easily from trees growing adjacent to the tower. For other trees an aerial ladder truck was used, which in conjunction with pruning equipment enables us to sample up to 60 ft. in the forest canopy. For higher samplings (60–90 ft.) in the canopy, a truck equipped with a 50-ft. hydraulic boom and basket is used.

Previous investigations had shown that radiocæsium is leached readily from leaves by rain-water[3]. Two kinds of rain-water collectors were used in the forest. One type consisted of ten stainless-steel funnels placed throughout the stand to collect rain which passed through the canopy. The second collected stem flow of rain-water from ten of the tagged and one control tree (Fig. 2). Fall of litter was measured by means of twenty bushel baskets randomly dispersed under the canopy on the forest floor.

After inoculation, leaves and stems from the trees adjacent to the tower were sampled weekly in order to measure radiocæsium build-up in the canopy. After the maximum concentration was attained, samples were taken monthly. Composite samples from various other trees in

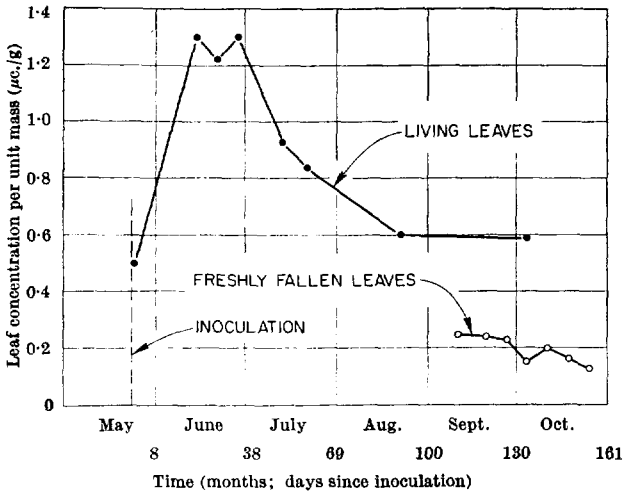

Fig. 3. Seasonal distribution of cæsium-137 into and out of *Liriodendron* canopy. Concentration of cæsium-137 in living leaves and freshly fallen leaves

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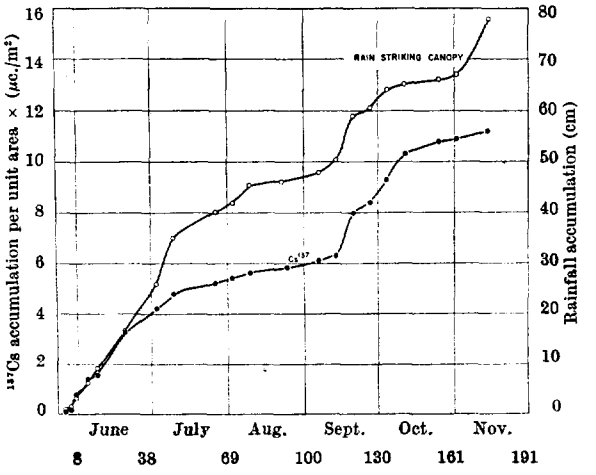

Fig. 4. Approximate cumulative rainfall striking canopy of *Liriodendron* forest, and cæsium-137 leached from the canopy by this rain (not including a small additional increment estimated by measurement of stem-flow)

the stand and from various heights in the canopy were made monthly during the summer of 1962. Freshly fallen litter was collected twice-monthly from the baskets, and additional collections were made each week at the time of maximum leaf-fall.

The rapid attainment of maximum foliage concentrations, averaging 1·3 μc./g dry weight on June 6 and June 20, 1962, was followed by a decrease throughout the growing season to about 0·6 μc./g dry weight during August 22–early October (Fig. 3). Concentrations in fallen leaves decreased from only 0·25 μc./g dry weight on September 10 to 0·13 by October 25. This decrease suggests a marked withdrawal of cæsium-137 (and presumably total content of alkali metal elements) before leaf drop and a leaching of leaves by rain before and after leaf drop.

Through-canopy rain-water collected in the funnels showed maximum cæsium-137 concentrations in June, when foliage radioactivity was highest (Fig. 4). The details of leaching in relation to time, of course, depended on the frequency and amount of rainfall. There is a suggestion of increased cæsium-137 per cm of rain late in the summer, which might reflect a period of re-mobilization of alkali metal reserves prior to translocation back

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into woody portions of the tree. Further investigations now under way are needed to confirm and explain this re-mobilization effect.

Transfer of radiocæsium to the forest floor via falling *Liriodendron* leaves reached a maximum rate of 3·2 μc./m²/day in the week of October 4–11, 1962. The cumulative leaf contribution was 40·5 μc./m² (out of a total litter contribution of 42·8 μc./m²) between September 3 and November 7. The total *Liriodendron* leaf-fall of 193 g/m² dry wt. during this period or 196 g/m² by January 9, 1963 (out of 304 g/m² total litter fall), provides a tentative basis for estimating maximum canopy content if this total approximates total mass of foliage present in late June. If the late June cæsium-137 concentration per unit mass of 1·27 μc./g dry wt. is representative of the whole canopy, then foliage activity on a unit-area basis was 1·27 μc./g × 196 g/m² = 249 μc./m² at a seasonal maximum. This quantity represents about 27 per cent of the total radiocæsium introduced into tree trunks (~1 mc./m²). This fraction is lower than the maximum canopy fraction of 40 per cent reported for white oak saplings[3]. The difference between the two species may be attributable to size. The oak saplings averaged 2·5 in. dbh whereas *Liriodendron* averaged 6 in. with individual trees up to 12·6 in. and 14·2 in. in diameter.

The prompt movement of cæsium ions into leaves must not cease during late June, nor does the export start suddenly. The concentration in the foliage at any time represents a balance between income and opposing loss rates. The rate of decrease of foliage activity through late summer appears to be about 1·2 per cent of foliage radiocæsium per day. The preliminary results (Fig. 4) emphasize the importance of rain as an agent in radiocæsium transfer. Approximately 20 per cent (~ 10·3 μc./m²) of the total litter burden (~ 52 μc./m²) was derived from rain leaching. Only 7 per cent of the original radiocæsium input to *Liriodendron* was transferred to the forest floor during the first growing season in contrast to white oak saplings[3] where 20 per cent of the original input was transferred. Further data and computer simulation of simultaneous income and loss need to be combined for evaluating the general model of cæsium flux for this interesting case of *Liriodendron* forest.

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