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PUERTO RICO NUCLEAR CENTER

THE RAIN FOREST PROJECT
ANNUAL REPORT FY-1967

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ABSTRACT

This is the annual report of work done on the Rain Forest Project at El Verde, Puerto Rico. The primary experimental plan of forest irradiation including 1 year of follow-up studies has been completed and will be reported by H. T. Odum in a published volume. Since completion of this phase, as of June 30, 1966, the experimental emphasis has been shifted to include detailed studies on radionuclide behavior in the tropical forest, and studies on the recovery and succession in the irradiated area. Reports are given on the behavior of fallout radionuclides in the forest, on the behavior of applied tracers, and on the behavior of tritium. Others are presented on the recovery of the area and include comparative studies of disturbed areas, leaf area index measurements, diversity measurements and observations on vegetative regeneration by sprouting. Some studies initiated as part of the broad ecological approach of the radiation experiment are being continued because of their general importance to the understanding of life processes. These include studies on phenology, light quality, water budgets, and forest metabolism.

TERRESTRIAL ECOLOGY PROGRAM I
THE RAIN FOREST PROJECT

Jerry R. Kline, Ph.D., Head

The Rain Forest Project is a series of studies on one small area of the montane rain forest 1500 feet up the side of El Yunque mountain in Eastern Puerto Rico. It has three objectives: (1) to study the effects of gamma radiation on the tropical ecosystem; (2) to study mineral cycling and dispersion in the system; and (3) to study the basic biological functions of this ecosystem such as respiration, transpiration, and photosynthesis to better understand phenomena related to the first two objectives. The project is in its fourth year. A section of the forest has been irradiated and many follow-up studies have been completed. (For details of the radiation experiment, see PRNC-82, Annual Report 1965). Present effort is being directed to long-term studies on recovery and succession of vegetation in the irradiated area, and to detailed investigations of mineral cycling and distribution in the tropical ecosystem.

RECOVERY AND SUCCESSION STUDIES

The arrival of Dr. Carl F. Jordan, a plant ecologist, to join the staff in July 1966, marked the beginning of the recovery and succession studies in the irradiated area. While most of the previous ecological studies dealt with the damaging effects of radiation, it was apparent by that time, 15 months after the cessation of radiation, that further damaging effects were becoming increasingly difficult to detect. The general canopy opening had progressed to about 25 meters from the radiation source but further opening was occurring only slowly, if at all. In the meantime, however, succession and recovery in the irradiated area had become very vigorous. A major effort was therefore initiated to ensure adequate documentation of this recovery.

The irradiated area was laid out on a grid system consisting of 900 one-meter squares. All plants within the grids were tallied, and data on diameter, height, species, and date of origin (before or after radiation) was recorded. Data will be presented to show in detail the qualitative character of recovery, and in addition, will be used as input to a series of regression equations to enable the computation of net biological productivity in the irradiated area. The necessary data for the equations is being obtained by cutting, weighing, and measuring plants of similar size in the cut center of the El Verde plot. All measurements in the irradiated center are of a nondestructive nature and no cutting is permitted there. Foot travel has been eliminated in the irradiated center by closing the paths which formerly crossed it and rerouting them around the borders of the center. This action was taken to insure that trampling will not be a variable in the recovery studies.

One complete survey of this type has been finished and plans are being formulated for a computer solution of the regression equations. It is currently being planned to repeat this series of measurements at yearly intervals so that rates of net production can be obtained.

The detailed studies of recovery are time-consuming and cannot be repeated at frequent intervals. In order to provide an index of recovery more often, a series of leaf area index measurements has been initiated. These measurements were made in both irradiated and cut centers and show the net production of new leaves. The data indicates that although there are slight differences between the two centers, these differences cannot be attributed to radiation. Two complete series of leaf area index measurements have been completed and plans have been formulated to repeat these measurements at 6-month intervals.

The old vegetation in both centers shows evidence of sprouting from the base of trunks. This action is far more vigorous in the cut center. It is suggested that the reduced sprouting in the irradiated area is due to possible radiation damage to the roots which proliferate on the soil surface in this forest. Evidence for this has been obtained by determining the proportion of total sprouts in the irradiated area which developed from positions that had local shielding by rocks, soil, or tree trunks. All species, with the exception of Palicourea riparia, showed higher sprout production with shielding. Palicourea riparia is one of the species shown to be extremely resistant to radiation effects by other studies, and it is suggested that a greater dose of radiation is required to induce sprouting in this species.

A series of optical density measurements was completed in the irradiated center in November 1966. These were taken at ground level and at 1-meter elevation. These measurements also function as an index of recovery and will be taken at regular intervals in the future with vertical increments added as the vegetation grows taller.

In order to supplement the data collections, it is essential to have a complete photographic record. This is being obtained from a 50-foot industrial type scaffold which was erected at the borderline of radiation damage during the autumn of 1966. This tower has three platforms, and affords an excellent view of the irradiated center. A complete photographic record in both black and white and color slides is being obtained at monthly intervals from all three levels of the tower.

The tower in the radiation center also gives access to several trees in the immediate area and permits the resumption of growth measurements in a limited portion of the canopy. Individual limbs, which can be reached from the tower, have been tagged and measured so that future growth can be determined. The longevity of leaves is being compared with that of trees further from the source by tagging the leaves, and counting them at periodic intervals. These measurements are expected to provide quantitative verification of canopy dieback if it occurs, since it is now so slow that it cannot be observed by visual inspection.

MINERAL CYCLING STUDIES

The objectives of the mineral cycling projects are to measure existing distribution of macro and micro elements in the rain forest, to study pathways of movement of these elements, and to measure rates of movement along these pathways. These studies are expected to provide in the short run, an empirical basis for the prediction of the fate of radionuclides which may be released in tropical vegetative communities, and may lead in the long run to a theoretical understanding of material handling mechanisms in tropical ecosystems. The mineral cycling studies are divided for convenience into four categories of activity: (1) fallout measurements; (2) radioactive tracer experiments; (3) stable element analyses; and (4) water balance measurements.

The forest at El Verde and other forests in the vicinity were previously found to have relatively large burdens of fallout radionuclides from nuclear weapons tests. In the months preceding the nuclear test by Communist China of May 9, 1966, the monthly input of stratospheric nuclear debris was not detectable. The opportunity was thus presented to carry out a study of the movements of the various isotopes then labeling the forest from past fallout. An attempt was made to measure the biological residence times for four nuclides of stratospheric origin in the forest by carrying out a monthly sampling program of leaves. The leaves were counted for radionuclide content by the method of gamma scintillation spectrometry. A computer program was written for resolution of the complex spectra and the resulting data for the nuclides ^{144}Ce, ^{137}Cs, ^{95}Zr, and ^{54}Mn was plotted as a function of time on a semilogarithmic scale. The data for freshly fallen litter indicates that the biological residence times for these nuclides are not different from their respective physical half-lives. This indicates that the biological residence times are long in this forest, and suggests the presence of efficient biological retention mechanisms. If other forests have similar mechanisms, it may be found that radionuclides released there would be trapped and retained rather than being dispersed and diluted in the environment by the normal processes of weathering and leaching. This study is continuing in spite of the input of Chinese debris, since this debris enables the observation of processes occurring immediately after injection.

In other studies with fallout radionuclides, extensive comparisons have been made between levels in the El Verde forest and other forests in Puerto Rico. In Appendix B, the nuclide levels in forests of different altitudes above sea level in Puerto Rico are shown. These levels increase with elevation at a rate faster than can be accounted for by increases in rainfall. This possibly suggests that the higher elevation forests have some particularly efficient retention mechanisms. Inquiry into these possible mechanisms led to the observation that plants with an epiphytic growth habit generally have far greater levels of fallout nuclide burdens than other plants of the same local area. An example of the burdens for some epiphytic plants of El Verde and the Elfin forest at the top of El Yunque mountain is shown in Appendix B. It has been observed informally that the frequency of epiphyte occurrence increases substantially with increasing altitude. Thus it appears that the increased levels of radionuclides at high elevations may be due to a combination of at least two factors: one, the normally greater input due to higher rainfall at high elevations, and the other, the more efficient biological retention due to the more common occurrence of epiphytic plants.

Drs. H. T. Odum and J. R. Kline investigated altitudinal sequences of this type during a trip to Darien Province, Panama, in the spring of 1966. This trip was financed through a purchase order from Battelle Memorial Institute in connection with bioenvironmental studies for a sea level canal. The actual levels of the nuclides in the forests of Panama were predictably lower than in Puerto Rico due to the known lower levels of fallout deposition in regions close to the earth's equator. The distribution of nuclides, however, was similar in Panamanian forests over the altitudinal sequences from sea level to 3600 feet. Epiphytic plants in Panamanian high elevation forests were the most highly contaminated plants found. It therefore appears that the binding mechanisms and altitudinal relationships first found in Puerto Rico may have a more general occurrence in tropical forests.

Strontium-90 is a nuclide of considerable biological interest for which little data exists in tropical vegetation. We have successfully adapted a chemical procedure to the analysis of tropical plant material for this nuclide. The procedure involves extraction of elements from plant ash with acidic solutions, and precipitation of yttrium as the phosphate, in the presence of yttrium carrier and strontium holdback carrier. At the end of a 2-week ingrowth period, yttrium is again precipitated and counted in a low background beta counting system. The samples are routinely checked for radioactive decay. Samples run by the most recently modified procedure decay within statistical error with the 64.8 hour half-life of ^{90}Y. More than 70 samples of forest materials have been analyzed thus far. Standardization procedures using calibrated ^{90}Sr solutions have been completed and permit the conversion of count rates into absolute disintegration rates. The data is being used to estimate biological retention for this nuclide in a manner similar to that described for the gamma emitting nuclides.

TRACER STUDIES

Radioactive tracer methodology offers a valuable means for direct study of mineral cycles in the tropical ecosystem. A tracer experiment involving the use of ^{85}Sr, ^{134}Cs, and ^{54}Mn was begun in January 1966, in cooperation with Dr. H. B. Tukey of Cornell University; and was terminated in January 1967. The objectives of the experiment were to measure the rates and amounts of nuclide uptake through roots by understory plants in the forest. The results of the experiment indicate extremely slow uptake of the nuclides. This indicates that much of the previously observed fallout radioactivity in this forest may have been intercepted directly from rain and has not been incorporated to a large extent into mineral cycling processes in this forest. This conclusion holds only for small understory plants. Whether canopy trees cycle minerals more rapidly is not known. This will be studied in a future experiment now in the planning stage.

Several preliminary experiments to study the chemical behavior of epiphyllae have been done. It has been verified experimentally that leaves containing epiphyllae actively adsorb ^{137}Cs from solutions. Leaves without epiphytic growth do this to a lesser extent. Furthermore, the adsorption is biological and not simply a surface exchange phenomenon, since the nuclide cannot be removed from the leaves by dipping in a solution containing 0.5 molar KCl. In field experiments, labeled epiphyllae have been transplanted to unlabeled leaves in an attempt to determine whether these plants have the ability to furnish, at least in part, some of the mineral nutrient requirements of the host plants. We are thus far unable to show that this happens. Labeled epiphyllae transfer nuclides to other epiphyllae, but foliar uptake by the underlying leaf has not been found during the short-time interval (24 hours) of the preliminary experiments. Refinements to these experiments are being planned in order to study these possibilities more exhaustively.

STABLE ELEMENT ANALYSIS

Analysis of stable elements in tropical forest vegetation will enable the establishment of present levels in the forest, the identification of possible biological accumulation mechanisms, and the determination of specific activities where the forest is labeled radioactively with the same element being measured chemically. Specific activity measurements will enable the determination of partitioning between stable and radioactive nuclides of the same chemical elements and will give some indication of the rate of attainment of steady-state conditions where all components of the forest have the same specific activities.

Some chemical analyses of stable elements have been completed on forest components during the past year under purchase order to other analytical laboratories. While the results obtained appear to be satisfactory, this general method of obtaining analyses is not satisfactory, since it lacks the flexibility required for an active research program. It has, therefore, been decided to make the project self-sufficient in analytical services. To this end, a research type atomic absorption spectrophotometer with ten hollow cathode lamps has been ordered, and will be put in service immediately upon arrival.

WATER BALANCE MEASUREMENTS

More than 30 lysimeters, of the type developed by Carl F. Jordan, have been installed at various depths in the soils at El Verde (Appendix A). These lysimeters in connection with specially designed rain gauges have been used to obtain preliminary descriptions of runoff and infiltration of rainwaters in the forest. These measurements confirm the past qualitative observations of many investigators that the soils in this region have high infiltration capacity since we have observed up to 95% of the total incoming waters being lost by this means rather than by runoff. This is surprising considering the slopes in this mountainous region, and raises further questions concerning the ultimate dispositions of excess water from the entire area.

The behavior of the lysimeter itself is not yet completely understood. An experimental system has therefore been prepared to study this behavior under controlled conditions (Appendix A). The system consists of a plastic box which contains soil and lysimeter. The box is used for water balance experiments, wherein known amounts of applied water can be traced to either percolation or interception by the lysimeter under conditions where runoff and evaporation are negligible.

Areas in the forest have been prepared to study water movement through soils using tritiated water. The first experiment was carried out in February 1967, when 20 mCi of THO diluted to 1 liter were applied to a 1-meter square plot which was equipped with lysimeters, runoff collectors, and air samplers. Data is shown in Appendix A.

STAFF

Dr. H. T. Odum terminated his position as director of the Terrestrial Ecology Project on September 1, 1966, and was replaced by Dr. Jerry R. Kline. A new staff position, that of Ecologist, was filled by Dr. Carl F. Jordan on July 1, 1966. Dr. Jordan's duties include making the ecological measurements required in the post-irradiation succession and recovery studies, and carrying out water balance measurements utilizing the lysimeters which he developed.

Dr. Elizabeth McMahan of the University of North Carolina spent June, July, and August 1966, as an Oak Ridge Research Participant studying termite behavior and radiosensitivity at the El Verde project site. She has prepared a report on this work and has submitted it for inclusion in the forthcoming book, <u>A Tropical Rain Forest</u>. Dr. Bassett Maguire, of the University of Texas, spent 2 weeks on the project during September 1966, studying arthropod behavior and distribution mechanisms and has prepared two manuscripts from this work for open literature publication.

The project had, in addition, several short-term visitors under the previously existing visitors program, who came to finish various phases of projects needed for the rain forest book publication. These included: Dr. Richard Wiegert and Dr. Joe Edmisten, University of Georgia; Dr. Martin Witkamp, Oak Ridge National Laboratory; Mr. Fred Holler and Dr. Gerald Cowley, University of South Carolina; Dr. Frank McCormick and Dr. Allen Stiven, University of North Carolina; and Dr. Jerry S. Olsen, Oak Ridge National Laboratory.

Dr. Robert F. Smith, a graduate student at the University of Georgia, successfully defended his dissertation which was prepared on this project and terminated his ORINS Fellowship in August 1966.

Mr. Richard Egen, an engineer from Battelle Memorial Institute, spent the month of January 1966, on the project erecting a tower and finishing the giant cylinder in preparation for a series of metabolism and water balance measurements in the forest. Costs of this service were covered by Battelle, since these measurements appear to have relevance in predicting the fate of tritium in tropical ecosystems. This is a problem of primary significance in the proposed construction of a sea level canal by nuclear excavation.

Staff participation in other projects included a trip to Darien Province, Panama, by Drs. J. R. Kline and H. T. Odum for the purpose of collecting plant and soil specimens for fallout radionuclide analysis. Dr. Carl F. Jordan visited Oak Ridge National Laboratory at the request of Dr. Jerry Olson for the purpose of demonstrating the proper installation of lysimeters to be used in studies of nuclide movement in soils.

Dr. H. T. Odum remained as a consultant to the project after his termination of employment and has obtained project aid for the completion of the proposed AEC publication, A Tropical Rain Forest, which is a report of the first 3 years of research activity of the Terrestrial Ecology Project. Other activities as a PRNC consultant include construction of the electrical analog model of a tropical ecosystem with project financial aid. The basic construction for this model, which has been described in previous annual reports, is now complete and performance testing has begun.

PUBLICATIONS

During the meetings of the American Institute of Biological Science which were held August 14-18, 1966, more than 40 papers dealing with various subprojects in the Terrestrial Ecology Project were presented. These papers were authored in large part by past participants in the visiting scientists program and were presented in a block as a symposium at the Ecological Society of America meetings. While the entire list is too lengthy to duplicate, a list of papers presented by project staff is given.

1. Drewry, G. E., Factors Affecting Activity of Rain Forest Frog Populations as Measured by Electrical Recording of Sound Levels.
2. Kline, J. R., Cycling of Fallout Radionuclides in Tropical Forests.
3. Kline, J. R., and H. T. Odum, Comparisons of the Amounts of Fallout Radionuclides in Tropical Forests.
4. Mercado, N., Report on Leaf Fall in the Radiation Center.
5. Murphy, P. G., and J. McIntyre, Tree Growth at the El Verde Site.
6. Odum, H. T., The AEC Rain Forest Project in Puerto Rico.
7. Odum, H. T., Forest Metabolism and the Giant Cylinder Experiment.
8. Odum, H. T., and A. Lugo, (presenting), Metabolism of Forest Floor Microcosmos from the Rain Forest.
9. Odum, H. T., A Functional Theory of Rain Forest Classification Based on Transpirational Control of Root Numbers, Height, Retention of Radioactive Fallout, and Energy.
10. Venator, R., and F. K. S. Koo, Cytogenetic Effect of Gamma Radiation on *Palicourea riparia*.
11. Watson, H., Report on Stem Growth in the Radiation Center.

All of the papers presented at the Ecological Society of America meetings are scheduled along with perhaps 40 others for publication in the forthcoming book, A Tropical Rain Forest, which is being edited by H. T. Odum with the assistance of the office of Technical Information, Oak Ridge. Approximately 60 manuscripts have been received as of December 31, 1966, with others coming in rapidly. Publication is presently scheduled for sometime during FY-1968.

Project scientists have also published information not committed to the rain forest book at other meetings. The following papers were presented at the annual meeting of the Soil Science Society of America which was held at Stillwater, Oklahoma, August 21-26, 1966.

1. Kline, J. R., and S. S. Brar, Instrumental Analysis of Neutron Activated Soils.

2. Jordan, C. F., Quantity and Composition of Water in Natural Soil Systems.

The following papers were presented at other meetings:

1. Kline, J. R., Radionuclide Studies in Tropical Forests. (Presented before the Radiation Research Society, May 9, 1967, San Juan, Puerto Rico).

2. Jordan, C. F., Recovery of a Tropical Rain Forest After Gamma Irradiation. (Presented before the Radiation Research Society, May 9, 1967, San Juan, Puerto Rico. Also, to Second National Symposium on Radioecology with manuscript for publication, May 17, 1967, Ann Arbor, Michigan).

Two written progress reports were completed and submitted to Battelle Memorial Institute in September 1966, in order to fulfill an obligation resulting from their partial support of project research activities. These reports are listed as follows:

1. Kline, J. R., Radionuclide Behavior and Distribution in Tropical Forests. (Later issued by Battelle as IOCS Memorandum BMI-1, Nov. 1, 1966, 20 p.)

2. Odum, H. T., Hydrogen Budget and Compartments in the Rain Forest at El Verde, P. R. Pertinent to the Consideration of Tritium Metabolism.

APPENDIX A

REPORT ON UNFINISHED PROJECTS

Measurement of Radionuclide Residence Times in Forest Compartments

Measurement of radionuclide residence times in the El Verde forest is a continuing effort in which the half time estimates in various compartments are revised approximately at 6-month intervals. The estimates are based on a group of samples collected monthly at the field site from canopy, understory, and litter. The samples are oven-dried after collection and counted in a Marinelli beaker by the method of gamma scintillation spectrometry utilizing a shielded NaI (TI) crystal connected to a 400 channel pulse height analyzer. The complex spectra are resolved into their individual components by computer solution of simultaneous equations. The data for each nuclide is then plotted as a function of time on a semi-logarithmic scale and regression lines are fitted by the method of least squares.

Strontium-90 analyses is also being carried out in order to obtain residence time estimates for this nuclide. These are carried out by a method involving dry ashing and dissolution of the sample followed by separation of ^{90}Y as the phosphate. After 2 weeks of ingrowth, the ^{90}Y is separated again and counted in a thin window gas flow beta counter.

Strontium-90 was estimated to have an effective residence half time of 3,600 days in freshly fallen leaf litter (Figure 1). Using an independent estimate of expected residence time of 430 days, if there was no input, it was calculated that the probable retained input to this system was about 0.19 nCi/m^2/month. It was independently calculated from ^{90}Sr deposition data, published in "Radiological Health Data and Reports," that the probable retained input was of the order of 0.26 nCi/m^2/month. This value is by coincidence identical to the average deposition which was reported for San Juan and was obtained by doubling the San Juan value to account for the greater rainfall scavenging in the El Verde area and then taking one-half of this value as the average canopy rainfall interception which has been previously estimated for this forest.

Residence times for ^{137}Cs in canopy, fresh leaf litter, and understory leaves are given in Figure 2. Understory leaves have the greatest burdens followed by canopy leaves and fresh leaf litter. The low values in leaf litter indicate a possible loss of ^{137}Cs by leaching since these leaves are collected only once each month. The computed residence times for each forest compartment are given in Table 1 along with deposition data. Understory leaves have the longest residence half time while canopy leaves have the shortest. The values of environmental half-life for ^{137}Cs are considerably shorter than those for ^{90}Sr and imply a less effective retention mechanism for ^{137}Cs. The estimate of 588 days obtained for canopy half-life approaches the independent estimate of 430 days which has been suggested to be a limiting environmental half-life. The longer value is of course attributable to fresh input over the period of measurement. Using the difference between the observed and estimated half-life, it was calculated that the retained ^{137}Cs was about 0.04 nCi/m^2/month. From the previously cited deposition data for ^{90}Sr and the ^{137}Cs/^{90}Sr ratio of 1.4, it was calculated that the actual input deposited on leaves by intercepted rainfall was 0.37 nCi/m^2/month. This would suggest a possible retention efficiency equal to 100 x 0.04/0.37 = 10.8%.

The independently derived estimate for residence half time of 430 days in the canopy of the El Verde forest was obtained on the basis of a simple physical dilution model. This model assumes that physical transference of nuclides to the forest floor is accomplished primarily by leaf fall and that other possible mechanisms such as leaching are insignificant by comparison. Measurements of leaf fall indicate that this quantity is fairly constant year-round with an average deposition equal to 40g/m^2/month. Since the forest is in an approximately steady state, it is reasonable to assume that leaves are replaced at the same average rate in the canopy. Thus the canopy leaf biomass remains constant, but with a relatively small loss and replacement going on constantly. The leaves which are lost have the average canopy burdens of radionuclides while those which replace them have initially much lower burdens. Thus the canopy radionuclides are continuously being diluted by the growth of new leaves.

Successive dilution processes are relatively simple to treat mathematically if one treats them as a series of discontinuous steps rather than a continuous process. In the forest, for instance, it is reasonable to assume that in any given month 40g/m^2 of leaves fall and then are replaced with a like amount of new leaves. This process is described in Equation 1.

$$(W-L)C_0 = WC_1 \tag{1}$$

or

$$(W-L)/W \times C_0 = C_1 \tag{2}$$

Where:

W = Average canopy biomass (g/m^2)

L = Average weight of fallen leaves = average weight of new leaves (g/m^2)

C_0 = Content of radionuclide in canopy leaves before dilution (pCi/g)

C_1 = Content of radionuclide in canopy leaves after dilution 1 (pCi/g)

The dilution given during the second month is given by Equation 3

$$(W-L)C_1 = WC_2 \qquad (3)$$

Rearranging and substituting from Equation 2

$$\left(\frac{W-L}{W}\right)^2 \times C_0 = C_2 \qquad (4)$$

In general then by induction

$$\left(\frac{W-L}{W}\right)^n \times C_0 = C_n \qquad (5)$$

Where n = the number of repetition (months) of the dilution

Equation 5 was evaluated over a period of 600 days (20 months) using an average value for canopy leaf biomass of 859 g/m^2 (derived from the data of Odum et al.) and 40.5 g/m^2 for leaf fall and replacement during one cycle. The calculated nuclide residence half time is 430 days. The actually observed effective half-lives are longer than this due to the low-levels of input of nuclides which are still occurring. Measuring these inputs directly has been a difficult problem and we have relied on published values for the purpose of calculation.

The model is subject to further modification. It does not at present account for root uptake of nuclides nor does it account for loss from the canopy by leaching. Both of these quantities are finite but have been shown by other measurements to be quite small. It may be possible to neglect them. Equation 5 does not now include an input term. This could be improved by adding the term $nK_1 K_2 D$ to the left-hand side of the equation, where D is the total average deposition of the nuclide per month, K_2 is the average rainfall interception efficiency, K_1 is the retention efficiency by leaves and n has the same meaning as in Equation 5.

Debris from the Chinese nuclear test of May 9, 1966, was observed in leaf samples collected on June 2, 1966, at El Verde. The most prominent nuclides were ^{95}Zr-^{95}Nb and ^{144}Ce (Figures 4 and 5). Prior to the test, the effective half time for ^{95}Zr was about 61 days, while after the fresh input it was 44 days. The corresponding environmental half time after the input was 137 days which is considerably shorter than our theoretically estimated 430 days and indicates that the freshly deposited material was subject to fairly rapid removal by leaching. The effective half time for ^{144}Ce before the test was 280 days, while afterward it was 98 days. The environmental half time after the test was computed to be 149 days which again indicates rapid removal of this nuclide by leaching.

It is apparent from observations of the behavior of freshly produced debris that interception by a rain forest canopy must be represented by at least a two-compartment model. One compartment will describe the physical processes of removal or retention and the other will describe the biological. Thus for any given input of radionuclides, part will be present on leaves as a physical deposit which is subject to fairly rapid removal, while another part will be incorporated into biological systems possibly through the action of epiphyllae and will be retained with greater efficiency. The actual partitioning will depend on the physical and chemical form of the debris. In the studies of the behavior of worldwide fallout of stratospheric origin, it is believed that much of the material is soluble and therefore subject to biological uptake, while the Chinese debris was probably in particulate form of tropospheric origin and was therefore subject to primarily physical removal.

The modeling represented by Equation 5 will apply only to the debris which has been incorporated into biological systems, while the processes of physical removal will probably be most fruitfully described by using a "black box" approach.

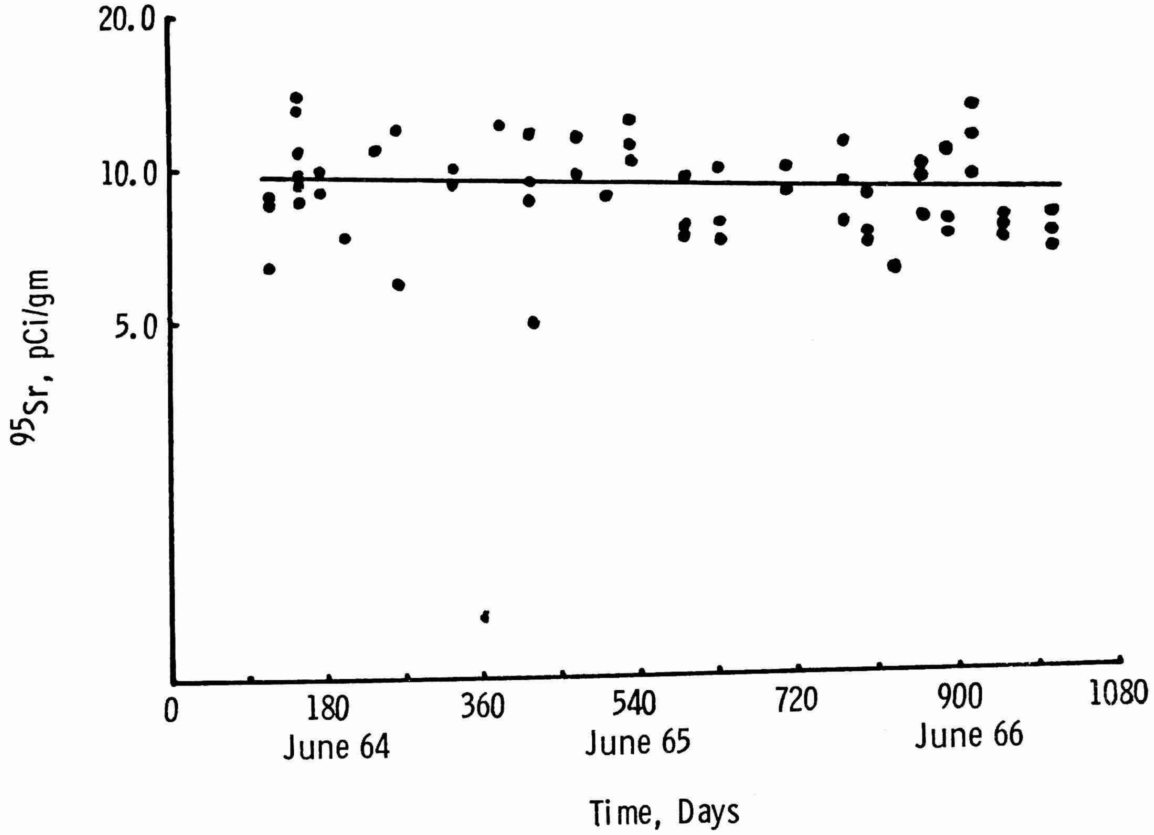


Figure 1. Environmental residence time of ^{90}Sr in freshly fallen leaf litter in the rain forest.

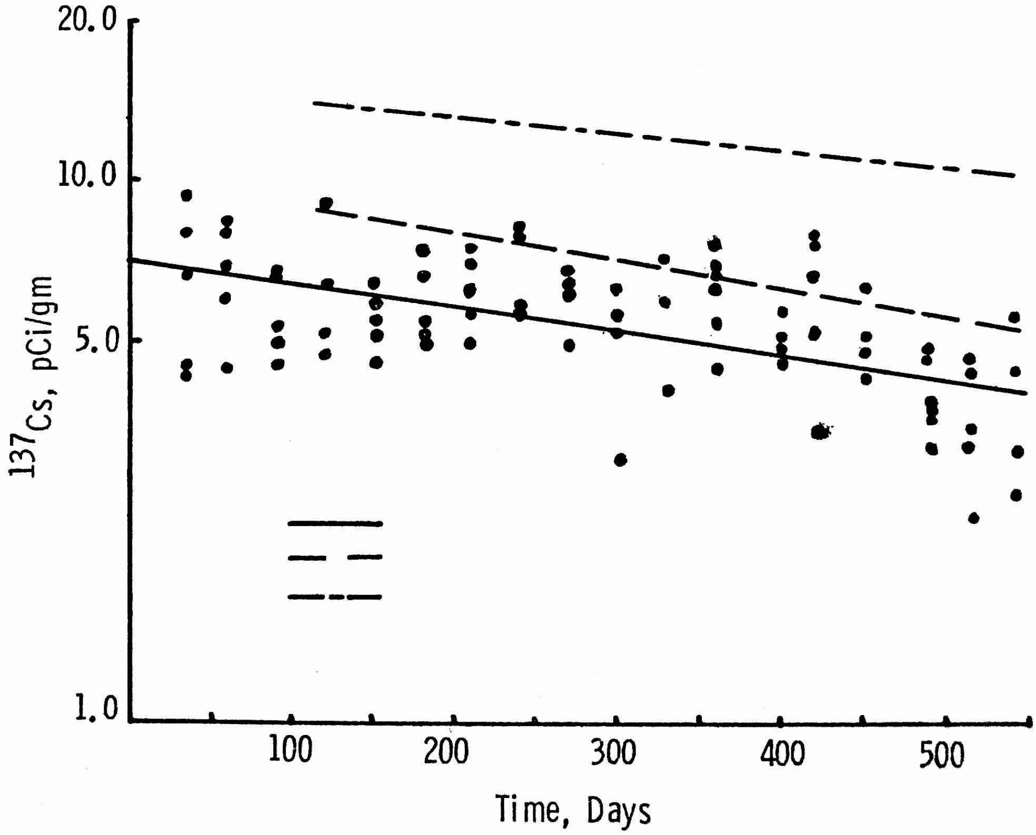


Figure 2. Effective residence times for ^{137}Cs in freshly fallen leaf litter, canopy leaves, and understory leaves in the rain forest at El Verde.

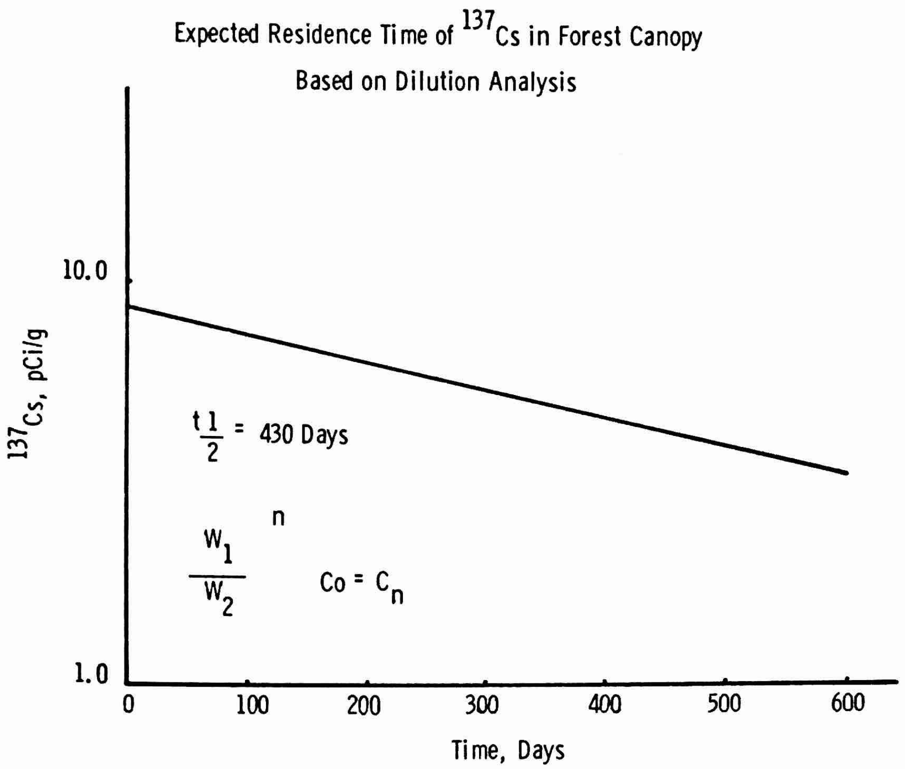


Figure 3. Computed residence time of ^{137}Cs in rain forest canopy based on dilution analysis of canopy leaves.

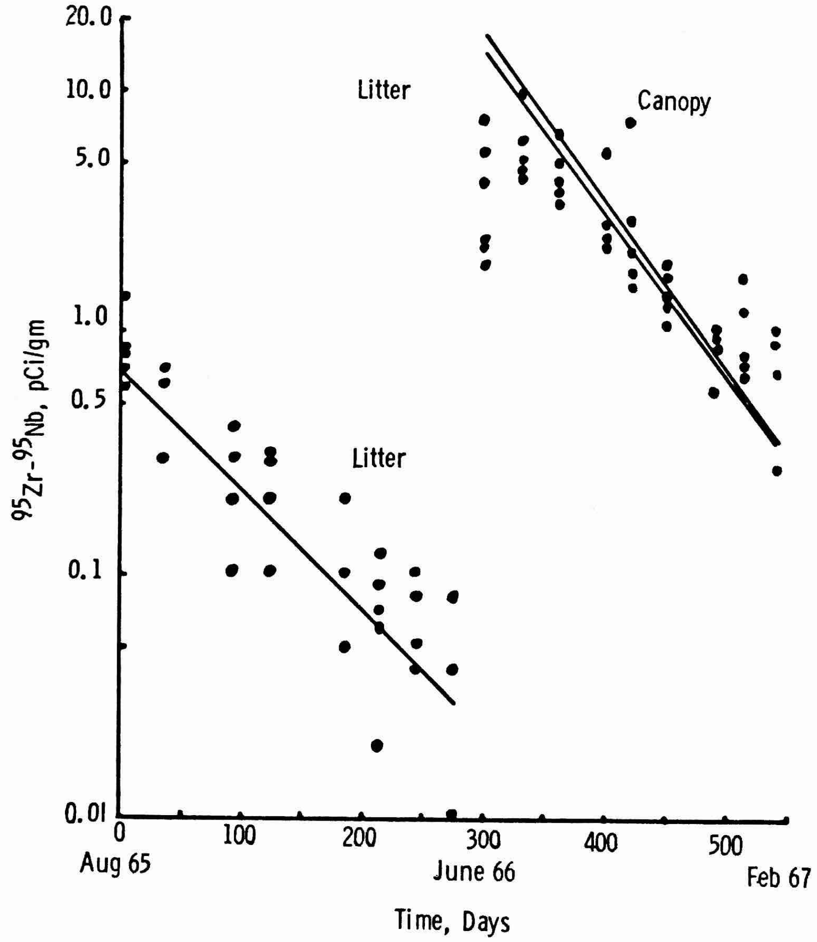


Figure 4. Behavior of ^{95}Zr-^{95}Nb in rain forest leaves before and after input of Chinese nuclear debris produced on May 9, 1966.

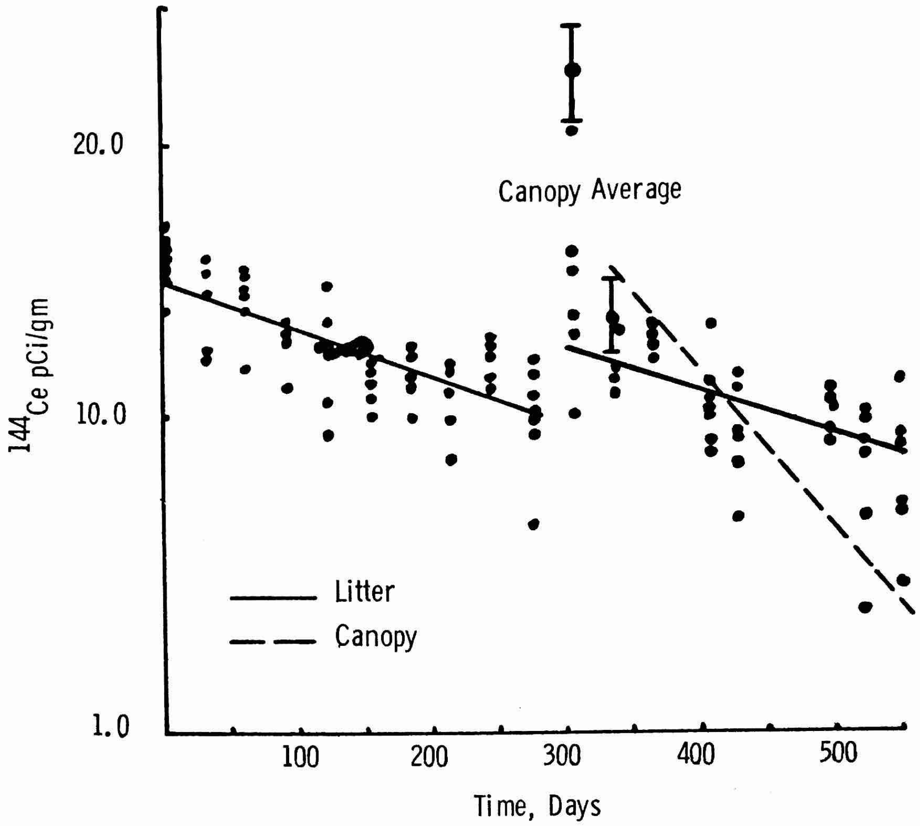


Figure 5. Behavior of ^{144}Ce in rain forest canopy leaves and fresh litter before and after the Chinese nuclear test of May 9, 1966. (Individual canopy averages show nuclide loss in the first month after deposition. Data points are for litter only.)

TABLE 1

Residence Times of ^{137}Cs of Fallout Origin in Various Rain Forest Compartments

Compartment	Environmental half-life (days)	Leaf Biomass (g/m^2 dry)	^{137}Cs Burdens nCi/m^2
Canopy	588	859	5.8
Understory	937	ND*	-
Leaf fall	710	40.5**	0.2**
Leaf litter	-	124	1.2

*ND = Not determined. Included in canopy estimate.
**Average per month.

Tracer Experiment

In order to determine whether the relatively high levels of fallout radionuclides in the El Verde forest could be accounted for on the basis of root uptake by trees, a tracer experiment involving ^{134}Cs, ^{85}Sr, and ^{54}Mn was established in January 1966. The objective of the experiment was to determine whether these nuclides could be transferred from litter or soil to roots of understory plants, and if so, at what rates.

Four plots were established within a fenced enclosure on a gently sloping ridge top within the El Verde contract area. These plots which ranged from 1 to 1.5 m^2, were completely encircled with corrugated aluminum garden edging to a depth of 3 inches, and roots to this depth were cut to prevent export of nuclides to trees outside of the plots. Two of the plots were stripped of all litter and two were left intact prior to the application of nuclides. On January 6, 1966, approximately 1 mCi/m^2 each of ^{134}Cs, ^{85}Sr and ^{54}Mn were applied to the plots in the form of a spray from a hand-pumped garden sprayer. All plants within the plots at this time were covered with plastic bags and aluminum foil to prevent contamination with spray.

Samples of leaves were collected from the understory plants, at first biweekly and later monthly, as it became apparent that the uptake of nuclides was slow. To prevent the depletion of plant material, all plants were not sampled every month; instead a stratified random sample was taken of leaves according to the size of the plant on which they were growing. Small samples were taken from plants 0-1, 1-3, and greater than 3 ft tall on each plot. This sampling plan was followed until January 28, 1967, at which time the experiment was terminated by completely harvesting all plant material on the plots. This material was dried and weighed and counted for radioactivity.

Figures 1 and 2 show the uptake over the 1-year period by understory plants growing on plots in which the forest litter was undisturbed. Figures 3 and 4 show the uptake from plots in which the litter was removed before nuclide application. Some of the variability in the data was attributable to the sampling method since the same plants were not necessarily sampled each month. The initial high levels of nuclides in the smaller plants could be the result of contamination of the spray. The very randomness of the data is, however, instructive; since no clear pattern of uptake kinetics was established after 1 year.

Several general conclusions can be drawn from these observations: First, the smaller plants (0-1 ft) appeared to take up nuclides more rapidly than the larger plants; second, uptake occurred more slowly in plants growing on litter covered plots than those growing on bare plots; and third, uptake was relatively slow on all plots with some pattern beginning to emerge within a short time before the termination of the experiment.

These conclusions were confirmed when the plants were harvested at the end of the experiment. Count rates per-unit-weight of all material were converted to total uptake of activity by multiplying by the total weight and then converting to fractional uptake by dividing by the total activity applied (Tables 1, 2, 3, and 4). Recovery of the original radioactivity in individual understory plants ranged from 3×10^{-5} to 0.6% for ^{134}Cs and from 0 to 4% for ^{54}Mn with the majority of values for both nuclides falling below 0.1%. These values may be deceptively low since the amount of activity in the soil of a square meter plot which is potentially available to an individual plant cannot be estimated.

It may be supposed that all of the activity on the plot was available to one plant or another, however, so the summation of recovery for each plot is instructive. These values range from 0.006 to 1.77 for ^{134}Cs and from 0.074 to 7.85 for ^{54}Mn and indicate, in general, a greater recovery of ^{54}Mn. This might be expected since Mn is known to be an essential nutrient for plants in trace amounts. Thus it appears that ^{134}Cs was cycled through roots to a lesser extent than an element known to be required in only trace quantities.

No report is given on the behavior of ^{85}Sr in harvested plant material since approximately seven half-lives of this nuclide had elapsed since the beginning of the experiment and it could not be reliably determined at the low-levels found in plant materials.

Freshly fallen leaf litter in the plots which were originally stripped of litter was found to be radioactive at the end of the experiment. The total activity in litter accounted for up to 3% of the original ^{134}Cs and 4% of the ^{54}Mn (Tables 1 and 2). This is probably due to soil particles splashed into the leaves by rainfall but could also indicate biological cycling processes in the litter-soil layers. The amounts found cannot be accounted for by cycling through trees since the live leaf burdens were found to be low.

Samples of soil and litter, from the litter undisturbed plots, were collected periodically throughout the experiment. Radionuclide content of soil surfaces averaged over all plots is given in Table 4. Levels of ^{134}Cs remained relatively constant throughout the duration of the experiment while ^{54}Mn values tended to decline. Clear conclusions are difficult because greater than anticipated variation was found.

Rates of radionuclide loss from organic litter originally sprayed with radioactive solution are shown in Figures 5 and 6. The data indicates a probable residence half time of the order of 10 to 20 days. These are environmental half-lives which are corrected for radioactive decay but are not corrected for the dilution effect caused by new leaf fall.

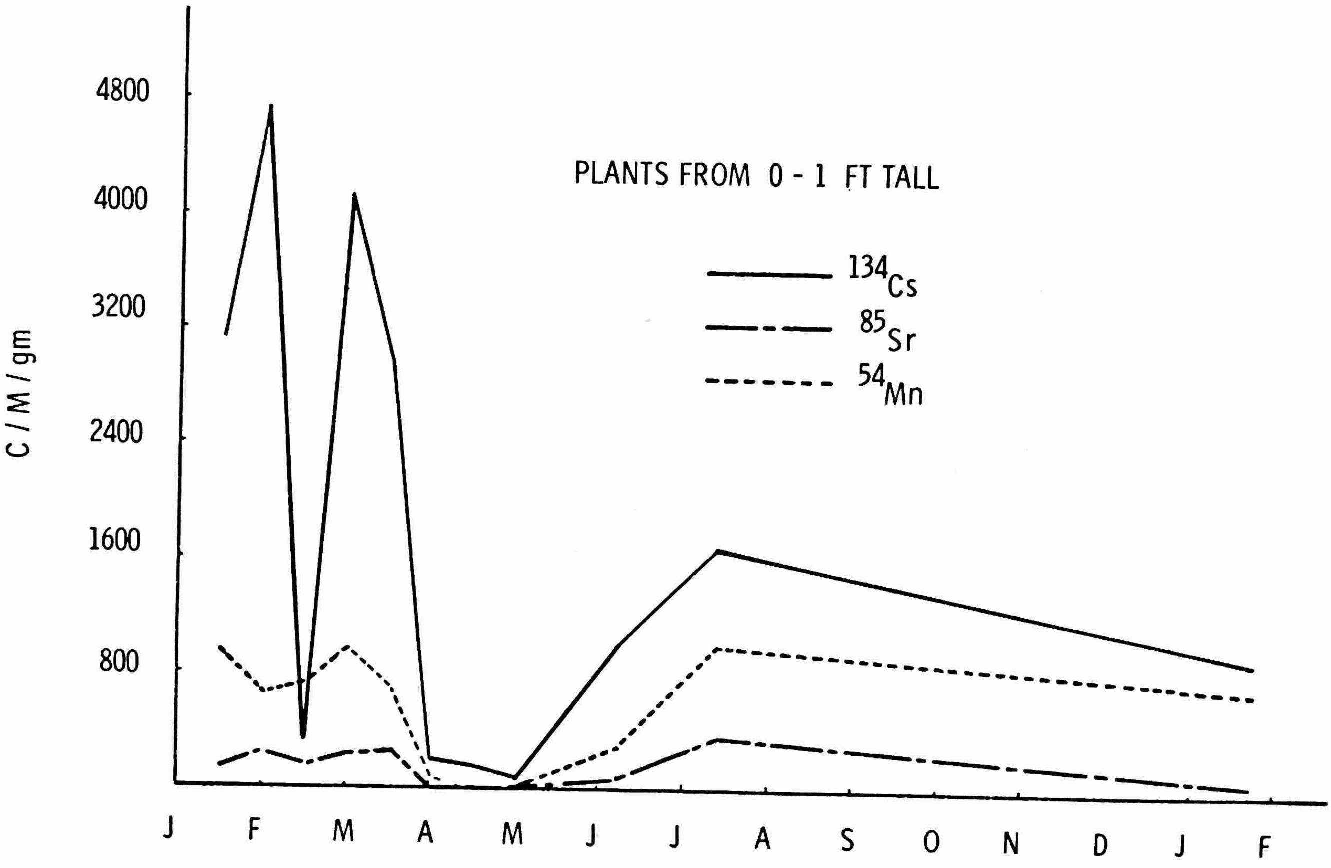


Figure 1. Uptake of ^{134}Cs, ^{85}Sr and ^{54}Mn through roots of understory plants (forest litter in place).

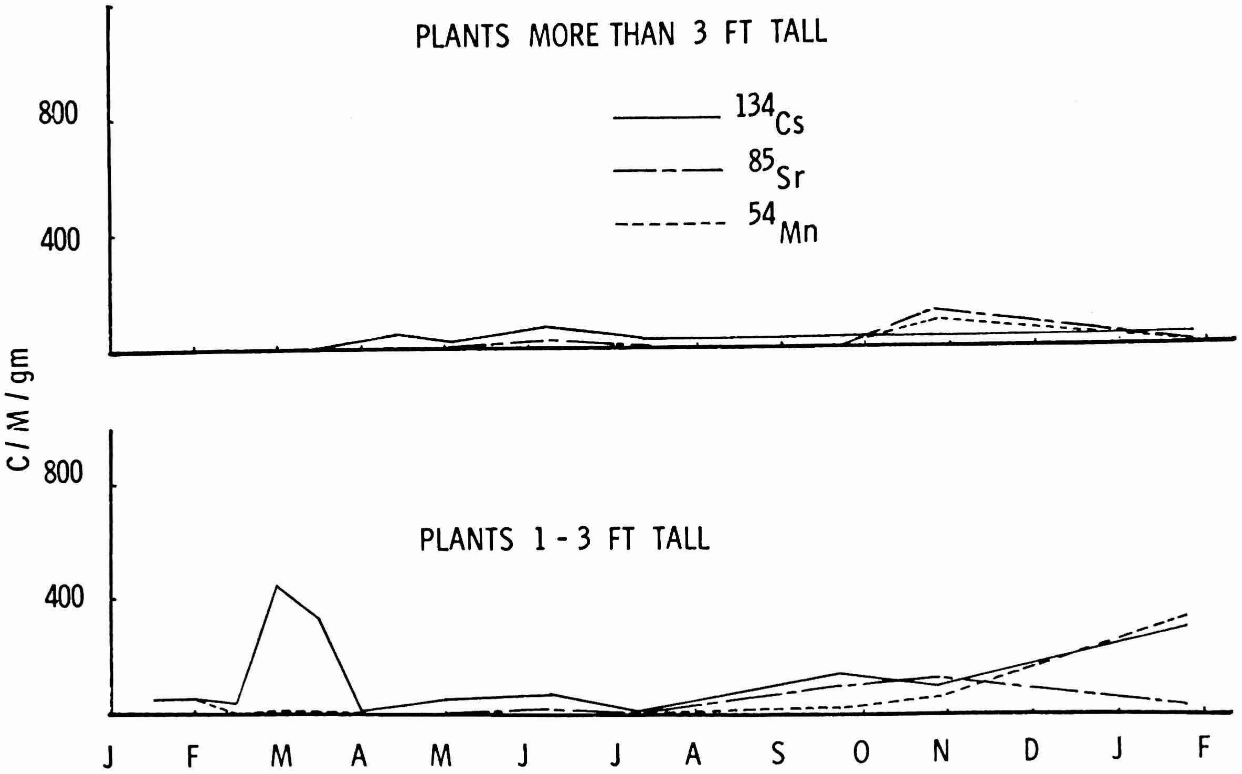


Figure 2. Uptake of ^{134}Cs, ^{85}Sr, and ^{54}Mn through roots of understory plants (forest litter in place).

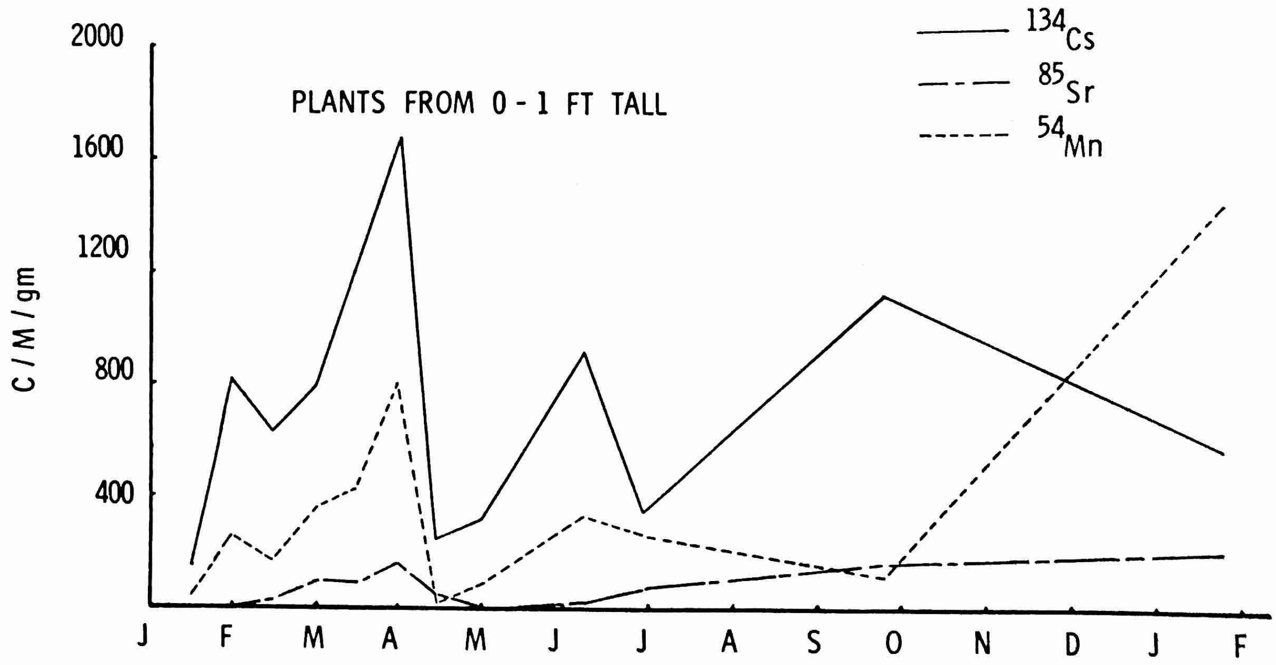


Figure 3. Uptake of ^{134}Cs, ^{85}Sr, and ^{54}Mn through roots of understory plants (forest litter removed).

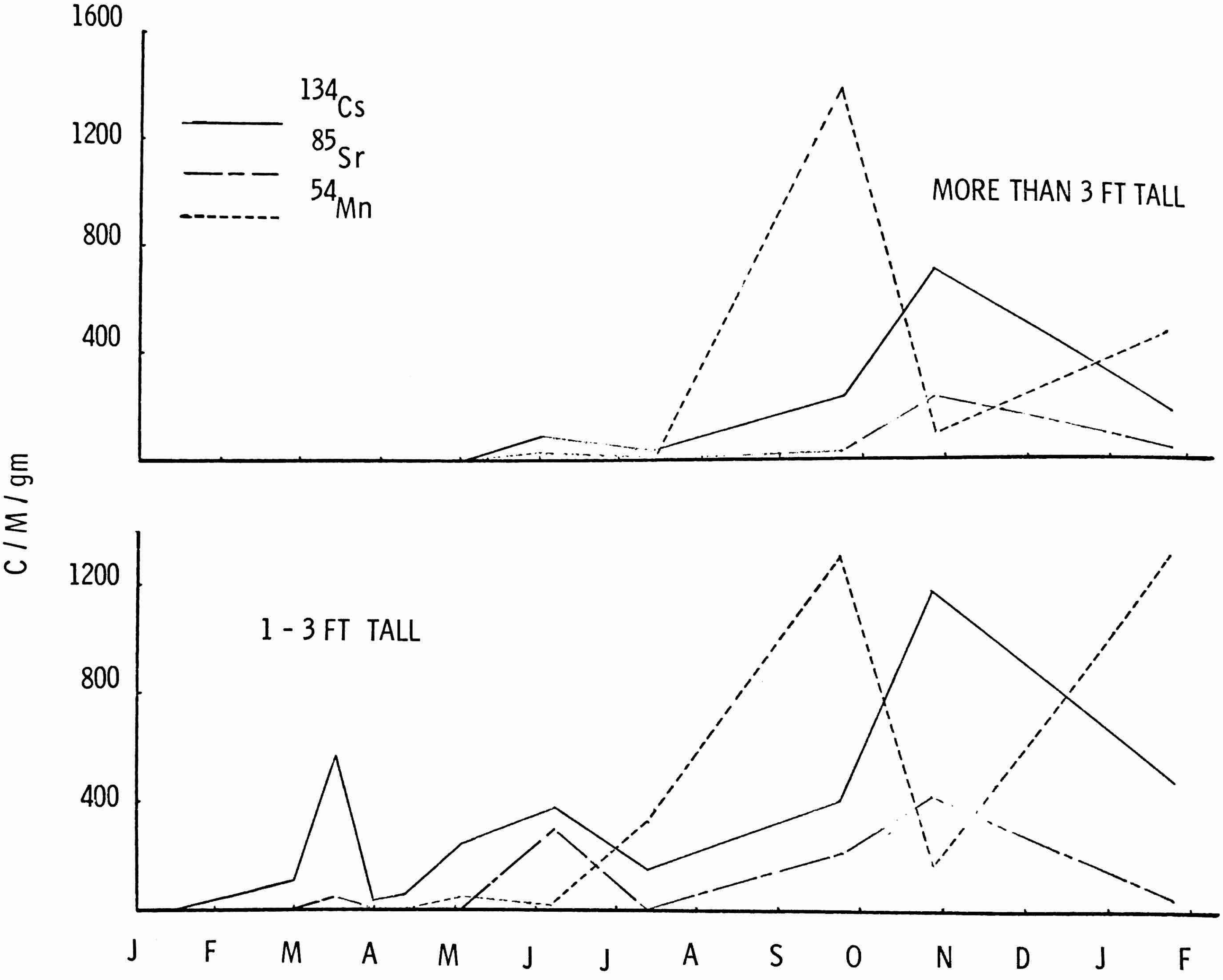


Figure 4. Uptake of ^{134}Cs, ^{85}Sr, and ^{54}Mn through roots of understory plants (forest litter removed).

TABLE 1

Total Uptake of ^{134}Cs and ^{54}Mn on Plot 1 by Understory Plants After 1 Year (Litter Removed)

Species Name	Height	Part of Plant	Percent Uptake Cs($x10^3$)	Percent Uptake Mn($x10^3$)
Banisteria laurifolia	10 in.	Seedlings	0.06	0.49
Dryopteris deltoidea	10 in.	Fern	0.64	1.14
Dacryodes excelsa	10 in.	Seedlings	0.03	0.38
Eugenia stahlii	10 in.	Seedlings	0.03	0.04
Eugenia stahlii	31 in.	Leaves	0.57	0.04
		Branches	0.34	0.50
Guarea trichiliodes	10 in.	Seedlings	0.08	0.07
Meliosma herbertii	62 in.	Leaves	0.62	4.55
		Branches	1.56	57.43
Philodendron krebsii	ground level	Vine	0.22	0.90
Rourea glabra	37 in.	Leaves	0.07	0.62
		Branches	0.61	5.04
Rourea glabra	10 ft.	Leaves	0.16	1.37
		Branches	0.71	0.10
T. balsamifera	10 in.	Seedlings	0.13	1.15
T. balsamifera	25 in.	Leaves	0.07	0.00
		Branches	0.34	0.50
Leaf litter	-	-	169.00	659.70

TABLE 2

Uptake of ^{134}Cs and ^{54}Mn on Plot 2 by Understory Plants After 1 Year (Litter Removed)

Species Name	Height	Part of Plant	Percent Uptake Cs(x10^3)	Mn(x10^3)
Eugenia stahlii	10 in.	Leaves	3.08	0.00
		Branches	4.52	0.30
Inga laurina	10 in.	Seedling	1.23	1.96
Rourea glabra	23 in.	Leaves	3.40	32.32
		Branches	18.42	54.88
Rourea glabra	44 in.	Whole Plant	30.57	19.76
T. balsamifera	15 ft.	Leaves	117.56	2258.93
		Branches	11.14	175.09
		Trunk Intermediate	21.87	724.64
		Trunk Ground level	129.71	4360.46
T. balsamifera	10 in.		2.49	14.66
T. balsamifera	30 in.	Leaves	0.44	8.24
		Branches	4.06	201.09
Leaf litter	-		3049.14	4038.26

TABLE 3

Uptake of ^{134}Cs and ^{54}Mn on Plot 3 by Understory Plants After 1 Year (Litter in Place)

Species Name	Height	Part of Plant	Percent Uptake Cs($\times 10^3$)	Mn($\times 10^3$)
Dacryodes excelsa	10 in.	Seedling	0.19	3.55
Guarea trichiliodes	10 in.	"	3.00	1.66
Inga laurina	10 in.	"	7.29	3.18
Myrcia leptoclada	18 in.	Leaves	0.81	0.84
		Branches	0.58	0.60
Myrcia leptoclada	15 ft.	Leaves	37.28	73.06
		Branches	27.89	314.93
		Trunk	202.74	4093.67
Rourea glabra	36 in.	Whole Plant	10.62	3.22
T. balsamifera	10 in.	Seedlings	2.23	7.38
Dead Stem	15 in.	Old Stem	1.76	11.31

TABLE 4

Uptake of ^{134}Cs and ^{54}Mn on Plot 4 by Understory Plants After 1 Year (Litter in Place)

Species Name	Height	Part of Plant	Percent Uptake Cs(x10^3)	Mn(x10^3)
Banisteria laurifolia	10 in.	Seedling	0.25	0.86
Inga laurina	10 in.	Seedling	1.07	1.30
Manilkara nitida	10 in.	Seedling	1.78	1.26
Manilkara nitida	24 in.	Leaves	1.70	0.39
		Branches	18.16	4.24
Manilkara nitida	17.5 in.	Leaves	166.22	8.32
		Branches	656.05	0.00
		Branches	265.90	0.00
		Trunk (Top)	35.88	0.00
		Trunk Intermediate	80.79	0.00
		Trunk Ground level	128.24	0.00
Meliosma herbertii	18 in.	Leaves	7.18	17.91
		Branches	6.48	45.27
Meliosma herbertii	7 ft.	Leaves	1.42	2.37
		Branches	341.83	1374.94
Myrcia leptoclada		Whole Plant	2.39	1.78
Myrcia leptoclada	16 in.	Leaves	9.24	8.78
		Branches	11.12	3.69
Neorudolphia volubilis	3 ft.	Vine	17.89	1.84
Ocotea leucoxylon	10 in.	Seedling	1.15	2.69
Rourea glabra	10 in.	Seedling	11.22	0.88
T. balsamifera	30 in.	Leaves	0.53	2.37
		Branches	2.78	29.74
T. balsamifera	10 in.	Seedling	0.48	1.54
Leaf litter			2053.78	9371.70

TABLE 5

^{134}Cs and ^{54}Mn in Soil Surface (CPM/gm)

	March 17, 1966	June 7, 1966	January 24, 1967
^{134}Cs	2636 ± 41%	2677 ± 19%	2246 ± 40%
^{54}Mn	885 ± 55%	517 ± 75%	305 ± 33%

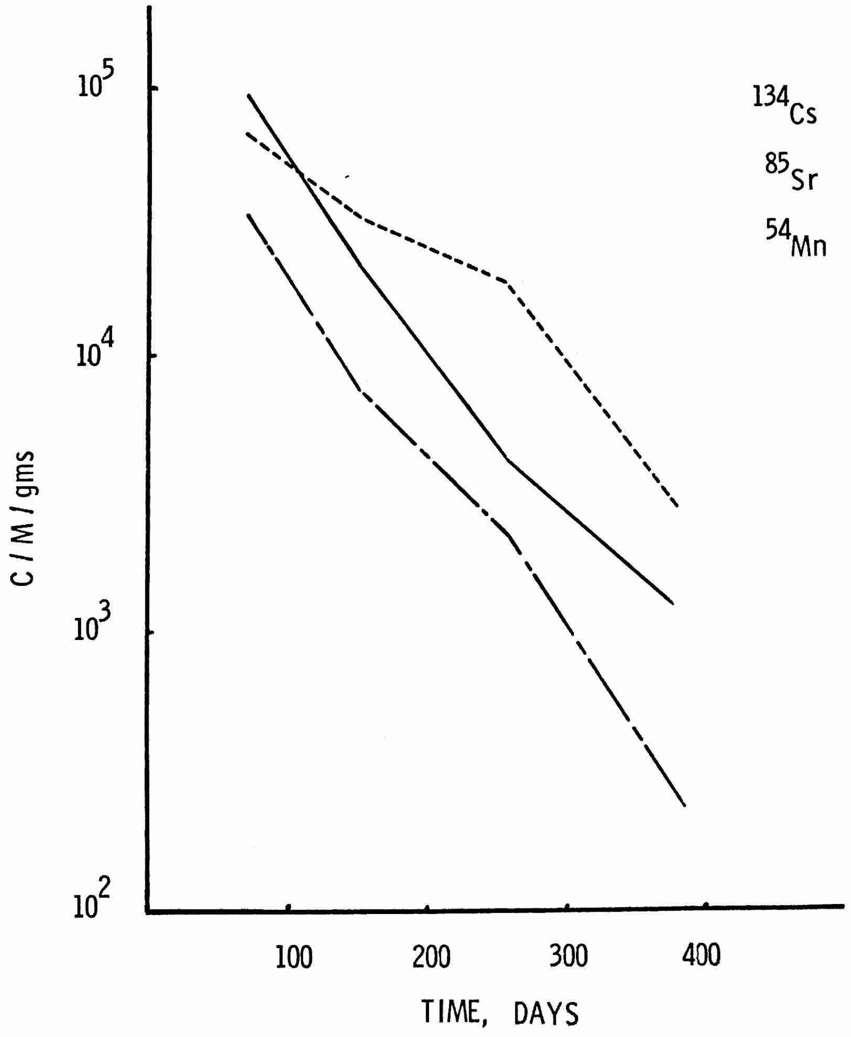


Figure 5. Rate of change of ^{134}Cs, ^{85}Sr, and ^{54}Mn in forest floor leaf litter (plot 4).

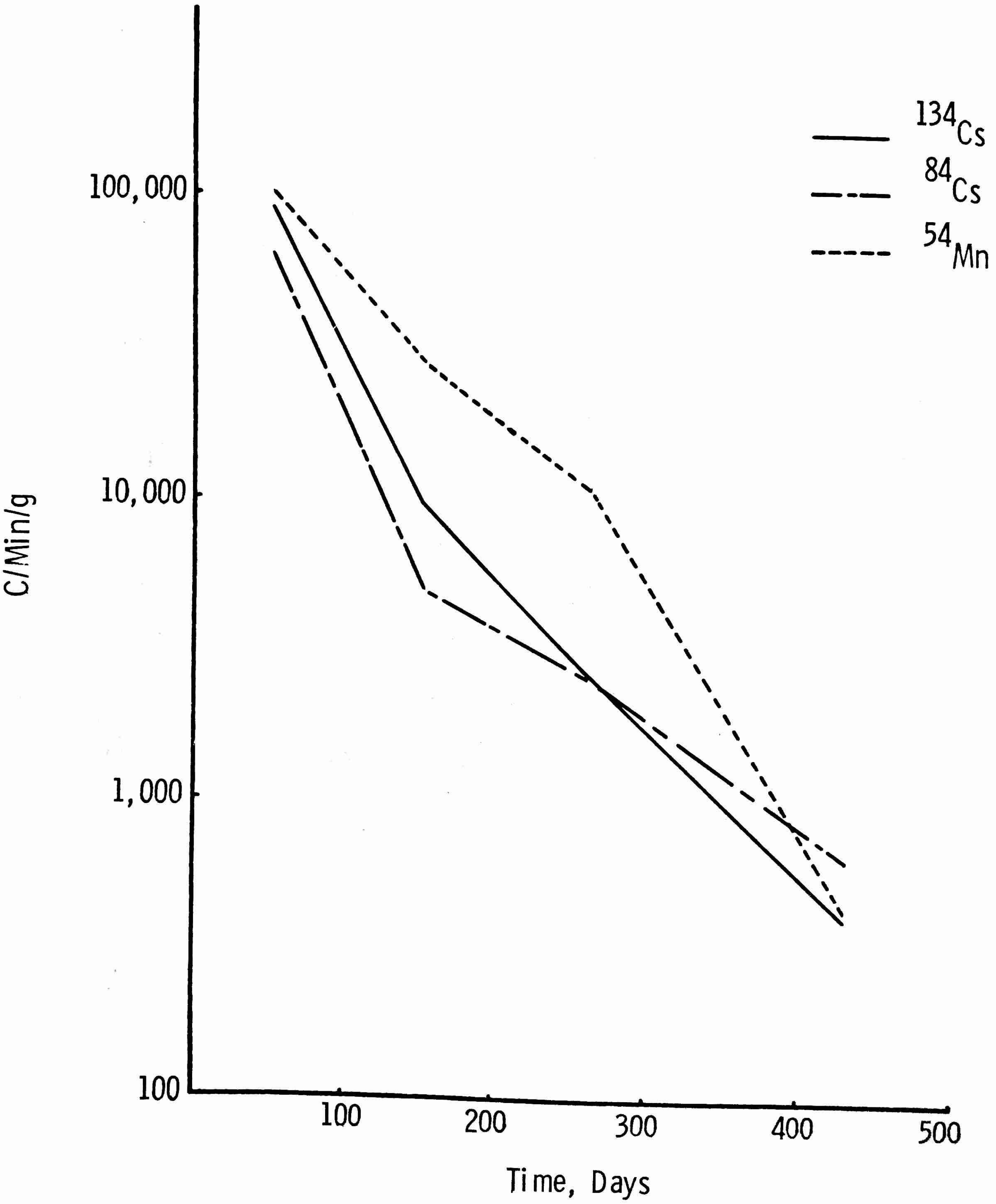


Figure 6. Rate of change of ^{134}Cs, ^{85}Sr, and ^{54}Mn in forest floor leaf litter (plot 3).

Tritium Experiment

On one of the lysimeter installations described elsewhere in this report, a preliminary experiment was established to determine the fate of water in the environment of the El Verde area. The objectives of the experiment were to utilize tritiated water (THO) to determine amounts and rates of movement of free water which evaporates into the atmosphere, which runs off soil surfaces and which percolates through soils. Transpiration of water by plants and uptake of tritium into biological tissues were not included in the original experimental objectives. These variables will be observed in subsequent experiments.

On February 14, 1967, 20 mCi of tritiated water were diluted to 1 liter with rain water and the mixture was applied to the surface of a soil plot with an ordinary garden sprinkling can. Immediately after application, the sprinkling can was rinsed with 500 ml of fresh water and this portion was also applied to the plot, making a total volume of 1500 ml that was applied. A small sample of the original liter was withheld for count rate standardization. After appropriate dilution, the solution was found to have a measured activity of 1.45×10^7 count/min/ml for a total application of 1.45×10^{10} count/min. The specific activity on the plot after application of the 500 ml rinse was then 0.97×10^7 count/min/ml. The counting was performed with an average efficiency of about 30%.

The soil plot was equipped with two lysimeters buried at 5 inches in the soil for the collection of percolating waters. In addition, the plot which terminated at a vertical cut in the soil was fitted with a runoff collecting trough for the collection of surface waters. Surrounding the plot at ground level and downslope from the plot were six liquid nitrogen-charged cold trap condensers for the collection of atmospheric water samples. Nine more condensers were arranged downslope from the plots in a vertical sequence at 1-meter intervals to study water vapor movements above the plots.

Immediately upon application of the tritiated water, the water vapor samples were placed in position and allowed to collect for 1 hour. The collectors were sampled at 1-hour intervals during the remainder of the first day and three times per day thereafter until a sequence of samples from each station extending to 245 hours had been obtained. Air sampling was then terminated.

The results of air sampling (Figures 1, 2, 3, and 4) show a rapid rise and fall of tritium activity which was essentially complete within the first 5 hours of the experiment. Thereafter tritium continued to diffuse into the atmosphere at very low but nearly constant levels. Highest levels of tritium activity were found in samples collected from one-half to 6 meters below the plots while the lowest levels were found at the sides of the plots and in the vertical sequence higher than 1 meter above the ground. These patterns of activity indicate that the tritium labeled water began to evaporate or diffuse immediately after application in a narrow band about 1 meter wide and less than 1 meter deep. This band was swept downhill continuously by the natural air drainage which occurs on the mountainside. Computation of the total loss of tritium by evaporation or self-diffusion is difficult because the grid system of vapor collectors was not sufficiently extensive to delimit the total volume of contaminated air.

Tritium activity found in runoff water is shown in Table 1. The highest levels of activity were found in the first collection and they declined uniformly thereafter until negligible levels were found approximately 1 month after the application. Only 1.3% of the total applied tritium was recovered in runoff water during the first month of the experiment.

The dilution of the original tritiated water as measured in runoff is shown in Figure 8. The first sample collected is shown to be diluted by a factor of the order of 100 although the rainfall which produced the runoff amounted to only 0.23 cm and the total volume of water intercepted by the plot was only 2.2 liters. Thus the dilution of tritium during the first 36 hours of the experiment was greater than can be accounted for by the input of water even though subsequent dilutions were roughly related to input. This might indicate rapid self-diffusion of the tritiated water after application, or it might indicate rapid bulk penetration of the originally applied tritium into the soil which allowed only a fraction of the original volume to be exposed at the surface.

Recovery of tritium through a lysimeter in the soil is shown in Table 2. Highest levels of activity were found approximately 2 weeks after application with lower levels before and after. This may indicate that tritium originally in the surface plane of the soil moved through the profile in a rather broad and diffuse front. Samples collected up to 6 weeks after application accounted for only 11.9% of that originally applied, indicating that the bulk of tritium remains somewhere in the profile.

The rapid original dilutions of tritium and the broad diffusion front may indicate that self-diffusion of tritiated water is a significant process in soil water. If this is the case, it is unlikely that it will be possible to flush an environment of tritium once contamination has occurred. The long persistence of tritium in this profile would indicate support for this belief. High specific activities have been found in soil water up to 4 months after application, even though in excess of 50 cm of rain corresponding to 500 liters of water have been intercepted by the plot during this time.

Observations on this plot will continue until a reasonable accounting of the originally applied tritiated water has been obtained.

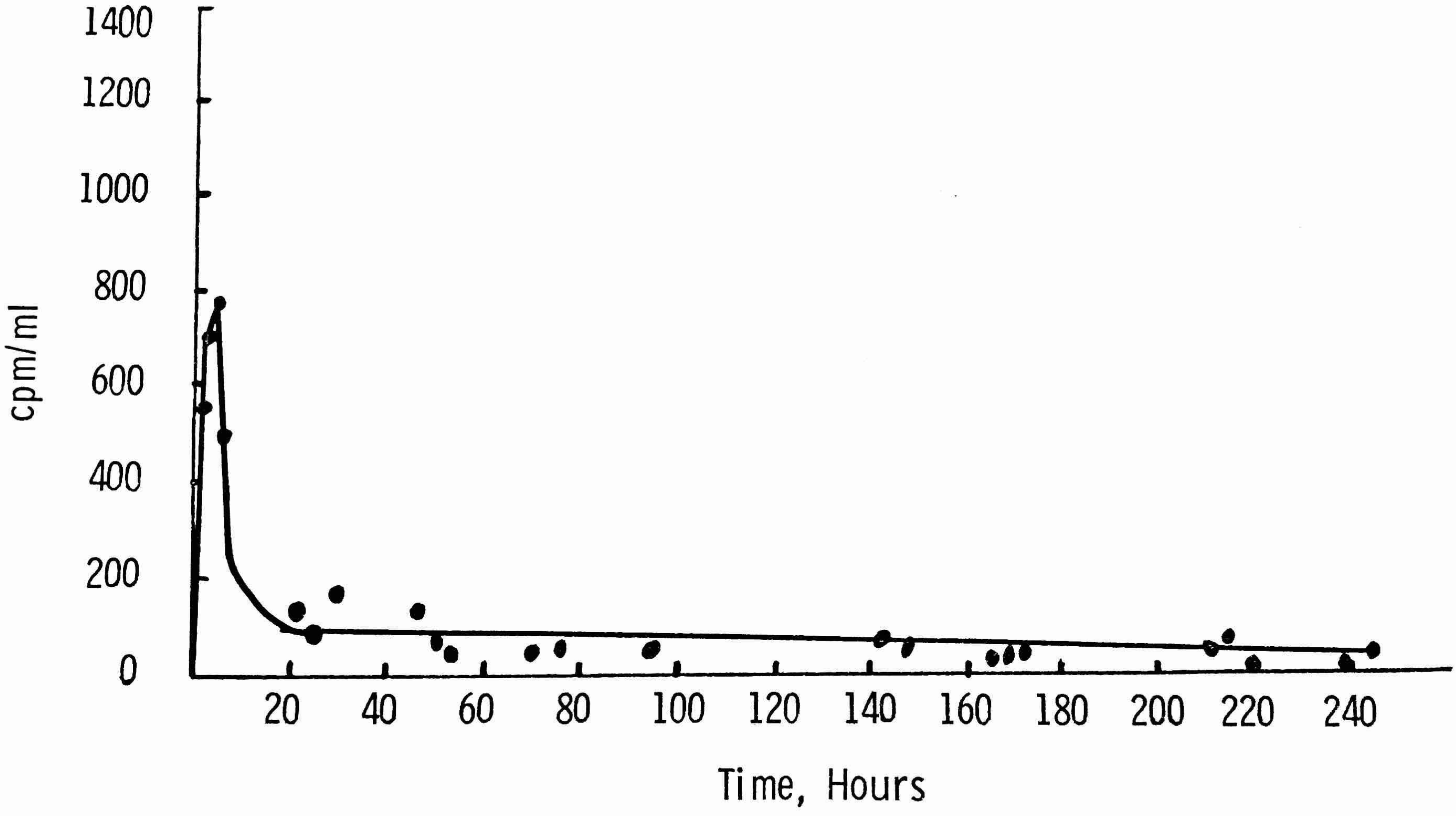


Figure 1. Average tritium activity in atmospheric water collected at ground level from four stations upslope and to the side of the experimental plot.

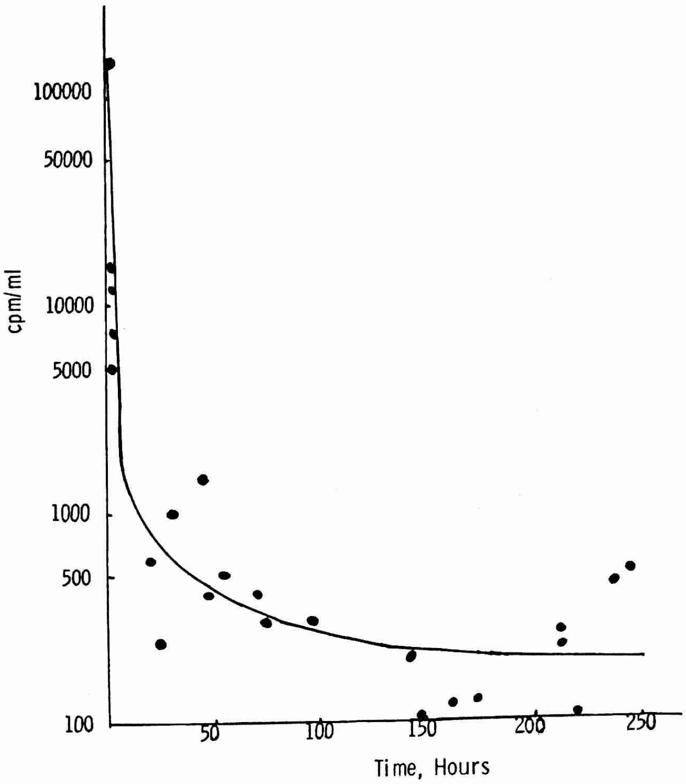


Figure 2. Tritium activity in atmospheric water collected at ground level one-half meter downslope from experimental plot.

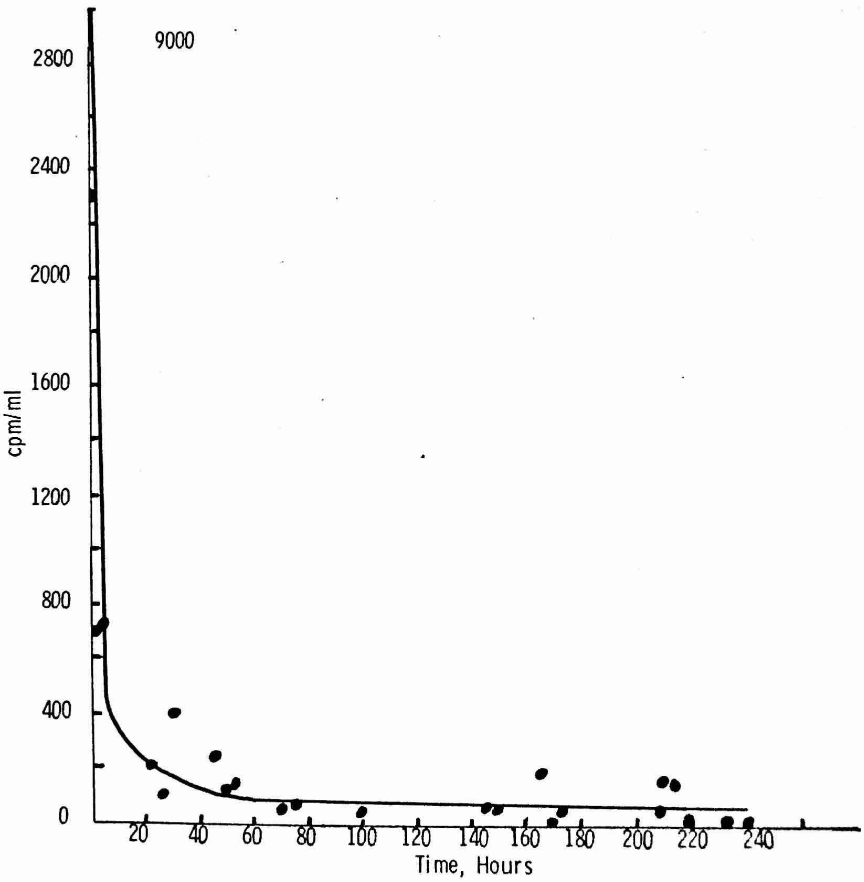


Figure 3. Tritium activity in atmospheric water collected 2 meters downslope from experimental plot at ground level.

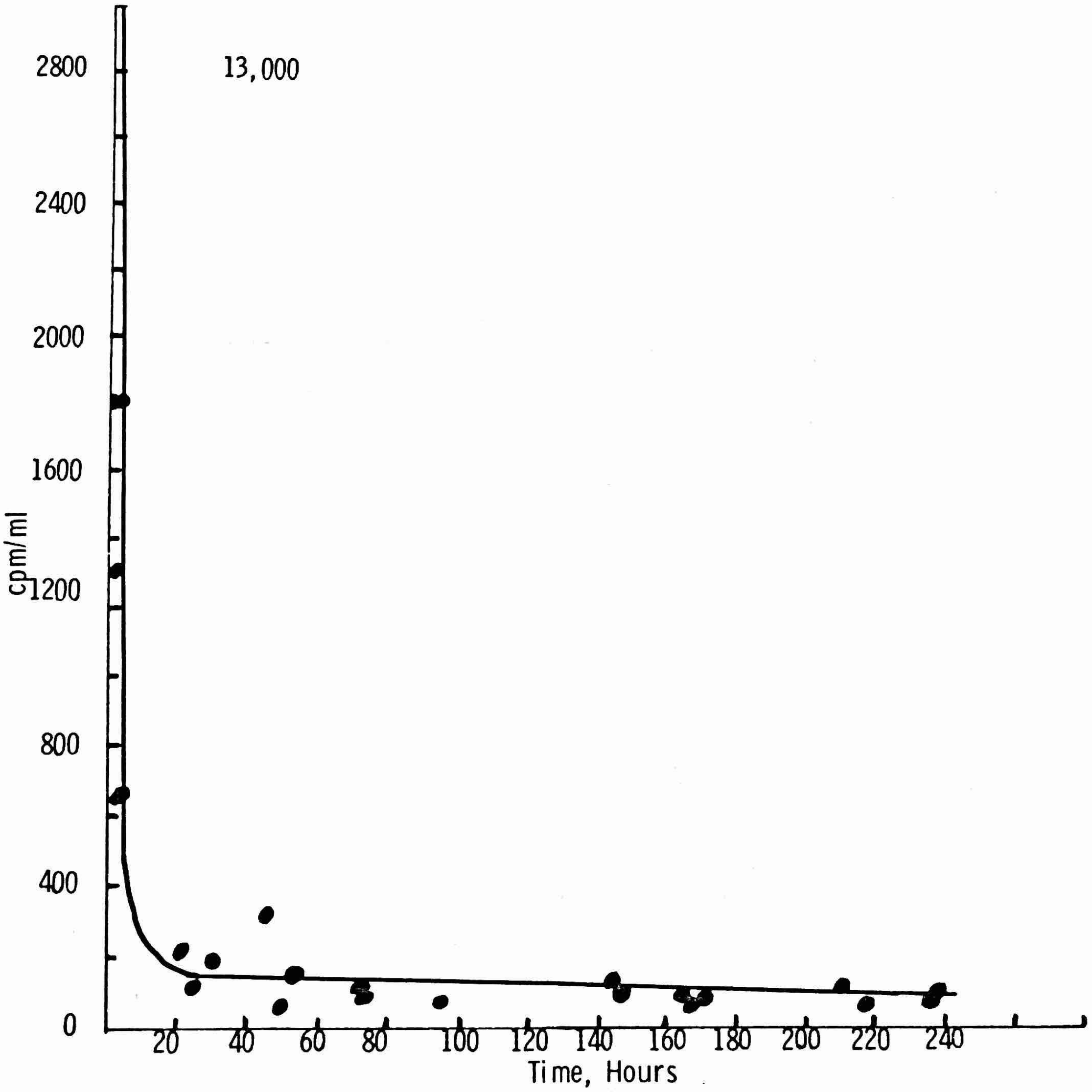


Figure 4. Tritium activity in atmospheric water collected 6 meters downslope from experimental plot at ground level.

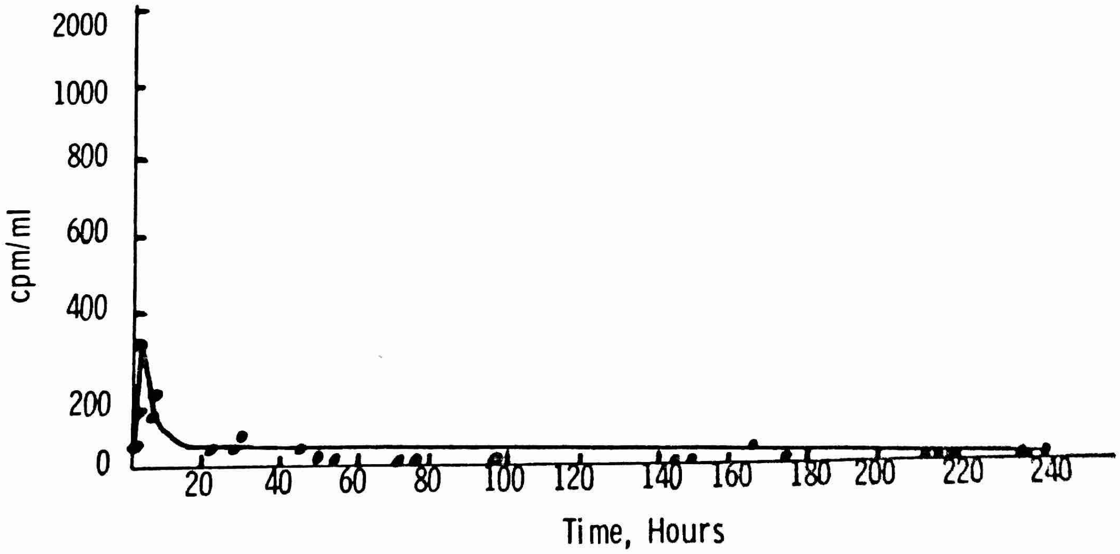


Figure 5. Tritium activity in atmospheric water collected 2 meters downslope and 1 meter above ground from experimental plot.

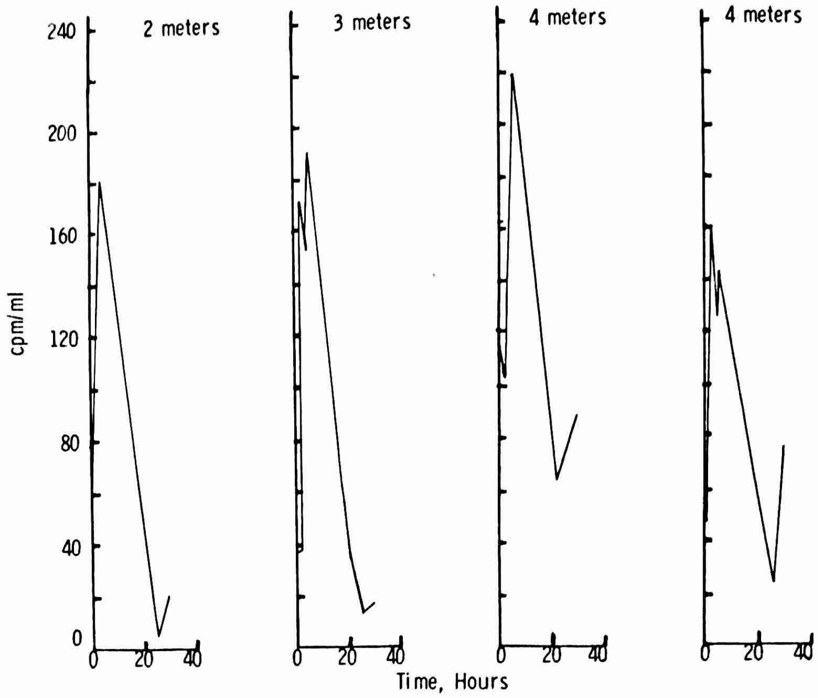


Figure 6. Tritium activity in atmospheric water collected 2 meters downslope from experimental plot and at varying distances above ground.

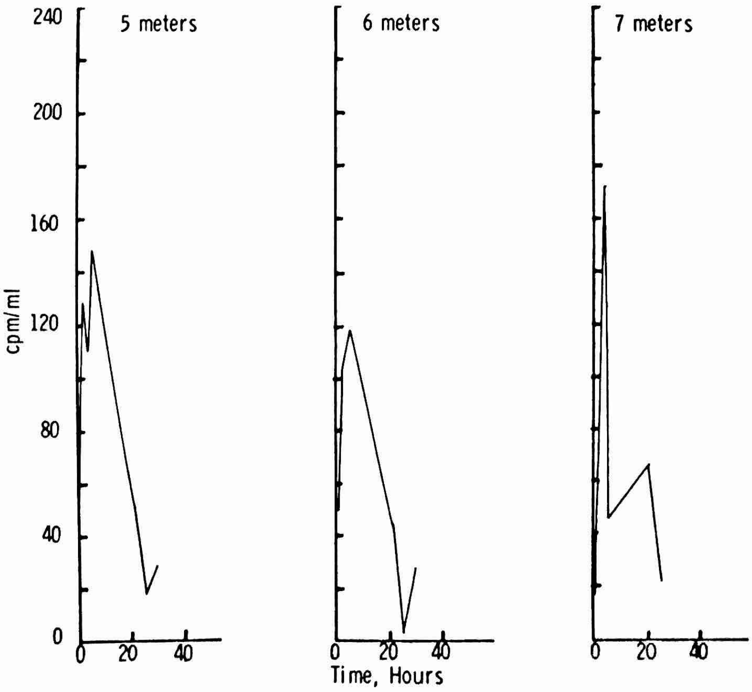


Figure 7. Tritium activity in atmospheric water collected 2 meters downslope from experimental plot and at varying distances above ground.

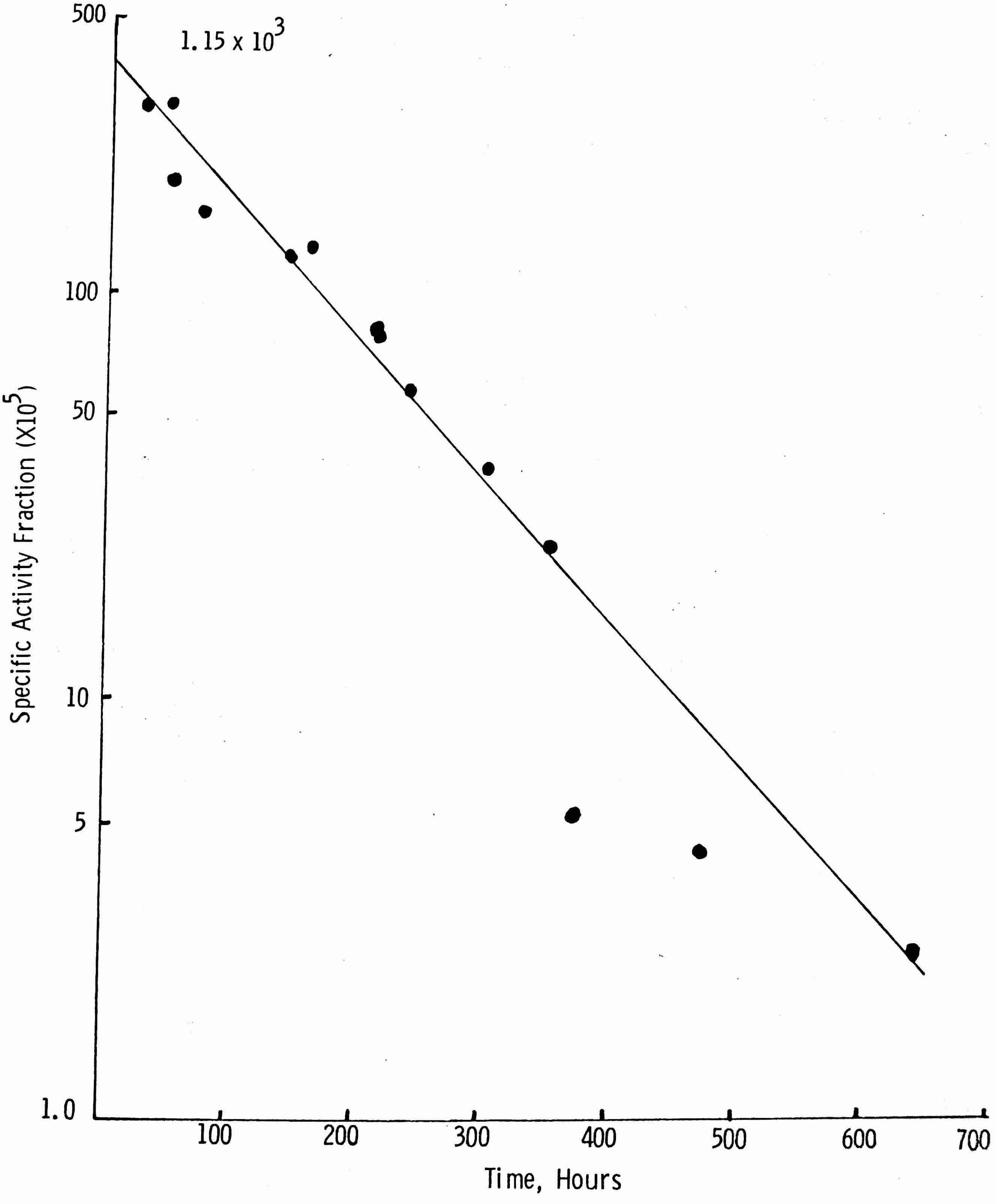


Figure 8. Specific activity fraction of tritium in surface runoff water. SAF = (cpm/ml) runoff/ (cpm/ml) original.

TABLE 1

Tritium Recovered in Surface Runoff Water

Date Collected	Time Calculated	CPM/ml	Volume Collected, ml	Percent Recovery
2/15/67	9:00 AM	111,547	200	0.15
2/15/67	1:00 PM	29,766	100	0.02
2/16/67	11:00 AM	29,150	100	0.02
2/16/67	1:30 PM	18,154	1,000	0.12
2/17/67	2:30 PM	15,524	3,800	0.41
2/20/67	11:00 AM	11,807	40	0.003
2/21/67	9:00 AM	12,700	190	0.02
2/23/67	9:00 AM	7,910	11	0.001
2/23/67	3:00 PM	7,719	2,100	0.11
2/24/67	4:00 PM	5,491	3,000	0.11
2/27/67	10:00 AM	3,629	20	0.001
3/1/67	10:00 AM	2,263	19,000	0.30
3/2/67	10:00 AM	513	5,000	0.02
3/6/67	10:00 AM	415	4,000	0.01
3/13/67	10:00 AM	243	175	0.001
	Cumulative recovery for 1 month			1.3%

TABLE 2

Recovery of Tritium in Percolating Soil Waters by a Lysimeter Buried 5 Inches in the Soil

Date Collected	CPM/ml	Volume Collected, ml	Percent Recovery
2/16/67	13,315	29	0.16
2/17/67	24,714	130	1.34
2/24/67	18,424	71	0.55
3/1/67	41,238	315	5.43
3/2/67	41,239	57	1.00
3/6/67	45,598	99	1.89
3/27/67	21,550	175	1.57
	Cumulative recovery after 6 weeks		11.94

Forest Chemistry

Prior to the establishment of analytical services within the Project, a series of samples of plant material were sent to the Soil Testing Laboratory of the University of Georgia in order to gather preliminary information on stable element concentrations. The samples were selected to provide chemical information on three different subjects. The first group of samples was obtained from 50 leaf collection stations during 1 month and was designed to provide an estimate of the variation to be expected from point-to-point in the forest, in the flux of elements cycling to the ground via leaf fall.

The second group consisting of monthly composites of the leaf collection stations near the radiation center and control center which were obtained before and after the irradiation, was designed to detect the influence of radiation on elemental composition, if any. The third group consisted of leaves pruned from various trees and was intended to demonstrate whether there are any consistent differences among species or among leaf types with regard to elemental composition.

Nine elements, P, K, Ca, Mg, Na, Zn, Mn, Fe, and Cu were determined in the ash of each sample by atomic absorption spectrometry.

Table 1 gives the mean, standard deviation, standard error of the mean, and coefficient of variation ($SD/\bar{X}$) for each of nine elements in the ash of freshly fallen leaf litter collected at one time from 50 stations. Coefficients of variation range from 35.6 for Mn to 94.2 for Na. The generally high values for Na in plant ash and the high variability may be due primarily to the influence of sea salts in the area rather than biological uptake. The high variability may not be completely random; stratified sampling may reduce it, and in so doing, yield information on nutrient element behavior in the forest.

Results from the study of the influence of radiation on elemental composition of freshly fallen leaf litter are shown in Table 2.

This data was collected in a 2 x 2 factorial design in which the factors "time" and "location" were studied. Thus samples collected from the radiation and control center before and after the radiation, were analyzed. This is a powerful design for this type of experiment since it allows study of the time x location interaction. Thus if alterations in nutrient levels were shown only in the radiation center only after radiation, this could be attributed to radiation effect with reasonable confidence. The main effects of time or location alone could be attributed to possible seasonal trends or permanent locational differences instead of radiation if they were statistically significant. Analyses for eight of the nine elements measured showed no significant main effects or interactions, thus establishing that radiation had no effect on the elemental composition of leaves. The time x location interaction for iron was statistically significant at the 0.95 level (Table 2E). The peculiar form of the interaction, however, has no convincing biological interpretation and it is concluded that this is a case of rejecting the null hypothesis when it is true, an event which is expected to occur in one of every 20 analyses.

A study of elemental composition by species is presented in Table 3. In general, leaves of different species have rather uniform nutrient content. In the case of Mg however, Dacryodes is shown to have lower levels than Manilkara or Croton at the 95% level of confidence. Only further sampling and analysis can verify whether this is generally true. Sodium content of leaf ash varies from 0.07% in Euterpe to 38% in Croton. Verifying analysis must be carried out in our own laboratories before any credence can be given to these values.

The elemental composition of leaves as related to age and position in shade or sun is presented in Table 4. In general, the composition is not related to age or position of the leaf. An exception, however, exists in the case of P. Here it is shown that the new leaves have higher P contents than old which is biologically reasonable assuming that the new leaves are in a more active state of growth. A similar trend appears to exist in the case of K and indeed the differences were significant at the 90% level of confidence, with new leaves having higher content than old. None of the other elements exhibit a particularly strong trend however and it is concluded that the stratification described in this section is not particularly instructive.

TABLE 1

Variation in the Elemental Composition of Leaf Ash from 50 Leaf Collection Stations in the Rain Forest at El Verde, Puerto Rico

	Element in Ash								
	P	K	Ca	Mg	Zn	Na	Mn	Fe	Cu
Mean (5%)	.3384	.5970	13.1501	2.8728	215(PPM)	1.8044	.1593	.0663	138(PPM)
SD	.1620	.4476	8.6907	1.5855	96.6	1.6994	.0567	.0336	119
SE	.0229	.0633	1.2292	.2243	13.7	.2404	.0080	.00476	16.8
CV = $\left(100 \frac{SD}{X}\right)$	47.87	74.97	66.09	55.19	44.89	94.18	35.59	50.68	86.23

TABLE 2

Interaction Tables for Elemental Content of Leaf Litter Ash Before and After Irradiation in Radiation and Control Centers

A) P (%)

Center	Before	After	Average
Radiation	.95	1.06	1.01
Control	1.06	1.12	1.09
Average	1.01	1.09	

B) K (%)

Center	Before	After	Average
Radiation	3.27	1.49	2.38
Control	2.77	1.90	2.33
Average	3.02	1.69	

C) Ca (%)

Center	Before	After	Average
Radiation	36.22	39.27	37.74
Control	33.84	29.39	31.62
Average	35.03	34.33	

D) Mg (%)

Center	Before	After	Average
Radiation	8.13	7.74	7.93
Control	6.93	7.94	7.43
Average	7.53	7.84	

E) Fe (%)

Center	Before	After	Average
Radiation	.028	.068	.048
Control	.062	.039	.050
Average	.045	.053	

F) Cu (PPM)

Center	Before	After	Average
Radiation	117	84	100
Control	108	125	116
Average	112	104	

G) Zn (PPM)

Center	Before	After	Average
Radiation	700	785	742
Control	700	890	795
Average	700	839	

H) Na (%)

Center	Before	After	Average
Radiation	5.49	2.50	4.00
Control	18.44	2.95	10.70
Average	11.97	2.73	

I) Mn (%)

Center	Before	After	Average
Radiation	.75	.61	.68
Control	.65	.56	.61
Average	.70	.59	

TABLE 3

Average Elemental Composition of Leaf Ash from Various Species of Trees Near El Verde, Puerto Rico

	Elements in Ash								
Species	% P	% K	% Ca	% Mg	PPM-Zn	% Na	% Mn	% Fe	PPM-Cu
Manilkara nitida	0.27	5.02	15.92	6.80	253	0.41	0.06	0.12	62
Dacryodes excelsa	0.33	2.56	11.93	2.94	263	5.26	0.34	0.03	110
Sloanea berteriana	0.39	3.54	15.31	3.30	330	6.87	0.63	0.09	290
Croton poecilanthus	0.53	2.04	10.53	5.18	282	38.25	0.19	0.07	117
Euterpe globosa	0.37	2.84	7.31	4.55	192	0.07	0.13	0.08	135
HSD (0.95)	-	-	-	1.90	-	5.79	-	-	-

TABLE 4

Relationship of Leaf Type and Elemental Composition of Ash in Several Tree Species from El Verde, Puerto Rico

Species	% P	% K	% Ca	% Mg	PPM-Zn	% Na	% Mn	% Fe	PPM-Cu
Old Sun	0.27	1.79	13.62	4.21	232	8.27	0.49	0.07	216
New Sun	0.44	4.23	8.46	4.72	306	10.91	0.30	0.06	92
Old Shade	0.24	1.88	12.71	4.64	220	9.86	0.17	0.08	98
New Shade	0.43	4.89	14.01	4.64	299	11.64	0.13	0.08	166
HSD (.95)	0.17	-	-	-	-	-	-	-	-

Forest Phenology and Tree Growth

Several subprojects in forest phenology and tree growth have been continued because of their general usefulness in the radiation recovery studies or radionuclide cycling studies. These include the monthly collections of leaf fall from radiation and control centers and the measurement at 6-month intervals of tree growth in both centers. In addition, observations on fruiting and flowering continue because the present record has not yet established reliable patterns in these cycles.

Leaf fall for the period June 1966, to April 1967, in both centers is shown in Figure 1. Average monthly leaf fall ranged from a high of $2g/m^2/day$ in the summer months to slightly more than $1g/m^2/day$ in the winter months. The annual monthly average was $40.5\ g/m^2/mo$. A broad pulse of leaf fall was previously shown to occur in this forest during the spring months of April, May, and June by H. T. Odum (The Rain Forest Project Annual Report FY-1965). This year's data indicates that the pulse lasted through September, showing considerable change in the pattern.

Fruit fall as collected in the 55 stations is given in Figures 2 and 3. Nine species are shown which produced a significant fruit fall. Approximately 30 other species produced fruit in numbers too small to be plotted.

Tree growth during the period June 1966, through April 1967, in the radiation center is shown in Figure 5. The data shown is for species which had sufficient numbers of individuals in the center to give an estimate of continued radiation effect. The data will henceforth be obtained at 6-month intervals rather than at monthly intervals as in the past, since this appears to be sufficient to show continued radiation effects.

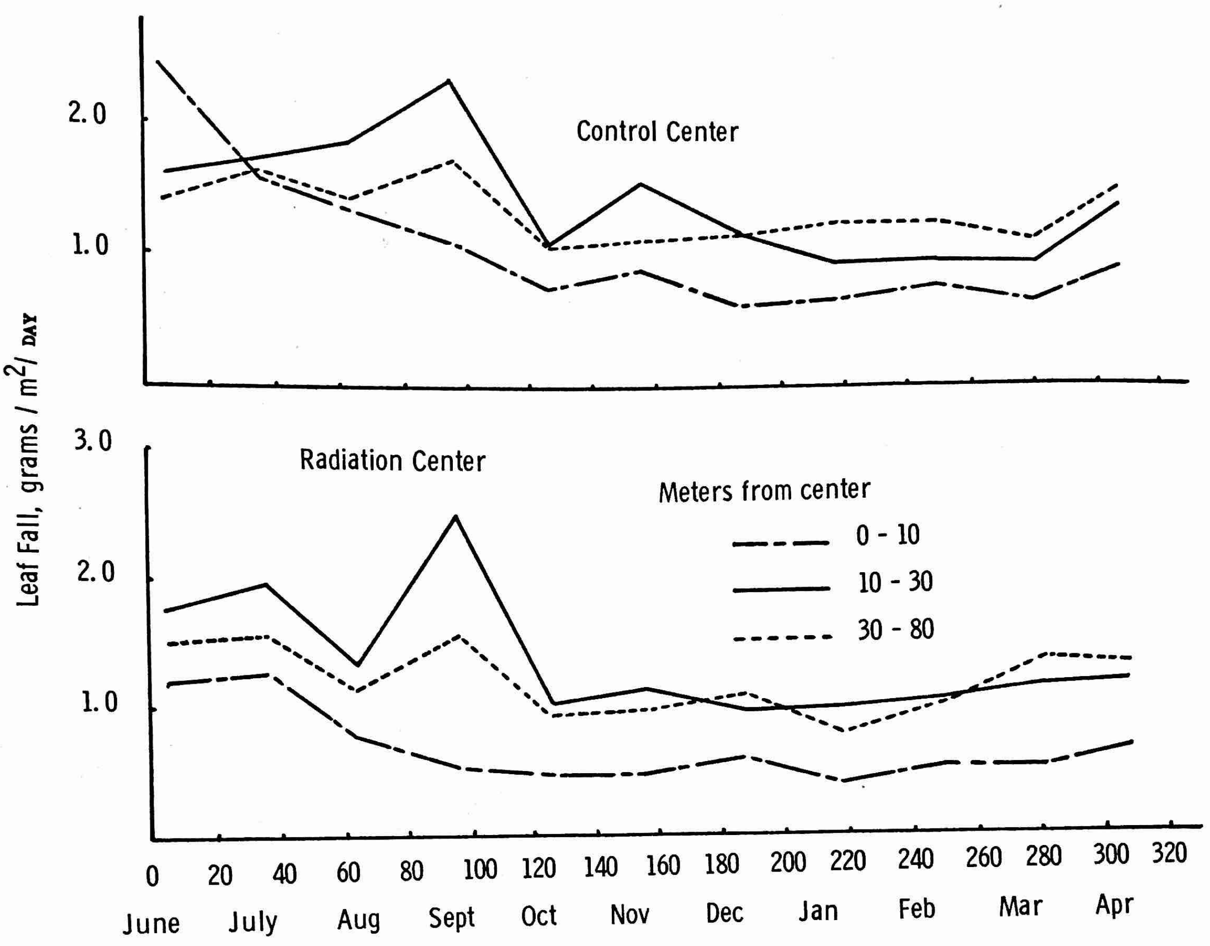


Figure 1. Leaf fall in the El Verde, Puerto Rico field site during the period June 1966, to April 1967.

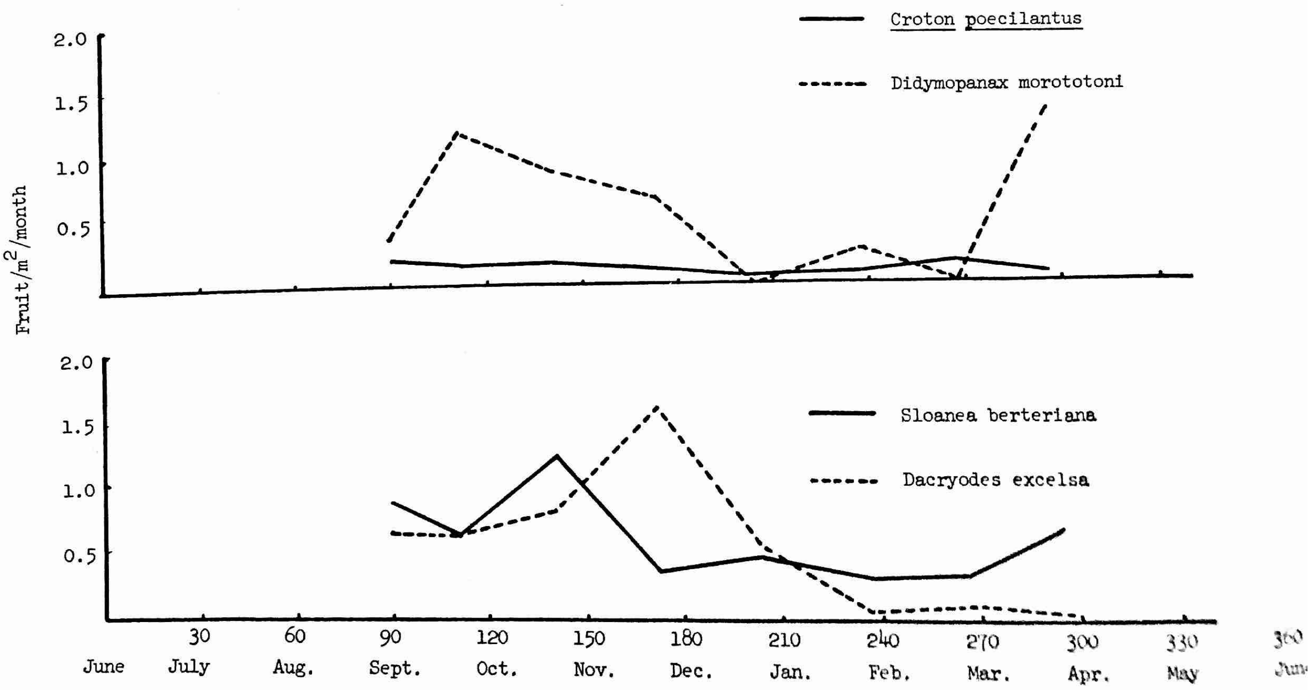


Figure 2. Fruit fall collected in 55 stations during the period September 1966, to April 1967, at the El Verde, Puerto Rico field site for 4 species.

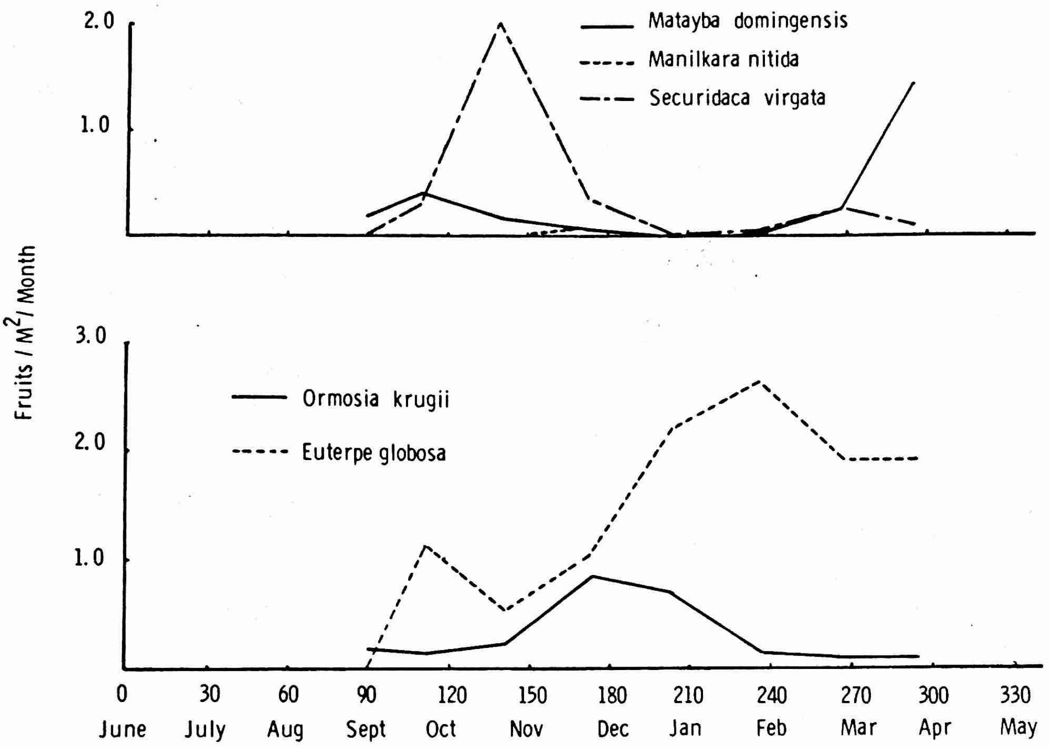


Figure 3. Fruit fall collected in 55 stations during the period September 1966, to April 1967, at the El Verde, Puerto Rico site for 5 species.

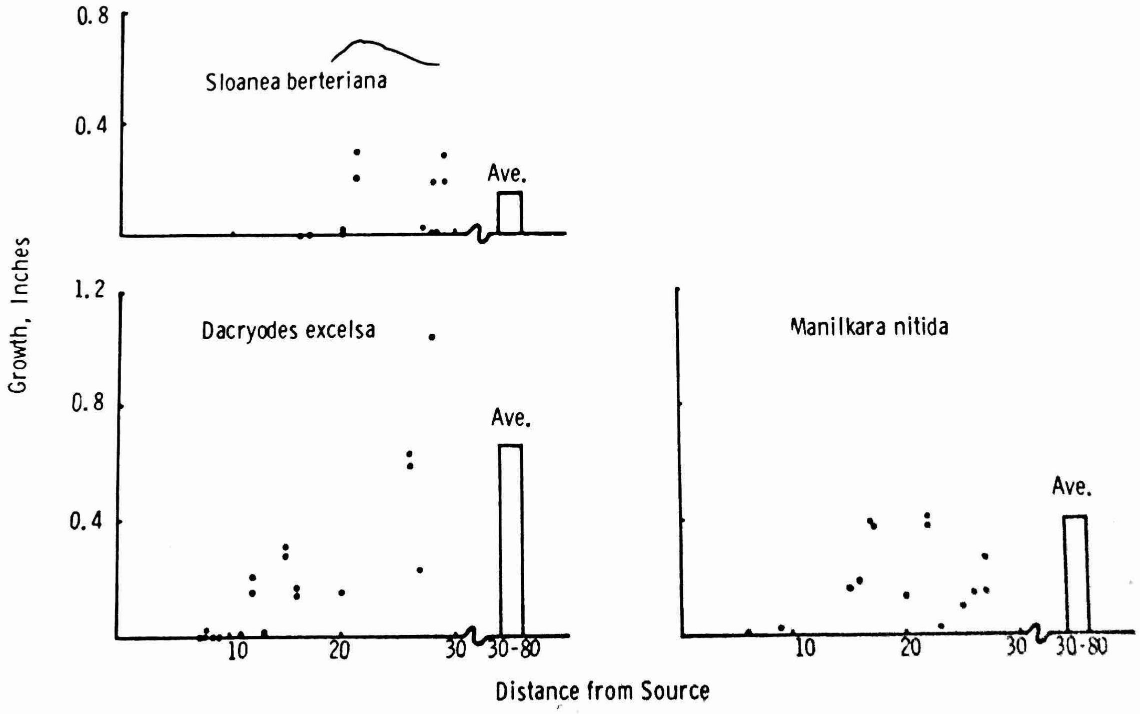


Figure 4. Total increases in tree circumference during the period June 1966, to April 1967, in the irradiation center.

Productivity Study in Irradiated Area

A study of total net productivity in the area surrounding the source location has been initiated. A 900 m^2 grid has been laid out in 1 m^2 squares with nylon cord, in the irradiated area. All vegetation within the grid, originating since cessation of radiation, was measured in the fall of 1966. All vegetation existing prior to radiation was measured in the spring of 1967. This data will be put on computer cards, one card for each plant. The format for these cards (Figure 1) shows what measurements have been taken.

Several plants of various sizes of each species will be taken from areas outside of the radiation area. Regressions of dry weight on diameter, height, or coverage will be calculated for each species. Total biomass, biomass per square meter, or biomass per species within the grid can then be calculated.

Biomass of new vegetation is also a measure of productivity, since all plants originated since the spring of 1965. Periodic measurements of the vegetation in the irradiated area, similar to the first measurements, will be made in the future. Productivity and biomass calculations will be done on the University of Puerto Rico's IBM 1130 computer.

Columns			
1 - 3	Job Code		
4	Skip		
5 - 6	Sample date		
7	Skip		
8	New (N) or old (O) vegetation		
9	Skip		
10 - 12	Species		
13	Skip		
14	Tree, (T), Grass (G), *Phytolacca* (P), or *Desmodium* (D)		
15	Skip		
16	Sprout (S) or not (N)		
17	Skip		
18 - 21	Coordinates of grid		
22	Skip		
23	Drainage, Well (W) or Poor (P)		
24	Skip		
25 - 26	Inches		
27 - 28	Sixteenths	Basal Diameter	
29	One hundred twenty eights		
30	Skip		
31 - 32	Inches		
33 - 34	Sixteenths	Dia. 30 cm	
35	One hundred twenty eights		
36	Skip		Tree
37 - 38	Inches		(New)
39 - 40	Sixteenths	Dia. 4.5 ft	
41	One hundred twenty eights		
42	Skip		
43 - 45	Length		
46	Skip		
47 - 48	Percent coverage of quadrat		
49	Skip		
50 - 51	Percent coverage in growth area		
52	Skip	Grass	
53 - 54	Max. height, cm		
55	Skip		
56 - 57	Average ht., cm		
58	Skip		
59	Coverage	*Desmodium*	
60	Skip		
61 - 62	Inches		
63 - 64	Sixteenths	Basal Dia.	*Phytolacca*
65	One hundred twenty eights		
66	Skip		
67 - 68	Inches	Dia. 4.5 ft	Old trees
69	Tenths		
70	Skip		
71 - 72	Percent canopy remaining		

Figure 1. Format for computer cards for plants within the radiation study area.

Leaf Age Observations

It is suspected that certain leaves of canopy trees, perhaps those on the top of the canopy, fall a short time after being produced, while others toward the bottom of the canopy have much longer lives. In order to determine whether an intensive investigation of this is warranted, canopy leaves of four trees were tagged in October 1966. The tagging was done shortly after a large number of new leaves had emerged. Tagged leaves were counted on March 28, 1967. In *Manilkara bidentata*, leaf fall was highest in both old and young leaves toward the top of the canopy (Table 1). In three other species, sampling difficulties prevented establishing height gradients. However, leaf fall at one height was obtained. At 42 feet in *Miconia tetrandra*, 100% of 9 young leaves, and 63% of 43 old leaves remained after 5 1/2 months. At 51 feet in *Linociera domingensis*, 76% of 58 old leaves remained. At 45 feet in *Inga laurina*, 100% of 28 young leaves, and 86% of 7 old leaves remained.

Further monitoring of these leaves will be done.

TABLE 1

Percent of Young and Old Leaves of *Manilkara bidentata* at Various Heights that Remained for 5 1/2 Months

Height feet	No. of tagged young leaves 10/11/66	Percent of tagged young leaves remaining on 3/28/67	No. of tagged old leaves 10/11/67	Percent of tagged old leaves remaining on 3/28/67
51	18	83	13	38
45	28	100	33	91
42	30	100	23	87
39	6	100	2	100
36	7	100	17	100
33	2	100	2	100
30	7	100	17	94

Leaf Fall and Twig Growth in Irradiated Canopy

In October 1966, a tower was built approximately 18 meters from the radiation source location, right at the edge of the apparent canopy damage. In November 1966, leaves were counted and twigs measured in the canopy of one *Manilkara bidentata*, and one *Dacryodes excelsa* adjacent to the tower. Young leaves were separated from old leaves on the *Manilkara*. There were no apparent young leaves on the *Dacryodes*.

The leaves were recounted and the twigs remeasured in March 1967, (Tables 1 and 2).

TABLE 1

Percent of Canopy Leaves of Radiation Exposed *Manilkara bidentata* and *Dacryodes excelsa* which Remained for 5 Months

Species	No. of tagged young leaves 11/66	Percent of tagged young leaves remaining, 3/67	No. of tagged old leaves 11/66	Percent of tagged old leaves remaining, 3/67
Manilkara bidentata	33	97	47	75
Dacryodes excelsa	-	-	34	35

TABLE 2

Change in Twig Length of Radiation Exposed *Manilkara bidentata* and *Dacryodes excelsa* between November 19, 1966, and March 19, 1967

Species	No. of twigs measured	Average change (cm)
Manilkara bidentata	10	+ 2.6
Dacryodes excelsa	8	- 1.9

Forest Metabolism

This report summarizes the work being done with the Beckman infrared analyzer in the forest. The system has been used in measuring the metabolism of several climax and successional species. During January 1967, the giant cylinder was operated and 2 days of data was collected. The data from the giant cylinder suggests that changes must be made in its operation.

The metabolism of trees close to the radiation center was compared with trees of the same species at the giant cylinder site. Also the metabolism of a successional species was compared between individuals growing in well-drained soils and poorly-drained soils.

MAXIMUM RATE OF PHOTOSYNTHESIS

The maximum rate of photosynthesis for the species studied is shown in Table 1. It is interesting that tree #2660, 18 m from the source, and tree #2707, 18 m from the source, had lower rates (0.98 $gC/M^2/hr$) than those measured on a tree of the same species at the giant cylinder site (.152 $gC/M^2/hr$).

Psychotria berteriana, a successional species growing at the radiation center, had higher maximum photosynthetic rates than the climax species.

Manilkara bidentata was found to have a maximum rate, somewhat higher than Dacryodes. Both are climax species.

P/R RATIO

Metabolism data from two climax species (Dacryodes excelsa and Manilkara nitada), and from one successional species (Psychotria berteriana) indicates that the photosynthesis to respiration ratio may increase with succession (Table 1). The low P/R ratios of the Dacryodes near the source were caused by a relatively high respiration rate. Previous work by Lugo (1965) showed that Dacryodes seedlings have a low P/R ratio.

As an example of the daily pattern of photosynthesis, respiration, and light; a plot of the raw data taken from the recording charts is given for the young leaves of the Dacryodes in the giant cylinder site (Figure 1).

LITERATURE CITED

1. Lugo, A., Photosynthetic Studies on Rain Forest Seedlings, Cecropia peltata, Anthocephalus cadamba, Dacryodes excelsa, and Sloanea berteriana. Master's thesis University of Puerto Rico, 1965.

TABLE 1

Summary of Maximum Rate of Net Photosynthesis and P/R Ratios for Three Species Being Studied

Species	Maximum Rate of Net Photosynthesis $gC/m^2/hr$	P/R Ratio
Dacryodes excelsa Old sun leaves, giant cylinder site	0.152	8.33
Dacryodes excelsa Young, Immature leaves (bright green), same tree as above	0.118	1.76
Dacryodes excelsa Tree #2660, Old sun leaves, 18 meters from source	0.098	7.67
Dacryodes excelsa Tree #2707, Old leaves facing source, tree 18 meters from source	0.098	1.77
Manilkara bidentata Tree #2730, Old sun leaves, 18 meters from source	0.181	7.75
Successional Species		
Psychotria berteriana Poorly-drained soil, radiation center	0.303	3.00
Psychotria berteriana Poorly-drained soil, radiation center	0.182	3.62
Psychotria berteriana Well-drained soil, radiation center	0.218	4.75

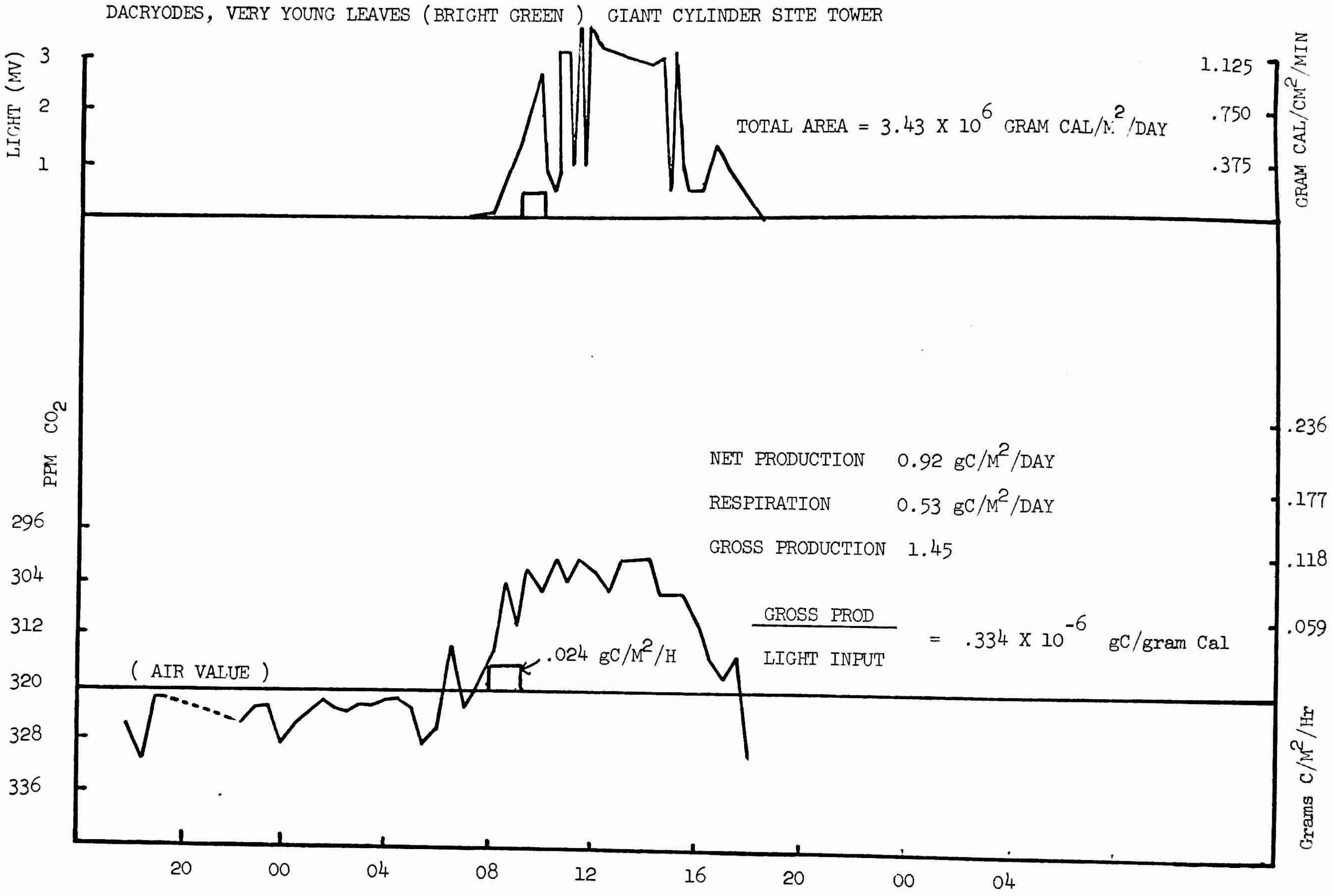


Figure 1. Carbon dioxide concentrations in metabolism chamber surrounding very young leaves of Dacryodes excelsa at the giant cylinder site, January 1967, and amount of light during the sampling period.

Spectral Quality of Light Within the Forest

A series of aerial photographs of the forest surrounding the irradiated area was taken in August 1966. To the west and downslope from the source location for several hundred meters, the forest canopy appeared to be more yellow and less green than in other areas of the forest. Since the effect was most pronounced where the forest canopy was unshielded from gamma radiation, there is the possibility that the effect is due to radiation.

In order to determine whether the color of the canopy really is different in the area west of the source, a series of spectroradiometric measurements was initiated from the ground. A wedge-prism type spectroradiometer was used for measurements.

Three of the spectra taken between 12:40 PM and 1:40 PM on March 29, 1967, during a period of "no clouds", are shown in Figures 1-3. Light above the canopy was measured on the top of a 72 ft tower. Light at a wavelength of 500 mμ was more intense than at any other wavelength (Figure 1). A fresh young leaf of Manilkara bidentata was placed directly on top of the light-receiving surface of the spectroradiometer, and a spectrum was taken on top of the tower (Figure 2). Most of the blue and red light was absorbed by the leaf, but much of the green and infrared was transmitted. The spectrograph taken on the forest floor near the base of the tower (Figure 3) shows relatively more blue and red light than is transmitted through a single leaf (Figure 2). This shows that a portion of the light reaching the forest floor must be scattered light, not transmitted light.

Spectra are time consuming to calculate and plot, and initial experience has shown that a large scale statistical survey must be made to show any differences in light quality between two areas of the forest. Since a peak of maximum absorption occurs at 675 mμ, and a peak of maximum transmittance around 800 mμ, it was felt that a ratio of transmitted light at these two wavelengths would be easier to plot, and it would convey just as much information about damage as the entire spectrum. Preliminary results are promising. In a radiation-damaged area, the change in red light absorption should be relatively great due to chlorophyll destruction, but change in infrared should be relatively less because a large amount of infrared gets through regardless of the condition of the leaves.

Showing that there is a difference in the red infrared ratio in a particular portion of the forest does not prove that the difference is caused by radiation. However, if a trend becomes evident in the forest to the west and downslope from the source, and the rest of the forest does not change, the trend could be due to radiation.

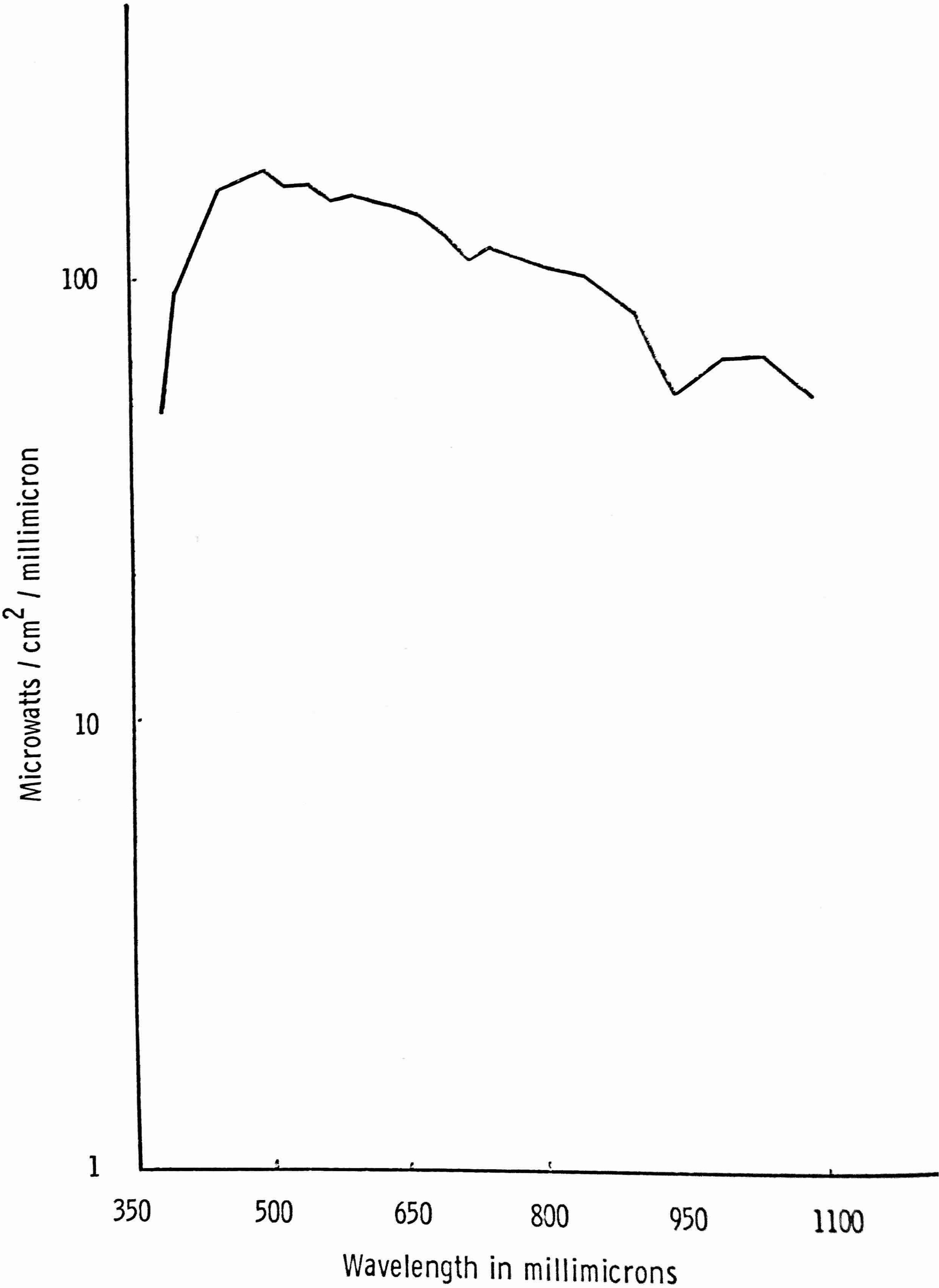


Figure 1. Radiation spectrum above the canopy, March 29, 1967, 12:55 PM

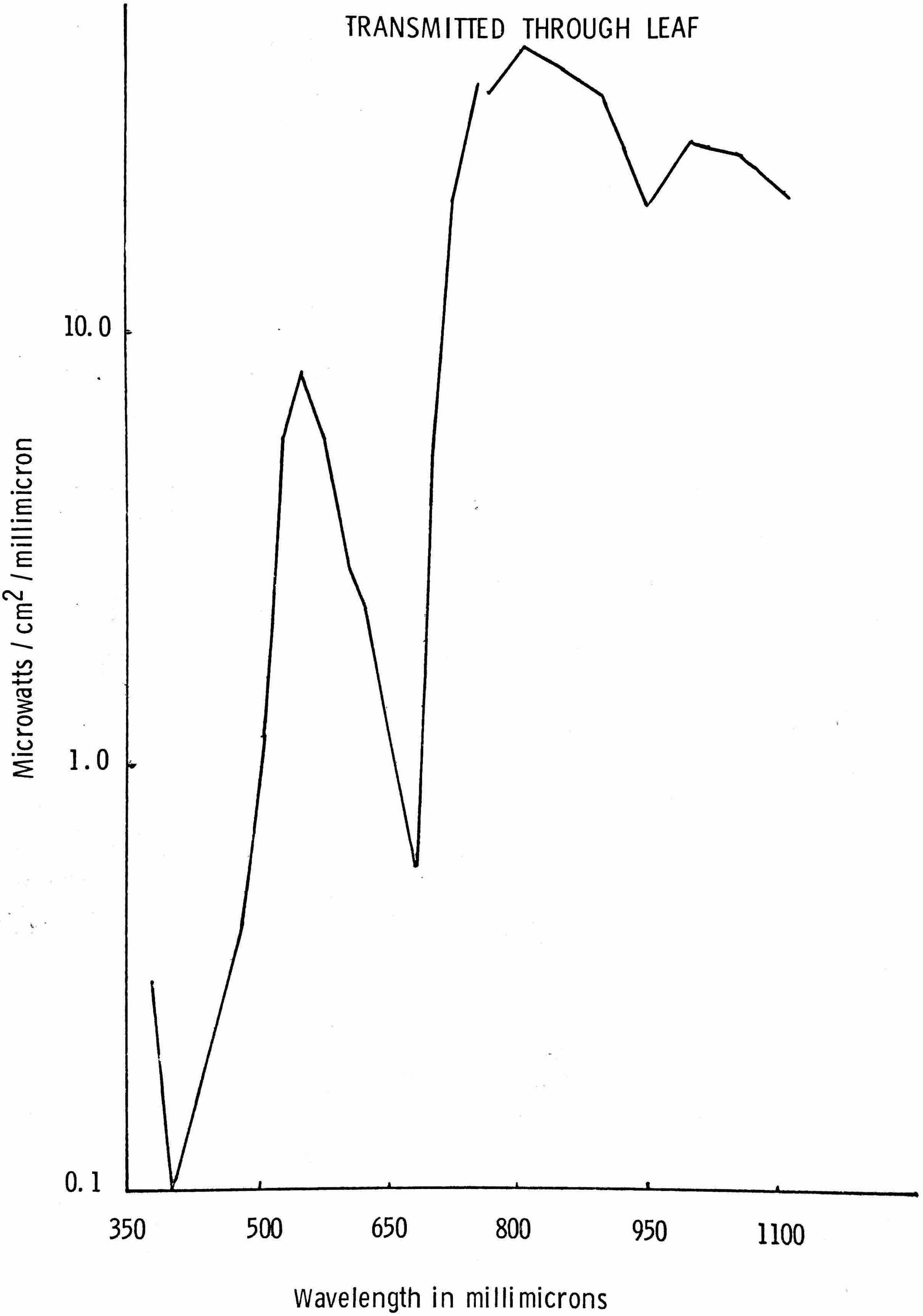


Figure 2. Quality of radiation transmitted through a leaf of <u>Manilkara bidentata</u>, March 29, 1967, 1:40 PM

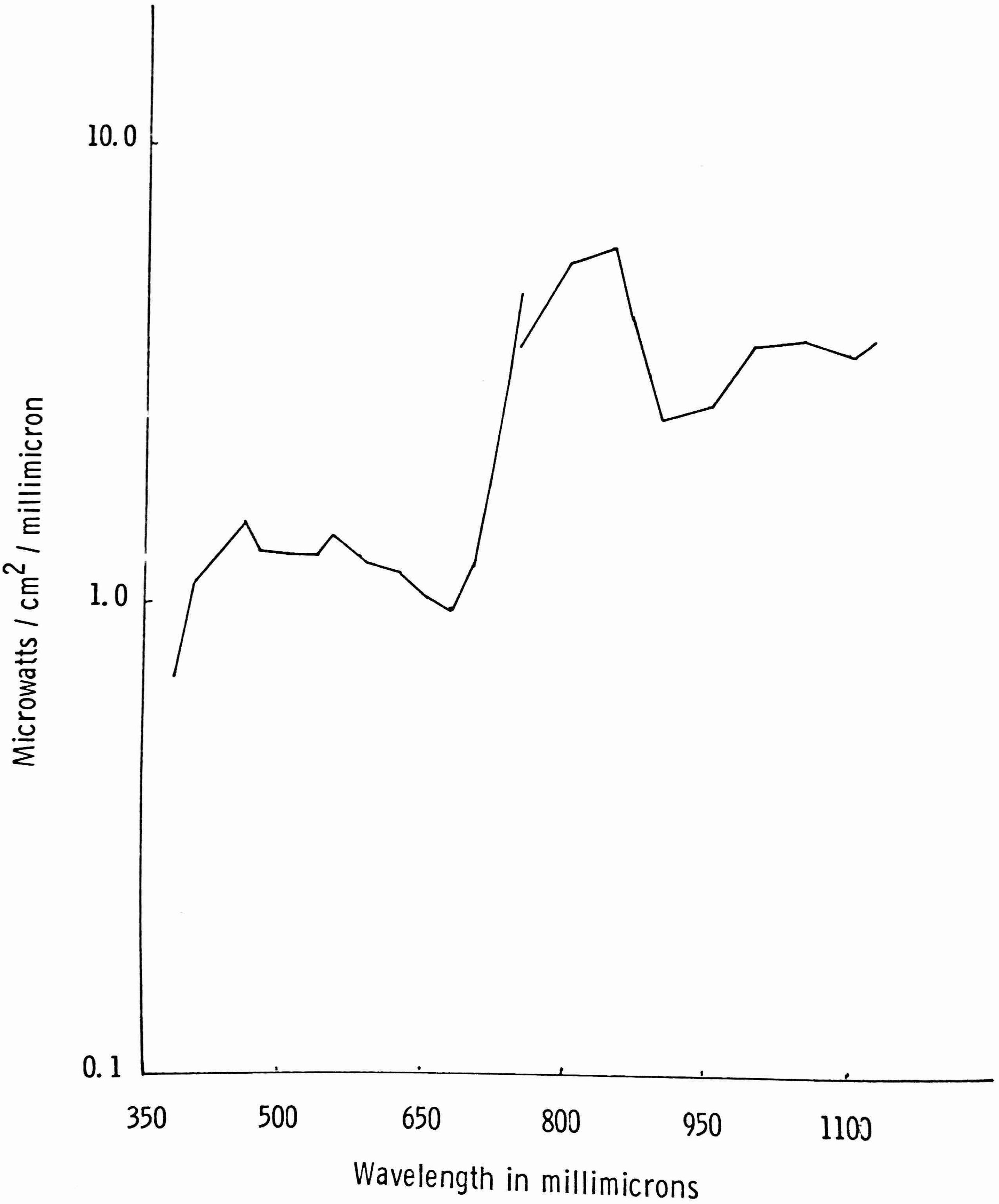


Figure 3. Radiation spectrum below the canopy, March 29, 1967, 12:45 PM

Lysimeter Studies

In order to study the soil water portions of the element cycles in the Puerto Rican rain forest, lysimeters were installed at various locations and at various depths (Table 1). The lysimeters are 2- by 12-inch stainless steel troughs with a mechanism inside for breaking surface tension. They are installed by digging a pit, and then at appropriate depths, digging a tunnel into the side of the pit. The lysimeter is then wedged up against the top of the tunnel, which is then refilled with soil. Lysimeters beneath the litter are installed by peeling back the organic matter, installing the lysimeter, and replacing the organic mat and litter. A precise description of the lysimeter is given elsewhere (Jordan, 1968).

In order to calculate water budgets and elemental cycling budgets, the volume of soil from which the lysimeter collects water must be known. To calculate this volume of soil, the "effective collection area" of the lysimeter must be determined. The "effective collection area" is defined as that area of ground at the soil surface from which all incoming water moves into the lysimeter below, and outside of which no water moves into the lysimeter below. In reality, water does not move straight down, but diffuses laterally as it moves downward, and thus the area from which the lysimeter actually collects water is larger than the "effective collection area." However, not all the water within the actual collection area moves into lysimeters.

Because of the problem of lateral diffusion of water, "effective collection area" is a useful concept.

The "effective collection area" was calculated by using a "Test Box," and with field plots.

TEST BOX

A box, slightly less than 1 m^3, and with an open top, was constructed of 1/2-inch plexiglass. A drainage tube connected to a vacuum pump was connected to the bottom of the box. The bottom of the box was filled with 2 inches of sand, and a foot of soil dug from the top few inches of the forest soil, was placed on top of the sand. An inch of organic matter was placed on top of the soil. A lysimeter was placed at a depth of 5 inches below the mineral soil surface of the box. A collection tube from the lysimeter ran out of the box.

Known amounts of simulated rainfall were applied to the box via a siphon tube to an ordinary shower sprinkler. The sprinkler was moved by hand in a systematic manner over the soil in the box during tests.

Before the test began, simulated rain was applied until there was a continuous flux of water through the lysimeter and also out through the drainage tube in the bottom of the box.

Once the flux was established, the lysimeter collection jug was quickly emptied and reconnected, and a measured amount of rainfall was applied to the box. As soon as the rainfall application was complete, the lysimeter collection jug was disconnected, and the volume of water collected was measured. The percent of water flux collected by lysimeters closely resembled the percent obtained when the top area of the lysimeter was divided by the top area of the test box (Table 2). This means that the "effective collection area" of the lysimeter is almost exactly equal to the top area of the lysimeter.

FIELD PLOTS

Lysimeters were also tested in field plots. Two areas, each slightly larger than 1 m^2, were surrounded on three sides with garden edging extending down into the mineral soil. The downhill side of each plot was excavated, and a flat collection pan was wedged in below the litter to collect surface runoff. Two lysimeters were installed beneath plot No. 1, and three beneath plot No. 2, all at a depth of 5 inches. Rain gauges, 5 ft long by 2 inches wide were installed along both sides of plot No. 1, and along one side of plot No. 2.

On December 22, 1966, it began to rain. During the afternoon water started to move through the lysimeters. The collection bottles for the lysimeters and runoff were emptied, and then reconnected, and the rain gauges were emptied. Rain continued intermittently throughout the night. It is assumed that the soil remained saturated throughout the night until the next morning when measurements were taken. Total water moving through the soil was calculated by subtracting runoff from rainfall reaching the soil surface. All calculations were converted to a square meter basis. The volume of water collected by lysimeters was divided by total volume of percolate to obtain percentage of percolate collected by lysimeter. This percentage closely resembled the percentage obtained by dividing the top area of the lysimeter by 1 m^2 (Table 3).

This data shows that the "effective collection area" of the lysimeter is almost exactly equal to the top area of the lysimeter.

LYSIMETER COLLECTIONS

Rainfall above the canopy as determined by one standard recording rain gauge, and rainfall reaching the forest floor as determined by

9 rain gauges, 5 feet long by 2 inches wide by 8 inches deep is shown in Figure 1.

Volumes of water collected from each lysimeter from December 1966, through January 1967, are shown in Figures 2-7. While there is considerable variation between lysimeters at the same depth at the same site, definite trends can be established.

Lysimeter collections for the 5-inch depth at the control center are shown in Figure 2. Lysimeter No. 4 collects less water than the others. Directly above this lysimeter is a large root, and this may account for the small volume. The aluminum disc lysimeter described by Cole (1958) collected[1] approximately the same amounts of water as lysimeters Nos. 1 and 2. A tension of 0.1 atm was placed on the disc by suspending a 3 ft column of water below the disc. The top area of the aluminum disc lysimeter is approximately four times larger than that of the other lysimeter (612 cm^2 vs. 154 cm^2).

Lysimeter collections at the 14-inch depth in the control center (Figure 3) are generally less than those at the 5-inch depth. However, lysimeter No. 1 collected considerably larger volumes of water during heavy rains than other lysimeters in the same area (except for No. 4 on April 3), and less during dry periods. This could be the result of lysimeter No. 1 being located directly under a root channel. During heavy rains, the root channel may drain a relatively large area, but during dry spells, no water moves through the channel while small amounts may move through the soil.

In the tritium area (Figure 4), lysimeters Nos. 1 and 2 are located only 18 inches apart under apparently identical soil conditions. Likewise, lysimeters Nos. 3 and 4 are close together. The volumes collected within these pairs were quite similar throughout the sampling period. This suggests that differences between collections on the same date are more a function of actual differences in nature than of variation in lysimeter performance.

Volumes in the cesium area (Figure 5) are similar to volumes in the nearby tritium area (Figure 4).

A second plot was established within the cesium area, with lysimeters at 2 and 5 inches (Figure 6). Although there is overlapping, the 2-inch deep lysimeters collected slightly more water than the 5-inch ones. Lysimeter No. 12 failed to function after March 3.

Large differences between lysimeters at 5 and 14 inches (Figures 2 and 3), and small differences between lysimeters at 2 and 5 inches (Figure 6) conform to what might be expected on the basis of soil structure. Down to a depth of about 10 inches, the soil is well

[1] Made and donated by the Ecology Section, Brookhaven National Laboratory.

aggregated and quite porous. During heavy rains, water should move quickly through this porous zone. Below 10 inches the soil aggregation disappears, and the soil is clay with very little, or no structure. Thus considerably less water might be expected to move down to this depth, except through root channels.

The lysimeters above the bell jar (Figure 7) are in "poorly-drained soil," which is discussed in the section entitled "Recovery of a Tropical Rain Forest after Gamma Radiation" in this report. "Poorly drained" indicates an abundance of water and reducing conditions. The lysimeters in this soil collected much more water than lysimeters in any other location. A hypothesis for this phenomena, as well as other variations in lysimeters at the 5-inch depth follows.

Figure 8 shows the amount of water falling upon an area of ground equal to the top area of a lysimeter (154.8 cm^2). This volume is greater than volumes moving into lysimeters in the cesium area, and lysimeters Nos. 1 and 2 in the tritium area (Figures 4, 5, and 6), but slightly less than volumes moving through the control area (Figure 2) and lysimeters Nos. 3 and 4 of the tritium area (Figure 4), and much less than volumes moving in the area above the bell jar (Figure 7).

The test box and field plots showed that the "effective collection area" of the lysimeter was equal to the actual top area of the lysimeter. If this is true, then when volumes of lysimeter water are greater than volumes falling upon the "effective collection area," there must be an accumulation of water in the surface soil due to downslope lateral movement.

Locations of lysimeter plots, and volumes of water collected in these lysimeters, give evidence that there is lateral downslope movement in the porous upper few inches of soil. The cesium plot lysimeters and lysimeters Nos. 1 and 2 of the tritium plots are located within 6 ft of a minor ridge, or divide. Thus there could not be much opportunity for a buildup of lateral flow. The lysimeter tests previously described to determine "effective collection area" were made in these areas. The lysimeter collections in these areas were the lowest of all the 5-inch collections. In the control center, the lysimeters are about 20 ft from the ridge top, and thus lateral flow could accumulate. Lysimeters Nos. 3 and 4 in the tritium area are also about 20 ft from a small ridge. In these areas, lysimeter volumes were slightly larger than volumes falling upon the "effective collection area." The lysimeters above the bell jar are located below a slope of several hundred feet. Collections here were much greater than volumes falling on the "effective collection area."

The amount of percolate increases with increasing length of slope above the lysimeter. Lateral downslope movement of water is likely in the top few inches of soil, yet there is no apparent surface runoff, and water soaks rapidly into the ground. In order to further study water movement, a series of runoff plots have been established. Their installation is not yet satisfactory and no results are yet available.

Collection tubes of two lysimeters have been diverted through tipping bucket recording rain gauges. Operation during the first few weeks was intermittent, but results indicated that the volumes moving through the lysimeter directly beneath the litter, closely followed fluctuations in rainfall, while the lysimeter at 5 inches produced a much more steady flow of water.

Data on volume of collections from lysimeters beneath the litter is extremely variable, due undoubtedly to micro-variations in throughfall. Installation of more lysimeters beneath the litter layer is planned.

Recently, conductivity readings of lysimeter collections were started. In addition, conductivity of percolate from one lysimeter is being continuously recorded. Data so far is insufficient to show any trends.

On January 9, 1967, Dr. Joe Edmisten collected lysimeter and river water samples from several locations. Analyses were made under his direction. Concentration in the lysimeter collection from beneath the deep litter generally was the highest, except for phosphorus, which was highest at the 14-inch depth. A soil sample collected near the lysimeter was also analyzed for exchangeable elements and pH (Table 4).

Cesium-134 will be sprayed on the "new tracer" (cesium) plots in a manner similar to that used in the "old tracer" site (Table 1). In order to anticipate the sort of results which can be expected from lysimeter collections in the "new tracer" areas, collections were made on one date from lysimeters beneath the litter layer in the old cesium area (Table 5). Resin columns were attached directly to the collection tubes, and the columns counted after percolate had moved through them in order to determine the feasibility of counting only the columns instead of the total volume of water.

LITERATURE CITED

1. Cole, D. W., Aluminum Tension Lysimeter, Soil Science 85: 293-296, 1958.

2. Jordan, C. F., A Simple, Tension-Free Lysimeter, Soil Science, 1968, in press.

TABLE 1

Lysimeter Installations

Site	No. of lysimeters	Depth of lysimeters
Old tracer	3	Beneath shallow litter
Control	1	Beneath shallow litter
	1	Beneath deep litter
	5*	5 inches
	4	14 inches
Above Bell jar	4	5 inches
Tritium	5	5 inches
New tracer (cesium)	2	Beneath shallow litter
	2	Beneath deep litter
	5	5 inches
	2	2 inches
Total	34	

*One of these is an aluminum oxide disc-type lysimeter.

TABLE 2

Water Balance Data for Lysimeters within Test Box

Top area of test box	6241 cm^2
Top area of lysimeter	154.83 cm^2
Area of lysimeter as a percent of box area	2.46%
Trial No. 1	
Flux of water through box	20 liters
Lysimeter collection	650 ml
Percent of flux collected by lysimeter	3.2%
Trial No. 2	
Flux of water through box	20 liters
Lysimeter collection	750 ml
Percent of flux collected by lysimeter	3.7%

TABLE 3

Water Balance Data from Field Plots, Dec. 23, 1966

		Plot No. 1	Plot No. 2
1.	Rainfall (liters/m^2)	65.500	102.000
2.	Runoff (liters/m^2)	11.907	4.500
3.	1-2 (percolate)	53.593	97.500
4.	Percolate collected in lysimeters (liters)	.905	.990
5.	$\frac{\#4}{\#3}$ (percent)	1.67	1.01
6.	$\frac{\text{area of lysimeter}}{\text{one square meter}}$ (percent)	1.54	1.54

TABLE 4

Concentration of Elements in Lysimeter Water, River Water, and Soil Extract. Samples Taken from near the Irradiated Forest on January 9, 1967

	PPM									
Sample	pH	P	K	Na	Fe	Cu	Mg	Zn	Ca	Mn
River water		0.50	0.5	11.7	1.0	0.1	1.27	.05	3.4	0.2
Lysimeter water, deep litter		1.75	5.2	19.9	1.0	0.2	2.10	.75	5.7	0.2
Lysimeter water, shallow litter		1.00	1.0	12.2	1.0	0.1	.48	.05	1.4	0.2
Lysimeter water, 5 inches deep (Site 1)		5.00	0.5	13.3	1.0	0.1	.92	.05	0.9	0.2
Lysimeter water, 5 inches deep (Site 2)		1.00	T	15.2	1.0	0.1	.72	.05	1.6	0.2
Lysimeter water, 14 inches deep		1.00	T	15.0	1.0	0.1	.65	.05	2.0	0.2
Soil sample	4.6	31.0	38.0	-	250	1.0	187	5	358	260

TABLE 5

Activity of Cesium-134 in the Litter and in the Water Moving Out of the Litter. Approximately Two Liters of Water Passed Out of Each Lysimeter and Through Each Resin Column. Water Was Collected from September 1-12, 1966

Litter	1609.5	c/m/g
Water collected directly from lysimeter No. 1	.32	c/m/g
Water passing through resin column on lysimeter No. 2	.15	c/m/g
Resin column on lysimeter No. 2	2.44	c/m/g of water that passed through column
Water passing through resin column on lysimeter No. 3	.09	c/m/g
Resin column on lysimeter No. 3	5.42	c/m/ml of water that passed through column

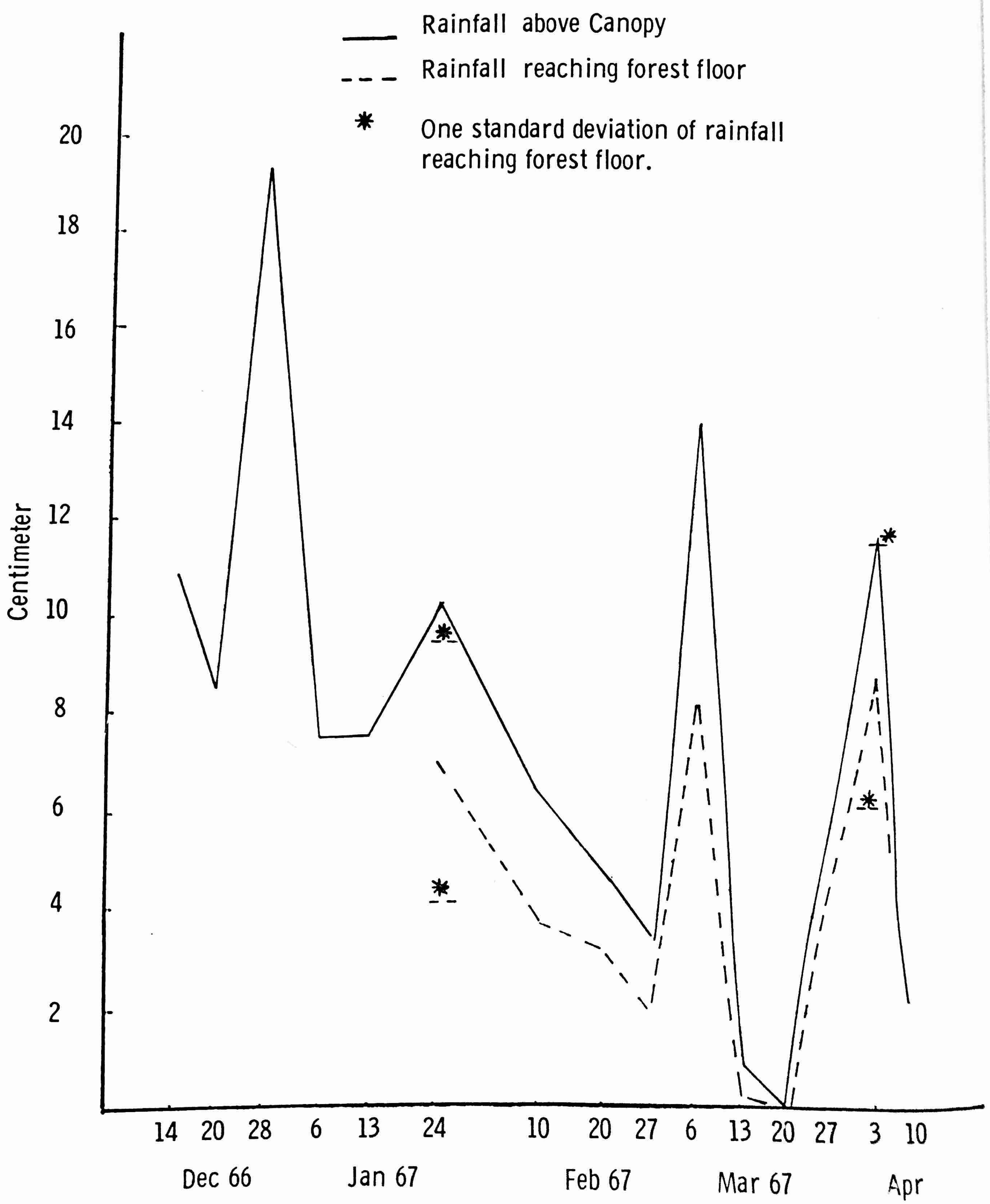
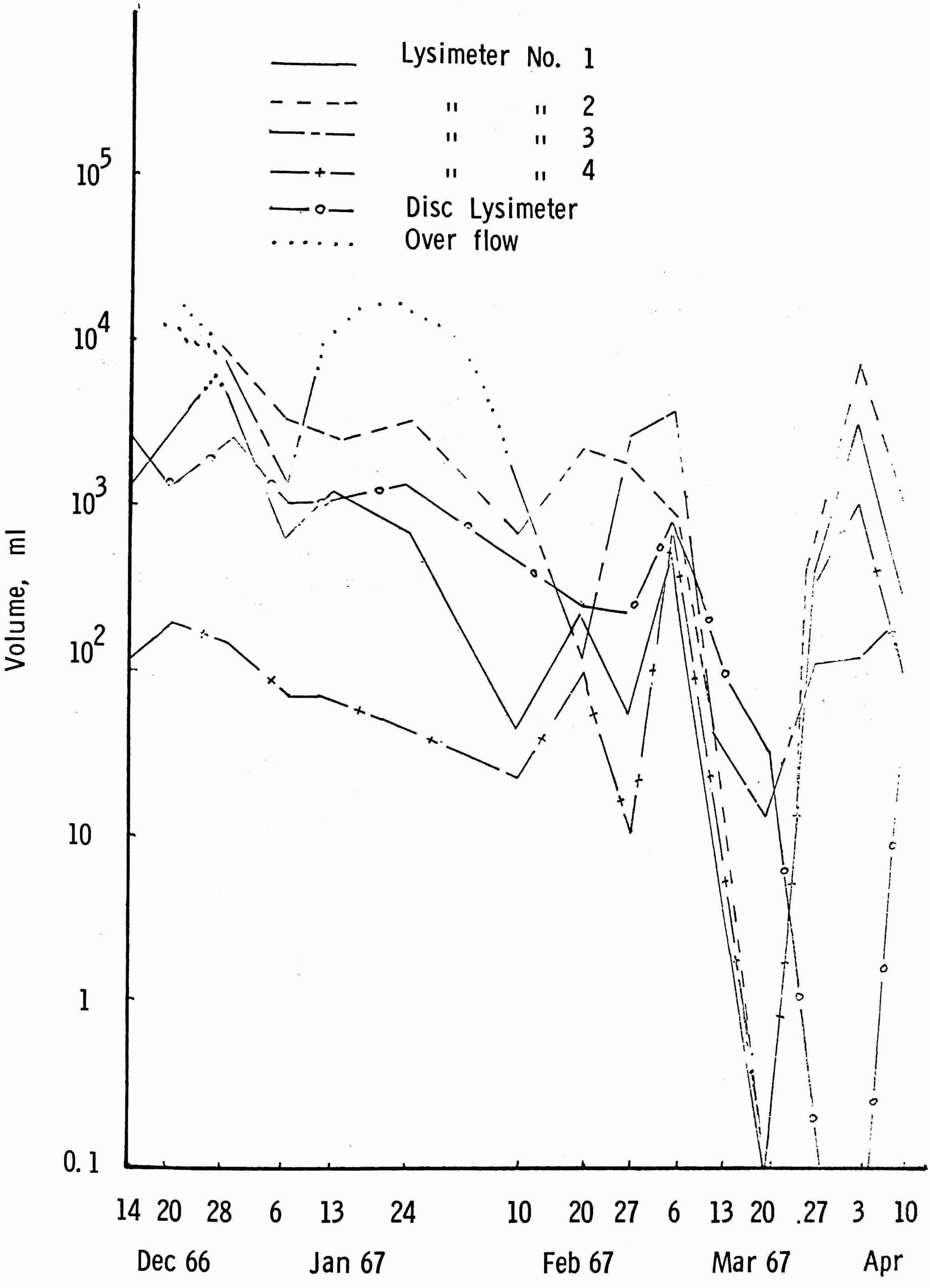


Figure 1. Rainfall above canopy, and throughfall, in the experimental forest near El Verde.


Lysimeter No. 1
" " 2
" " 3
" " 4
Disc Lysimeter
Over flow
Volume, ml
10^5
10^4
10^3
10^2
10
1
0.1
14
20
28
6
13
24
10
20
27
6
13
20
.27
3
10
Dec 66
Jan 67
Feb 67
Mar 67
Apr

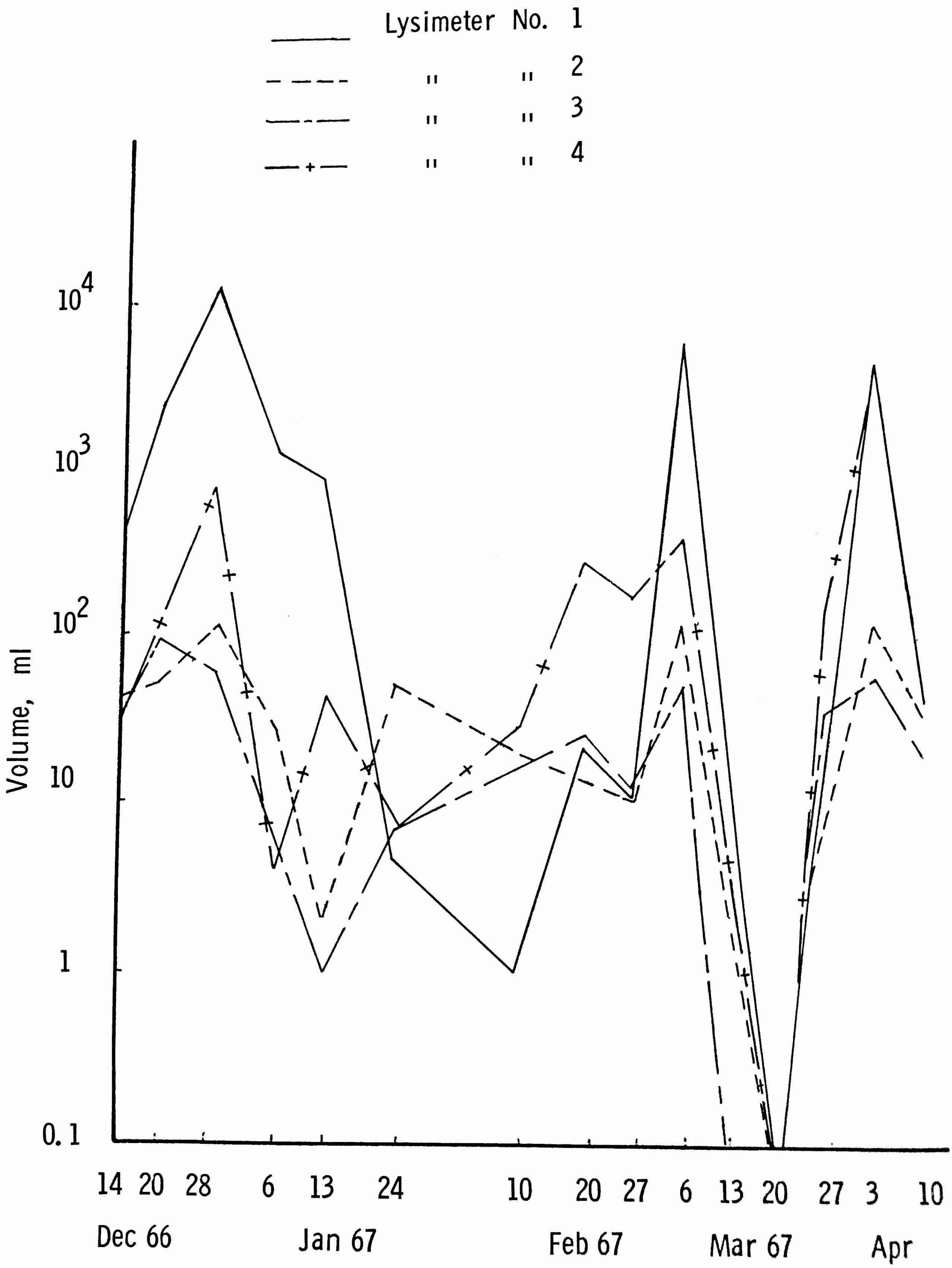


Figure 3. Lysimeter collections, 14-inch depth, control area.

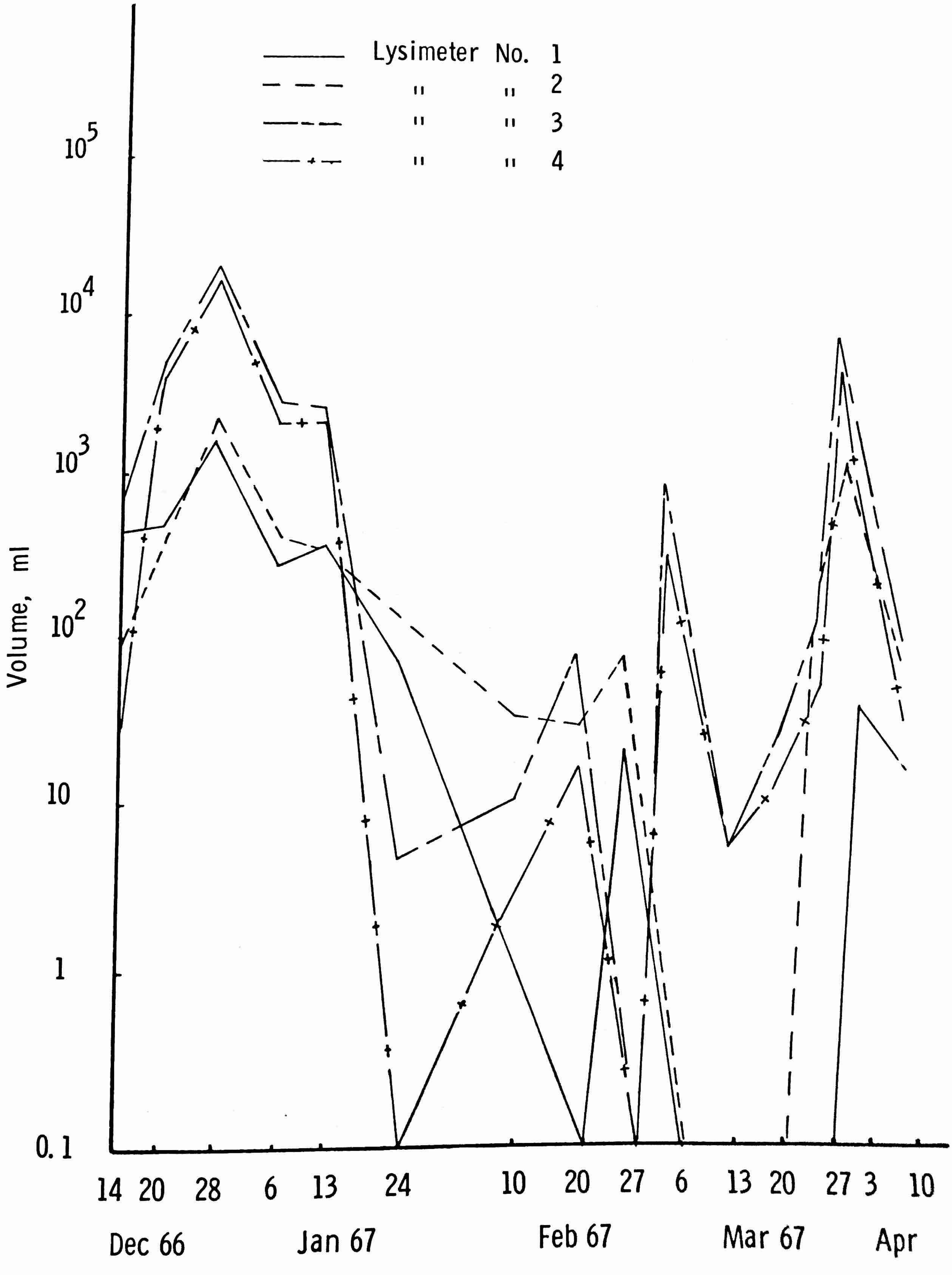


Figure 4. Lysimeter collections, 5-inch depth, tritium area.

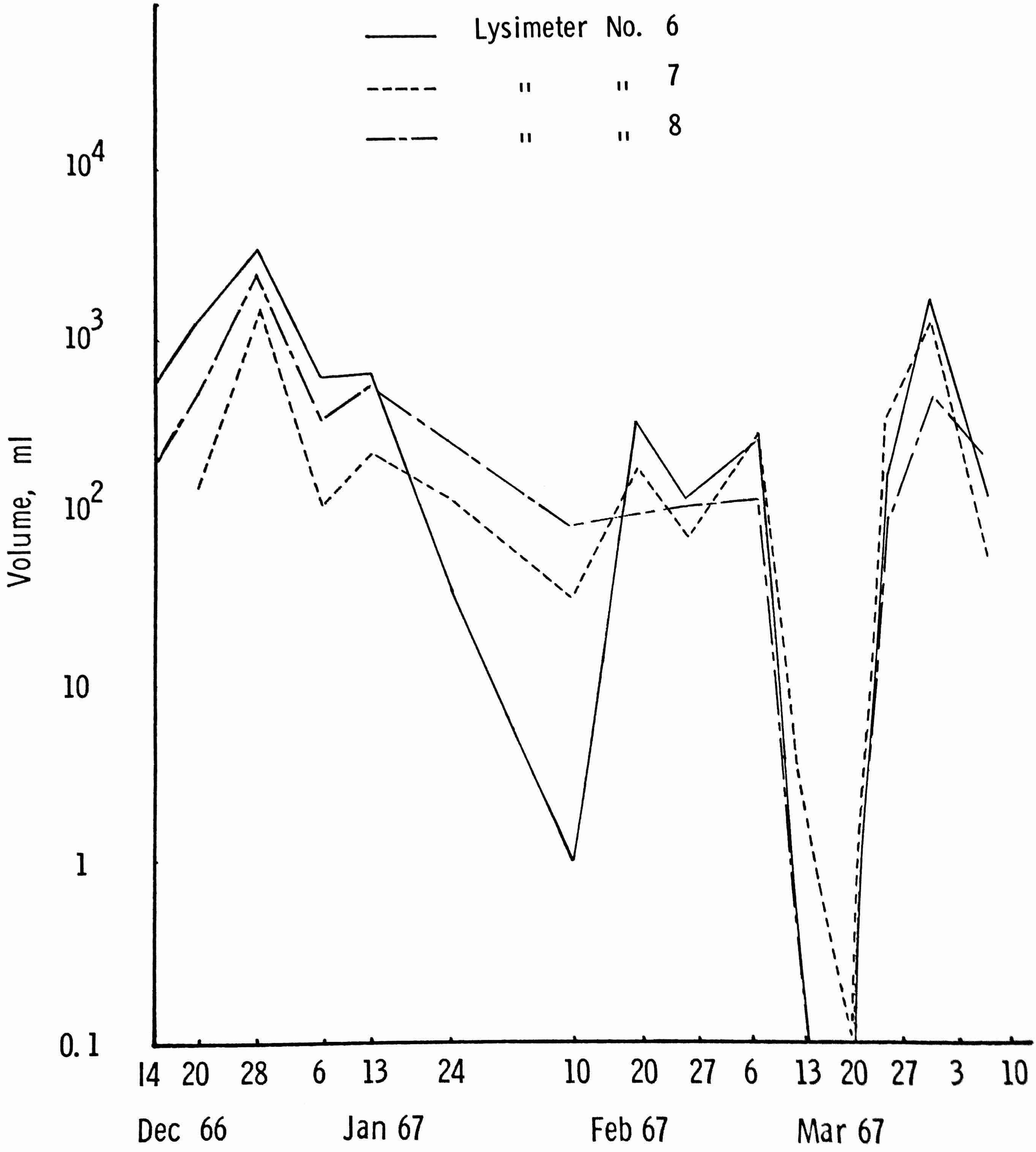


Figure 5. Lysimeter collections, 5-inch depth, cesium area.

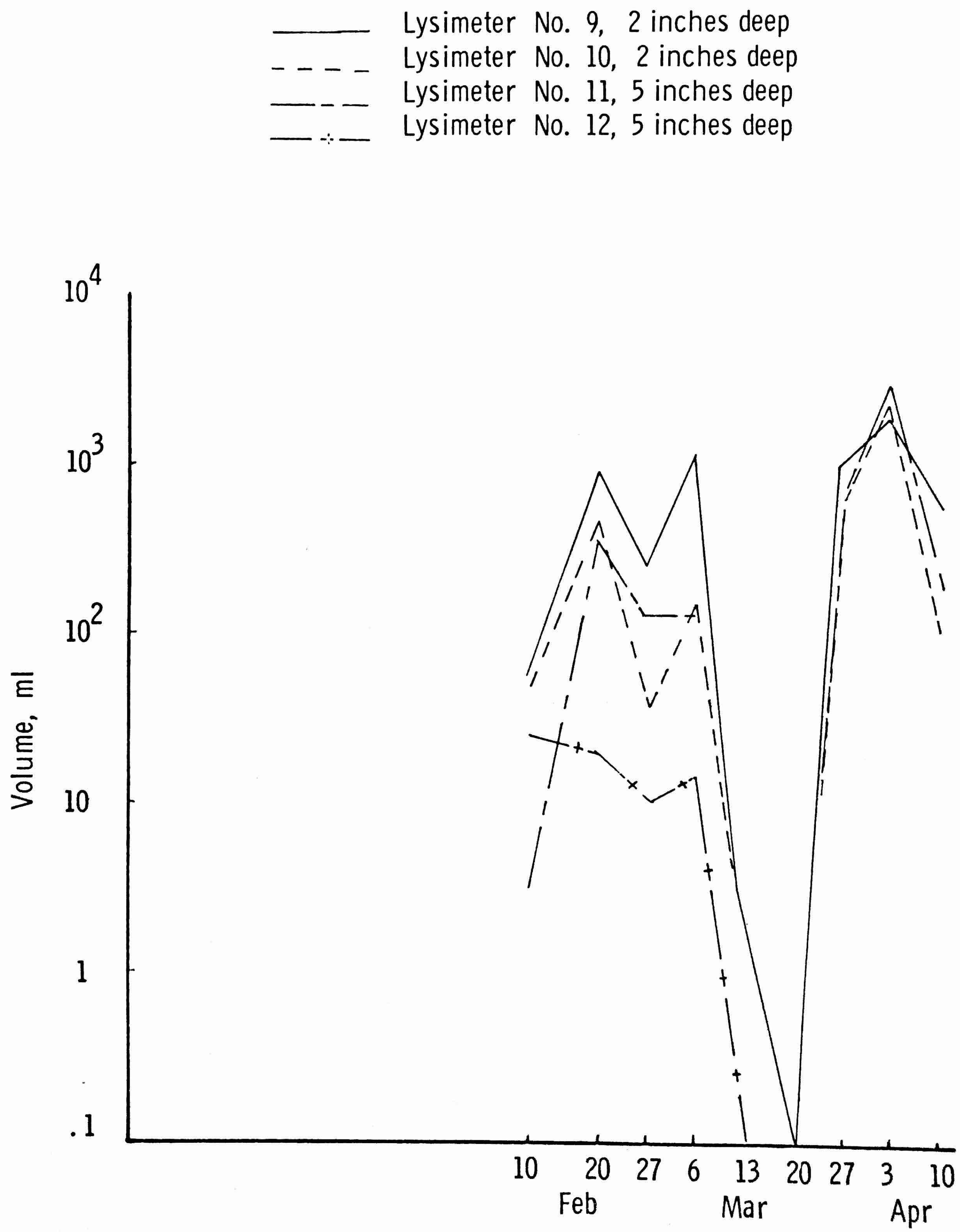


Figure 6. Lysimeter collections, 2- and 5-inch depths, cesium area.

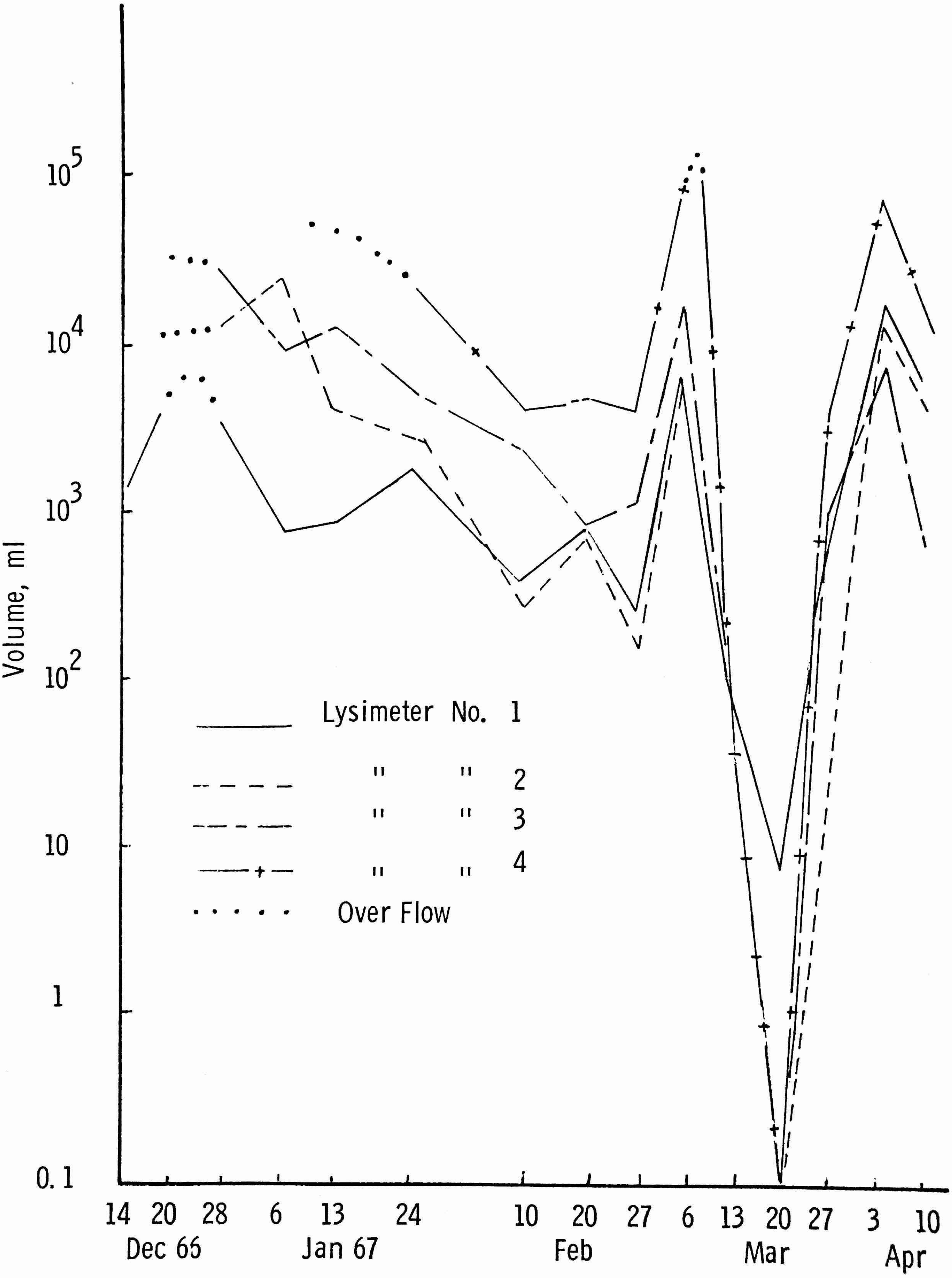


Figure 7. Lysimeter collections, 5-inch depth, above bell jar.

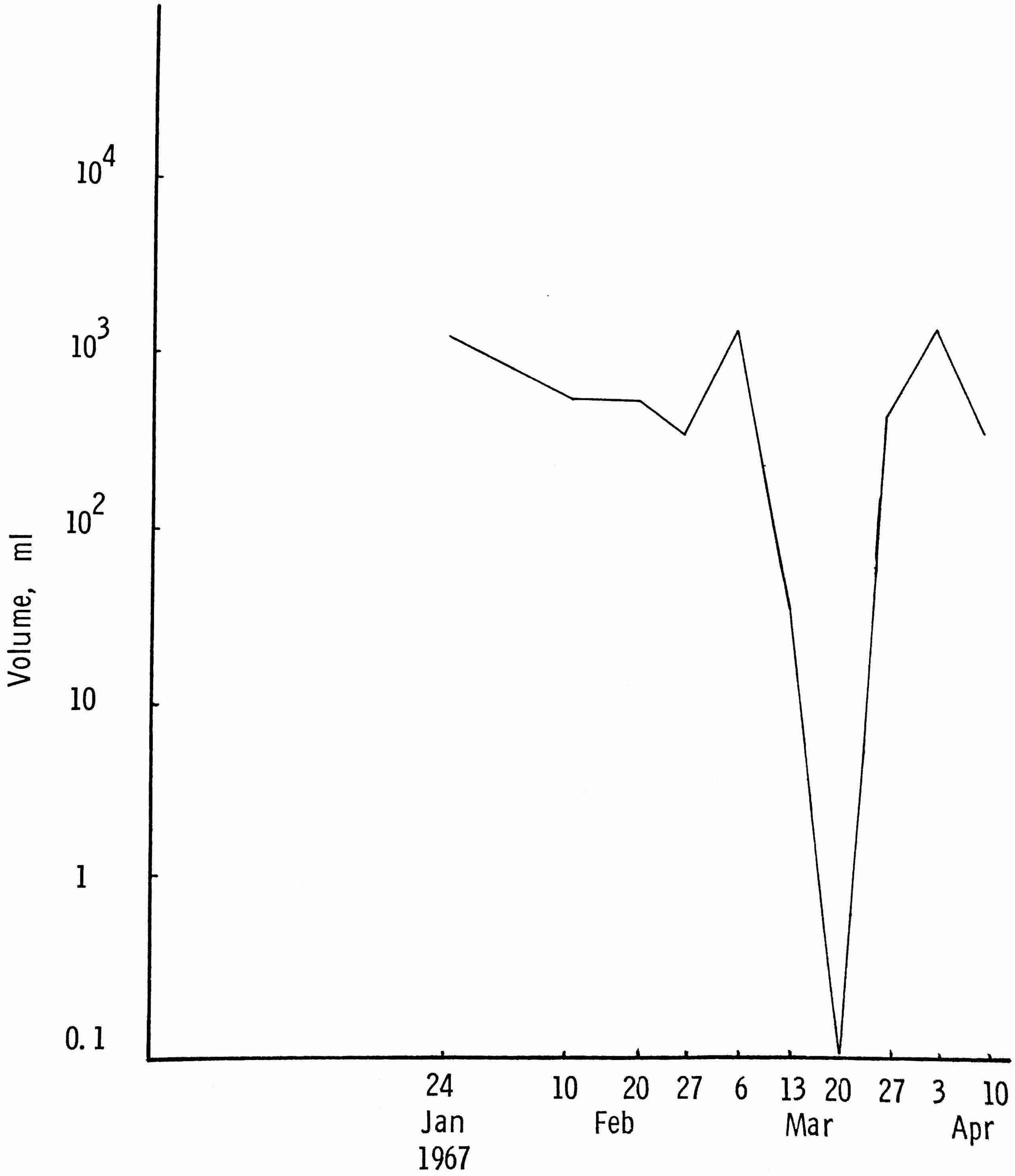


Figure 8. Volume of water falling upon an area of ground equal to the top area of a lysimeter (154.8 cm^2).

Checklist of Insects Collected at El Verde Field Station

George E. Drewry

The following report covers insects collected at the El Verde field station of the Puerto Rico Nuclear Center and identified before October 1, 1966. Identification of the numerous species still undetermined is being continued in cooperation with the staff of the U.S. National Museum in Washington, D.C., and the U.S. Department of Agriculture, whose entomological specialists are also housed in the National Museum. Species of all groups were initially separated by me, identified to family, and given code letters under each family heading, in order of collection. To facilitate digital handling of the ecological data, insects are always identified by code names in routine collecting.

In general, insects collected by means of light traps, sticky traps and Berleze funnel methods are species restricted to, or at least typical of, the rain forest. Because the station itself is in a clearing, and overlooks the valley below, some species collected at the station lights are more properly considered grassland, cropland, or domestic species; and a few are typical of the lowland sugar cane fields some 5 miles to the north. Insects collected by hand or net were taken in the experimental areas of the forest or in the station clearing, except for a very few species collected in the forest at higher elevations. None of the insects listed were collected below an elevation of 300 meters or outside of the Luquillo National Forest.

The form selected for the checklist is largely self-explanatory. The notation "det." (determinations) followed by a person's name indicates that the insects identified in that family or order were either determined by a specialist in the group, or compared by the person named, to a well-identified museum collection. Generic or specific names in families, where no determination is listed, are tentative identifications by me from literature sources such as the "Scientific Survey of Porto Rico and the Virgin Islands," published by the New York Academy of Sciences; and "The Insects of Puerto Rico," by George N. Wolcott; or by comparison to the collections of the U.S. Department of Agriculture and the University of Puerto Rico.

The determiners frequently included additional information concerning a species, especially in lieu of a complete determination. These statements are summarized in the "remarks" column. Uncertainties in determination were due to several causes, including: the absence of existing descriptions for species new to science; uncertain systematics owing to past neglect or recent reevaluation of groups; identification requiring both sexes, other stages in the life cycle, or host information not available; or damage to diagnostic structures of the specimens.

This initial attempt at identification has revealed most of the species definitely or probably new to science, and many of the specialists in the various groups have been notified that specimens are available for further study. Some of the undescribed species will receive nomenclatural treatment in the near future, others will be postponed because the specialist is otherwise occupied or because the group currently has no specialist. I have written keys to my species separations in all groups. The classification of families and subfamilies generally follows that of Borror and DeLong (1954) with some nomenclatural changes in accordance with general usage.

Assisting with collections were: Peter Murphy, Susan Drewry, Eusebio Díaz Pagán, Joaquín Molinari, Dr. David Walker and the mosquito collecting team of the PRNC Terrestrial Ecology II program under Dr. Paul Weinbren.

Abbreviations used in the checklist are as follows:

Collection Method
L - station lights
LT - light traps within the forest
ST - sticky traps within the forest
BF - Berleze funnel, Wiegert modification
N - insect collecting net
H - hand capture, including inverted jars, etc.

Institution of person making determination
USNM - Smithsonian staff of U.S. National Museum
USDA - U.S. Department of Agriculture staff of U.S. Nat. Museum
UPR - The University of Puerto Rico
PRNC - Puerto Rico Nuclear Center
Other institutions not abbreviated

Other
det. - determinations
poss. - possibly
prob. - probably
= - has as a synonym

Checklist of Insects Collected at El Verde Field Station

Classification Subclass Order Suborder Family Subfamily Genus species subspecies	Determined (Det.) by Collection method	 Other remarks	Remarks # Fam.	 # sp.
Subclass Apterygota			4 Fam.	20 sp.
Order Thysanura - bristletails			1 Fam.	1 sp.
Family Machilidae - jumping bristletails				1 sp.
1 sp. - undetermined	ST, BF			
Order Collembola - springtails			3 Fam.	19 sp.
Family Poduridae				2 sp.
1 sp. - undetermined	ST, BF			
Family Entomobryidae				14 sp.
14 sp. - undetermined	ST, BF			
Family Sminthuridae				3 sp.
3 sp. - undetermined	ST, BF			
Subclass Pterygota			224 Fam.	1115 sp.
Order Ephemeroptera - mayflies			1 Fam.	1 sp.
Family undetermined				1 sp.
1 sp. - undetermined	L, LT			
Order Odonata - dragonflies, damselflies			3 Fam.	4 sp.
Suborder Anisoptera - dragonflies				
	Det. in progress - Oliver S. Flint Jr. USNM			
Family Aeschnidae				2 sp.
2 sp. - undetermined	L, N			
Family Libellulidae				1 sp.
1 sp. - undetermined	N			
Suborder Zygoptera - damselflies				
	Det. in progress - Oliver S. Flint, USNM			
Family Coenagrionidae				1 sp.
Order Orthoptera - grasshoppers, etc.			8 Fam.	44 sp.
	Det. Ashley B. Gurney USDA, except as noted			
Family Acrididae - short horned grasshoppers				1 sp.
Shistocerca colombina (Thunberg)	H			
Family Tettigoniidae - long horned grasshoppers				7 sp.
Subfamily Phaneropterinae - bush katydids				

Microcentrum triangulatum Brunner	L, H		
Turpilia rugosa Brunner	L, H		
Anaulocomera laticauda Brunner	L, H		
Subfamily Copiphorinae - cone headed grasshoppers			
Neoconocephalus triops (Linn.)	L, H		
Erioloides species	L, H	prob. new species	
Subfamily Agraecinae			
1 sp. - new genus, new species	H		
Subfamily Conocephalinae - meadow grasshoppers			
Conocephalus cinerous Thunberg	H		
Family Gryllacrididae - cave crickets, etc.			1 sp.
Subfamily Gryllacridinae - leaf rolling grasshoppers			
Abelona species	H		
Family Gryllidae - crickets			13 sp.
Subfamily Gryllinae - field crickets			
Amphicausta caribea Saussure	H		
Anurogryllus muticus (De Geer)	L, H		
Gryllus assimilis (Fabr.)	L, H		
Subfamily Trigonidiinae - sword bearing bush crickets			
Cyrtoxipha gundlachi Saussure	L, H, ST		
Anaxipha species	L, H	poss. new species	
Subfamily Eneopterinae - brown bush crickets			
Orocharis vaginalis Saussure	L, H, ST		
Orocharis terebrans Saussure	L, H		
Orocharis species a	L, H, ST		
Orocharis species b	L, H		
Orocharis species c	L, H		
Orocharis species d	L, H		
Laurepa krugii Saussure	L		
Tafalisca lurida Walker	H		
Family Gryllotalpidae - mole crickets ("changas")			1 sp.
Scapteriscus vicinus Scudder	L, H		
Family Phasmatidae - walking sticks Det. incomplete			6 sp.
Phibalosoma adumbratus (Saussure)	H	common in mossy forest, rare lower	
Phibalosoma adumbratus (Saussure)	H		
Lamponius species	H		
3 sp. - undetermined	H		
Family Mantidae - mantids			1 sp.
Gonatista grisea (Fabr.)	L, H		
Family Blattidae - cockroaches			14 sp.
Panchlora sagax Rehn & Hebard	L	poss. new species	
Cariblatta craticulata Hebard	L		
Cariblatta plagia Rehn & Hebard	L		
Cariblattoides suave Rehn & Hebard	L		
Neoblattella borinquensis Rehn & Hebard	L, H		

Neoblattella vomer Rehn & Hebard	L			
Neoblattella species a	L	new species		
Neoblattella species b		poss, new species		
Pelmatosilpha coriacea Rehn	H			
Pseudosymploce personata Rehn	L, H			
Pseudosymploce species	L	prob. new species		
Epilampra wheeleri Rehn	L, H			
Eurycotis species	H	new species		
Plectoptera infulata Rehn & Hebard	L, H			
Order Isoptera - termites			2 Fam.	2 sp.
Family Rhinotermitidae - subterranean termites				1 sp.
Tenuirostritermes discolor Banks	L, ST, H			
Family Termitidae - comejen				1 sp.
Nasutitermes costalis Holmgren	L, ST, H			
Order Dermaptera - earwigs			2 Fam.	2 sp.
Family Labiduridae (Psalididae)				1 sp.
Carcinophora americana (Palisot de Beauvois)	L			
Family Labiidae				1 sp.
1 sp. - undetermined	ST			
Order Embioptera - web spinners			1 Fam.	1 sp.
Family undetermined				1 sp.
1 sp. - undetermined	ST	poss. *Oligotoma saundersii*		
Order Psocoptera - psocids, bark lice			7 Fam.	10 sp.
Suborder Trigomorpha				
Family Lepidopsocidae				1 sp.
1 sp. undetermined	ST, LT, L			
Suborder Troctomorpha				
Family Pachytroctidae				1 sp.
1 sp. - undetermined	L, ST			
Family Liposcelidae - booklice				1 sp.
Liposcelis divinatorus (Muller)	H			
Suborder Eupsocida				
Family Epipsocidae				3 sp.
3 sp. - undetermined	LT			
Family Myopsocidae				1 sp.
1 sp. - undetermined	LT			
Family Psocidae				2 sp.
2 sp. - undetermined	LT			
Family Pseudocaeciliidae				2 sp.
Pseudocaecilius pretiosus Banks	LT			
1 sp. - undetermined	LT			
Order Thysanoptera - thrips			± 3 Fam.	±10 sp.
Families undetermined				
about 10 sp. - undetermined	ST			
Order Hemiptera - true bugs			10 Fam.	25 sp.
Family Belostomatidae - water bugs Det. Jon. L. Herring, USDA				1 sp.
Belestoma subspinosum Palisot de Beauvois		= *B. boscii* L. & S.		
Family Schizopteridae - jumping ground bugs				3 sp.
3 sp. - undetermined	ST			

Family Miridae - plant bugs				6 sp.
Det. J. Maldonado Capriles, UPR				
Itacoris trimaculatus Maldonado	LT			
Antius miniscula Carvalho	LT			
Pycnoderes heidemanni Reuter	LT			
Fulvius anthocorides Ståhl	LT			
Dagbertus species	L			
Collaria oleosa (Distant)	L			
Family Enicocephalidae - unique-headed bugs				1 sp.
1 sp. - undetermined				
Family Nabidae - damsel bugs				1 sp.
Det. R. C. Froeschner, USNM				
Neogorpis neotropicalis (Barber)	L			
Family Lygaeidae - cinch bugs				4 sp.
Det. J. Maldonado Capriles, UPR				
Ozophora atropicta Barber	ST, L, LT, H			
Ozophora subimpicta Barber	LT			
Ozophora species	LT			
Pachybrachius species	LT			
Family Coreidae - leaf footed bugs				
Det. Jon L. Herring, USDA				1 sp.
Phthia rubropicta (Westwood)	L			
Family Cydnidae - burrower bugs				1 sp.
Det. J. Maldonado Capriles, UPR				
Amnestus species	L	prob. A. pusio		
Family Scutellaridae - shield bugs				1 sp.
Det. J. Maldonado Capriles, UPR				
Pachycoris fabricia (Linn.)	H			
Family Pentatomidae - stink bugs				6 sp.
Det. J. Maldonado Capriles, UPR				
Piezosternum subulatum (Thunberg)	H			
Loxa pilipes Horvath	H, L			
Acrosternum marginatum Palisot de Beauvois	L			
Edessa cornuta Burmeister	L			
Edessa parvinula Barber	ST			
Fecelina minor (Vollenhoven)	ST			
Order Homoptera			5 Fam.	66 sp.
Family Cicadidae - cicadas				
Det. George E. Drewry, PRNC				
Borencona aguadilla Davis	H, L, LT			
Family Cicadellidae - leafhoppers				14 sp.
Det. James P. Cramer USDA, det. incomplete				
Cicadulina tortilla Caldwell	ST			
Hortensia similis (Walker)	L			
Krisna insularis Oman	L			
Deltocephalus flavicosta Stål	LT			
Protalebrella brazilinsis Baker	LT			
Tylozygus fasciatus (Walker)	L			

Protalebra species	L	
Xestocephalus species a	ST, LT	
Empoasca species	ST, LT	
Balclutha species	ST, LT	
Osbornellus species	ST, LT	
Graminella species	L	
Xestocephalus species b	L	
Family Fulgoridae - planthoppers		45 sp.
Det. George E. Drewry, PRNC; Checked James P. Grammer, USDA		
Subfamily Cixiinae		
Bothriocera undata (Fabr.)	ST, LT, L	
Oliarus borinquensis Caldwell	ST, L	
Pintalia alta Osborn	ST, LT, L	
Pintalia supralta Caldwell	ST, LT, L	
Pintalia nemaculata Caldwell	ST, LT, L	
Pintalia martorelli Caldwell	ST, LT, L	
Pintalia osborni Caldwell	ST, LT, L	
Pintalia species	ST, LT, L	undescribed species
Cubana tortriciformis Muir	LT	
Subfamily Delphacinae		
Ugyops osborni Metcalf	ST, L	
Ugyops occidentalis Muir	ST, L	
Neomalaxa flava Muir	LT	
Nilaparvata species	ST	
Abbrosoga species	LT	
Euidella species	LT	
Punana species	L	
1 sp. - undetermined	ST	
Subfamily Derbinae		
Dysimia maculata Muir	ST, LT	
Dawnaria sordidulum Muir	ST, LT, L	
Dawnaria species	LT	undescribed species
Patara albida Westwood	ST, LT, L	
Cedusa wolcotti Muir	ST, LT, L	
Cedusa species	ST	
Subfamily Achilinae		
Catonia cinerea Osborn	ST	
Catonia dorsivittata Caldwell	ST	poss. color type of *C. cinerea*
Catonia arida Caldwell	L	
Quadrana punctata Caldwell	ST, LT, L	
Subfamily Tropiduchinae		
Ladella stahli Fennah	ST, LT, L	
Ladella nepallata Caldwell	ST, LT, L	
Ladella or *Neurotmeta* species	ST, L	undescribed species
Subfamily Flatinae		
Petrusa marginata Brunnich	L, H	
Petrusa pivota Caldwell	L, LT, H	
Petrusa torus Caldwell	L, LT, H	
Petrusa rocquensis Caldwell	L	
Flatormenis pseudomarginata Muir	L	
Flatormenis nefuscata Caldwell	L	

Puertormenis virginia Caldwell	L			
Melormenis antillarum (Kirkaldy)	L			
Melormenis basalis (Caldwell)	L, H			
Melormenis magna Caldwell	L, H			
Pseudoflatoides albus Caldwell	L, H			
Subfamily Issinae				
Thionia borinquensis Dozier	ST, L			
Neocolpoptera puertoricensis Dozier	ST, L			
Subfamily Aconaloniinae				
Acanalonia agilis (Melichar)	ST			
Acanalonia vivida (Fabr.)	L			
Family Psyllidae - jumping plant lice				
Det. incomplete				5 sp.
5 sp. - undetermined	SP, LT, L			
Family Coccidae - scale insects				1 sp.
1 sp. - undetermined				
Order Neuroptera - lacewings etc.			5 Fam.	9 sp.
Det. Oliver S. Flint Jr., USNM				
Family Mantispidae - mantispid files				2 sp.
Mantispa species	ST, L	near *M. sayi* or *M. gracilis*		
Climaciella species	L	near *C. brunnea*		
Family Hemerobiidae - brown lacewings				1 sp.
Nusalalia cubana (Hagen)	ST, L			
Family Chrysopidae - common lacewings				4 sp.
Chrysopa collaris Schneider	L			
Chrysopa species a	L	near *C. cubana*		
Chrysopa species b	L	poss. new species		
Nodita sp.	L			
Family Ascalphidae - owl flies				1 sp.
Ululodes species				
Family Coniopterygidae - dusty-wings				1 sp.
Systematics uncertain - Oliver S. Flint Jr., USNM				
1 sp. - undetermined				
Order Coleoptera - beetles			34 Fam.	101 sp.
Det. in progress - 8 specialists USDA and USNM				
Family Carabidae - ground beetles				1 sp.
1 sp. - undetermined	ST, L			
Family Histeridae - hister beetles				1 sp.
Ormalodes species	H			
Family Hydrophilidae - water scavenger beetles				1 sp.
1 sp. - undetermined	ST			
Family Silphidae - carrion beetles				1 sp.
1 sp. - undetermined	ST			
Family Staphylinidae - rove beetles				7 sp.
7 sp. - undetermined	ST			
Family Pselaphidae - ant loving beetles				4 sp.
4 sp. - undetermined	ST			
Family Scydmaenidae - ant like stone beetles				1 sp.

1 sp. - undetermined	ST		
Family Cantharidae - soldier beetles			1 sp.
Tylocerus barberi Leng & Mutchler	ST, H		
Family Lampyridae - fireflies			5 sp.
Calopisma borencona Leng & Mutchler	H		
Diphotus triangularis (Olivier)	H	= *Photinus t.* Oliver	
Photinus vittatus Olivier	H, LT, L		
Photinus dubiosis Leng & Mutchler	H, LT, L		
Photinus species	H, LT, L		
Family Lycidae - net winged beetles			4 sp.
4 sp. - undetermined	ST		
Family Dermestidae - dermestid beetles			1 sp.
1 sp. - undetermined	L		
Family Cleridae - checkered beetles			1 sp.
1 sp. - undetermined			
Family Elateridae - click beetles			5 sp.
Dicrepidius ramicornis Palisot de Beauvois	L		
Pyrophorus luminosus Illiger	H, L		
Platycrepidius species	H		
2 sp. - undetermined	H, SP		
Family Throscidae - pseudo click beetles			1 sp.
1 sp. - undetermined	ST		
Family Dascillidae - soft bodied plant beetles			3 sp.
1 sp. - undetermined	ST		
Family Dascillidae - soft bodied plant beetles			3 sp.
3 sp. - undetermined	ST, LT		
Family Ptilodactylidae - soft bodied plant beetles			5 sp.
5 sp. - undetermined	ST, LT		
Family Elmidae - rifle beetles			1 sp.
1 sp. - undetermined	L		
Family Rhizophagidae			1 sp.
1 sp. - undetermined	ST		
Family Crytophagidae - silken fungus beetles			1 sp.
1 sp. - undetermined	ST		
Family Cucujidae - flat bark beetles			1 sp.
1 sp. - undetermined	ST		
Family Endomychidae - hansome fungus beetles			2 sp.
2 sp. - undetermined	ST		
Family Coccinellidae - ladybird beetles			1 sp.
Curinus sp.	H		
Family Colydiidae - cylindrical bark beetles			1 sp.
1 sp. - undetermined	ST		
Family Euglenidae - euglenid beetles			1 sp.

1 sp. - undetermined	ST		
Family Oedemeridae - oedomerid beetles			1 sp.
1 sp. - undetermined	ST		
Family Mordellidae - tumbing flower beetles			1 sp.
1 sp. - undetermined	ST		
Family Melandryidae - bark beetles			1 sp.
1 sp. - undetermined	ST		
Family Passalidae - betsy beetles			1 sp.
Paxillus crenatus MacLeay	H		
Family Scarabaeidae - scarabs, dung beetles, etc.		Det. O. L. Cartwright, USNM	10 sp.
Strategus oblongus Palisot de Beavios	H, L	palm rhinoceros beetle	
Phyllophaga portoricensis Smyth	H, L		
Phyllophaga species a	L		
Phyllophaga species b	L		
Phyllophaga species c	L		
Phyllophaga species d	L		
Chalepides barbata (Fabr.)	L		
Canthonella parva Chapin	ST	Det. Eric Matthews UPR	
Canthochilum borinquensis Mathews	ST	Det. Eric Matthews UPR	
Canthochilum histeroides (Harold)	ST	Det. Eric Matthews UPR	
Family Cerambycidae - long horned wood boring beetles		Det. George B. Vogt USNM, some in progress	14 sp.
Stenodontes exserta Olivier	L		
Callipogon proletarius Lameere	L		
Parandra cribrata Thomson	L		
Derancistrus thomae Linn.	L, H		
Chlorida festiva Linn.	L, H		
Neocladus species	H		
Leptostylus species	L		
Oreodera species	L	probably *O. glauca* Linn.	
Typanidius species	L		
Batocera rubus Linn.	H		
4 sp. - undetermined	L, H, ST		
Family Chrysomelidae - leaf beetles			3 sp.
Diabrotica species	L		
2 sp. - undetermined	ST		
Family Brentidae - primitive weevils			1 sp.
Belophorus species	H		
Family Curculionidae - snout beetles, weevils		Det. in progress Rose Warner Spillman, USDA	9 sp.
Diaprepes abbreviata Linn.	L, H		
Compus species	L, H		
7 sp. - undetermined	L, ST		
Family Scolytidae - bark beetles, timber beetles, ambrosia beetles			8 sp.
8 sp. - undetermined	ST, L		

Order Trichoptera - caddisflies		6 Fam.	8 sp.
Det. George E. Drewry, PRNC, to be checked Oliver S. Flint, Jr.			
Family Rhyacophilidae - primitive caddisflies			
Atopsyche species	LT	poss. *A. trifida* Denning	
Family Philoptamidae - finger-net caddisflies			2 sp.
Chimarra maldonadoi Flint	LT, L		
Family Psychomyiidae - tube making caddisflies			2 sp.
Polycentropus zaneta Denning	LT		
Antillopsyche tubicola Flint	LT		
Family Hydropsychidae - net-spinning caddisflies			1 sp.
Smicridea protea (Denning)	LT		
Family Calamoceratidae			1 sp.
Phylloicus species	LT	prob. *P. pulchrus* Flint	
Family Heliocopsychidae			1 sp.
Heliocopsyche minima Siebold	LT		
Order Lepidoptera - butterflies and moths		25 Fam.	246 sp.
Family Pieridae - sulfurs			5 sp.
Dismorphia spio (Latreille)	N		
Phoebis sennae (Linn.)	N		
Phoebis philea (Johansson)	N		
Phoebis species	N	prob. P. argante (Fabr.)	
Eurema species	N		
Family Satyridae - satyrs			1 sp.
Calisto nubila Lathy	N		
Family Nymphalidae - fritillaries, etc.			4 sp.
Prepona antimache Fruhstorfer	N		
Marpesia petreus (Fabr.)	N		
Heliconius charithonius (Linn.)	N		
1 sp. - undetermined	N		
Family Lycaenidae - blues and hairstreaks			2 sp.
Thecla species a	N		
Thecla species b	N		
Family Hesperidae - skippers			6 sp.
Panoquina nero (Fabr.)	N		
Perichares phocion (Fabr.)	N, L		
Choranthus vittelinius (Fabr.)	N, L		
Urbanus species	L	prob. *U. dorantes* Stoll	
Family Sphingidae - sphinx moths			9 sp.
Manduca sextus (Johannson)	L	= *Protoparce sextus*	
Erinnyis alope (Drury)	L		
Pholus fasciatus (Sulzer)	L		
Xylophanes tersa (Linn.)	L		
Pachylia ficus (Linn.)			
Aellopos fadus (Cramer)	L		
Aellopos species	L		
1 sp. - undetermined	L		
Family Amatidae (Ctenuchidae) - ctenuchas			7 sp.
Det. William D. Field, USNM			
Cosmosoma auge (Linn.)	L, LT		

Cosmosoma achemon (Fabr.)	L		
Lymire flavicollis (Dewitz)	L, LT		
Correbida terminalis (Walker)	L		
Nyridela chalciope Hubner	L		
Eunomia colombina Fabr.	L		
Euceron species	L	undescribed sp. near *E. pica* Wlki	
Family Arctiidae - tiger moths Det. William D. Field, USNM			8 sp.
Eupseudosoma involutum Sepp	L		
Ecpantheria icasia (Cramer)	L		
Ecpantheria species			
Utethesia ornatrix (Linn.)	L		
Phegoptera bimaculata (Dewitz)	L		
Tricypha proxima Grote	L		
Lomuna negripuncta Hampson	L		
Talaria species	L, LT		
Family Noctuidae (Phalaenidae) - noctuid moths Det. Edward L. Todd, USDA, some in progress			58 sp.
Blosyris mycerina (Fabr.)			
Ophisma tropicalis Guenee	L		
Gonodonta sicheus (Cramer)	L		
Gonodonta incurva (Sepp)	L		
Mocis diffluens (Guenee)	L	new record for P. R.	
Mocis megas (Guenee)	L		
Prodenia pulchella Herrich-Schaffer	L		
Prodenia rubrifusa Hampson	L		
Prodenia eridania (Cramer)	L		
Heliothis virescens (Fabr.)	L		
Eulepidotis addens (Walker)	L		
Heterochroma berylliodes Hampson	L		
Heterochroma species	L	undescribed species	
Ephrodes cacata Guenee	L		
Sylectra erycata (Cramer)	L		
Condica cupentia (Cramer)	L		
Messala obvertens (Walker)	L		
Speocropia scriptura (Walker)	L		
Mastigophorus demissalis Moschler	L		
Phlyctaina irregularis (Moschler)	L		
Mamestra soligena Moschler	L		
Gonodes liquida Moschler			
Metalectra analis Schaus	L		
Lascoria phormisalis Walker	L		
Anespischetos porrectalis (Fabr.)	L		
Anespischetos mactatalis (Walker)	L		
Phalaenophana eudorealis (Guenee)	L		
Carteris oculatalis (Moschler)	L		
Callipistra floridensis (Guenee)	L		
Callipistra jamaicensis (Moschler)	L		
Plusia admonens Walker	L		

Araeoptera vilhelmina Dyar	L		
Afrida tortrociformis Moschler	L		
Nymbis garnoti Guenee	L		
Leucania rosea Moschler	L		
Leucania species	L		
Plusiodonta species a	L		
Plusiodonta species b	L	Near *P. thomae* Guenee	
Calpe species	L	poss. *C. exitans* (Walker)	
Diptherigia species	L		
Bleptina species a	L		
Bleptina species b	L		
Antiblema species	L		
Diomyx species	L		
Tortricoides orneodalis Guenee	L		
Tortricoides species a	L		
Tortricoides species b	L		
Thursania species	L		
Physula species	L		
Pseudaletia species	L		
Lascoria species	L		
Disphragis species	L		
Zale species	L	poss. *Z. fictilis* (Guenee)	
5 sp. - undetermined	L		
Family Nolidae			1 sp.
Det. Edward L. Todd, USDA			
Nola bistriga (Moschler)			
Family Geometridae - measuring worms, loopers			27 sp.
Det. in progress, Edward L. Todd, USDA			
Microgonia vesulia (Cramer)	L		
26 sp. - undetermined	L, LT		
Family Pericopidae			2 sp.
Ctenuchida virginalis Herrich Schaffer	L, LT		
Hyalurga vinosa (Drury)	L		
Family Notodontidae - prominents			4 sp.
Det. Edward L. Todd, USDA			
Rifargia distinguenda (Walker)	L		
Proelymniotis aequipars (Walker)	L		
Disphragis baracoana (Schaus)	L		
Disphragis species	L		
Family Megalopygidae - flannel moths			1 sp.
Megalopyge krugii (Dewitz)	L, LT		
Family Pyralidae			80 sp.
Det. George E. Drewry, PRNC, Det. in progress, Ronald W. Hodges, USDA			
Pachymorphus subductellus Moschler	L		
Cataclysta miralis Moschler	L, LT		
Cataclysta species	L, LT		
Diatraea saccharalis Fabr.	L		
Argyria diplomachalis Dyar	L, LT		

Syngamia florella (Gramer)	L, LT	
Diaphania costata (Fabr.)	L, LT	
Diaphania flegia (Cramer)		
Diaphania hyalinata (Linn.)	L, LT	
Diaphania nitidalis (Cramer)	L, LT	
Diaphania species	L	
Maruca testualis (Geyer)	L	
Sparagmia gigantalis Guenee	L	
Terastia meticulosalis Guenee	L	
Sylepta elevata (Fabr.)	L, LT	
Sylepta silicalis (Guenee)	L	
Sylepta species a	L	
Sylepta species b	L	
Sylepta species c	L	
Eulepte concordalis Hubner	L, LT	
Azochis rufidiscalis Hampson	L	
Azochis species	L	
Desmia ufeus (Cramer)	L, LT	
Desmia species	L	
Pyrausta cerata (Fabr.)	L, LT	
Pyrausta cardinalis (Guenee)	L	
Phostria humeralis (Guenee)	L	
Phostria species a	L	
Phostria species b	L	
58 sp. - undetermined	L, LT	
Family Pterophoridae - plume moths		5 sp.
Oidaematophorus basalis (Moschler)	L, LT	
Pterophorus species	L, LT	
3 sp. - undetermined	L	
Family Alucitidae - many-plumed moths		1 sp.
Orneodes species	L	
Family Olethreutidae - codling moths, etc.		2 sp.
Bactra species	L	
1 sp. - undetermined	L, LT	
Family Tortricidae - leaf rollers		2 sp.
2 sp. - undetermined	L	
Family Cossidae - carpenter moths		1 sp.
Psychonoctua personalis Grote	L, LT	
Family Gelechiidae		1 sp.
Dichomeris species	L, LT	
Family Ethmiidae		1 sp.
Ethmia notatella (Walker)	L	
Family Acrolophidae - borrowing webworms		15 sp.
15 sp. - undetermined	L, LT	
Family Tineidae - clothes moths, etc.		2 sp.
Tiquadra aeneonivella (Walker)	L	
1 sp. - undetermined	L	
Family Gracilariidae - leaf miners		1 sp.
1 sp. - undetermined	L	

Order Diptera - files			34 Fam.	454 sp.
Suborder Nematocara - long horned flies				
Family Tipulidae - crane flies				38 sp.
Subfamily Tipulinae				
Det. George E. Drewry, PRNC				
Dolichopeza puertoricensis	LT, L			
Brachypremna unicolor Osten Sacken	L			
Subfamily Limoniinae				
Det. Alan Stone, USDA				
Helius albitarsus (Osten Sacken)	LT			
Limonia diva (Schiner)	L, LT			
Limonia gowdeyi Alexander	LT			
Limonia cinereinota Alexander	LT			
Limonia tibialis (Loew)	LT			
Limonia myersiana Alexander	LT			
Limonia subrecisa Alexander	LT			
Limonia rostrata antillarum Alexander	LT			
Limonia tetraleuca Alexander	LT			
Limonia domestica (Osten Sacken)	LT			
Limonia species k	LT	poss. new, near *domestica*		
Limonia species hh	LT	poss. new, near *domestica*		
Limonia willistoniana Alexander	LT, L			
Limonia schwarzi (Alexander)	LT, L			
Limonia species aa	LT	poss. new, near *willistoniana*		
Limonia hoffmani Alexander	LT			
Limonia divisa Alexander	LT			
Limonia trinitatis Alexander	LT			
Limonia species t	LT	poss. new, near *L. caribea* Alex.		
Limonia species bb	LT	poss. new, near *L. caribea* Alex.		
Atarba species s	LT	poss. new, near *A. angustipennis* Alex.		
Polymera geniculata pallipes Alex.	LT			
Hexatoma species a	L	undescribed species		
Hexatoma species b	L	undescribed species		
Psiloconopa portoricensis (Alexander)	LT			
Psiloconopa caliptera (Say)	LT			
Teucholabis species gg	LT	poss. *T. portoricana* Alex.		
Gonomyia pleuralis (Williston)	LT			
Gonomyia puer Alexander	LT			
Gonomyia subterminalis Alexander	LT			
Trentepohlia nivetarsis Alexander	LT			
Trentepohlia species kk	LT	poss. new, near *nivetarsis*		
Shannonomyia leonardi	LT			
Shannonomyia species p	LT	poss. new, near *leonardi*		
Shannonomyia species m	LT	prob. undescribed		
Family Psychodidae - moth flies				37 sp.
Det. in progress, Alan Stone, USDA				
37 sp. - undetermined	ST, LT			
Family Chironomidae - midges				51 sp.
Det. in progress, Willis W. Wirth, USDA				

51 sp. - undetermined			
Family Ceratopogonidae - biting midges, punkies Det. Willis W. Wirth, USDA, most in progress			34 sp.
Monohela johannseni Wirth	LT		
Culicoides species gg	ST		
Palpomyia species n	LT		
Atrichopogon, 3 species undetermined	ST, LT		
Stilobezzia, 3 species undetermined	ST, LT		
Dasyhela, 3 species undetermined	ST, LT		
Forcipomyia, 22 species undetermined	ST, LT		
Family Simulidae - black flies			2 sp.
2 sp. - undetermined	L, H		
Family Culicidae - mosquitos and phanton midges Det. Brooke Worth, Rockefeller Foundation			12 sp.
Chaoborus brasiliensis (Theobald)	ST, LT		
Chaoborus species a	LT		
Chaoborus species c	ST		
Aedes mediovittatus (Coquillett)	LT, L, H	Det. Brooke Worth, RF	
Aedes taeniorhynchus (Wiedemann)	LT, H	Det. Brooke Worth, RF	
Aedes serratus	LT, H	Det. Brooke Worth, RF	
Culex nigripalpus Theobald	LT, H	Det. Brooke Worth, RF	
Culex quinquifasciatus Say	LT, H	Det. Brooke Worth, RF	
Culex species	LT	Det. Brooke Worth, RF	
Wyeomia species	LT, H	Det. Brooke Worth, RF	
Uranotaenia species	LT	Det. Brooke Worth, RF	
Mansonia flaveolus (Coquillett)	LT	Det. Brooke Worth, RF	
Family Dixidae - dixid midges			1 sp.
Dixa species	LT	prob. *D. hoffmani* Lane	
Family Scatopsidae - minute black scavenger flies			2 sp.
Rhegmoclema species	ST		
Aldrovandiella species	ST		
Family Mycetophilidae - fungus gnats			28 sp.
Leia species	ST		
Manota species	ST		
Platyura, 5 species undetermined	ST, LT		
Megopthalmida species	ST		
Boletina incompleta Curran	ST, LT		
Boletina species	ST	prob. undescribed	
Neompheria species	LT		
Zygomyia, 4 species undetermined	ST, LT		
Exechia, 5 species undetermined	ST, LT		
Rhymosia species	ST		
Mycetophilia, 6 species undetermined	ST	poss. new genus	
1 sp. - undetermined	ST	poss. new genus	
Family Sciaridae - dark wing fungus gnats			33 sp.

33 sp. - undetermined	ST, LT, L		
Family Cecidomyiidae - gall midges			30 sp.
30 sp. - undetermined	ST, LY, L		
Suborder Brachycera - short horned flies			
Family Stratiomyidae - soldier flies			6 sp.
Det. Willis W. Wirth, USDA, some in progress			
<u>Hermetia illucens</u> (Linn.)	L, ST, H		
<u>Nothomyia nigra</u> James	L, ST		
4 sp. - undetermined	ST, LT		
Family Tabanidae - horse flies			
Det. Alan Stone, USDA			1 sp.
<u>Stenotabanus brunettii</u> (Bequaert)	L		
Family Empididae - dance flies			6 sp.
6 sp. - undetermined	ST, L, LT		
Family Dolichopodidae - long-legged flies			
Det. George C. Steyskal, USDA			
<u>Condylostylus graenicheri</u> (Van Duzee)	LT		
<u>Condylostylus flavicornis</u>	ST		
<u>Condylostylus</u> species r	LT	prob. undescribed	
<u>Condylostylus</u> species d	ST, LT	prob. undescribed	
<u>Pelastoneuras</u> species	ST	prob. undescribed	
<u>Neurigonia</u> species	LT		
<u>Thrypticus</u> species	ST	poss. <u>T. fraterculus</u> (Whlr.)	
<u>Chrysotus flavohirtus</u> Van Duzee	ST		
<u>Chrysotus</u> species a	ST	prob. undescribed	
<u>Chrysotus</u> species c	ST	prob. undescribed	
<u>Chrysotus</u> species h	ST	prob. undescribed	
<u>Chrysotus</u> species j	ST, LT	prob. undescribed	
<u>Chrysotus</u> species g	ST		
<u>Chrysotus</u> species l	ST		
2 sp. - undetermined	ST		
Family Phoridae - hump-backed flies			65 sp.
Det. in progress, Willis W. Wirth, USDA			
65 sp. - undetermined	ST, LT		
Family Syrphidae - flower flies			5 sp.
Det. Willis W. Wirth, USDA			
<u>Meromacrus cinctus</u> (Drewry)	N		
<u>Ornidia obesa</u> (Fabr.)	N		
<u>Eristalis cubensis</u> Macquart	L, N		
<u>Baccha capitata</u> Loew	L		
<u>Baccha latiuscula</u> (Loew)	N		
Family Otitidae - picture-winged flies			2 sp.
<u>Euxesta thomae</u> Loew	L, ST		
<u>Euxesta</u> species	L		
Family Trypetidae - fruit flies			1 sp.
<u>Anastrepha</u> species	L		
Family Lonchaeidae			2 sp.
<u>Lonchaea</u> species	ST, L		

1 sp. - undetermined	LT		
Family Lauxanidae			6 sp.
Det. George C. Steyskal, USDA			
Pseudogriphoneura albovittata (Leow)	ST, LT		
Pseudogriphoneura octopunctata (Wiedemann)	ST, LT		
Pseudogriphoneura species	LT	poss. undescribed	
Neogriphoneura sordida (Wiedemann)	ST		
Poecilominettia picticornis (Coquillett)	ST		
Sapromyza species	LT	not *S. vitigera*	
Family Micropezidae - stilt-legged flies			
Det. George E. Drewry, PRNC			4 sp.
Taeniaptera lasciva (Fabr.)	L, H		
Taeniaptera species	H		
Systellapha scurra Enderlein	ST		
Systellapha species	ST		
Family Neriidae - neriid flies			3 sp.
3 sp. - undetermined			
Family Sepsidae - black scavenger flies			1 sp.
Det. George C. Steyskal			
Palaeosepsis haemorrhoidalis (Schimer)	L		
Family Clusiidae			3 sp.
3 sp. - undetermined	ST, LT		
Family Agromyzidae - leaf miner flies			2 sp.
Det. Curtis W. Sabrosky, USDA & George C. Steyskal, USDA			
Odinia biguttata Sabrosky	ST		
Melanagromyza species	ST		
Family Milichiidae (Phyllomyzidae) - phyllomyzid flies			2 sp.
2 sp. - undetermined			
Family Drosophilidae - small fruit flies, pomace flies			8 sp.
Drosophila, 3 sp. undetermined	ST		
Aulacigaster species	ST		
4 sp. undetermined	ST		
Family Chloropidae - fruit flies, eye gnats			2 sp.
Det. Curtis W. Sabrosky, USDA			
Oscinella lutzi (Curran)	ST		
Pentanotaulax species	ST	undescribed species	
Family Sphaeroceridae (Barboridae) - dung flies			4 sp.
4 sp. - undetermined	ST		
Family Tachinidae - tachinid flies			20 sp.
Det. in progress, Curtis W. Sabrosky, USDA			
Euphasiopteryx dominicana (Townsend)	L, ST		
Eucelatoria armigera (Coquillett)	L, ST		

Tachinophyto species	ST, H	poss. *T. floridensis* Tns		
17 sp. - undetermined	ST			
Family Calliphoridae - blow flies				1 sp.
Det. R. J. Gagne, USDA				
Phaenica rica (Shannon)	ST, L, N			
Family Sarcophagidae - flesh flies				
Det. in progress, R. J. Gagne, USDA				14 sp.
Paraphrissopoda capitata (Aldrich)	ST			
Sarcophaga species a	ST			
Sarcophaga species d	ST			
11 sp. - undetermined	ST			
Family Muscidae - horse flies, etc.				12 sp.
Det. George C. Steyskal, USDA				
Neomuscina species	L, ST			
Neodexiopsis ditiportus Snyder	ST, L			
Neodexiopsis discolorisexus Snyder	ST			
Neodexiopsis crassicrurus Snyder	LT			
Neodexiopsis maldonadoe Snyder	LT			
Bithoracochaeta species	ST	undescribed species		
4 sp. undetermined	ST			
Order Hymenoptera - sawflies, ants, wasps, bees, etc.			24 Fam.	140 sp.
Suborder Apocrita				
Family Ichneumonidae - ichneumonid wasps				4 sp.
4 sp. - undetermined	ST, L			
Family Braconidae - braconid wasps				8 sp.
Det. Carl F. W. Musebeck, USNM				
Apanteles carpatus (Say)	ST			
Heterospilus species	ST			
Xenarcha species	ST			
Ecphylus species	ST			
Orthostigma species	ST			
Spathius species	ST			
Macrocentrus species	LT			
Clinocentrus species	LT			
Family Mymaridae - fairyflies				13 sp.
13 sp. - undetermined				
Family Trichogrammatidae				3 sp.
3 sp. - undetermined	ST			
Family Eulophidae				14 sp.
14 sp. - undetermined	ST			
Family Encyrtidae				7 sp.
7 sp. - undetermined	ST			
Family Eupelmidae				1 sp.
1 sp. - undetermined	ST			
Family Agaontidae - fig wasps				1 sp.
Blastophaga species	ST			
Family Cynipidae - gall wasps				4 sp.
Det. Carl F. W. Musebeck, USNM				

Hypolethria species	ST		
Kleidotoma species	ST		
2 sp. - undetermined	ST		
Family Ceraphronidae			11 sp.
Det. Carl F. W. Musebeck, USNM			
Ceraphron, 5 sp. undetermined	ST		
Aphanogmus, 4 sp. undetermined	ST		
2 sp. - undetermined	ST		
Family Diapriidae			12 sp.
12 sp. - undetermined	ST		
Family Scelionidae			17 sp.
17 sp. - undetermined	ST		
Family Platygastridae			9 sp.
9 sp. - undetermined	ST		
Family Bethylidae - bethylid wasps			4 sp.
4 sp. - undetermined	ST		
Family Formicidae - ants			21 sp.
Det. William L. Brown, Jr., Cornell Univ.			
Strumigenys rogeri (Emery)	ST		
Strumigenys eggersi (Emery)	ST		
Strumigenys gundlachi	ST		
Paratrechina myops	H		
Paratrechina species r	ST	poss. *P. vividula* (Nylander)	
Paratrechina vividula (Nylander)	H		
Paratrechina species o	ST		
Pheidole subarmata borinquensis Wheeler	ST		
Pheidole moerens Wheeler	ST, H		
Solenopsis geminata (Fabr.)	ST		
Solenopsis corticalis Forel	ST		
Tetramorium guineense (Fabr.)	H		
Ondontomachus bauri	ST, L, LT		
Iridomyrmex melleus Wheeler	ST, LT, H		
Cyphomyrmex rimosus (Spinola)	ST		
Monomorium floricola (Jerdon)	ST		
Camponotus ustus Forel	ST, LT, H		
Trachymesopus stigma (Fabr.)	ST		
Myrmelachista ramulorum Wheeler	ST, H		
Tapinoma littorale Wheeler	ST		
Brachymyrmex heeri Forel	ST, H		
Amblyopone species	LT	poss. undescribed sp.	
Family Scoliidae - scoliid wasps			1 sp.
Det. George E. Drewry, PRNC			
Campsomeris atrata (Fabr.)	N		
Family Vespidae - paper wasps			2 sp.
Det. George E. Drewry, PRNC			
Polistes crinitus Felton	N		
Mischocyttarus cubensis (Saussure)	N		

Family Pompilidae - spider wasps		1 sp.
Det. George E. Drewry, PRNC		
Pepsis ruficornis (Fabr.)		
Family Sphecidae - sphecid wasps		3 sp.
Ammobia ichneumonea (Linn.)	N	
2 sp. - undetermined	N, L	
Family Dryinidae - dryinid wasps		1 sp.
1 sp. - undetermined	ST	
Family Apidae - bees		1 sp.
Xylocopa brasilianorum (Linn.)	N	
Family Halictidae - miner bees		2 sp.
2 sp. - undetermined	H	

ADDENDA AND NOTES FOR INSECT CHECKLIST

October 1, 1966

1. Additional insects reported

Order Odonata			
Family Aeschnidae			2 sp.
Triacanthagyana septima (Selys)	N		
Gynacantha nervosa Rambur	L		
Family Libellulidae			1 sp.
Erythrodiplax umbrata (Linn.)			
Family Coenagrionidae			1 sp.
Enallagma coecum (Hagen)	N		
Order Neuroptera			
Family Mantispidae			2 sp.
Climaciella cubana (End.)	L	(instead of *C.* species)	
Above Det. Oliver S. Flint, Jr., USNM			

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SOIL DESCRIPTION

On August 1, 1966, soil scientists from the U.S. Soil Conservation Service made a description of three profiles in the El Verde experimental area. The descriptions are written in standard SCS format and are suitable for quantitative and semi-quantitative comparisons of soils in other areas (Table 1, 2, and 3).

TABLE 1

Description of Soil Profile Near Radiation Source

Site No. 1
Location: Near source
Native Vegetation - Tropical rain forest vegetation
Parent Material - Residium from basic volcanic rocks
Physiography - Mountainous
Elevation - 1500 ft
Slope - 15 to 20%
Aspect - Northern exposure
Erosion - Slight
Permeability - Moderate
Drainage - Somewhat poorly drained
Ground Water - Deep free water at 13 inches probably from seepage
Moisture - Wet
Climate - Tropical, humid
Root Distribution - Abundant at surface and few fine roots in lower horizons. In the rain forest due to the saturated condition of the upper soil horizons, the roots tend to form a mat in the surface.

Salt or alkali - None
Stoniness - Abundant stones and boulders on surface
<u>Soil Profile</u>:

A1	0-8"	Dark brown (10YR 4/3) silty clay loam, weak fine subangular blocky structure; slightly sticky, slightly plastic; abundant rocks and thick roots at surface; common fine thin roots in the soil mass, this horizon in waterlogged; very strongly acid; clear wavy boundary.
B1	8-13"	Dark grayish brown (10YR 4/2) silty clay with common medium distinct reddish brown (2.5YR 4/4) mottles; weak medium subangular blocky structure; slightly sticky, slightly plastic; many fine roots, very strongly acid; clear wavy boundary. Free water at 13 inches.

B21	13-24"	Olive (5Y 5/2) clay with common distinct strong brown (7.5YR 5/6) mottles; moderate medium; subangular blocky structure; slightly sticky, slightly plastic; few fine roots, root channels filled with A1 material, patchy clay films; numerous thick earth worms; very strongly acid; clear wavy boundary.
B3	24-35"	Strong brown (7.5YR 5/6) clay with common medium distinct grayish brown (10YR 5&2) mottles; weak fine subangular blocky structure; slightly sticky and slightly plastic; very strongly acid, clear wavy boundary.
C1	35" +	Saprolite - very highly weathered volcanic rocks that can be crushed between fingers, with variegated colors.

TABLE 2

Description of Soil Profile Southwest of Radiation Source

Site No. 2
Location: 300 feet approximately southwest of Site 1
Native Vegetation - Tropical rain forest vegetation
Parent Material - Residuum from weathered basic volcanic rocks
Physiography - Mountainous
Elevation - 1700 ft
Slope - 20 to 40%
Aspect - Northern exposure
Erosion - Slight
Permeability - Moderate
Drainage - Well drained
Groundwater - Deep
Moisture - Moist
Climate - Tropical humid
Root Distribution - In this oil the root distribution is normal
Salt or alkali - None
Stoniness - None

Soil Profile:

Aoo	2-1	Undecomposed and partially decomposed leaves and twigs
Ao	1-0	Decomposed organic matter
A1	0-15"	Strong brown (7.5YR 5/6) clay; weak fine subangular blocky structure; slightly sticky, slightly plastic; many fine to medium roots, organic matter from above in worm channels; very strongly acid; abrupt smooth boundary.
B21	15-35"	Red (2.5YR 4/6) clay; weak fine subangular blocky structure breaking to granular; slightly sticky, slightly plastic; root channels, filled with organic matter from surface horizons; very strongly acid; gradual wavy boundary.
B3	45-60"	Red (2.5YR 4/6) clay, similar material as above, but with evidence of saprolite that increases with depth.
C	60" +	Saprolite - highly weathered volcanic rock that retains rock structure but which can be easily crushed between fingers.

TABLE 3

Description of Soil Profile Northeast of Radiation Source

Site No. 3
Location: 500 feet approximately northeast of Site 1
Native Vegetation - Tropical rain forest vegetation
Parent Material - Residuum from weathered volcanic rocks
Physiography - Mountainous
Elevation - 1500 ft
Slope - 15%
Aspect - Western exposures
Erosion - Slight
Permeability - Moderate
Drainage - Well drained
Ground water - Deep
Moisture - Moist
Climate - Tropical humid
Root Distribution - Abundant on surface and decreases with depth
Salt or alkali - None
Stoniness - Abundant on surface

Soil Profile:

Ao	1-0	Consists of partially decomposed and undecomposed leaves and twigs.
A1	0-1"	Yellowish brown (10YR 5/4) silty clay loam; weak fine granular structure; slightly sticky and slightly plastic; very strongly acid; abrupt wavy boundary.
B21	1-6"	Dark yellowish brown (10YR 4/4) silty clay; weak medium subangular blocky structure; slightly sticky and slightly plastic; very strongly acid; gradual wavy boundary.
B22	6-19"	Dark yellowish brown (10YR 4/4) clay; moderate medium to coarse subangular blocky structure, slightly sticky, slightly plastic; root channels and krotovinas filled with dark organic matter from above horizons; very strongly acid; gradual wavy boundary.
C1	19-27"	Yellowish brown (10YR 5/8) silty clay loam; massive saprolitic material.

Idealized Forest Profile

In November 1966, an idealized forest profile of the type advocated by L. R. Holdridge was made of the El Verde experimental site (Figure 1, Table 1). This profile was made in cooperation with the firm of Wilson, Nuttall, and Raimond Inc., of Chestertown, Maryland, in order to provide another basic description of the site which can be used for comparison with other sites and to provide the data needed to complete a manuscript which has been submitted for publication in A Tropical Rain Forest.

The quantitative information on tree heights, species density, and DBH's needed for the diagrams was kindly provided by Dr. Frank Wadsworth, Director of the Institute of Tropical Forestry, who has transect information from over 20 years of observations in the area (Table 2). Mr. Jack Schroeder of the above firm made onsite drawings of 39 tree species of which 23 were used in the diagram. Selection of species for representation was made by the method developed by L. R. Holdridge. The transects include all individuals greater than 5 cm DBH.

EL VERDE FOREST - Puerto Rico

IDEALIZED PROFILE

SUBTROPICAL WET

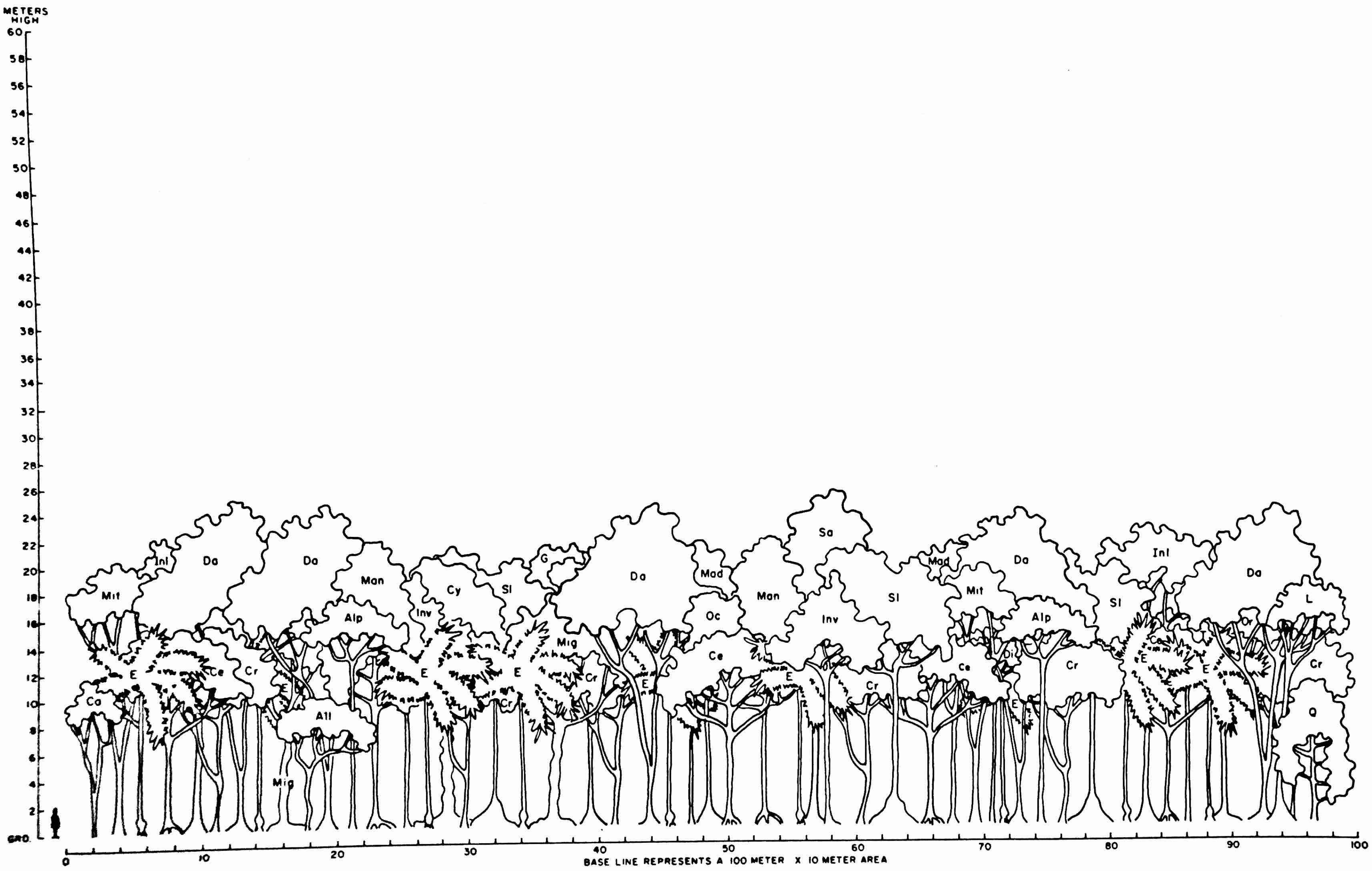

Figure 1. Idealized profile of the El Verde forest according to the method of L. R. Holdridge.

TABLE 1

Species Symbols for Idealized Profile of El Verde Forest, Puerto Rico

		Symbol
1.	*Euterpe globosa*	E
2.	*Croton poecilanthus*	Cr
3.	*Dacryodes excelsa*	Da
4.	*Cecropia peltata*	Ce
5.	*Sloanea berteriana*	Sl
6.	*Manilkara nitida*	Man
7.	*Miconia tetandra*	Mit
8.	*Micropholis garciniaefolia*	Mig
9.	*Inga vera*	Inv
10.	*Alchorheopsis portoricensis*	Alp
11.	*Matayba domingensis*	Mad
12.	*Inga laurina*	Inl
13.	*Quararibaea Turbinara*	O
14.	*Ormosia krugii*	Or
15.	*Didymopanax morototoni*	Di
16.	*Cyrilla racemiflora*	Cy
17.	*Calycogonium squamulosum*	Ca
18.	*Alchornea latifolia*	All
19.	*Linociera domingensis*	L
20.	*Tabebuia heterophylla*	T
21.	*Sapium lavrocerasus*	Sa
22.	*Guarea trichiliodes*	G
23.	*Ocotea maschata*	Oc

TABLE 2

Measurements of the Most Common Tree Species in the El Verde Forest Which Were Examined for Inclusion in the Forest Profile

No.	Total No. Found in 8 Transects	Latin Name	Common Name	DBH CM	Basal Area (M^2)	H (M)	T.H. (M)	Crown Width (M)	But.H (M)	But.W (M)
1	146	Euterpe globosa	Palma Sierra	16.7	.0219	15	11	8	.4	.6
2	86	Croton poecilanthus	Sabinon	15.2	.0182	13	4	8	2.0	.6
3	74	Dacryodes excelsa	Tabonuco	43.9	.1521	25	4	13	.4	2.2
4	53	Cecropia peltata	Yagrumo hembra	23.6	.0438	15	7	12	.8	.7
5	35	Sloanea berteriana	Cacao motillo	45.7	.1645	21	12	12	3.0	4.0
6	34	Manilkara nitida	Ausubo	35.3	.0981	22	9	7	.9	2.4
7	32	Miconia tetandra	Camasey	26.1	.0537	20	5	8	3.0	1.2
8	26	Micropholis garciniaefolia	Caimitillo verde	52.5	.2161	22	9	7	1.5	3.3
9	23	Inga vera	Guaba	32.7	.0844	19	12	10	.5	1.1
10	20	Alchorheopsis portoricensis	Palo de gallina	27.1	.0576	18	14	9	1.2	2.0
11	20	Matayba domingensis	Negra lora	22.8	.0409	22	8	10	.5	1.3
12	17	Inga laurina	Guama	43.1	.01461	23	11	11	.9	2.0
13	17	Quararibaea Turbinara	Garroecho	10.9	.0094	9	1	7	--	--
14	17	Ormosia krugii	Mato	39.6	.1231	22	6	11	.7	3.2
15	16	Didymopanax morotoni	Yagrumo macho	25.4	.0507	15	11	6	--	--
16	15	Cyrilla racemiflora	Colorado	95.7	.7200	21	10	9	1.0	5.8
17	13	Calycogonium squamulosum	Jusillo	11.6	.0106	12	5	4	--	--
18	12	Alchornea latifolia	Achiotillo	16.7	.0219	10	6	9	--	--
19	12	Linociera domingensis	Hueso blanco	17.5	.0241	19	13	6	4.0	1.8
20	10	Tabebui heterophylla	Roble	23.6	.0438	16	13	7	--	--
21	9	Sapium lavrocerasus	Hincha Bueno	56.3	.2501	26	12	12	1.4	2.0
22	7	Guarea trichiliodes	Guaraguao	43.1	.1461	21	8	13	1.0	2.0
23	7	Ocotea maschata	Nuez moscada	34.3	.0929	18	9	7	1.4	2.5
24	7	Guettarda laevis	Cucubano	21.8	.0374	18	8	6	--	--
25	6	Tetragastris balsamifera	Masa	27.9	.0614	16	6	9	.4	1.2
26	5	Cordia borinquensis	Muñeco	10.9	.0094	7	6	2	--	--
27	4	Cordia sulcata	Moral	9.9	.0077	15	11	4	--	--
28	4	Homalium racemosum	Caracolillo	80.0	.5050	23	11	10	2.5	3.7
29	3	Meliosma herbertii	Aguacatillo	10.6	.0089	11	9	3	.3	.6
30	3	Buchanavia capatata	Granadillo	32.7	.0844	22	13	14	1.0	2.4
31	3	Drypetes glauca	Cafeillo	16.5	.0214	13	4	8	.4	1.2
32	4	Phyllanthus nobilis	Yuguilla	16.0	.0201	12	2	7	--	--
33	2	Eugenia stahlii	Guayabota	21.6	.0368	18	11	4	4.0	1.6
34	3	Myrcia leptoclada	Guayabacon	21.3	.0357	13	8	5	.5	.9
35	1	Casearea arborea	Rabojunco	21.0	.0348	15	9	7	--	--
36	1	Roystonea borinqueña	Palma Real	35.5	.0991	22	17	7	.5	.9
37	1	Byrsonima coriacea	Maricao	17.8	.0249	14	4	7	--	--
38	1	Helecho	--	11.4	.0102	10	10	6	1.4	.9
39	1	Hirtella rugosa	Teta de burro	10.4	.0085	9	5	5	--	--

Trees listed in transects but not drawn

No.	Total No. Found in 8 Transects	Latin Name	Common Name
40	2	Byrsonima wadsworthii	Almendrillo
41	2	Ocotea spatulata	Nemoca
42	1	Andira inermis	Moca
43	1	Citharexylam caudatum	Pendula
44	12	*Laurel	
45	1	Trema micrantha	Palo de cabra

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*Laurel - Dr. Wadsworth used this for 1 or more different species. H. Watson used Octotea moschata to represent this. A separate representative was not drawn but was counted in average number of species per transect.

Weather Records

This section contains summaries of selected weather variables which were recorded at the El Verde experimental site. These summaries include weekly total rainfall, average monthly temperatures for various locations in the forest, wind direction frequencies, and monthly average wind speeds for several locations in the forest.

Weekly rainfall totals for the period July 1964, to May 1965, are presented in Table 1. These records were obtained by digital recording of events from a tipping bucket rain gauge placed above the canopy on a tower where each event corresponds to a single cycle of the gauge or 0.01 inches of rain. A daily log of the mechanical register is kept which permits convenient summaries to be made over any interval of time from 1 day to 1 year.

During January and February 1967, a program was written for a commercial NCR 315 computer, to process IBM punch paper tape which contained raw weather data collected at El Verde. This computer was chosen because of its high speed capability in paper tape reading, memory sorting, and intermediate magnetic tape readout of sorted data, with no need for intermediate card punch. When acquired, the magnetic tapes then form the primary input for any of the various summarizing programs. This action was taken not only to retrieve the data existing on tape but because it is the first necessary step in the conversion of the El Verde weather station from analog to digital data acquisition.

The digital data logging machine functioned only during the period from July 1965, to March 1966. During this period it required continuous maintenance and surveillance. In spite of this effort its reliability was low and it frequently produced skips, zeros, and gaps in the record. No further effort was invested in it after its final breakdown. At that time it had produced approximately two bushels of tape. The heavy maintenance requirements and the lack of a feasible way to handle the tape were the reasons for stopping. The primary data record was then acquired in the form of Rustrak charts. These charts required two persons working full time for 6 weeks to extract a single 3-year record at half-hourly intervals. Thus in spite of the problems with data logging, it appears to be the only feasible way to acquire data in a continuously functioning station.

Two primary steps are required to successfully operate a digital data logger: achievement of reliability at the time of punching and achievement of rapid processing of tapes. To this end, and with the advice of the 1967 Site Review Committee, we have placed an electronic technician on the staff whose full time assignment is to maintain instrument reliability. The computer program was written to demonstrate the feasibility of the second step. With the existing program we now have the potential for producing fast reliable weather summaries at a cost lower than any method involving hand processing.

A summary of monthly average temperatures from above the forest canopy, within the canopy, and from ground level is presented in Figures 1, 2, and 3. This data was acquired from the computer in the form of daily and 10-day averages from a paper tape input. Monthly averages were obtained by hand calculator but could easily be incorporated into the basic program. This data shows generally that higher average temperatures persisted during this interval above the canopy than within or at ground level. Peak temperatures occurred within and below the canopy during the months of September and October. These might be related to the apparent drop in forest ventilation which occurred during these months as shown on the wind-speed diagrams (Figures 4, 5, and 6).

Wind-direction frequency at the El Verde site during the period covered by paper tape recording is given in Table 2. These were acquired by programming the computer to assign all observations on tape for a month into 16 sectors of 22.5 degrees each, and then to sum the total number of observations and to calculate the fraction of the total which occurs in each sector. The results show that this area is dominated by easterly to south-southeasterly winds the year around. No seasonal trends are yet apparent in the data although this may be due in part to the fact that the data is incomplete due to malfunctions of the data logger.

Wind speeds averaged by months are given for tower, canopy, and ground level in Figures 4, 5, and 6. The data is presented by the computer in the form of averages every 6 hours for each day, and averages for each part of a day computed at 10-day intervals. Data from above the canopy (Figure 4) shows considerable variation and inconsistent wind patterns. This may be due to the fact that wind speeds are generally higher in this position and that hot-wire anemometers are generally not suitable for measuring these speeds. The program for the cup-type anemometer requires further debugging and the data will be presented in a subsequent report. Wind speeds from within the canopy and at gound level are shown in Figures 5 and 6. This data shows more internal consistency and is thought to be more reliable. There was an apparent lull in average monthly wind speed during the months of September and October 1965, which is closely related to an increase in average temperature during this same period. This may be due to a reduction in average ventilation. There are, in general, higher wind speeds at ground level than in the canopy and this is reflected in the temperature pattern also, with slightly higher temperatures in the canopy.

TABLE 1

Weekly Total Rainfall Record El Verde, Puerto Rico

Begin Date/Time		End Date/Time		Rainfall
7/18/64	10:00 AM	7/23/64	9:30 AM	1.71
7/23/64	9:30 "	7/28/64	10:00 "	.63
7/31/64	9:30 "	8/7/64	10:00 "	3.99
8/7/64	10:00 "	8/14/64	10:00 "	3.72
8/14/64	10:00 "	8/21/64	10:00 "	3.48
9/9/64	10:00 "	9/16/64	10:30 "	.62
9/16/64	10:30 "	9/23/64	9:30 "	6.37
9/23/64	9:30 "	9/30/64	8:50 "	5.98
9/30/64	8:50 "	10/7/64	9:30 "	2.57
10/7/64	9:30 "	10/14/64	9:36 "	3.94
10/14/64	9:36 "	10/21/64	9:17 "	1.14
10/21/64	9:17 "	10/28/64	9:43 "	4.49
10/28/64	9:43 "	11/4/64	8:50 "	3.35
11/4/64	8:50 "	11/11/64	9:25 "	.54
11/11/64	9:25 "	11/18/64	9:50 "	2.36
11/18/64	9:50 "	11/25/64	9:16 "	3.23
11/25/64	9:16 "	12/2/64		.99
12/2/64		12/9/64	9:25 "	2.71
12/9/64	9:25 "	12/16/64	10:50 "	2.06
12/16/64	10:50 "	12/23/64	9:00 "	2.81
12/23/64	9:00 "	12/30/64	10:40 "	.96
12/30/64	10:40 "	1/6/65	9:00 "	2.74
1/6/65	9:00 "	1/13/65	10:35 "	1.41
1/13/65	10:35 "	1/20/65	10:15 "	10.72
1/20/65	10:15 "	1/27/65	10:00 "	3.06
1/27/65	10:00 "	2/4/65	10:45 "	.45
2/4/65	10:45 "	2/11/65	11:15 "	2.71
2/11/65	11:15 "	2/18/65	11:00 "	.99
2/18/65	11:00 "	2/25/65	9:00 "	.41
2/25/65	9:00 "	3/1/65	9:50 "	1.62
3/1/65	9:50 "	3/8/65	11:30 "	.42
3/8/65	11:30 "	3/15/65	9:30 "	.23
3/15/65	9:30 "	3/22/65	10:30 "	.09
3/22/65	10:30 "	3/29/65	10:00 "	3.14
3/29/65	10:00 "	4/5/65	11:00 "	1.84
4/5/65	11:00 "	4/12/65	2:45 PM	1.17
4/12/65	2:45 PM	4/19/65	10:30 AM	.00
4/19/65	10:30 AM	4/26/65	4:58 "	3.53
4/26/65	9:58 "	5/4/65	10:00 "	9.28
5/4/65	10:00 "	5/11/65	10:00 "	21.38
5/11/65	10:00 "	5/18/65	8:45 "	14.35
5/18/65	8:45 "	5/25/65	9:15 "	5.31
5/25/65	9:15 "	6/1/65	9:30 "	3.56
6/1/65	9:30 "	6/8/65	9:15 "	7.19
6/8/65	9:15 "	6/15/65	5:45 PM	2.77

TABLE 1 (Continued)

Begin Date/Time		End Date/Time		Rainfall
6/15/65	5:45 PM	6/22/65	9:00 AM	1.14
6/22/65	9:00 "	6/29/65	9:30 "	3.72
6/29/65	9:30 "	7/6/65	9:30 "	3.88
7/6/65	9:30 "	7/13/65	10:30 "	4.62
7/13/65	10:30 "	7/20/65	9:45 "	8.40
7/20/65	9:45 "	7/27/65	2:00 PM	1.57
7/27/65	2:00 "	8/3/65	9:45 AM	3.79
8/3/65	9:45 "	8/10/65	9:00 "	12.12
8/10/65	9:00 AM	8/17/65	9:00 "	6.94
8/17/65	9:00 "	8/24/65	9:30 "	8.54
8/24/65	9:30 "	8/31/65	10:25 "	2.74
8/31/65	10:25 "	9/8/65	10:30 "	.67
9/8/65	10:30 "	9/15/65	9:30 "	3.74
9/15/65	9:30 "	9/22/65	9:30 "	5.63
9/22/65	9:30 "	9/29/65	8:45 "	1.72
9/29/65	8:45 "	10/6/65	8:55 "	.48
10/6/65	8:55 "	10/13/65	1:30 PM	1.90
10/13/65	1:30 PM	10/20/65	8:45 "	1.33
10/20/65	8:45 "	10/23/65	10:00 "	2.49
10/28/65	10:00 "	11/4/65	10:15 "	11.77
11/4/65	10:15 "	11/12/65	8:45 AM	4.49
11/12/65	8:45 AM	11/19/65	9:15 "	4.01
11/19/65	9:15 "	11/26/65	9:30 "	2.94
11/26/65	9:30 "	12/3/65	9:00 "	2.08
12/3/65	9:00 "	12/10/65	9:15 "	6.40
12/10/65	9:15 "	12/18/65	11:30 "	12.13
12/18/65	11:30 "	12/24/65	11:55 "	4.91
12/24/65	11:55 "	12/31/65	9:45 "	1.47
12/31/65	9:45 "	1/7/66	11:45 "	6.87
1/7/66	11:45 "	1/14/66	10:00 "	.54
1/14/66	10:00 "	1/21/66	9:00 "	.27
1/21/66	9:00 "	1/28/66	9:45 "	.19
1/28/66	9:45 "	2/4/66	10:30 "	5.03
2/4/66	10:30 "	2/11/66	9:00 "	2.22
2/11/66	9:00 "	2/18/66	10:15 "	2.66
2/18/66	10:15 "	2/24/66	9:00 "	2.21
2/24/66	9:00 "	3/3/66	9:30 "	.97
3/3/66	9:30 "	3/10/66	9:00 "	3.01
3/10/66	9:00 "	3/17/66	9:00 "	5.10
3/17/66	9:00 "	3/24/66	9:00 "	5.62
3/24/66	9:00 "	3/31/66	9:15 "	.11
3/31/66	9:15 "	4/7/66	9:00 "	.01
4/7/66	9:00 "	4/14/66	9:00 "	.42
4/14/66	9:00 "	4/21/66	8:00 "	8.71
4/21/66	8:00 "	4/28/66	9:00 "	1.13
4/28/66	9:00 "	5/5/66	8:30 "	5.92
5/5/66	8:30 "	5/12/66	9:30 "	8.58
5/12/66	9:30 "	5/20/66	2:30 PM	2.79
5/20/66	2:30 PM	5/27/66	8:55 "	1.32

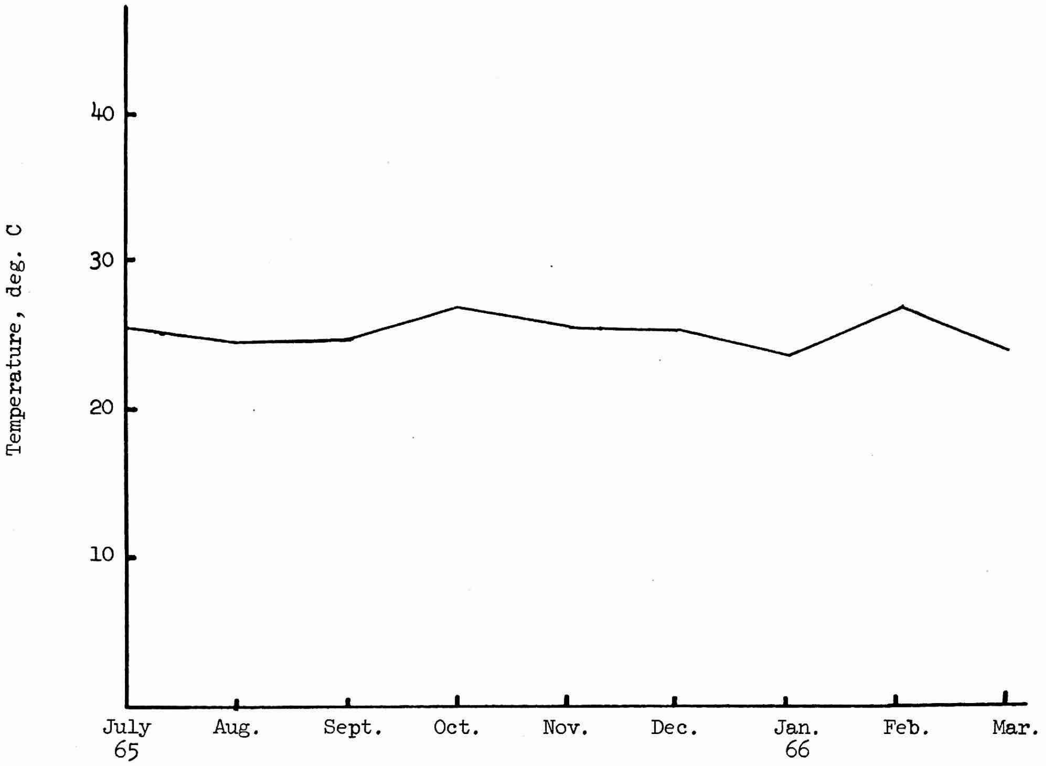

Figure 1. Average monthly temperature above the canopy at the El Verde field site.

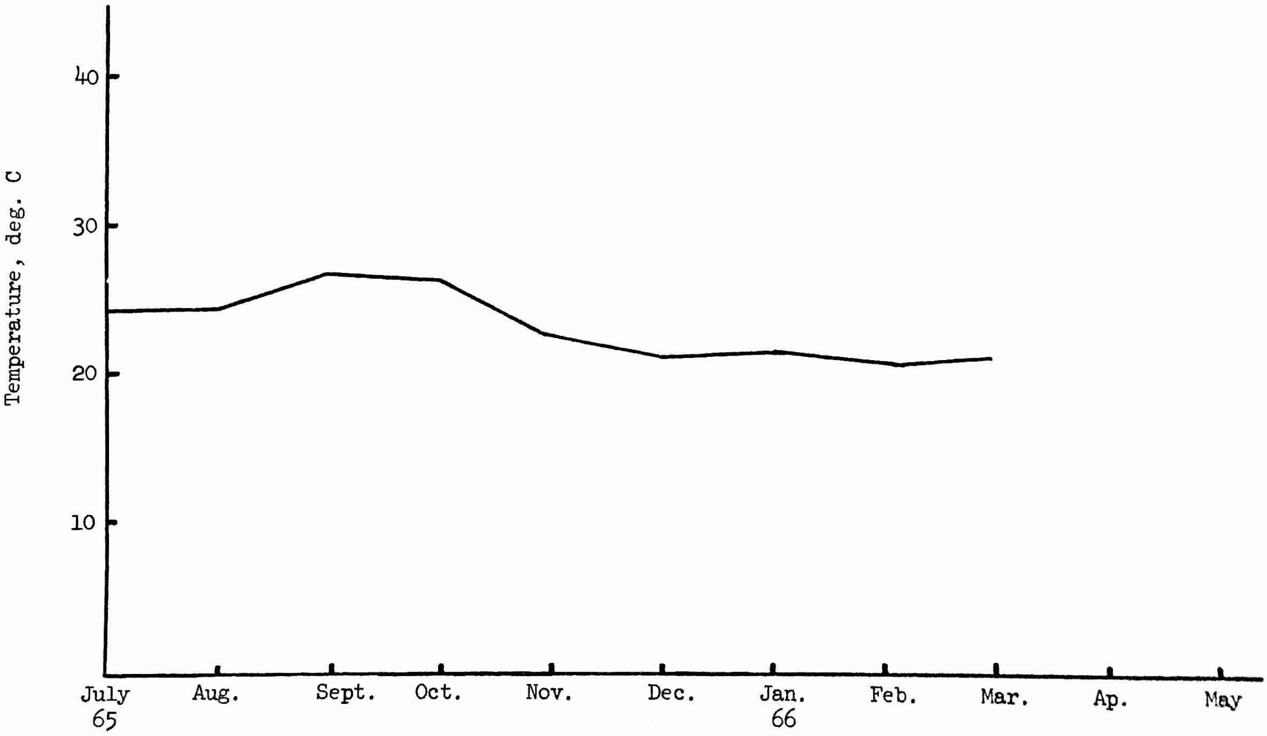

Figure 2. Average monthly temperatures within the canopy at the El Verde field site.

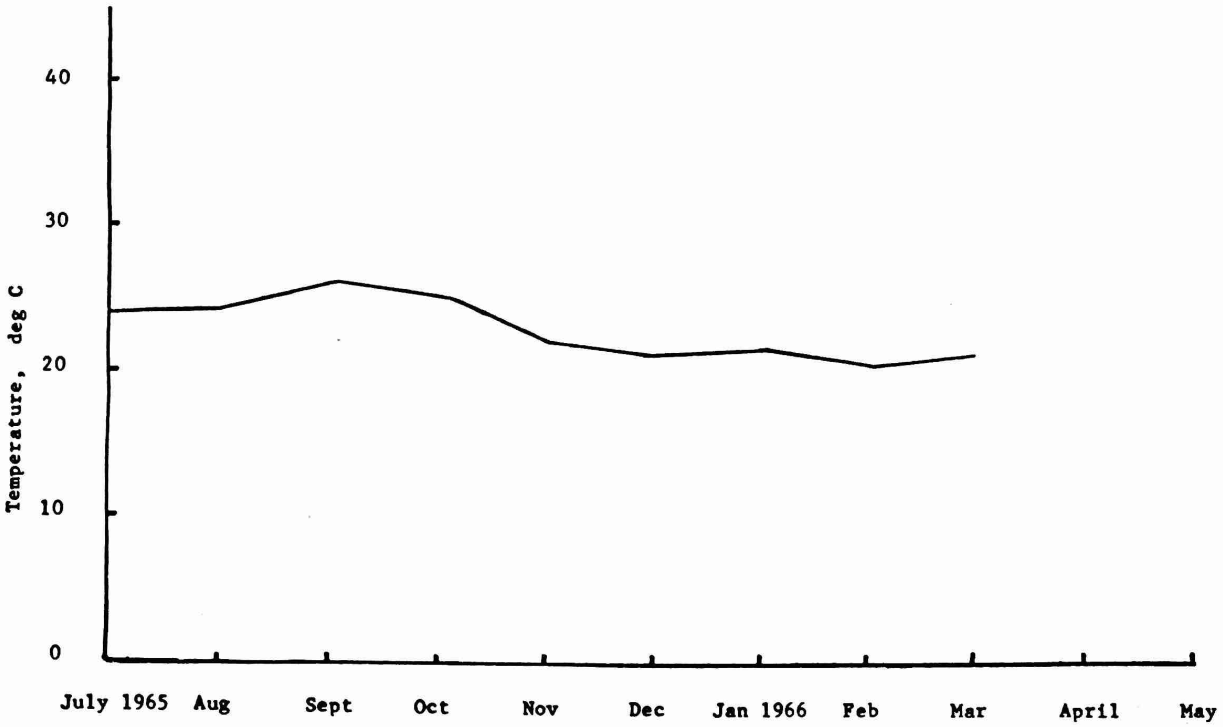

Figure 3. Average monthly temperatures at ground level at the El Verde field site.

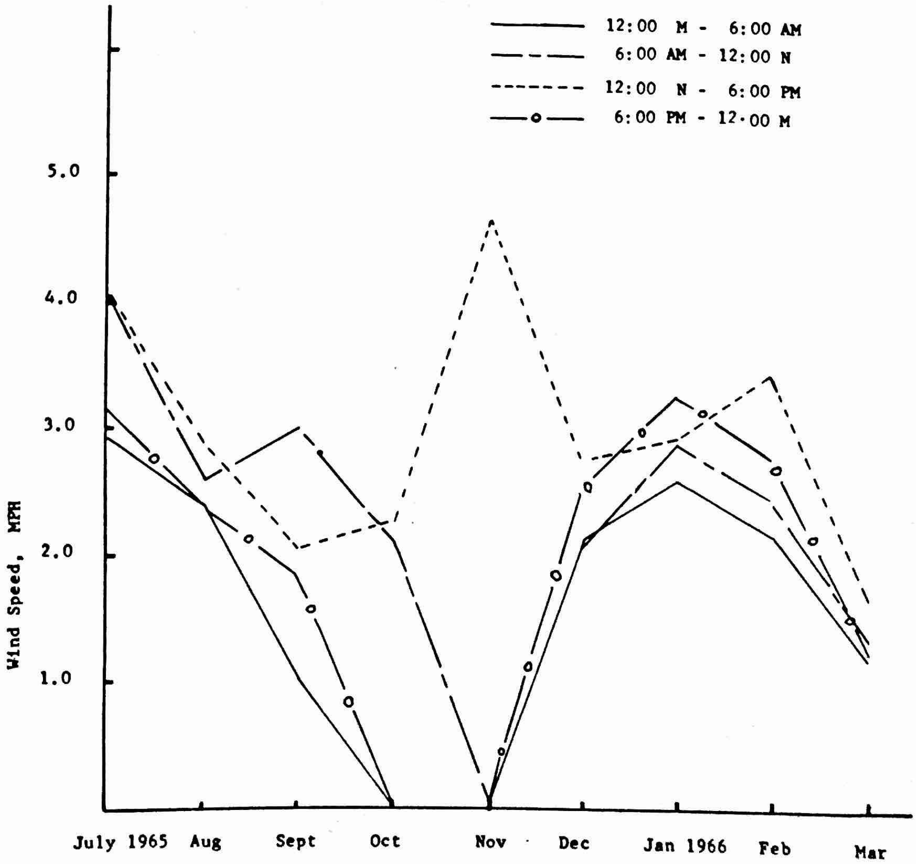

Figure 4. Monthly average wind speeds for quarter-day intervals from above the canopy at the El Verde field site.

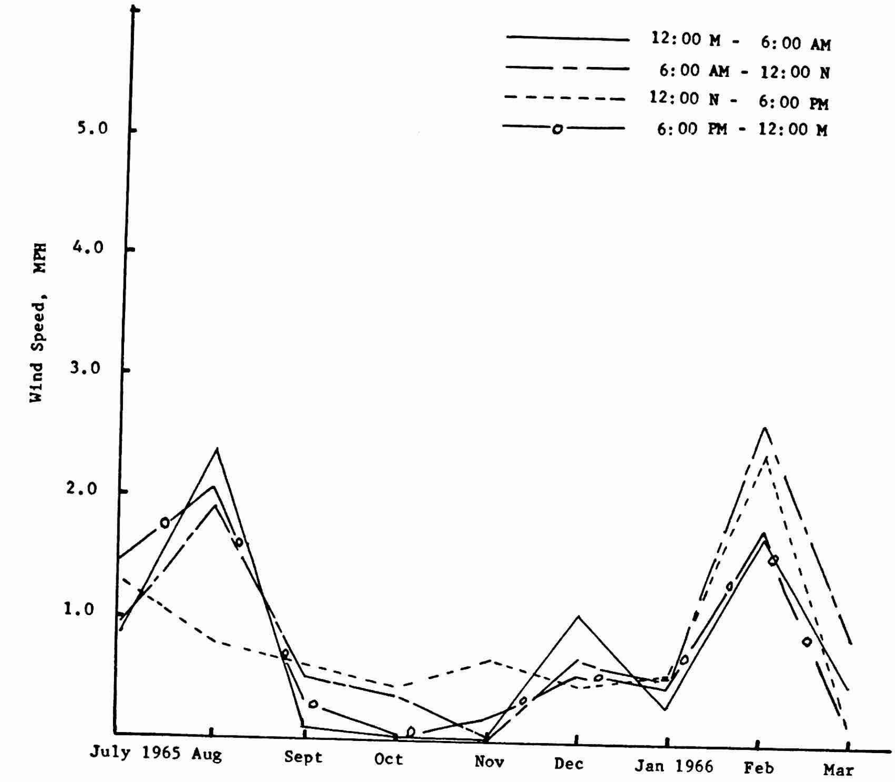

Figure 5. Monthly average wind speeds for quarter-day intervals from within the canopy at the El Verde field site.

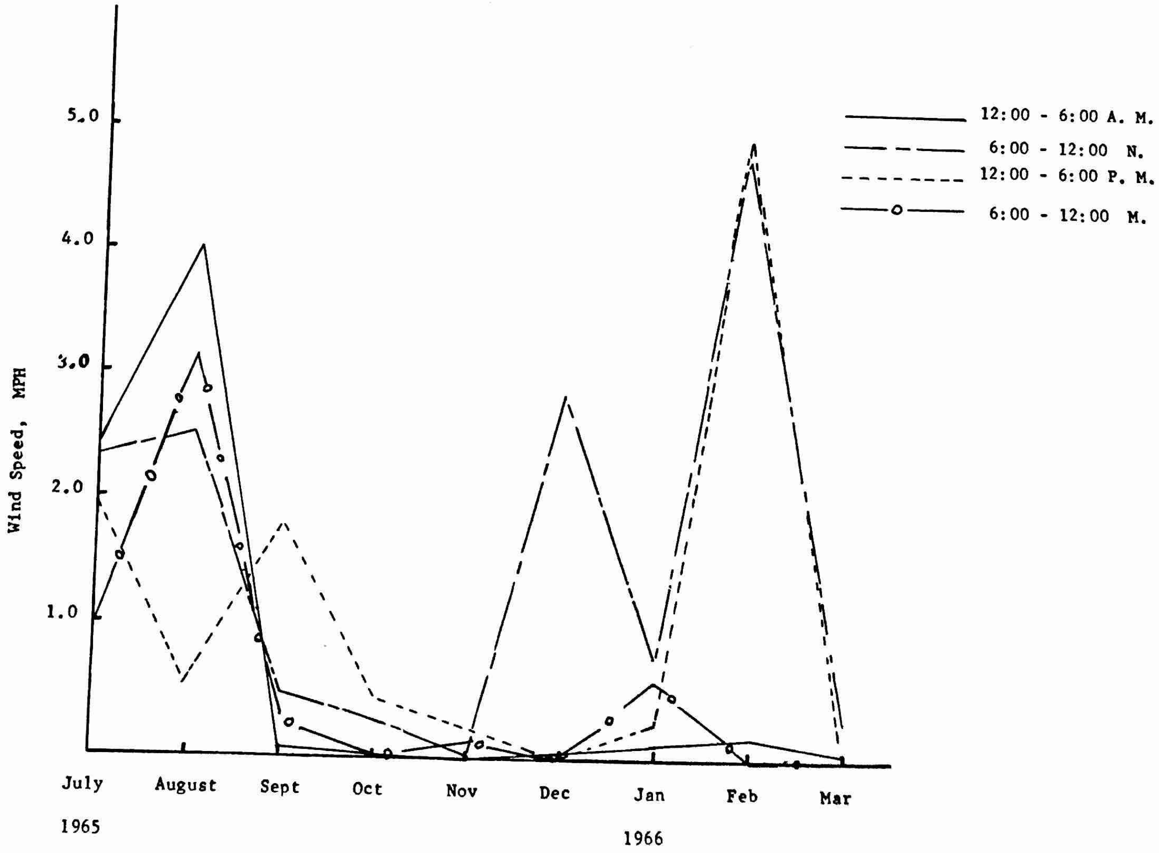

Figure 6. Monthly average wind speed for quarter-day intervals from ground level at the El Verde field site.

TABLE 2

Wind Direction Frequency at El Verde

Direction	7/65	8/65	9/65	10/65*	11/65*	12/65	1/66	2/66	3/66
N	0	0	2	0	0	1	0	2	2
NNE	4	3	2	0	0	2	0	5	4
NE	5	3	0	0	0	3	2	3	8
ENE	8	4	4	27	0	6	5	11	7
E	20	16	14	18	6	10	14	17	18
ESE	19	9	18	45	31	17	18	16	19
SE	19	14	17	9	50	23	23	13	13
SSE	13	14	21	0	6	14	14	5	6
S	2	7	12	0	0	1	0	0	0
SSW	2	3	1	0	0	4	5	4	0
SW	1	4	1	0	0	5	5	3	2
WSW	0	1	1	0	0	2	2	4	1
W	1	4	0	0	0	3	2	5	3
WNW	0	7	1	0	0	4	4	4	5
NW	2	6	2	0	0	3	2	4	6
NNW	2	6	2	0	0	4	3	4	7

*Based on 10 days or less for the month.

APPENDIX B

MANUSCRIPTS SUBMITTED

This section includes manuscripts which have been completed during FY-1967 by project scientists and submitted for publication. All manuscripts, except two, have been submitted for inclusion in A Tropical Rain Forest, H. T. Odum, editor. Radionuclide Behavior and Distribution in Tropical Forests by J. R. Kline was submitted to Battelle Memorial Institute as an account of activities partly financed by them in Darien Province, Panama. This was later released by them as IOCS memorandum BMI-1, for distribution to subcontractors. Recovery of a Tropical Rain Forest After Gamma Irradiation by Carl F. Jordan was submitted for inclusion in the Proceedings of The Second National Symposium on Radioecology.

Comparisons of the Amounts of Fallout Radionuclides in Tropical Forests

J. R. Kline and H. T. Odum

ABSTRACT

Leaves and forest litter were collected from 10 tropical forests in Puerto Rico, Dominica, Trinidad, and Central America for analyses of fallout radionuclide content. Measurements were made by gamma scintillation spectrometry for ^{144}Ce, ^{137}Cs, and ^{54}Mn. Highest levels of these isotopes were found in the northernmost tropical forests at the highest elevations above sea level. The amounts of contamination showed a general decrease with decreasing latitude. Forests at the same latitude were contaminated in relation to the mean annual rainfall at the sampling site. Individual species within a given forest showed wide variations in the levels of contamination but, in general, plants with an epiphytic growth habit were more heavily contaminated than the surrounding tree species.

Comparisons of leaves and forest litters indicated an apparent accumulation of ^{144}Ce, ^{54}Mn but not of ^{137}Cs, in the litter of all of the forests examined.

All of the forests, except one, showed detectable but low-level amounts of ^{95}Zr-Nb in both leaves and litters. The one exception, a forest in Mexico, showed an average of 3.5 pCi/g in the leaves and 10.3 pCi/g in the forest litter. Levels of ^{144}Ce, ^{137}Cs and ^{54}Mn were not correspondingly high in this forest. Fresh fission products such as ^{131}I, ^{140}Ba-^{140}La, and ^{103}Ru were not found.

INTRODUCTION

Monitoring of fallout radionuclides in forest materials at the El Verde project site has been in progress since 1963. These measurements, which were made first by gross beta counting and later by gamma scintillation spectrometry, indicated significant amounts of radionuclides in leaves and forest litter at this location. Samples taken in the summer of 1965 continued to have ^{137}Cs levels up to 25 pCi/g in leaves, although the last U.S. and USSR atmospheric weapons tests occurred in late 1962 (3). Rain water samples taken in 1965 indicated undetectable amounts of ^{137}Cs then entering the forest system and it was therefore concluded that the nuclear debris found in the forest was the result of past injections which had been retained by the trees.

If tropical forests have a mechanism for retaining nuclear debris, either through foliar adsorption of intercepted isotopes or by recycling of the isotopes through roots, it then becomes important to know how this mechanism varies in different forests at other locations. A survey was therefore undertaken with the objectives of comparing present levels of fallout isotopes in several different tropical forests and to identify the factors which could account for any differences found.

MATERIALS AND METHODS

Samples of leaves and leaf litter were collected from forests of the Caribbean Islands of Puerto Rico, Dominica, and Trinidad, and from Panama, Costa Rica, and Mexico in Central America in July and August 1965. Descriptions and locations of these forests are given in Table 1.

Ten samples from different species were obtained from each of the Puerto Rican forests, while four to seven samples were taken from each forest of the Caribbean and Central American survey. Normally only one sample from a large area was taken of forest litter.

Trees were sampled from primarily understory growth because of the difficulty in climbing to canopies in forests where no equipment was available. A sample consisted of live leaves and petioles from as many different branches as possible with no wood, flowers, or fruit included. Sample size was usually 1 kg fresh weight.

The samples were ovendried and counted nondestructively in a Marinelli beaker for 100 minutes each by gamma scintillation spectrometry. The counting equipment consisted of a 3 by 3 inch NaI (TI) crystal enclosed in a Cd-Cu lined lead cave with 4-inch walls. The crystal was connected to a 400 channel TMC pulse height analyzer calibrated to 10 Kev/channel. At the end of the 100 minute counting runs, backgrounds were subtracted and the date integrated within the analyzer. Data readout was accomplished by a Tally punch tape system and an IBM electric typewriter. Calibration of the system both for disintegration rate and spectral ratios was done by adding solutions of known disintegration rate for each isotope to a quantity of vermiculite which would just fill the Marinelli beaker. Then it was counted under the same conditions as the samples were counted.

The complex spectra were resolved into eight individual components by computer solution of empirically determined simultaneous equations. Isotopes determined were ^{144}Ce, ^{125}Sb, ^{103}Ru, ^{106}Ru, ^{137}Cs, ^{95}Zr-Nb, ^{54}Mn, and ^{40}K. Minor quantities, close to detection limits, were found of ^{125}Sb, ^{103}Ru, ^{106}Ru and ^{40}K but these are not included in this report. The isotopes to be discussed which were most prominent in the gamma-ray spectra are ^{137}Cs, ^{144}Ce, and ^{54}Mn.

All data obtained was corrected for radioactive decay to the date collected. The data in this report is therefore corrected to different dates within the July-August sampling interval. This was thought to be preferable to extrapolating decay rates either forward or backward in time, since the processes of removal of isotopes from forest systems are largely unknown.

RESULTS AND DISCUSSION

Fallout Radionuclides in Forest Leaves

Levels of ^{144}Ce, ^{137}Cs, ^{54}Mn for the 10 forests in the survey are given in Table 2. The results show considerable variation in the degree of contamination of these forests which is suggested to be the result of the interaction of several variables. These variables are: (1) latitudinal position of the forest, (2) annual rainfall entering the forest, and (3) plant species within the forest.

The forest sites in Table 2 are arranged in three groups according to descending latitudinal position starting with the Puerto Rican forests at 18° north and ending with the Panamanian and Costa Rican forests at 9° to 10° north latitude. The forest at Uxmal, Mexico, is anomalous in this grouping and is omitted from the sequence for reasons shown later in this report. The levels of ^{144}Ce, ^{137}Cs and ^{54}Mn for all forests at the same latitudinal position show a significant decrease from north to south. This is consistent with the findings of Lockhart et al. (4) in the 80th meridian sampling network where it is shown that airborne ground level nuclear debris in the northern hemisphere breaks sharply from high levels at 20° north latitude and declines rapidly towards the equator. Thus the general decline in forest contamination is consistent with the decline in levels of airborne debris in the air masses of this region.

Deposition of nuclear debris varies with rainfall (5,6) and such a mechanism appears also to be operative in the tropical forests. Variations in contamination within a given latitudinal position are shown by the sampling series from Puerto Rico where samples were obtained from locations ranging from 70 inches to 200 inches in annual rainfall. The data in Table 2 for Puerto Rico, representing 10 samples from each location is arranged according to increase annual rainfall. The correspondence between fallout levels and rainfall, indicates that within a given latitudinal position local variations in deposition occur as a function of scavenging by precipitation.

It appears that the scavenging history of air masses may also play a role in the amounts of fallout found. The forest at Maricao, Puerto Rico, has lower burdens than might be expected from its mean annual rainfall. This forest is located at the western end of the Island while the other three sites are on the east end of the Island. It therefore seems that the moisture laden air masses moving with the easterly trade winds which prevail over the Island are effectively scavenged of their nuclide burdens by the torrential rainfall which occurs on the mountainous east coast. The air masses which pass over the western interior of the Island are therefore relatively depleted of radionuclides resulting in lower burdens in the western forest. This effect is similar to that described by Roser and Cullen (6) who showed greater levels of ^{90}Sr fallout along South American coasts than in the interior.

Annual precipitation is also related to altitude in the Island environment. The forests of the coastal limestone plains and hills are at near sea level while the Elfin forest at the top of El Yunque mountain in Eastern Puerto Rico is at 3000 ft or more above sea level. The forest type changes markedly with this rainfall-altitudinal change. The forests of the lowlands are semi-deciduous with few prominent epiphytes while those of the lower montane regions are evergreen in character with many epiphytic plants and extensive epiphytic algae growth on leaf surfaces. The Elfin forest is also an evergreen forest which shows extensive growth of mosses, lichens, bromeliads, and leaf epiphytes.

The apparent overall contamination of a forest is influenced by the ability of the species present to retain the radionuclides against loss. Table 3 shows the variations found in contamination of the Puerto Rican forests. The tree species of a given forest show wide variations in the ability to retain radionuclides. Plants which have an epiphytic growth habit such as bromeliads, ferns, and mosses, have an overlapping range of contamination with the trees, but often have a much greater level of maximum contamination. The epiphytic plants derive their mineral nutritional requirements from the minerals washed from the forest canopy by rainfall or by interception of rainfall and appear to be adapted to binding radionuclides. Elder and Moore have reported a similar binding mechanism in Spanish moss (2).

It is apparent that the average level of contamination in a forest at a particular latitudinal position and within a single rainfall zone is dependent upon the tree species present and upon the numbers and types of epiphytic plants. In the Elfin forest many of the trees have no greater levels of contamination than trees at the El Verde or Maricao sampling sites. These trees apparently do not have efficient mechanism for the retention of aerially injected nutrients or radionuclides. However, other trees within the same zone have retained the presumably greater input with higher efficiency and are contaminated to far greater levels than in the lower elevation forests.

Variations in tree contamination may be the result of specific differences in the ability of trees to intercept, retain, or recycle these nuclides or they may be the result of differences in the growth of epiphylous plants on leaf surfaces. These plants also appear to derive their mineral nutrients by interception of canopy drip or rain water and may also intercept aerially injected radionuclides.

The relationship between fallout isotopes and epiphyllous plants has been shown by Briscoe and Briscoe (1). They showed that leaf scrapings which include the surface epiphyllous growth plus fragments of the leaf epidermis have far greater counting rates than the remaining leaf tissue or leaf tissue which had little original epiphytic growth. The greater part of the fallout isotopes is therefore in the surface tissue of leaves. This supports the hypothesis that much of the fallout in tropical vegetation is in the form of surface-held deposits from aerial injections as has been found in temperate zone systems (2,7).

Once interception has occurred, the isotopes may of course be absorbed into the metabolic system of the plant. The extent to which isotopes are taken into the plant as opposed to remaining on the surface is not established by scraping experiments since these inevitably include epidermal leaf cells as well as the epiphytic growth.

The interception mechanism does not rule out the possibility of the incorporation of fallout isotopes into the regular nutrient cycles of the system involving uptake by roots. That cesium at least can be taken up by tree roots has been shown by Witherspoon (8) with white oak. Ward et al. (7), however, have shown negligible recycling of Cs in alfalfa. Apparently the extent of recycling depends on the specific variables of the ecosystems including soil types, prevailing moisture conditions, root proliferation, and species under consideration.

The fact that leaves of the limestone forest in Puerto Rico are relatively low in fallout nuclides and have fewer visible epiphytes than other forests of the study, may indicate a relatively greater importance of recycling as opposed to interception in this forest. The fallout levels found in other forests are probably a result of both cycling and interception with interception becoming increasingly important at higher elevations due to greater amounts of epiphytic growth.

Fallout in Forest Litters

Bulk samples of forest litters were taken from all sites where the forest itself was sampled. The data is presented in Table 4. In general it was not possible to compute a standard error of the mean for these measurements since only a single sample from several square meters was taken for each site. Because of the homogenizing effect of mixing of leaves as they fall, it was assumed that these samples have about the same degree of reliability as the canopy samples. The forest litters show levels of fallout isotopes which follow the latitudinal association previously shown in forest trees. The data from Puerto Rico also shows the relationship with rainfall which was previously shown.

The forest litters show a considerable accumulation of ^{144}Ce and ^{54}Mn over the levels found in the forest trees (Table 5). This is not the case however for ^{137}Cs. This isotope shows no uniform pattern of distribution from tree to litter and in many cases the levels are about the same in both compartments.

The accumulation of ^{144}Ce in leaf litters is the result of the fact that Ce is not a plant nutrient and ^{144}Ce which was originally intercepted by leaves makes an essentially one-way trip to the litter by leaf fall or washout from which it is not recycled. The accumulation of ^{54}Mn in litters is probably due to the fact that Mn is an element required by plants in only trace amounts. As the originally intercepted ^{54}Mn is returned to the forest floor, it becomes diluted by the stable Mn there, and hence is recycled back to the tree only in proportion to the diluted ^{54}Mn/Mn ratio.

The apparent failure of ^{137}Cs to accumulate in forest litters may be due to the more rapid loss of this isotope from the litter. Such loss may occur either by direct leaching from the litter or by rapid recycling. More rapid recycling of ^{137}Cs may occur for two reasons: First, Cs is similar in behavior to Na and K, both of which are recycled in plants in large amounts; thus ^{137}Cs may simply join a macro element cycle. Second, Cs is a trace element in the earth's crust and thus little isotopic dilution would be expected as ^{137}Cs reaches the forest floor. These two factors may combine to produce a more rapid recycling of ^{137}Cs in the forest and hence an apparent lack of accumulation in the litter.

^{95}Zr-^{95}Nb in Canopies and Litters

As part of the solution of simultaneous equations for the complex spectra ^{95}Zr-^{95}Nb values were obtained for each sample. They generally showed detectable but low amounts of this isotope in both the Central American and Caribbean areas. An exception to this was found in the samples taken from Uxmal,Yucatan, Mexico, (Table 6). In this region, highly significant amounts of ^{95}Zr-^{95}Nb were found in both leaves and forest litters. The results for this site show an accumulation of ^{95}Zr-^{95}Nb in the forest litter as was previously shown for ^{144}Ce and ^{54}Mn.

Zirconium-95 decays with a half-life of 65 days, and therefore can be regarded as a fairly recent contamination when it is found. If the source of ^{95}Zr-^{95}Nb was the U.S. or USSR testing of nuclear devices in 1962, for instance, the decay corrected activities would correspond to initial contamination of the order of 3000 pCi/g in the forest canopies; a figure difficult to accept. A more likely source would be one of more recent origin such as the atmospheric testing of weapons by Communist China in October 1964, and May 1965, although other fresh fission products such as ^{140}Ba-^{140}La, ^{131}I, or ^{103}Ru were not found.

CONCLUSIONS

The average levels of contamination of tropical forests with fallout radionuclides are related to latitudinal position of the forest in the region from 18° north to 9° north with the northernmost forest the most highly contaminated. This is consistent with reported findings of the 80th meridian sampling network where a sharp decline in radionuclide content of air is shown to occur south of the vicinity of 20° north latitude.

Airborne radioactive debris has been shown by others to be scavenged from air masses by precipitation. This survey indicates that this relationship apparently holds for tropical forest contamination. Thus, while the latitudinal position of the forest determines the potential amount of nuclear debris available for deposition; precipitation scavenging determines the amounts actually deposited. Pelletier et al. (5) have shown a functional relationship between these factors.

When the nuclear debris has been deposited, the long-term contamination of the forest plants depends on the species and their relative proportions within the forest. Epiphytic plants such as mosses, bromeliads, lichens, ferns, and epiphytic leaf algae were found to be efficient in retaining nuclear debris. Trees within a given forest were highly variable in the amounts of nuclides retained although it is not known whether this is due to differences in binding of intercepted nuclides, in recycling of nuclides, or in tree-epiphyte associations.

Comparisons of forest litters and canopies showed ^{144}Ce and ^{54}Mn to be accumulating in the litters of all of the forests examined. Results were not so clear for ^{137}Cs since some forests showed apparent accumulations and others showed apparent depletions in the litter. The accumulation of ^{144}Ce is suggested to be due to negligible recycling of this element in plant communities while that of ^{54}Mn is probably the result of low rates of recycling and high isotopic dilution. The variable results for ^{137}Cs probably indicate that this element has been incorporated into the same pathways followed by Na and K and is either rapidly leached from the forest floor into the ground water or is rapidly recycled back to the trees.

Measurements of ^{95}Zr-^{95}Nb showed detectable but low levels of these isotopes in most of the forest observed. An exception to this was the forest at Uxmal, Yucatan, Mexico, where an average of 3.5 and 10.3 pCi/g of these isotopes was found in canopies and litters. The source of these isotopes was probably the weapons testing by China in late 1964, and the spring of 1965.

Future sampling surveys of tropical forests for radionuclide contamination may be carried out with reasonable economy by selection of samples which may be indicators of the general canopy burden. Values from leaf litters tend to overestimate ^{144}Ce and ^{54}Mn levels in leaves but give approximately the same values for ^{137}Cs. Epiphytic plants such as bromeliads and mosses are often easily obtainable from forest understories and tend to give maximum estimates for canopy burdens.

TABLE 1

Description of Tropical Forests Included in Fallout Radionuclides Survey

Forest Puerto Rico	Elevation	Description
Limestone	200 ft	Semideciduous; grown along north coastal hills on shallow residual limestone soils with trees to 60 ft. Many surface roots, epiphytic plants.
Maricao	2800 ft	Evergreen, lower montane forest on west end of Island, with trees to 60 ft. Deep residual serpentine soils with few surface root runners. Few bromeliads; leaf surfaces moderately covered with algae.
El Verde	1500 ft	Evergreen, lower montane rain forest on east end of Island with trees 60-75 feet. Deep residual basaltic or andesitic soils. Extensive surface roots. Bromeliads and epiphylous plants common.
Elfin	3000 ft	Evergreen, montane rain forest on El Yunque peak, east end of Island with trees to 20 feet. Deep residual basaltic or andesitic soils. Extensive surface roots. Bromeliads and epiphylls extensive. Trees extensively covered with filamentous hanging mosses.
Other Islands		
Dominica		Evergreen, lower montane rain forest similar in structure to El Verde project site but with some taller, larger diameter trees.
Trinidad		Evergreen, lower montane rain forest similar in structure to El Verde project site.

TABLE 1 (Continued)

Central America		
Costa Rica	1900 ft	Turrialba site. Evergreen montane rain forest with trees to 90 ft. Soils residual over igneous rocks. Surface roots similar to El Verde.
Costa Rica	200 ft	Sarapiqui site. Evergreen rain forest with trees to 150 feet. Soils residual over igneous rock. More deeply rooted than El Verde.
Panama	200 ft	San Lorenzo site. Evergreen rain forest with trees to 100 feet. Soils residual over igneous rock. Deeply rooted, few epiphytic plants.
Mexico	200 ft	Uxmal, Yucatan site. Seasonal rain forest with trees to 70 feet. Soils residual over igneous rock.

TABLE 2

Average ^{144}Ce, ^{137}Cs and ^{54}Mn Levels in Leaves from 10 Tropical Forests of the Caribbean and Central America

Forest	Latitude	Mean Annual Rainfall (inches)	^{144}Ce	^{137}Cs* (pCi/g)	^{54}Mn
Puerto Rico					
Limestone	18°	70	3.3 ± 0.6	3.5 ± 0.7	0.7 ± 0.1
Maricao	18°	100	4.3 ± 1.0	2.9 ± 0.5	0.9 ± 0.4
El Verde	18°	135	15.2 ± 2.4	14.2 ± 2.5	2.9 ± 0.8
Elfin	18°	200	30.5 ± 5.2	25.6 ± 5.4	7.0 ± 2.4
Other Islands					
Dominica	15°	100	13.3 ± 2.0	9.5 ± 1.3	2.7 ± 0.7
Trinidad	10°	100	6.6 ± 0.1	4.1 ± 0.9	0.5 ± 0.3
Central America					
Costa Rica (Turrialba)	10°		3.1 ± 0.7	1.2 ± 0.2	0.2 ± 0.1
Costa Rica (Sarapiqui)	10°		8.8 ± 1.3	6.7 ± 0.9	2.5 ± 0.3
Panama	9°		3.0 ± 0.8	1.6 ± 0.3	0.5 ± 0.2
Mexico (Uxmal, Yucatan)	20°		5.0 ± 1.7	1.7 ± 0.5	0.1 ± 0.8

*Error terms: $\bar{X} = \Sigma \frac{x}{\sqrt{N}}$ for sample variability. Errors in gamma-ray spectrometry not included.

TABLE 3

Ranges of Contamination of Plant Types in Puerto Rican Forests

Forest	$^{144}\mathrm{Ce}$	$^{137}\mathrm{Cs}$ (pCi/g)	$^{54}\mathrm{Mn}$
Limestone forest			
Tree Leaves	1.4 - 5.8	1.6 - 7.9	0.1 - 1.3
Maricao			
Tree Leaves	1.2 - 9.2	1.4 - 5.2	0.1 - 3.4
Bromeliad*	7.6	12.9	2.4
Ferns*	5.1	10.8	0.6
El Verde			
Tree Leaves	2.7 - 25.3	5.4 - 24.8	0.2 - 8.1
Bromeliad	15.5 - 20.9	26.3 - 43.5	3.8 - 6.6
Ferns*	19.7	39.5	7.9
Elfin Forest			
Tree Leaves	12.7 - 56.9	10.1 - 49.5	1.1 - 23.8
Bromeliad	37.1 - 41.5	53.0 -124.	8.9 - 9.4
Moses	27.8 -111.	61.7 -210.	4.1 - 10.8
Ferns	18.6 - 35.4	35.7 - 50.0	2.4 - 3.5

*Single Samples

TABLE 4

^{144}Ce, ^{137}Cs, ^{54}Mn Levels in Leaf Litter from Caribbean and Central American Forests

Forest	^{144}Ce	^{137}Cs (pCi/gram)	^{54}Mn
Puerto Rico			
Limestone	8.0	4.3	1.2
Maricao*	-	-	-
El Verde	18.3	8.9	3.3
Elfin (El Yunque)	45.4	16.4	10.8
Other Islands			
Dominica	34.6	12.9	7.3
Trinidad	11.6	4.7	2.0
Central America			
Costa Rica (Turrialba)	5.6	1.3	0.7
Costa Rica (Sarapiqui)	5.2	1.7	1.9
Panama	4.0	1.6	0.7
Mexico	11.1	0.6	ND**

* Litter sample not collected
** ND = Not detected

TABLE 5

Relative amounts of ^{144}Ce, ^{137}Cs and ^{54}Mn in Leaves and Litter from Caribbean and Central American Forests

Forest	$\frac{^{144}\text{Ce Leaves}^{**}}{^{144}\text{Ce Litter}}$	$\frac{^{137}\text{Cs Leaves}^{***}}{^{137}\text{Cs Litter}}$	$\frac{^{54}\text{Mn Leaves}^{****}}{^{54}\text{Mn Litter}}$
Puerto Rico			
Limestone	0.4	0.8	0.6
Maricao*	-	-	-
El Verde	0.8	1.6	0.9
Elfin	0.6	1.7	0.7
Other Islands			
Dominica	0.4	0.7	0.4
Trinidad	0.6	0.8	0.2
Central America			
Costa Rica (Turrialba)	0.5	0.9	0.7
Costa Rica (Sarapiqui)	1.7	4.0	1.3
Panama (San Lorenzo)	0.7	1.0	0.7
Mexico (Uxmal, Yucatan)	0.5	3.0	-

*Litter sample not collected

**Population 1 at 94% confidence level

***Population not different from one

****Population 1 at 97% confidence level (All tests Wilcoxon signed rank).

TABLE 6

^{95}Zr-^{95}Nb Levels in Forest at Yucatan, Mexico, as Compared with Other Central American and Caribbean Forests

Forest	Leaves ^{95}Zr- ^{95}Nb (pCi/g)	Litter
Uxmal, Yucatan, Mexico	3.5 ± 1.7	10.3*
Central American forests (and Trinidad)	0.3 ± 0.1	0.1 ± 0.08
Island forests	1.2 ± 0.2	0.5 ± 0.1

*Single sample

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Effect of Gamma Radiation on Leaching of ^{137}Cs and ^{54}Mn from Tropical Forest Trees by Rainwater

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ABSTRACT

The effect of gamma radiation on loss of fallout radionuclides by leaching from rain forest trees was investigated. Samples of canopy leaves were collected from radiation and control centers of the El Verde, Puerto Rico site, both before and after irradiation with 10,000 curies of ^{137}Cs. Collections of leaf litter were made monthly, before and after the irradiation, for measurement of radionuclide burdens. The results from both collections show that radiation had no measurable effect on the rates of leaching of ^{137}Cs and ^{54}Mn from forest canopies. The accumulation of fallout isotopes in epiphyllous plants rather than leaves themselves, and the probable high resistance of these plant types to leaching loss are offered as explanations of the observed results.

INTRODUCTION

Leaching of mineral and organic substances from the leaves of living plants by rainwaters is well established in plant biology (4,5,6). Tukey et al. (8) have reported that no exception to the general occurrence of leaching in 140 species of plants has so far been found. Species which have been examined include deciduous and coniferous trees, ornamental plants, tropical plants, vegetable crops and grain crops (5). Witherspoon (19) has reported that 16% of ^{134}Cs injected into White Oak was removed from the foliage by leaching in 1 year. Most leaching data is reported for higher plants, however, Elder and Moore (2) have shown that the leaching of fallout radioisotopes from Spanish moss is far more difficult than leaching from pangola hay. Tukey (7) has shown that conditions injurious to plants including nutrient and moisture deficiencies, temperature extremes, toxic chemicals and mechanical damage, all result in increased leaching.

The lower montane rain forest at El Verde, Puerto Rico is heavily labeled with fallout radioisotopes (3). The apparently general occurrence of leaching and the accelerating effect caused by plant injury raised the question of whether gamma-radiation damage would

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result in increased loss of the isotopes from the forest canopy. To explore this problem, comparisons of radioisotopes content of live leaves pruned from tree canopies were carried out before and after irradiation. These comparisons were necessarily restricted to trees which had received sufficiently low doses of radiation to survive the experiment. In order to obtain comparisons with leaves which received lethal doses of radiation, freshly fallen litters were collected monthly for 8 months prior to irradiation and 10 months after irradiation. If accelerated leaching took place as the leaves were accumulating a lethal dose of radiation, it would be expected that this would be reflected in lower isotope levels in the newly-fallen leaves of the radiation center.

MATERIALS AND METHODS

Fresh leaves were collected by pruning from canopies of several prominent trees from the two centers in September and October 1964. The trees had been previously tagged and the tag number was recorded at the time of sampling. After the irradiation in September 1965, the same trees were sampled by the same methods. Samples consisted of leaves and petioles only, with no flowers, fruits, or branches included. Normally about 1 kilogram fresh weight of leaves was obtained from several branches of each tree.

During the period from April 1964, through February 1966, fresh leaf fall was collected at ground level in 55 one-half square meter collection baskets. The newly-fallen litter was composited monthly from the radiation center and from the control center. The composites consisted of 25 stations in the radiation center and 30 stations in the control center.

Determinations of ^{137}Cs and ^{54}Mn were made on the live leaves and the leaf litters by gamma scintillation spectrometry. All samples collected prior to irradiation were ashed in a furnace at 400°C and counted in ash form on a 2 by 2 NaI (TI) crystal mounted in a lead brick cave and connected to a 400 channel TMC pulse height analyzer. In the interval between the first and second sampling, the detector equipment was modified by the installation of a 3 by 3 NaI (TI) crystal. The larger crystal permitted the counting of samples in a Marinelli beaker and all post-irradiation samples were counted non-destructively by this means. Details of counting and calibration techniques have been given by Kline and Odum (2).

RESULTS AND DISCUSSION

Average level of ^{137}Cs and ^{54}Mn in live leaves before and after the irradiation are presented in Table 1. A "t" test at the 99% confidence level showed no significant differences in the levels of either nuclide when the irradiated and control centers were compared before or after irradiation. Comparisons between pre- and post-irradiation foliage within the same center were not made since sample preparation and counting methods were different between these groups of data, and also the rates and pathways of radioisotope accumulation or loss in the rain forest are not known.

Data for freshly fallen leaves is given for ^{137}Cs and ^{54}Mn in Figure 1. The data is given in the form of the following ratios:

$$\frac{^{54}\text{Mn (Rad)}}{^{54}\text{Mn (Con)}} \quad \text{and} \quad \frac{^{137}\text{Cs (Rad)}}{^{137}\text{Cs (Con)}}$$

where the numerator is the average of 25 one-square meter collection stations and the denominator is the average of 30 similar stations for the centers shown in the subscript.

The ^{54}Mn ratios showed no apparent deviation from the expected value of one either before or after the irradiation experiment. The ^{137}Cs ratios indicate that the radiation center originally had greater levels of ^{137}Cs than the control center, but that the irradiation had no apparent effect on these ratios. One unusually high value for the ratio is shown for the March 1965 collection, which was taken during the irradiation period. This high ratio is derived from an unusually low value of ^{137}Cs from the control center for that month. Actual ^{137}Cs levels in the irradiated center were unchanged. The high value of the ratio for that month is therefore not an irradiation effect.

Data from both living and freshly fallen leaves shows no radiation effect on accumulation or loss of ^{137}Cs and ^{54}Mn from tropical foliage. This is contrary to expectations since as Tukey (7) has found, damage to leaves would normally increase their leachability. The results may be due to the possibility that patterns of leaching of inorganic substances from leaves may be modified by epiphytic plants growing on leaf surfaces. Epiphyllous plants may derive their mineral nutrients in part by interception from rain water or by uptake from leaf leachates and, in so doing, accumulate isotopes as well. Briscoe and Briscoe (1) have shown that most of the gross beta activity of leaves from El Verde is in epiphyllous plants scraped from leaf surfaces. Kline and Odum (3) have shown that plants with an epiphytic growth habit normally have greater levels of fallout radioactivity than other plants. Loss by leaching from this type of plant may be minor. Elder and Moore (1) have shown powerful retention of fallout radionuclides in Spanish moss, another non-rooted plant with an epiphytic growth habit. Even when cell structure was damaged by grinding, these authors reported significant amounts of fallout radionuclides retained by the moss against leaching.

The failure of isotope to be leached preferentially from forest canopies in the area damaged by radiation may be accounted for on the basis of two factors. First, the epiphyllous plants and not leaves may contain the bulk of fallout nuclides and second, epiphytic plants may have powerful resistance to leaching even when their cell structures are damaged. The El Verde forest has extensive distributions of leaf epiphytes which could provide a mechanism for the prevention of isotope leaching. The role of epiphytic plants in mineral cycling processes appears to be an important one in the tropical rain forest and it is currently undergoing further investigation.

TABLE 1

Pre- and Post-Irradiation Values of ^{137}Cs and ^{54}Mn in Canopy Leaves in Irradiated and Control Centers of the El Verde Forest

Isotope	Pre-Irradiation*				Post-Irradiation*			
	Irradiated		Control		Irradiated		Control	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
^{137}Cs	7.7	1.3-28.0	5.1	2.0-9.4	10.3	4.3-18.9	7.6	3.2-12.9
^{54}Mn	2.1	0.1-5.6	2.7	0.4-5.6	2.1	0.4-5.5	1.3	0.6-2.2

*A "t" test at 0.99 confidence level shows no significant differences between irradiated and control centers either before or after irradiation.

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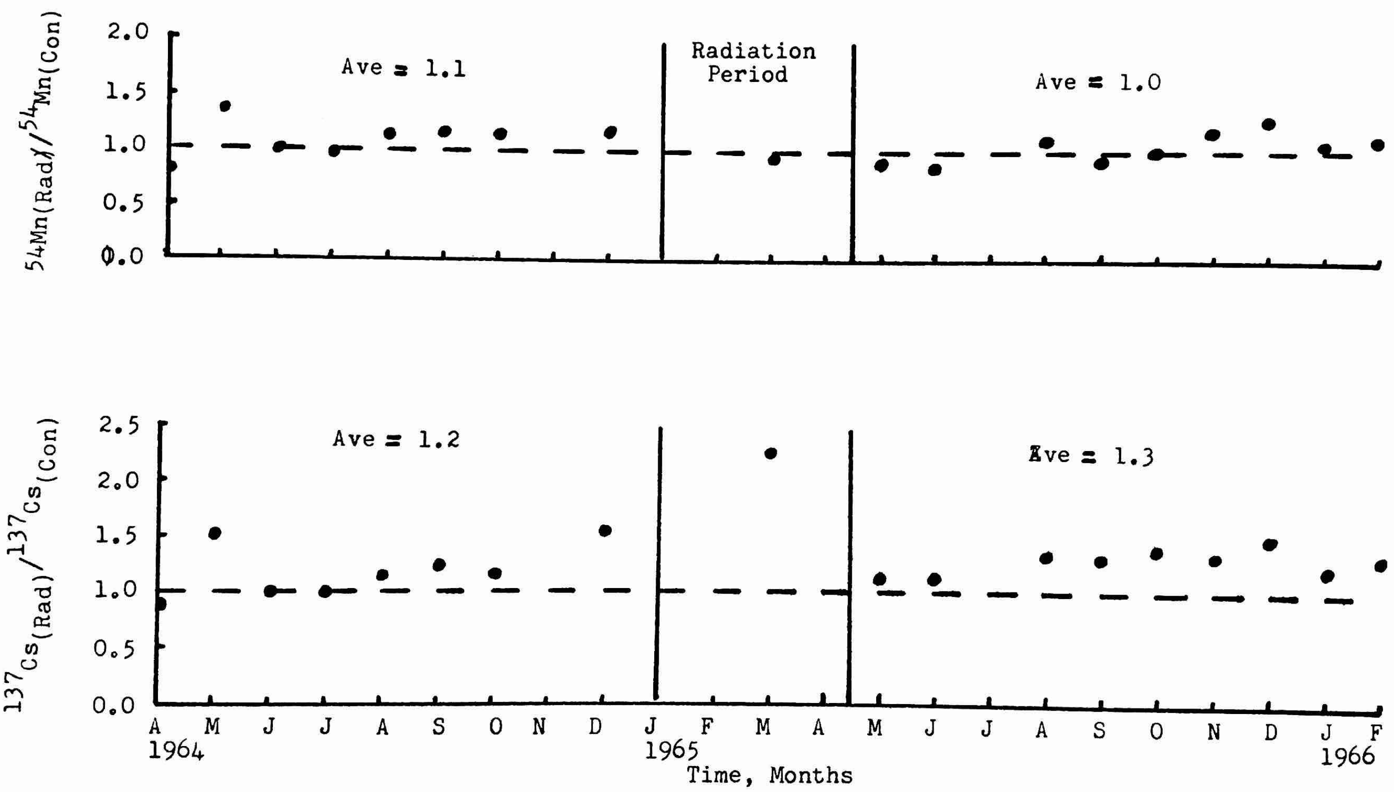

Figure 1. Ratios of ^{54}Mn and ^{137}Cs in irradiated and control centers obtained from monthly collections of freshly fallen leaf litter.

IOCS MEMORANDUM BMI-1
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BIOENVIRONMENTAL AND RADIOLOGICAL-SAFETY FEASIBILITY STUDIES

ATLANTIC-PACIFIC INTEROCEANIC CANAL

RADIONUCLIDE BEHAVIOR AND DISTRIBUTION IN TROPICAL FORESTS

November 1, 1966

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November 1, 1966

SUBJECT: Radionuclide Behavior and Distribution in Tropical Forests

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R. S. Davidson

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RADIONUCLIDE BEHAVIOR AND DISTRIBUTION IN TROPICAL FORESTS

A progress report to Battelle Memorial Institute covering research activities of the Terrestrial Ecology Project of the Puerto Rico Nuclear Center which were financed in part by Battelle in connection with Interoceanic Canal Study Commission bioenvironmental studies in Central America (under U. S. Atomic Energy Commission Contract No. AT (26-1)-171), and in part by the Division of Biology and Medicine, U. S. Atomic Energy Commission, Contract No. AT(40-1)-1833.

by

Jerry R. Kline

ABSTRACT

Fallout radionuclides in forests of Darien, Panama, were found to be lower by approximately a factor of ten than those in the forests of Puerto Rico. These findings are consistent with previously reported results of the 80th meridian survey, which indicate that airborne radioactivity declines rapidly from north to south in the Northern Hemisphere. However, the distribution of radionuclides among various vegetational types was similar to that found in Puerto Rico. Lowland forests were invariably the least contaminated and the contamination levels generally increased in forests with increasing altitude. Plants which have an epiphytic growth habit were found to be apparent accumulators of fallout nuclides in all forest types.

A variety of foods collected in Panama were found to have fallout radionuclide burdens which were lower by a factor of ten than forest vegetation of the immediate environment.

A tracer experiment carried out on understory vegetation at the El Verde experimental site in Puerto Rico using the nuclides ^{134}Cs, ^{85}Sr, and ^{54}Mn indicated extremely slow uptake by the plants. The results of this experiment suggest that the high levels of fallout radionuclides found in the El Verde forest in both understory and crown vegetation cannot be accounted for on the basis of recycling of these nuclides through roots but is more likely the result of interception on surfaces from rainfall.

INTRODUCTION

Surveys of environmental radiation have been in progress at the El Verde test site in Puerto Rico since 1963. They have been used to establish existing levels of fallout radionuclides in the forest at El Verde and to study some aspects of the behavior of these nuclides in tropical forests. Since this type of study appears to have relevance to the bioenvironmental studies for the sea level canal project, it was proposed that project staff carry out similar surveys along the proposed canal route in Panama (Route 17) in order to establish existing levels of environmental contamination and to compare the existing distributions of nuclides with those in Puerto Rico. The benefits of such studies include the possibility that radionuclide behavior in tropical forests could be found which would have predictive value in evaluating potential effects of nuclear excavation in the tropics.

A preliminary survey of the type being made in Puerto Rico was made in Darien province of Panama by project staff during the period from April 22 to April 30, 1966. During this survey, plant leaves and soils were collected from forest sites near sea level and at varying altitudes up to 3600 feet. Local foods and farm crops were also sampled. In all, more than 100 samples were collected for gamma spectrum analysis.

Much of the literature relating to the behavior of fallout nuclides in Temperate Zone vegetation indicates that these nuclides contaminate plants mainly in the form of surface deposits which have been intercepted from rainfall or in the form of dry dust deposits. Plant contamination due to recycling of these nuclides through root systems appears to be of lesser significance. Such views have not yet been tested in tropical communities. Under the long-term objectives of the Terrestrial Ecology program a series of tracer experiments were planned to study the entry of nuclides into forest trees via root systems. Battelle aided in the acceleration of these plans by partially funding the first experiment in the series which involved a study of the uptake of ^{134}Cs, ^{85}Sr, and ^{54}Mn through the roots by tropical understory vegetation. This experiment was initiated on January 6, 1966, and is still in progress. It is now planned to obtain observations on this experiment for at least one year before it is terminated.

METHODS

Panama Collections

Samples from the field were collected from a series of sites which represented either discrete vegetational types or points along an identifiable vegetational gradient. Gradients which are most often encountered are those which occur in relation to changing altitude. At each sampling site leaves from eight to ten different tree species, prominent epiphytic plants, leaf litters, and soils are taken.

In the Panama collections, several sites were sampled near the Boca de Lara base camp which varied significantly in vegetative type. These sites are designated in the report as follows:

> Circle Road. A site near sea level about 1/4 mile from camp along the graded road which forms a loop near the camp; an area of no apparent recent logging activity.
>
> Sante Fé Road. Sites along the graded road which connects camp Boca de Lara with the village of Santa Fé. Two sites were sampled along this road: One was a small banana farm and the other was an area of recent logging activity which contained considerable second growth.

> Mangrove. Samples collected from the mangroves immediately adjacent to the camp on the downstream side.
>
> Pidiaque. Collections made from the top of a small ridge known as "Pidiaque" near the site of the grading activity in preparation for a weather station.

Experience from the Puerto Rican collections indicated the desirability of obtaining a series of samples from varying altitudes. The highest altitude site available was on Pidiaque which reached an elevation of only about 975 feet above sea level. It was desired to sample peaks of several thousand feet but no access to peaks of this size was available. It was suggested that the required altitudinal sequence be obtained from the peak known as Cerro Jefe which occurs outside of the Canal Zone. Since this was the only feasible alternative the sequence was obtained from this peak. Samples were also taken from forests of Barro Colorado and Fort Clayton in the Canal Zone at near sea level in order to intercompare the amounts of fallout at low elevation between the latitude of the Canal Zone and that of Darien Province.

The samples collected in Panama were biologically decontaminated in San Juan under the supervision of USDA Plant Quarantine officials either by heat treatment or by freezing. They were then oven-dried and counted in bulk in a Marinelli beaker by gamma scintillation spectrometry using a 3x3 NaI(Tl) crystal connected to a 400 channel pulse height analyzer. The resulting gamma ray spectra were resolved by computer solution of simultaneous equations using coefficients generated from standards of known activity.

Errors in the resolution of the complex gamma spectra are difficult to assess because of the difficulty in computing the propagation of errors involved in arithmetic operations, the uncertainty in the determination of coefficients, and the absolute uncertainty in the disintegration rates of the standards. Repeated measurements on a sample which gave in excess of 100,000 detected gamma rays per 100 minutes indicated that all of the reported nuclides could be determined with a precision of 5 per cent of the mean. Errors due to other sources have not been measured but would tend to bias the results in a constant direction since the values once determined are used as constants. The bias may be at least as large as the random error so that it would seem that the samples containing the largest amounts of radioactivity could have uncertainties of 10 per cent. Samples with low count rates, notably the food results given in this report, have considerably greater levels of uncertainty. Minimum detectable levels for the nuclides given in this report are variable but approach 0.01 pCi/g under favorable conditions.

Tracer Experiment

The tracer experiment described here was established in January, 1966, at the El Verde Puerto Rico experiment station in cooperation with Dr. H. B. Tukey, Jr., of Cornell University who was acting as a consultant to the project at the time. The experiment was designed with four plots of one to two meters square each of which enclosed representative specimens of understory vegetation ranging in height from a few inches to 15 feet. Two of the plots were stripped of the natural forest litter in order to expose the soil and surface roots and two of the plots were left unaltered. All of the plants in the plots were protected prior to the application of nuclides by wrapping with plastic bags or with aluminum foil. The nuclides ^{134}Cs, ^{85}Sr, and ^{54}Mn were applied in carrier-free aqueous mixture in the form of a spray delivered from a hand-pumped garden sprayer. Approximately one mCi/m^2 of each nuclide was applied directly to the soil. Within 24 hours after the application of the spray the plants were uncovered.

Leaf samples were collected from small (0-1 ft), medium (1-3 ft), and large (>3 ft) plants at first on a biweekly basis and later on a monthly basis. The collections were composited on a size basis to avoid the depletion of plant material which would occur if collections were made from each individual in the plots. The monthly sampling program was also instituted in order to conserve plant material when it was found that uptake of the nuclides was sufficiently slow to be characterized by samples taken over this interval.

The samples were oven-dried and counted by gamma scintillation spectrometry. The spectra were resolved by desk calculator solution of simultaneous equations which were generated by counting standards of each nuclide. Nuclide count rates were corrected for decay to the beginning of the experiment and the results were plotted as a function of time for each size class within littered and unlittered plots.

RESULTS

Panama Collections

Levels of ^{144}Ce, ^{137}Cs, and ^{54}Mn in leaves and litters collected in lowland forests of Darien, Panama, are presented in Table 1.

The results for lowland forests indicate generally low levels of all the nuclides for several vegetation types regardless of past history of management or of growth habit. Similarly situated forests in Puerto Rico have levels of 2-6 pCi/g of ^{144}Ce and ^{137}Cs with lesser amounts of ^{54}Mn. The low levels of nuclides in the Panamanian forests are consistent with findings of the 80th meridian survey(3) where it is reported that fallout levels normally decline sharply near the equator relative to the northern

TABLE 1. LEVELS OF ^{144}Ce, ^{137}Cs, AND ^{54}Mn IN PLANTS OF SEA LEVEL FORESTS OF DARIEN, PANAMA

Location	Plant Type	^{144}Ce	^{137}Cs	^{54}Mn
			pCi/g	
Circle Road	Trees (Ave)	0.51	0.20	0.08
	Cuipo fruit	1.27	0.12	Not Detected
	Vine	0.03	0.31	Not Detected
	Termite Nest	0.27	0.07	0.01
	Litter	0.08	0.10	0.07
Santa Fé Road:				
Cut Over Site	Trees (Ave)	0.57	0.22	0.05
	Litter	1.52	0.54	0.15
Banana Farm	Trees (Ave)	1.36	0.38	0.07
	Litter	0.82	0.20	0.14
	Banana	0.30	0.07	0.03
	Platano	0.25	0.05	0.15
Mangrove	Red Mangrove	0.15	0.05	0.05
	Moss	1.21	0.59	0.07
	Mora	0.42	0.18	0.17
	Lichen	1.71	1.43	0.04
	Salt Water Fern	0.20	0.54	Not Detected

latitudes. The data show that there is little tendency for plants of the lowland forests to accumulate fallout nuclides or to concentrate them in any differential manner. A possible exception is in the mangroves (Rhizophora) where it is found that the red mangrove plant appears to have significantly less radioactive material than trees of the surrounding forests while the epiphytic plants of the mangroves including mosses, lichen, and fern appear to have higher levels of ^{144}Ce and ^{137}Cs but not of ^{54}Mn, than the surrounding vegetation.

The relationship between amounts of fallout nuclides in forests and altitude is shown in Table 2. A generally increasing level of contamination with increasing altitude is shown. It is well known that fallout scavenging from air is related to amounts of rainfall and it is assumed that the increases with altitude shown here are at least partially explainable on this basis although no rainfall data are available for these sites. It is apparent from the data, however, that many plants in the altitudinal sequence are contaminated to much higher levels than surrounding vegetation at the same elevation and appear to be accumulators of the nuclides. The plants which appear to be the most efficient accumulators are those with an epiphytic growth habit. As has been found in the high altitude forests of Puerto Rico by Kline and Odum(2) the mosses which hang from limbs in the Panamanian Elfin forest are most highly contaminated. The general role of epiphytic plants as accumulators has been observed repeatedly in the forests of Puerto Rico and the results from Panama seem to indicate that this behavior may be widespread in tropical forests.

Table 2 also shows results from specimens which were collected from an area of about 3000 feet elevation on Cerro Jefe which had recently

TABLE 2. LEVELS OF ^{144}Ce, ^{137}Cs AND ^{54}Mn IN PLANTS OF MOUNTAIN FORESTS OF PANAMA

		^{144}Ce	^{137}Cs	^{54}Mn
Location	Plant Type		pCi/g	
Pidiaque (1000 ft)	Trees (Ave)	0.82	0.91	0.14
	Ferns	0.34	2.81	0.16
	Philodendron	0.78	5.39	0.57
	Surface litter	1.21	0.97	0.52
	Soil "A" horizon	2.85	2.06	0.20
	Soil "B" horizon	1.60	0.05	0.06
Cerro Azul	Trees (Ave)	0.43	1.15	0.11
	Spiny epiphyte	0.19	3.10	0.06
	Leaf litter	1.07	0.51	0.07
	Soil 0-3"	3.35	3.25	0.30
Cerro Jefe Elfin forest (3600 feet)	Trees (Ave)	2.84	3.57	0.83
	Mixed bryophytes (trunks)	6.35	4.81	0.48
	Mixed bryophytes (ground)	10.42	8.14	0.72
	Mosses (tree canopy)	31.13	9.88	1.00
	Lycopodium (edge)	5.57	5.19	0.85
	Litter	8.30	4.11	1.60
Burned area below Cerro Jefe	*Cyrilla*	1.06	2.13	0.26
	Tree fern	0.03	3.01	0.10
	Phytolacca	3.73	4.23	2.28

been burned. The Cyrilla sp. and tree fern (unidentified) were collected from intact forest adjacent to the burned area while the Phytolacca sp. was collected in the burned area. The former two species were collected to verify that relatively high levels of nuclides were present in the burned area prior to burning. The Phytolacca is a fast growing successional shrub which is often found to be the first species to invade a disturbed area. The radionuclide content of this species may reasonably be assumed to be the result of uptake by roots rather than surface contamination on leaves since the plants were young and did not have long duration of exposure to airborne nuclides. The relatively high levels of nuclides present in Phytolacca therefore indicate that radionuclides present in plant ash may be biologically available to young, fast-growing plants. This would appear to be of significance in sea-level canal planning since agricultural practice in Central America includes cutting and burning of forest vegetation prior to planting crops.

The observations on Phytolacca which have been made in Panama were previously made on the same species in Puerto Rico on plants of known age. In Puerto Rico it was found that this species acquired levels of fallout radioactivity which were approximately the same as that of surrounding old vegetation after only six months of growth.

Foods were collected in Panama by workmen from their accustomed sources of supply near the base camp. Levels of fallout nuclides in the food are given in Table 3. None of the foods were peeled or washed prior to counting. The radionuclide contents of foods appear to be significantly lower than those of surrounding sea level forest vegetation. It seems likely that levels could be reduced to even lower levels by following the normal preparative practices of peeling and washing prior to consumption.

TABLE 3. LEVELS OF ^{144}Ce, ^{137}Cs, AND ^{54}Mn IN FOODS OF DARIEN, PANAMA

Food	^{144}Ce	^{137}Cs	^{54}Mn
	pCi/g		
Corn	0.04	0.02	Not Detected
Rice	0.55	0.06	Not Detected
Square banana	0.05	Not Detected	0.02
Plantain	0.22	0.03	Not Detected
Otó	0.01	0.01	0.04
Yuca	0.01	0.01	0.01
Ñame	0.12	0.04	0.05
Sweet potato	0.40	0.07	0.17
Banana	0.04	0.07	0.06
Ave	0.18	0.06	0.04

The data in Table 4 indicate levels of fallout nuclides in forest litters of some sites in the Canal Zone. These are included as a rough index of comparison of the amounts of nuclides between Canal Zone sites and Darien sties. There is no reason to reject the hypothesis that the amounts of fallout between the two sites are the same. The palm shown in Table 4 was deliberately chosen for its heavy burden of epiphytic growth and is therefore probably abnormally high in fallout nuclides in comparison with vegetation in the immediate vicinity.

TABLE 4. LEVELS OF ^{144}Ce, ^{137}Cs, AND ^{54}Mn IN LITTER AND LEAVES OF CANAL ZONE FORESTS

Sample	^{144}Ce	^{137}Cs	^{54}Mn
	pCi/g		
Litter (Ft. Clayton)	1.28	0.77	0.16
Litter (Barro Colorado)	0.65	0.47	0.27
Palm leaves (Barro Colorado)	2.15	1.98	0.19

Measurements of radionuclides in soils were generally uninstructive due to the fact that fission products were obscured by the natural radioactive nuclides which were present. This was most often the case in soils of the lowlands which were formed on the residual material from limestone weathering. Figure 1 shows a sample gamma ray spectrum from soil taken from the banana farm on the Santa Fé road. The prominent peaks are those of ^{226}Ra daughters or of ^{40}K. Radium daughters have also been found to occur prominently in the limestone soils of Puerto Rico. At this writing, procedures have not yet been established for the quantitative measurement of ^{226}Ra daughters in soil.

Tracer Experiment

Uptake of ^{134}Cs, ^{85}Sr, and ^{54}Mn is shown for plants of different size in Figures 2, 3, 4, and 5. Figures 2 and 3 show results from plants grown on plots from which the forest litter had been removed and Figures 4 and 5 show results for plants grown on undisturbed plots. There was little apparent difference in nuclide uptake due to the presence or absence of litter. The data show, however, that only the very smallest plants appear to have made appreciable uptake of nuclides through the roots. Plants from 1 to 3 feet tall and those greater than 3 feet show very low radioactivity after six months of growing in soil which contained about one mCi/m^2 of each of three nuclides.

The large fluctuations in nuclide concentrations in the plants from 0-1 foot tall early in the experiment are thought to be due to possible surface contamination of some of the plants by the nuclide spray. It was calculated that the activity found on these possibly contaminated plants could be accounted for if only 50λ of the spray solution reached the plant

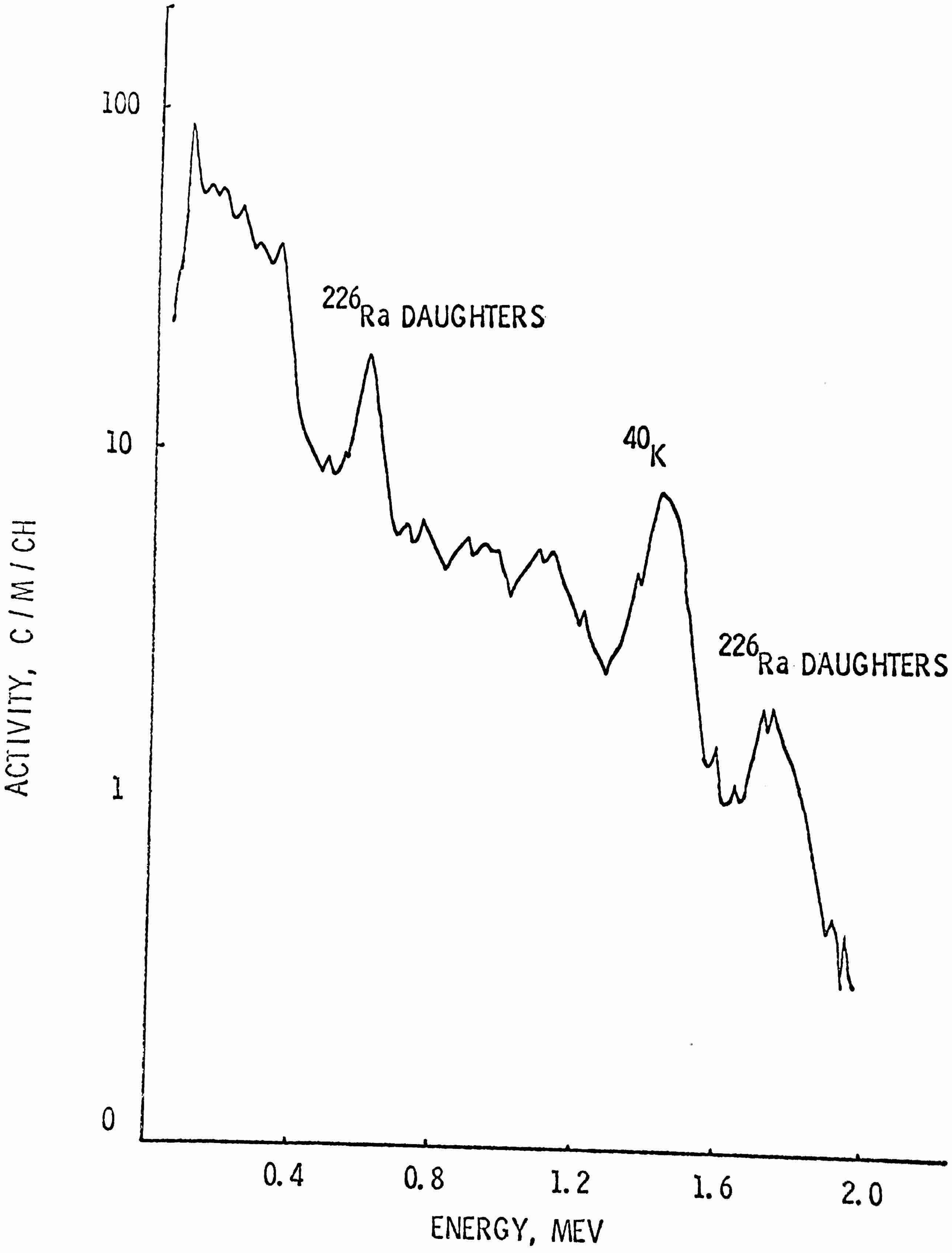

FIGURE 1. RADIUM DAUGHTERS IN SURFACE SOIL TAKEN FROM A BANAMA FARM IN DARIEN, PANAMA

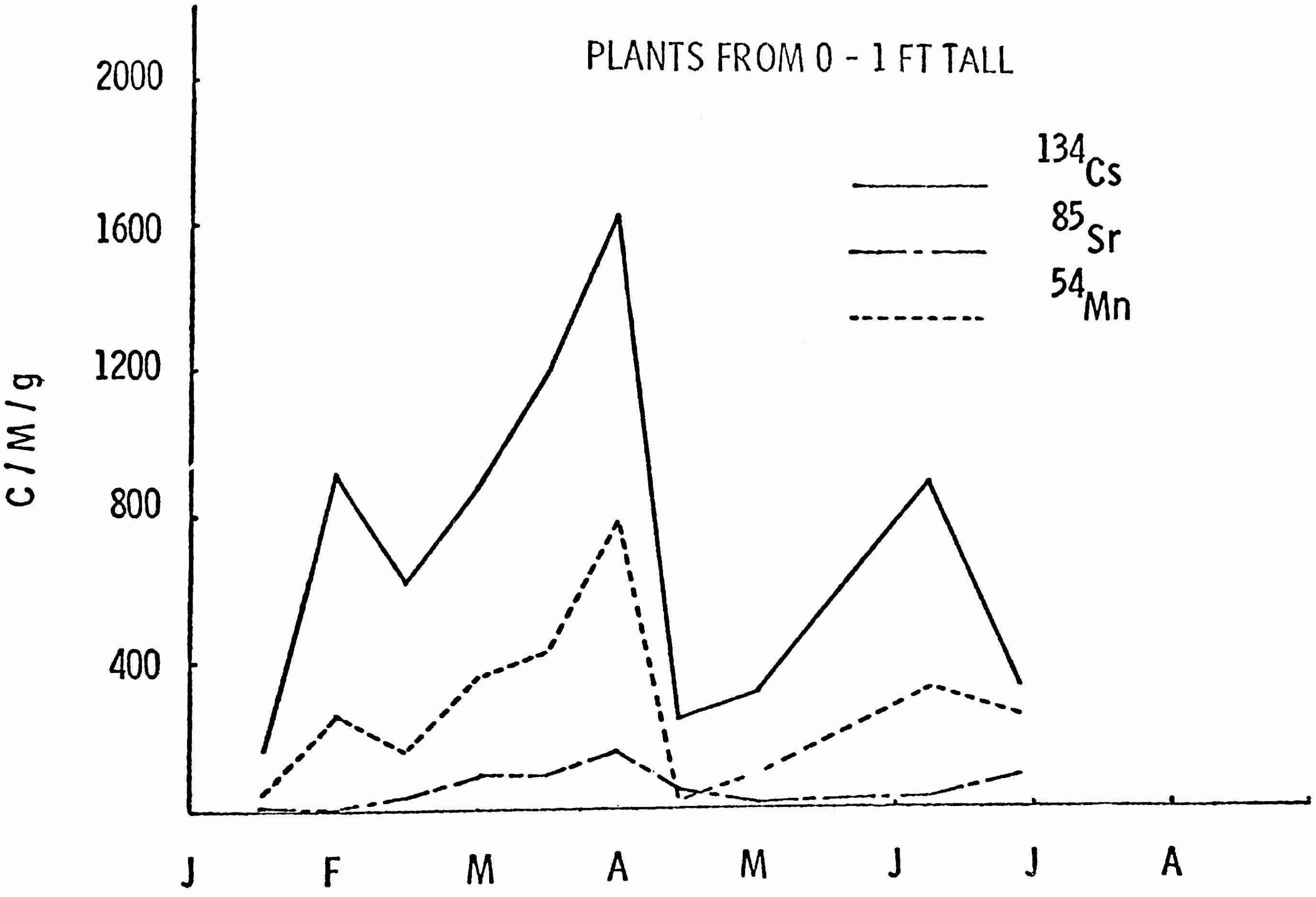

FIGURE 2. UPTAKE OF ^{134}Cs, ^{85}Sr, AND ^{54}Mn THROUGH ROOTS OF UNDERSTORY PLANTS (FOREST LITTER REMOVED).

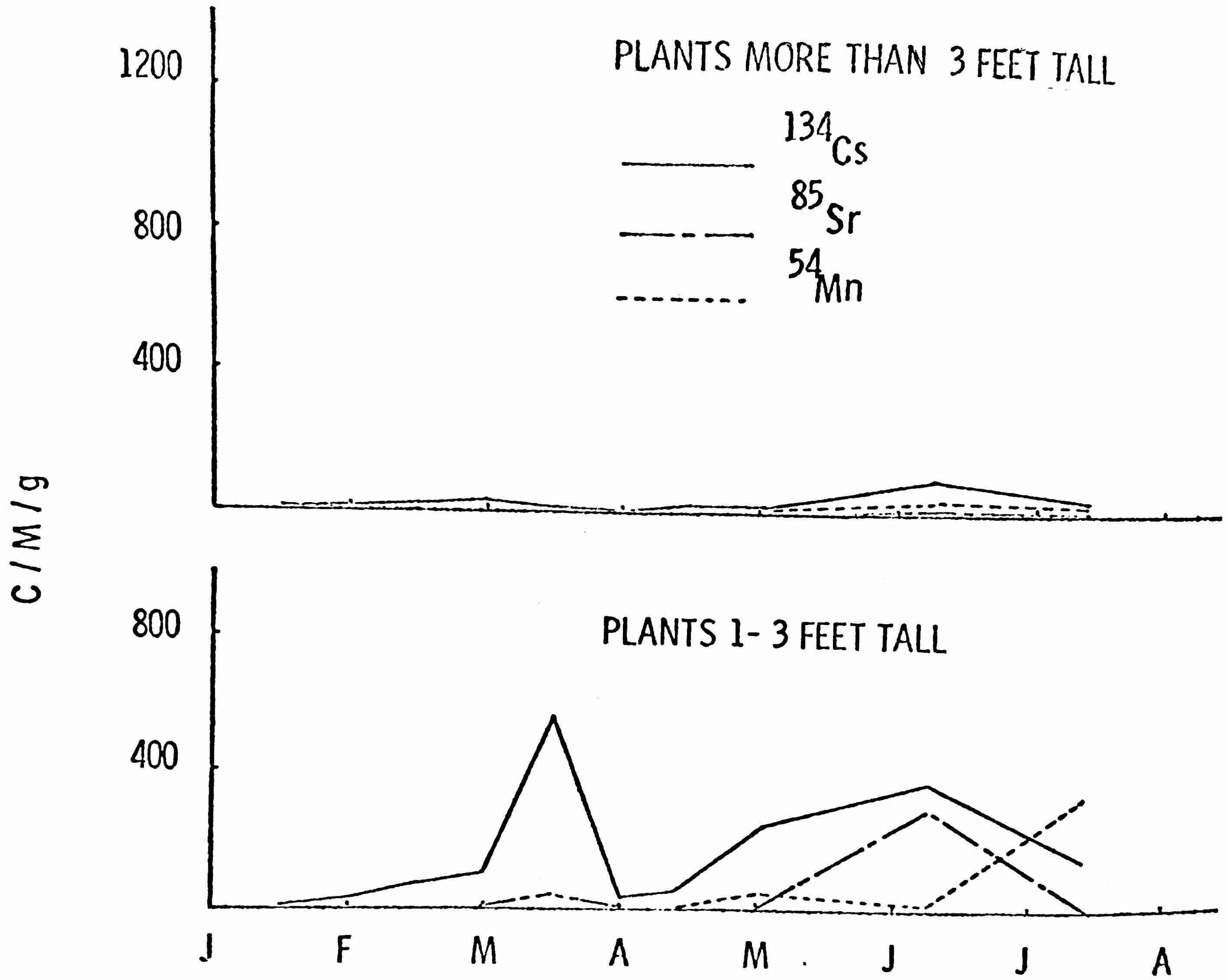

FIGURE 3. UPTAKE OF ^{134}Cs, ^{85}Sr, AND ^{54}Mn THROUGH ROOTS OF UNDERSTORY PLANTS (FOREST LITTER REMOVED).

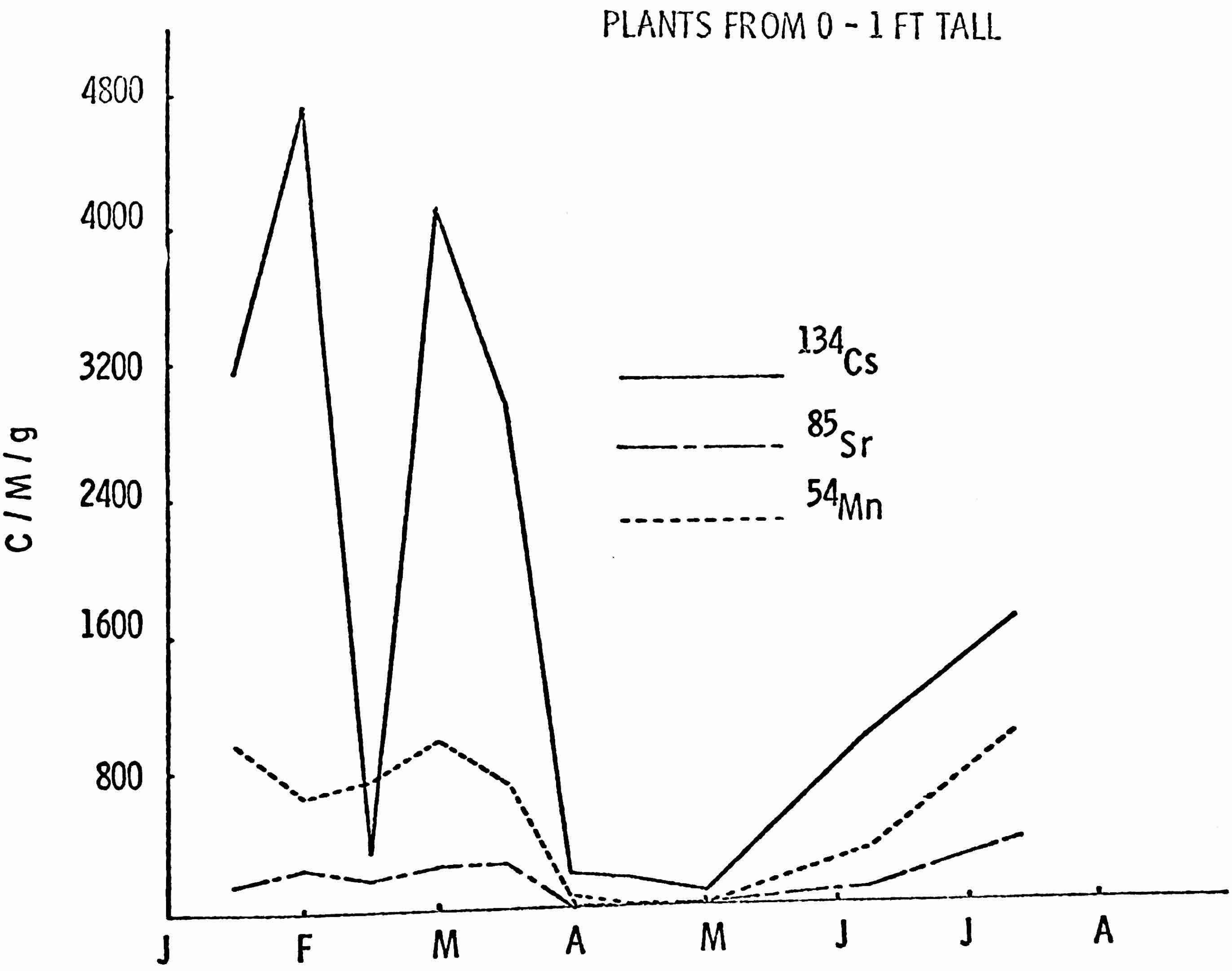

FIGURE 4. UPTAKE OF ^{134}Cs, ^{85}Sr, AND ^{54}Mn THROUGH ROOTS OF UNDERSTORY PLANTS (FOREST LITTER IN PLACE).

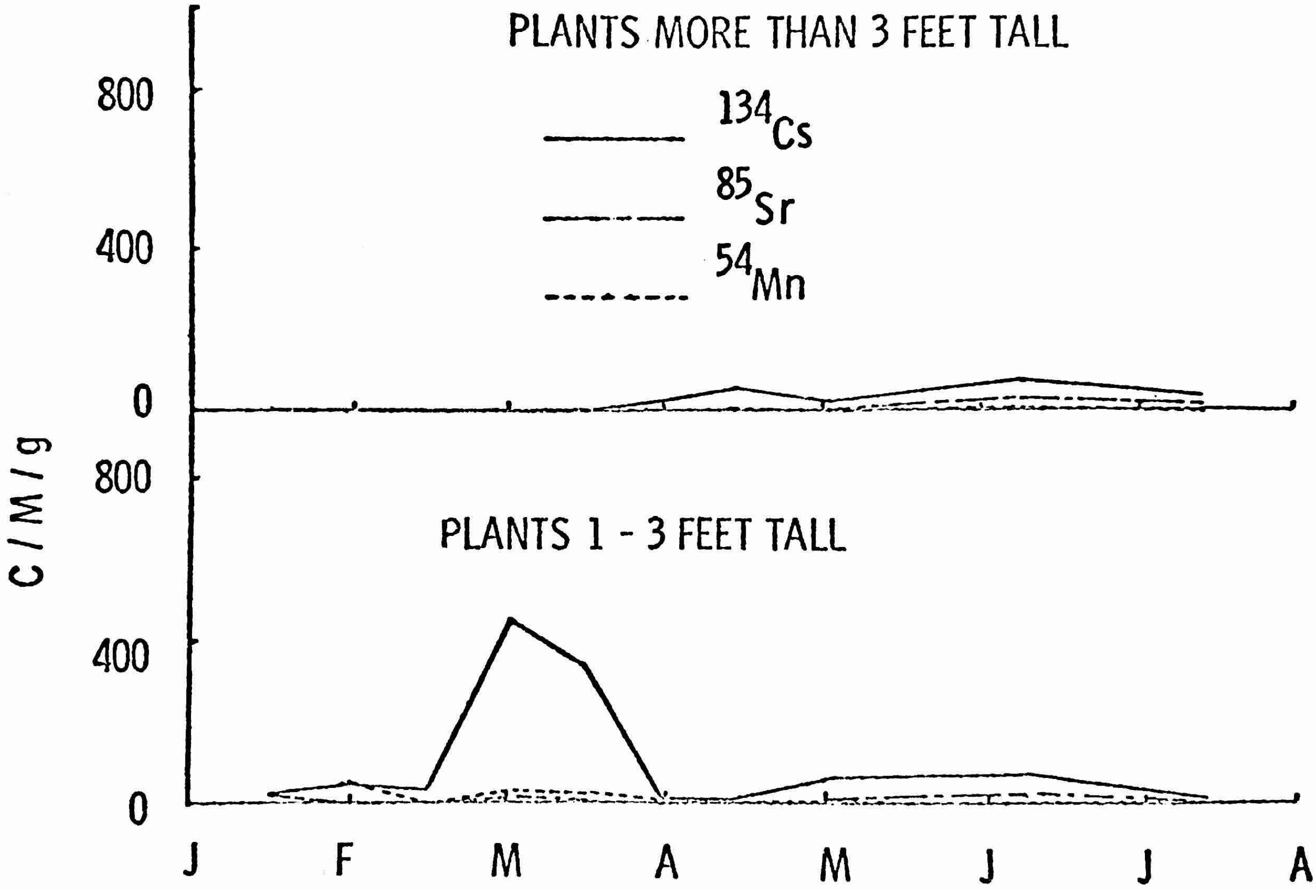

FIGURE 5. UPTAKE OF ^{134}Cs, ^{85}Sr, AND ^{54}Mn THROUGH ROOTS OF UNDERSTORY PLANTS (FOREST LITTER IN PLACE).

surface. Even though the plants were covered during the spray process, this amount of the spray liquid could have reached the surfaces in the form of fine mist.

The low levels of nuclides in the larger plants may be accounted for in part by the fact that the nuclides undergo greater dilution in these plants than in the smaller plants. The rates of uptake, however, are independent of dilution and indicate that the larger plants are not rapidly cycling the nuclides through roots. These conclusions are applicable only to understory vegetation where it is known from previous work that the growth rates are slow. Conclusions on movement of nuclides in overstory vegetation must await further experiments since it has been observed repeatedly at El Verde that canopy trees are constantly replacing old fallen leaves with new growth and in addition appear to make new net growth on a year-round schedule.

Comparisons between nuclide levels in vegetation and in litter are shown in Table 5 for plants contaminated in the understory tracer

TABLE 5. COMPARISON OF THE DISTRIBUTION OF FALLOUT RADIONUCLIDES WITH THAT OF ROOT ABSORBED NUCLIDES IN UNDERSTORY FOREST PLANTS OF EL VERDE, PUERTO RICO

	Fallout pCi/g		Tracer c/m/g	
Nuclides	Trees	Litter	Trees	Litter
^{54}Mn	2.9	2.4	3.8	34429
^{137}Cs	10.9	6.4		
^{134}Cs			79.2	21354
^{85}Sr			48.9	7387

experiment. The data show that nuclide levels in the fallout contaminated plants are approximately the same for litter and leaves while in the tracer experiment radioactivity levels in litter exceed those in leaves by factors of 500 to 1000. It is apparent that the nuclide content of plants in the El Verde forest probably cannot be accounted for on the basis of root uptake, and that much of the activity must be in the form of surface deposits which were intercepted from rainfall.

Measurements of environmental half-lives of fallout radionuclides by Kline(1) indicate that these periods are very long in tropical forests when determined for nuclides of probable stratospheric origin. Tracer experiments of the type described here will enable assessment of the relative importance of root uptake in the incorporation of nuclides into tropical vegetation. Neither observations on worldwide fallout nor tracer experiments, however, duplicate the situation likely to be encountered during possible nuclear excavations in the tropics. Martin has pointed out(4) that much of the close-in fallout which occurs immediately after a nuclear detonation is in particulate form and that effective half-lives of this form on leaf surfaces are relatively short in comparison to the radioactive half-life. The actual residence time of close-in fallout in tropical forests will then depend on the chemical nature of the particles produced. If the contaminating particles are sufficiently soluble to allow appreciable transfer of nuclides to leaf surfaces and epiphyllous and epiphytic plants then these components of the forests are likely to be contaminated in such a way as to have long environmental half-lives. If the particles are insoluble, however, then environmental half-lives may be short due to the opportunity for removal from plant surfaces by physical processes such as wind or rain.

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Dr. James A. Duke	Professional botanist, BMI. Location and identification of plant specimens.
Dr. Robert Hutton	Biologist Army Tropical Test Center, Fort Clayton, Canal Zone. Use of facilities and equipment for sample processing.

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Vegetative Sprouting Following Irradiation of a Tropical Rain Forest

Carl F. Jordan

Recovery of a forest that is damaged by radiation can occur either by sprouting of vegetation that existed prior to radiation, or by seeds that germinate after radiation ceases. Recovery of the radiation damaged forest in Dawson County, Georgia, was entirely by sprouting. No new tree growth was found which originated from seed (Cotter and McGinnis, 1965). In the irradiated forest near El Verde, Puerto Rico, sprouting is playing a less important part in the recovery than is vegetation established from seed. The object of this study was to determine the pattern of sprouting in the irradiated tropical rain forest, and to compare the importance of recovery by sprouting with recovery by trees established from seed.

In a general survey of the area, it appeared that sprouting often occurred at locations that had been shielded from the gamma radiation by rocks, or by soil where the topography dropped sharply downward to the northwest of the source. To determine whether sprouting actually was associated with shielding; in November 1966, a sighting was taken from the base of each sprout of every sprouting tree towards the gamma source, and the presence or absence of intervening rocks or soil was noted.

Showing that a large percentage of the trees that sprouted occurred in a shielded location does not necessarily show that sprouting is associated with shielding. For example, 80% of the sprouts might arise from protected locations, but if 98% of the entire area was protected, most of the sprouting would necessarily have to originate from protected locations regardless of whether protection had anything to do with sprouting. Therefore, it was necessary to determine what proportion of the irradiated area was naturally shielded by rocks or by soil on steep slopes.

To determine the proportion of the area that was shielded, 128 points were located around the source. Most of the sprouting occurred between 10 and 15 meters from the source. Therefore, points were located 10, 11, 14, and 15 meters from the source on 32 radials of the compass. From each of these ground level points, a sighting was made towards the source, and the presence or absence of shielding was noted. Forty-eight percent of the points were shielded. Therefore, if shielding had no influence on sprouting, 48% of the sprouts should have occurred at protected locations. To determine at what level of confidence the percentage of protected sprouts differed from this theoretical 48%, the formula

$$Z = \frac{P - Po}{\sqrt{\frac{Po\ (1-P_o)}{N}}}$$

was used (Dixon and Masses, 1957). The letter P is the percentage of protected sprouts, Po the theoretical percentage if there was no association (48%), and Z is the level of confidence taken from a normal distribution table.

The percentage of sprouts occurring at protected locations differed from 48% at the 99% level of confidence for all species except Palicourea riparia (Table 1). Palicourea riparia differed at the 87% level, but the percentage of protected sprouts was less, rather than greater than 48%. This means that for all species except P. riparia, shielding increases the chances that a tree will sprout. Palicourea riparia was the most radiation resistant species in the rain forest near El Verde (Watson).

In the temperate region, the roots of almost all trees are below the soil surface and thus are shielded by soil. In the irradiated forest in Georgia, most of the sprouts originated about 4 inches below the soil surface, and 3 inches of soil was a sufficient shield to effectively decrease the dose to underground tissue (Cotter and McGinnis, 1965).

In the tropical rain forest in Puerto Rico, a large percentage of the roots are on top of the soil (Odum - a) (McCormick - a), and thus are not protected from radiation as are trees in the temperate latitudes. Sprouting usually occurs when rocks or steep slopes shield the base of the tree and surrounding roots from direct radiation. Therefore, the importance of sprouting in recovery of a tropical rain forest from any critical radiation exposure probably will depend on what portion of the roots are shielded from radiation. It is likely that if the radiation field consisted of both neutrons and gamma radiation as in Georgia (Cowan and Platt, 1963), there would have been little, if any, sprouting because rocks and soil between the source and the vegetation are not an effective barrier against neutrons because of scatter (Cowan and Platt, 1963).

If sprouting in the tropical rain forest is associated with shielding, why were there some apparently unshielded sprouts? McCormick (b) said that meristems and other tissue on the rear sides of trees receive only 39 to 77% as much radiation as tissues on the front sides. Some of the apparently unshielded sprouts may have been shielded by their own trunk, or trunks of other trees which had fallen before this study was made. Another possibility might be that unshielded trees that were relatively far from the source received enough radiation to initiate sprouting, but not enough to kill the trees. However, this cannot be proven, because the percent of unshielded trees at relatively great distances from the source did not differ significantly from the percent of unshielded trees close to the source.

Since sprouting was the sole means of forest recovery in Dawson County, Georgia, a study was made to determine the relative importance of sprouts versus trees established from seed in the tropical rain forest. A grid of 900 one-square meter squares was laid out with nylon string in the area surrounding the source. At each grid corner, a plumb bob was dropped, and all leaves that touched the line were tallied except those of grass. Only 16% of the leaves of vegetation originating since radiation was of sprout origin. Of the 84% which originated from seed, 89% were tree species, and 11% were vines, herbs, and ferns.

In assessing the differences in relative importance of seedlings and sprouts in Georgia and Puerto Rico, differences in periods of time of radiation exposure to the forests must be considered. While the tropical rain forest was irradiated during one continuous three-month period (Odum - b), the reactor at Georgia was operated intermittently for 2 years, with two periods of high level operation in July 1959, and August 1960. Cotter and McGinnis (1965) state that although production of new seeds was eliminated by radiation, seedlings may have played a more important part in the recovery of the forest if radiation had stopped after 1 year, because there may have been seedlings in 1960, which had originated from seeds produced prior to radiation.

Extended periods of irradiation of temperate forests such as the one at Brookhaven would eventually kill back-sprout growth even though roots are protected (Sparrow and Woodwell, 1963).

Location of sprouts on individual trees in the tropical rain forest followed a trend. For all species, a greater percentage of sprouts occurred on the side of the tree facing the source than on the side away from the source. If the side of the tree on which the sprouts occurred was not influenced by the location of the source, 50% of the sprouts should have occurred on each side of all sprouting trees. With the use of the same formula as above, the level of confidence at which the actual percent differed from 50% was calculated (Table 2).

This response could be a complex interaction of shielding, radiation scatter and distance, or it could be a simple response to light. Because of radiation damage to the canopy, more light enters the forest from above the source than other locations.

Sprouting occurred in a relatively narrow band surrounding the source (Tables 3 and 4). No sprouting occurred closer than 5 meters from the source, nor further than 18 meters, as of November 1966. The dose range for that distance was 5 x 10^5 R to 10^4 R (McCormick - b).

The largest trees had the most and the longest sprouts, but there was no strong correlation between any particular species and number or length of sprouts.

SUMMARY

Sprouting is less important in the recovery of a tropical rain forest in Puerto Rico from a short period of radiation than in the recovery of a temperate forest in Georgia. In the tropical rain forest most of the roots are on the soil surface, and thus are directly exposed to radiation whereas in the temperate zone, roots are shielded by soil. Sprouting in the rain forest usually occurred only where there was shielding by rocks or soil.

Sprouting occurred in a relatively narrow band surrounding the radiation source, and usually on the side of the tree facing the source.

TABLE 1

Number and Percentage of Sprouts Occurring at Protected Locations in the Irradiated Area

Species	Total number of sprouts	Number of protected sprouts	Percent protected	Confidence level at which percent differs from 48%
Sloanea berteriana	338	321	95	99
Meliosma herbertii	22	19	86	99
Palicourea riparia	125	51	41	87
Dacryodes excelsa	134	118	88	99
Inga laurina	67	52	77	99
Rourea glabra	34	31	91	99
24 other species	263	189	72	99

TABLE 2

Percentage of Sprouts Occurring on the Side of the Tree Facing the Source, and the Levels of Confidence at Which These Percentages Differ from 50 Percent

Species	Percentage of sprouts on the side of the tree facing the source	Level of confidence at which percentage differs from 50%
Sloanea berteriana	63	99
Meliosma herbertii	72	97
Palicourea riparia	64	99
Dacryodes excelsa	56	83
Inga laurina	55	57
Rourea glabra	73	99
24 other species	70	99

TABLE 3

Distances of Sprouting Trees from the Gamma Source

Species	Average distance of tree from source (meters)	One standard deviation from the average (meters)
Sloanea berteriana	14.6	3.6
Meliosma herbertii	15.3	2.5
Palicourea riparia	12.9	4.0
Dacryodes excelsa	13.3	4.3
Inga laurina	12.3	2.7
Rourea glabra	12.5	4.6
24 other species	13.6	2.6

TABLE 4

Number of Sprouting Trees in Concentric Rings Around the Source

Meters from source	Number of sprouting trees
0-5	0
5-10	25
10-15	117
15-18	121
18	0

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*These papers will appear in the forthcoming book "A Tropical Rain Forest." H. T. Odum, ed. Final chapter numbers and page numbers have not been assigned at this writing.

Recovery of a Tropical Rain Forest After Gamma Irradiation

Carl F. Jordan

SUMMARY

A tropical rain forest in Puerto Rico was subjected to irradiation from a 10,000 curie cesium source from January through April 1965. At approximately the same time, a nearby forested area was mechanically stripped of green vegetation, and two other areas were treated with herbicides. Two years after treatment, indices of vegetation quality, quantity, and species diversity were measured in the experimental areas. Although minor differences existed, most of them could be accounted for by factors other than radiation effect. The only difference that was uniquely a radiation response was sprouting of trees near their base where they were shielded from radiation.

INTRODUCTION

One of the objectives of irradiating an ecosystem is to find out how a radiation-damaged ecosystem recovers. Such knowledge is not only useful in forecasting conditions following nuclear disasters, but also helps man understand how ecosystems work.

Several temperate-zone ecosystems have been irradiated, such as the ones at Brookhaven National Laboratory, New York (Sparrow and Woodwell, 1963), and Dawsonville, Georgia (Platt, 1963). This report deals with the recovery of vascular vegetation of a tropical rain forest damaged by gamma radiation, and compares succession following irradiation with succession following other disturbances.

METHODS

The irradiated area is located near El Verde, Puerto Rico, in the Luquillo Experimental Forest, on the eastern end of the Island. The site is at an elevation of 510 m in a forest type described as Tabonuco (Wadsworth, 1951). Rainfall is approximately 240 cm a year, with greater than 10 cm every month. A 10,000 curie cesium source irradiated the forest with gamma radiation from January through April 1965. A precise description of the irradiation technique, as well as effects of gamma radiation on the tropical ecosystems are given by Odum et al. (1966).

For this recovery study, indices of vegetation quality and species diversity were taken in January 1967, in the irradiated area, in a "cut center," and in two areas treated with herbicides. Indices of vegetation quantity were taken in the irradiated area and the "cut center" in August 1966, and February 1967.

The "cut center" was treated in the spring of 1965. It is an area 20 m in diameter from which all green living material was removed by cutting small branches from trees, and by stripping small vegetation from the ground, so that it resembled the irradiated area at that time (Smith, 1966).

The herbicide areas are plots 52 by 74 m, which were treated from the air on October 14, 1965, with the herbicide Picloram. Herbicide area No. 1 received 6 pounds per acre, and No. 2 received 10 pounds per acre. The herbicide persisted in the soil for approximately 3 to 6 months (C. C. Dowler, personal communication).

All study areas are at approximately the same elevation, and near the top or on the sides of moderately sloping ridges. The mature forests surrounding all study areas appeared to be similar.

Surrounding the source location in the irradiated area, a grid of 900 one-square meter squares was laid out with nylon cord. In the four cardinal directions, the grid extended 15 m from the source. On the axes which pass through the source in these directions, the squares were run out beyond the edge of the grid to a distance of 30 m. These additional strips were 2 m wide. In the "cut center," strips 2 m wide consisting of $1m^2$ squares were run out to 30 m in the four cardinal directions.

At every corner of the grid squares, leaf area index of vegetation was measured. Leaf area index is an index of the quantity of vegetation. An index of three indicates that there are $3m^2$ of leaf surface for every square meter of soil surface. Leaf area indices were divided into indices for new, and indices for old vegetation. New vegetation is defined as seedlings established after treatment in 1965, and sprouts near the base of damaged trees in the irradiated center. Old vegetation is that which existed prior to treatment in 1965. Leaves on twigs sprouting in the canopy of the "cut center" trees were considered old vegetation. Occasionally there was doubt as to whether a seedling was established before or after treatment. If it was a shade-intolerant species typical of secondary succession, it was considered new, but if it was a shade-tolerant canopy species, it was considered old.

Leaf-area index of vegetation less than 6 ft high was measured by dropping a plumb bob and counting the leaves touching the string. Leaf-area index of vegetation over 6 ft was measured as follows: A mirror with a hairline cross in the center was mounted at 45 degrees on one end of a level; on the other end was mounted a peep-sight. When the device was level, a vertical line of sight was obtained; and the number of sprays of leaves through which the line of sight passed was counted. It was assumed that a spray of leaves averaged one leaf in thickness. While there was no difficulty in counting sprays when there were less than about three, it was impossible to count sprays in areas with thicker canopies; therefore, a visual estimate was required. As a basis for this estimation, leaf-area index of an undamaged canopy in the forest 50 m from the radiation center was measured as follows: A plumb bob on a long line was thrown 16 times from the top of a 72 ft tower, 12 ft above the top of the canopy; the leaves touching the line were counted. The average leaf-area index was 4.87, and one standard deviation was .82.

The leaf-area index values for each m^2 of the grid and of the strips were obtained by averaging the measurements from each of the four corners of every square. The values for the strips are averages of the two squares on either side of the axes.

To determine quality of vegetation, importance values of species in all areas were calculated by adding relative density, relative frequency, and relative dominance (Phillips, 1959). Data was taken as follows: Seventy-five points were located 1 m apart on strips running through the center of each of the two herbicide areas, and one-half meter apart on compass radials in the cut and irradiated centers. Since there appeared to be two vegetational types in the irradiated center, 75 points were taken in each type. At each point, a cross was laid down, and the diameter was measured of the plant nearest the center in each of the four quarters. Only new vegetation was counted. Since basal sprouts were not encountered on the radials in the "cut center," and since comparisons between areas were desired, basal sprouts were not tabulated in the importance value measurements.

To quantify the similarity of plots, "percentage similarity" was calculated between all pairs of plots with the formula: Percentage similarity =min. (a,b) (Whittaker and Fairbanks, 1958). In this study, _a_ and _b_ were importance values of each individual species divided by total importance values of all species in that area.

Species diversity for each area was determined by counting individuals and species as they occurred in the field notebook used for importance values. Species diversity lines were plotted using standard regression analysis techniques, and differences between lines were calculated by analysis of covariance. Species diversity for seedlings in the irradiated area in March 1964, was from McCormick (1966).

RESULTS AND DISCUSSION

Perhaps the most important question concerning radiation recovery of a forest is whether the recovery is unique in any way, or whether it resembles recovery from other disturbances. To answer this question, the irradiated area was compared with other disturbed areas by measuring indices of vegetation quantity, quality, and diversity.

Quantity of Vegetation

Leaf-area index is an index of quantity of vegetation. It is also an index of productivity per m^2 of new vegetation, since all new vegetation in this study originated since April 1965.

In the irradiated area, production of new vegetation varied widely (Figure 1). It was suspected that soil conditions might be a cause of this variation, so approximately 100 soil cores from throughout the area were inspected. In some areas, the soil was a reddish-yellow color (7.5 YR/6/8) (Munsell, 1954) from the surface down to 12 inches, while in other areas it was dark brown (10 YR/4/3) at the surface grading to a dark gray (10 YR/4/1) at 12 inches.

Richard (1957) states that the reddish-yellow color of the soil, formed under conditions of umimpeded drainage in the tropics, is due to the abundance of iron oxides; while non-peaty swamp soils often have a grey or brown color, and occur under conditions of superabundance of water and poor aeration. These generalizations seem to hold true in the forest at El Verde. The reddish-yellow soils always occur on the top or sides of ridges where drainage should be good, while the brown color exists on relatively flat topography, and in valley bottoms between ridges. For convenience in this report, areas with the reddish-yellow soil will be called well drained, and the area with the grey-brown soil, poorly drained.

In the irradiated area in August 1966, the large quantities of new vegetation coincided with the well-drained soil, while small quantities coincided with poorly-drained soil (Figures 1 and 2), except in the southwest corner, where the low leaf-area index of new vegetation coincided with high leaf-area index of old vegetation (Figure 4). The quantity of vegetation in the poorly-drained area in August 1966, was small because very few seedlings had become established. Once the seedlings were established and started to grow during the fall of 1966, productivity in the poorly-drained area increased (Figures 1, 2, and 3).

Between April 1965, and August 1966, there was greater production of new vegetation in the cut area than in the irradiated area (Figures 6-9). The lower production in the irradiated area could be a result of trampling by ecologists who were studying radiation effects (McCormick, 1966). The low production shown just to the east of the source (Figure 7) may be a result of drainage conditions. The lack of vegetation in the middle of the irradiated area (Figures 7 and 9) is due to the 2 by 2 m cement platform which supported the radiation source.

From August 1966, to February 1967, production of new vegetation was higher in the irradiated area than in the cut area. This is probably due to shading in the cut area caused by greater canopy coverage (Figures 6-9).

When leaf-area index measurements of new vegetation were being made in the irradiated area, a notation was made as to whether leaves that touch the plumb bob string were of plants of seed origin or sprout origin. Only 16% of the new leaves originated from sprouts. These sprouts occurred where the cambium was shielded from radiation by rocks and soil (Jordan, 1967). There were very few basal sprouts in the cut area, and none were encountered in the leaf area index measurements.

Canopy response is probably a major difference between recovery of the irradiated area, and the cut area. Immediately after the cut center was treated in 1965, the canopy damage resembled that of the irradiated area (Smith, 1966). However, while the branches in the canopy of the cut center sprouted after treatment, the canopy in the irradiated area continued to dieback. As a result, in the fall of 1966, there was a greater canopy cover in the cut area than in the irradiated area (Figures 6-9). Between August 1966, and February 1967, the canopy in the cut area continued to increase slightly (Figures 6 and 8) while dieback was still occurring in the irradiated area, at least in some parts (Figures 4 and 5). Where an increase in the irradiated canopy occurred, such as the area to the northeast of the source, it was due to growth of small, apparently undamaged trees which were shielded from the source by larger trees.

While gamma radiation apparently does not have any direct influence on the quantity of vegetation which becomes established after radiation ceases, the form of the vegetation following radiation differs somewhat from secondary succession following mechanical defoliation. Trees defoliated by mechanical means sprouted in the canopy. Radiation damaged trees lost their ability to sprout, except where the cambium was shielded by rocks, soil, or large tree trunks.

Quality of Vegetation

To compare quality of vegetation in the experimental areas, the importance values of all species were calculated, and the most important values are presented (Table 1). *Psychotria berteriana* and *Palicourea riparia* are woody species which become established in open areas near El Verde. They are subcanopy trees, and can survive, at least for a while, beneath the shade of canopy trees. *Tabebuia heterophylla*, *Didymopanax morototoni*, and *Cecropia peltata* are canopy trees, and also commonly become established in open areas. *Heliconia bihai* is a semi-herbaceous plant similar to the banana tree. It does not always appear in openings of the Puerto Rican rain forest, but sometimes occurs when the soil is disturbed, as might have happened in the cut center. *Phytolacca icosandra* is an herb having a niche similar to *Phytolacca americana* of the Northeastern United States, that of an early colonizer of forest openings. *Phytolacca icosandra* had a low importance value in the irradiated area at the time of sampling. Most of the plants were decaying, and there were no new seedlings. However, *P. icosandra* was the most conspicuous plant in the irradiated area several months after radiation ceased (J. R. Kline, personal communication).

An herb, *Sauragesia erecta*, formed dense patches in one herbicide area, and a grass, *Icnanthus pallens*, covered areas in the other herbicide area, and in the irradiated area. These species were not tabulated in the importance value measurements, because the method of measuring importance value is not applicable to plants such as these, which send runners over large areas of ground.

Because the disturbed areas in this study were relatively small, it was anticipated that there could be a difference between them not due to treatment, but due to small sample size. In order to determine the difference in species quality that could appear as a result of sampling small plots, two, rather than just one, herbicide plots were studied. Unfortunately, one plot received 40% more herbicide than the other. However, since both areas resumed recovery at about the same time (C. C. Dowler, personal communication) a comparison is instructive.

To quantify differences between plots, percentage similarities between all pairs of plots were calculated (Table 2). The well-drained area of the irradiated plot was approximately as similar to all other plots as the two herbicide plots were to each other. This indicates that differences between the irradiated plots and other plots may not be a function of treatment.

The percentage similarities between the poorly-drained area, and the cut and herbicide plots were somewhat lower than that between the herbicide plots. Smith (1966) in his study of the forest vegetation near El Verde, divided the forest into a lower montane rain forest and montane rain forest. The poorly-drained soil type occurs in Smith's montane forest, and the well-drained soil occurs in his lower montane forest.

Some genera and species in the study areas near El Verde are typical of secondary successional areas throughout tropical America. Richards (1957) lists *Didymopanax morototoni*, as well as species of the genera *Cecropia*, *Heliconia*, *Inga*, *Solanum*, *Miconia*, and *Cyathea* as being common successional species. *Didymopanax* and *Cecropia* were relatively important in all study areas, and *Heliconia* was common in the cut area. *Inga*, *Solanum*, *Miconia* and *Cyathea* appeared in the study areas, but with relatively low importance values.

The importance values give no evidence that the quality of the species occurring in secondary succession following radiation of the Puerto Rican tropical rain forest is any different than the quality of species following other disturbances.

Species Diversity

Species diversity did not differ significantly between the two herbicide areas, and between the well-drained and the poorly-drained portions of the irradiated area. Differences between all other areas existed at greater than the 99% level of confidence (Figure 10).

It is difficult to hypothesize why cutting should produce a greater diversity than radiation, and radiation a greater diversity than herbicide treatment. However, the differences might be caused by occurrence of one or two species of fast-growing, dense, herbaceous plants which hinder the establishment of other species, and the quantity of these weedy species could be dependent on the amount of light reaching the ground. The amount of light reaching the ground in relatively small forest openings is directly dependent on size of canopy opening.

The canopy opening in each herbicide was 52 by 74 m, larger than the canopy openings in the other study areas. One herbicide area was densely covered with the grass *Icnanthus pallens*, and the other with a mat of the herb *Sauragesia erecta*. Species diversity in the herbicide areas was the lowest of the study areas. In the irradiated area, canopy destruction was 30 m in diameter, intermediate in size between the hole caused by herbicide and the hole caused by cutting, and toward the center of the irradiated area there were patches of *Icnanthus pallens*. Species diversity here was intermediate between the herbicide and cut areas. In the cut center, the canopy hole was 20 m in diameter in 1965, and it had closed in during the following 2 years. There was no *Sauragesia erecta*, and very little *Icnanthus pallens* in the cut center. Species diversity was highest in the cut center.

These comparisons show that a small quantity of weedy species was associated with a small canopy opening and higher species diversity, and a large quantity was associated with a large canopy opening and lower species diversity.

Further evidence that species diversity could be influenced more by size of canopy opening than by treatment is that the well-drained and poorly-drained areas of the irradiated center, both exposed to the same canopy opening, did not differ in diversity. Similarly, the two herbicide areas, both having the same size canopy opening, did not differ in diversity.

Length of time since disturbance could also have been an influence on species diversity. The herbicide areas with the low species diversity were the most recently disturbed, while the irradiated area, with intermediate diversity, was delayed in recovery because of trampling.

This study gives no evidence that radiation has any unique effect on species diversity of the Puerto Rican tropical rain forest during recovery.

Another result of this study was that seedling diversity in the irradiated area was greater 2 years after treatment than before treatment. An explanation might be that in the undisturbed forest, only shade tolerant species survive, while after irradiation, both secondary successional species and shade tolerant species become established. Seedlings of canopy trees such as *Dacryodes excelsa*, *Alchorneopsis portoricensis*, and *Linociera domingensis* occurred in the irradiated area in January 1967, but their importance values were usually less than one.

CONCLUSION

Slight differences in quantity of vegetation existed between the irradiated and cut areas, and small differences in quality and species diversity occurred between the irradiated area, cut area, and herbicide areas. However, most of these differences could have been caused by factors other than radiation effect. The only difference that was uniquely a radiation response was sprouting of trees near their base where they were shielded from radiation.

The primary conclusion of this study is that recovery of a tropical rain forest damaged by gamma radiation closely resembles secondary succession following other types of disturbances in the tropical rain forest of Puerto Rico.

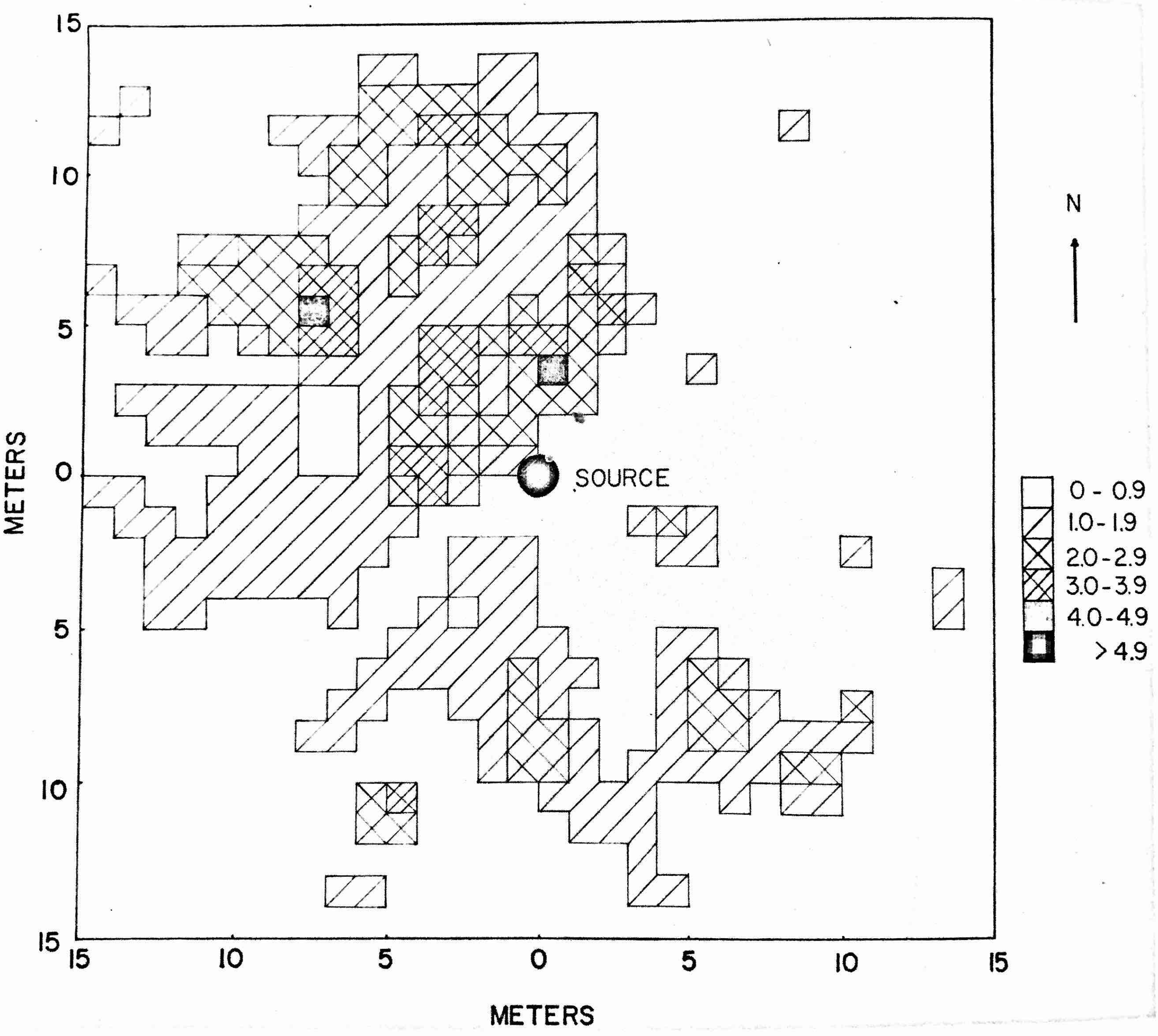

Figure 1. Map of leaf area indices of new leaves, irradiated area, August 1966.

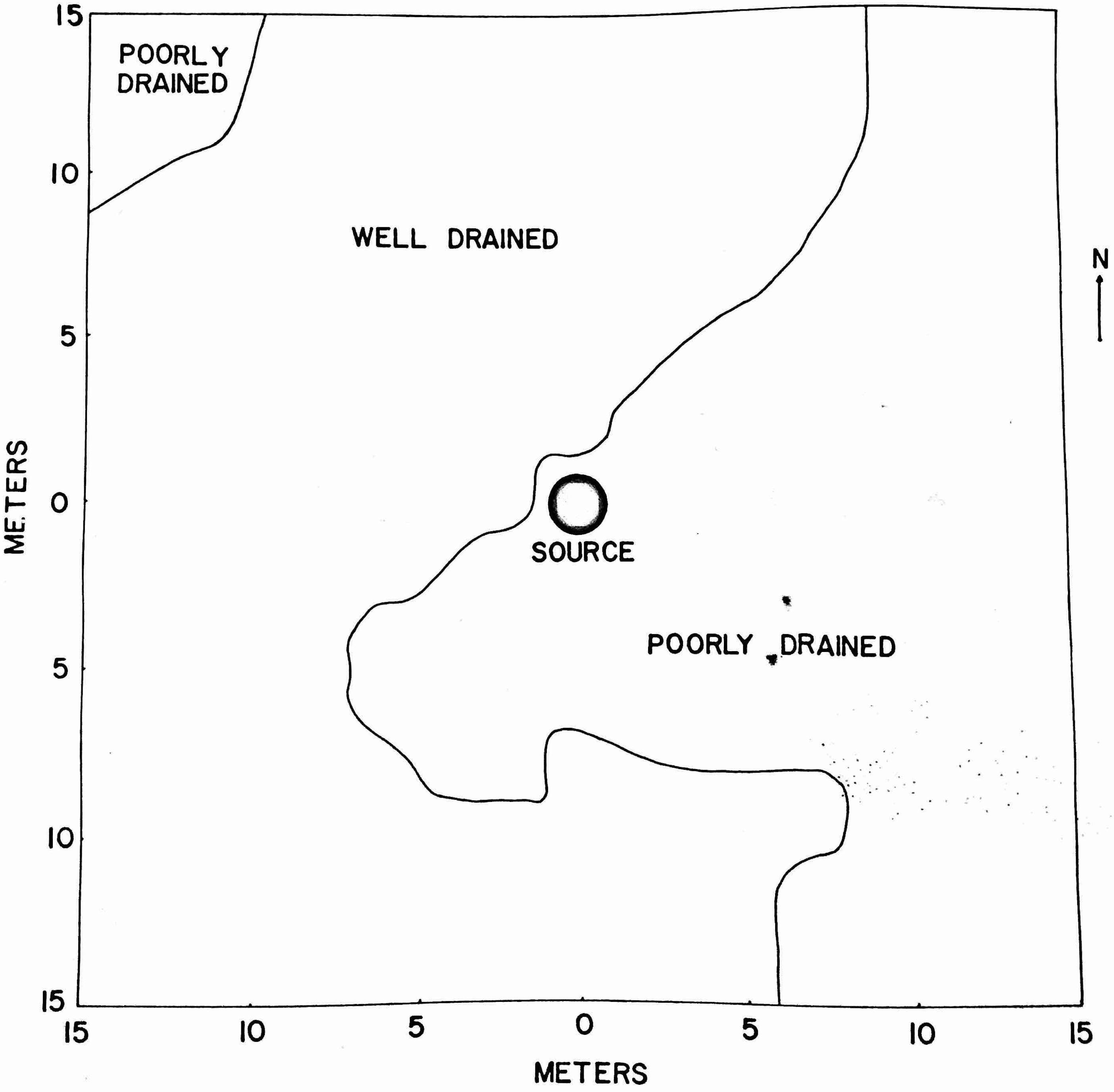

Figure 2. Map of soil drainage in irradiated area.

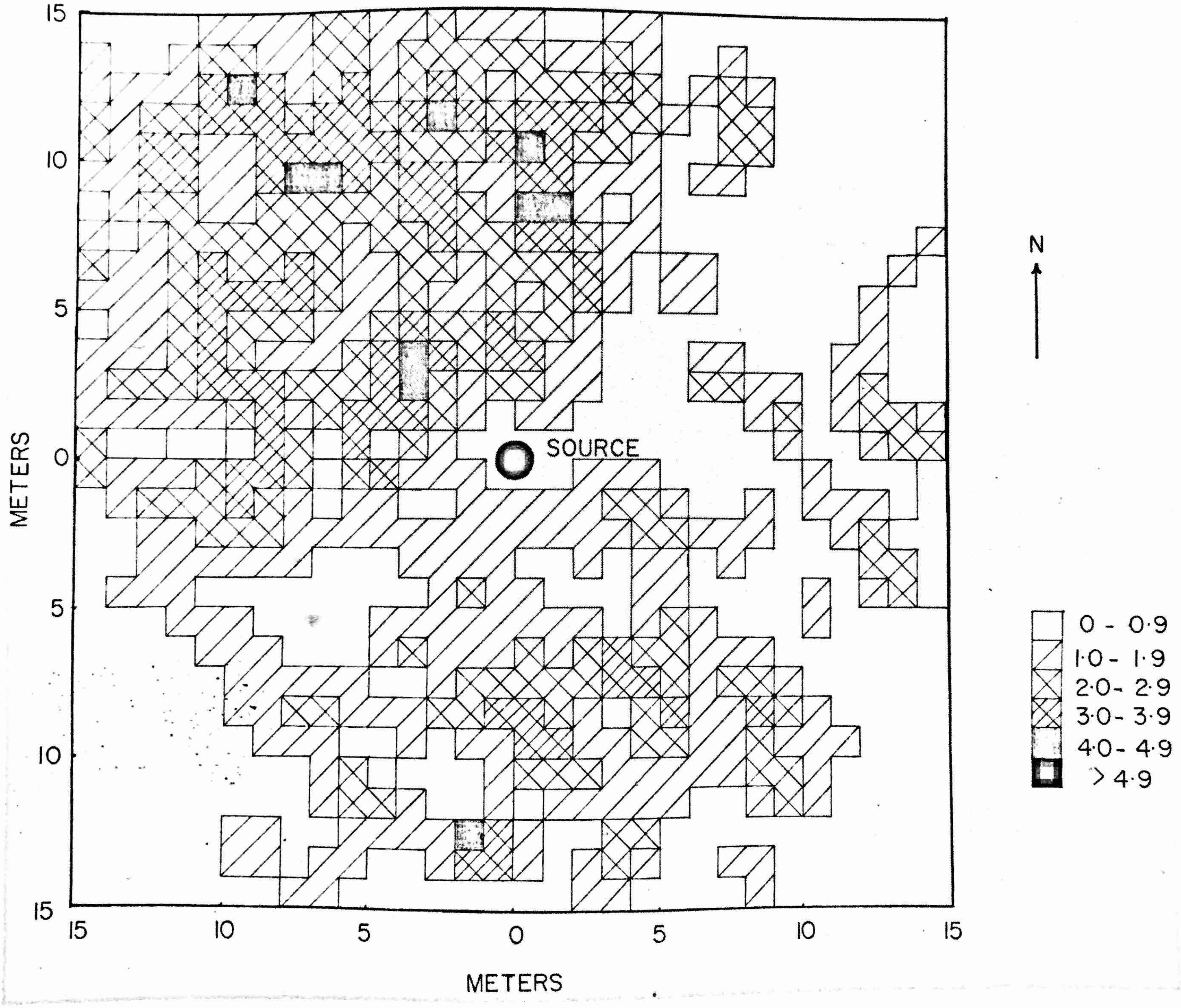

Figure 3. Map of leaf area indices of new leaves, irradiated area, February 1967.

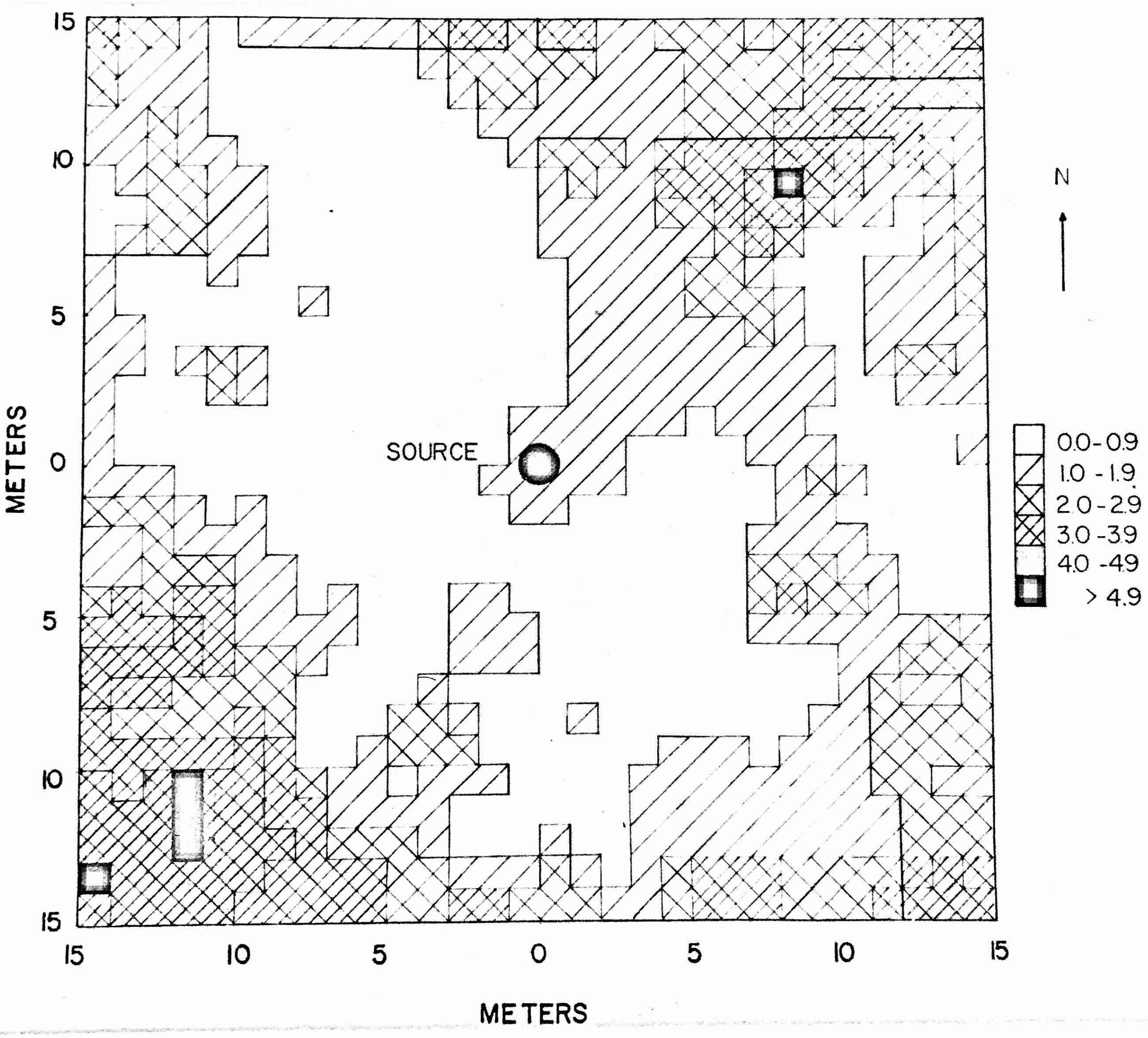

Figure 4. Map of leaf area indices of old leaves, irradiated area, August 1966.

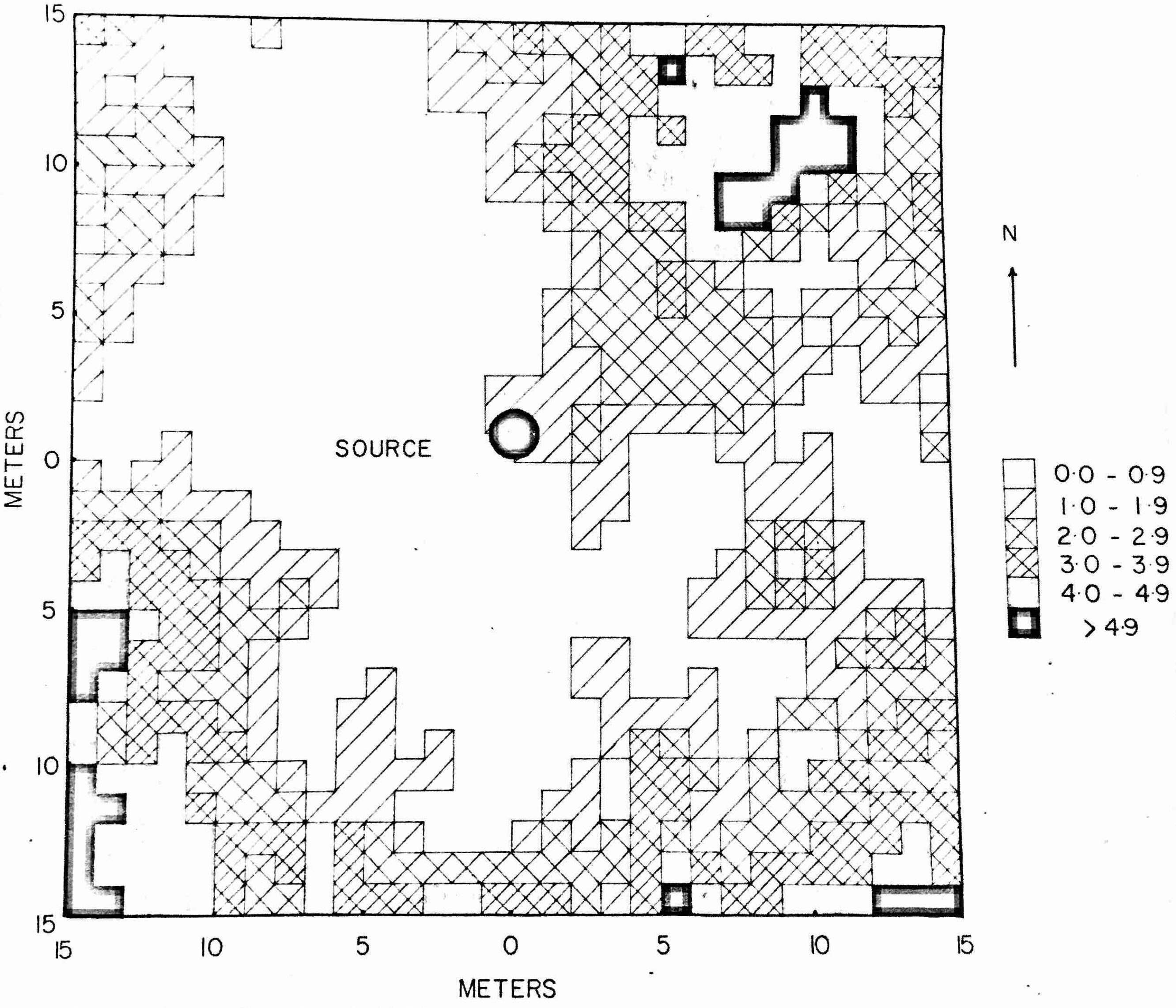

Figure 5. Map of leaf area indices of old leaves, irradiated area, February 1967.

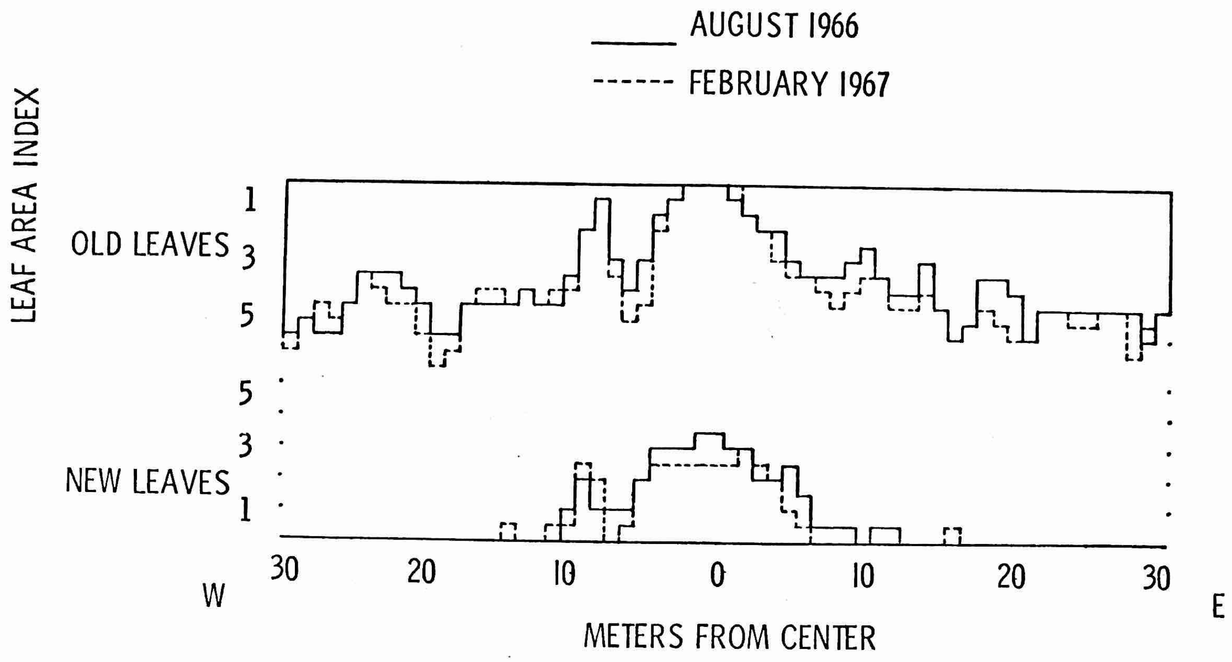

Figure 6. Leaf area indices along the East-West transect of the cut area.

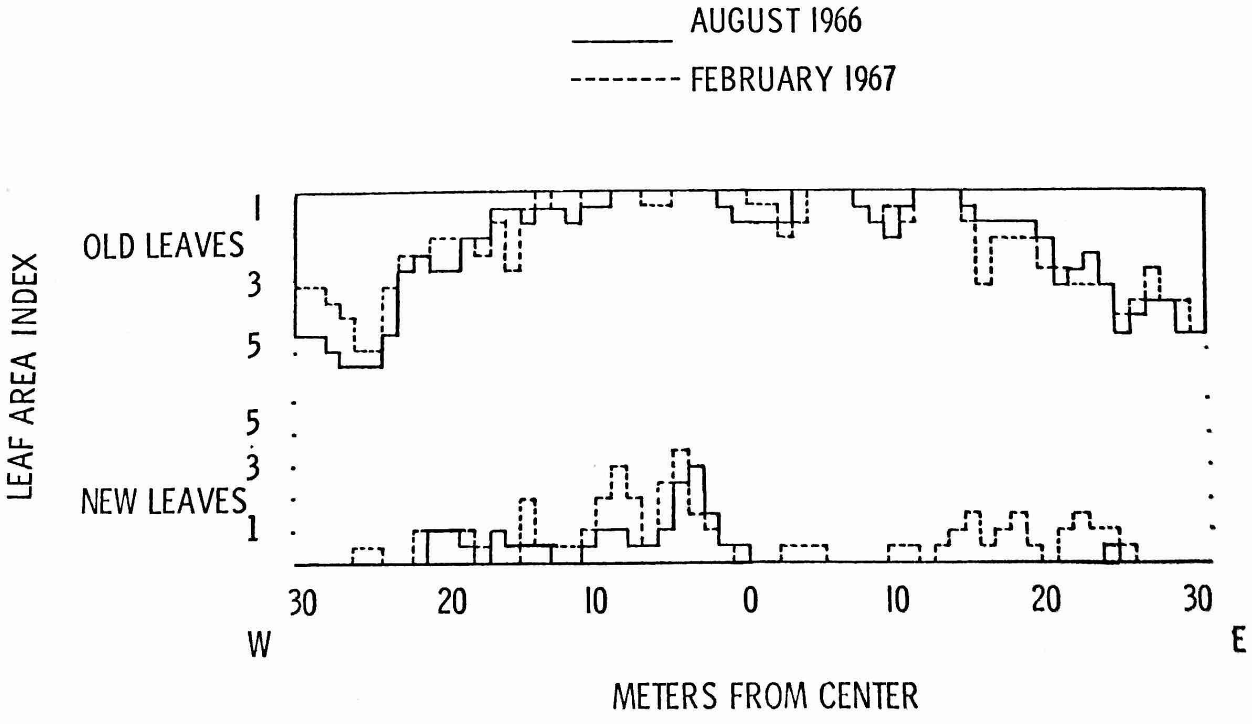

Figure 7. Leaf area indices along the East-West transect of the irradiated area.

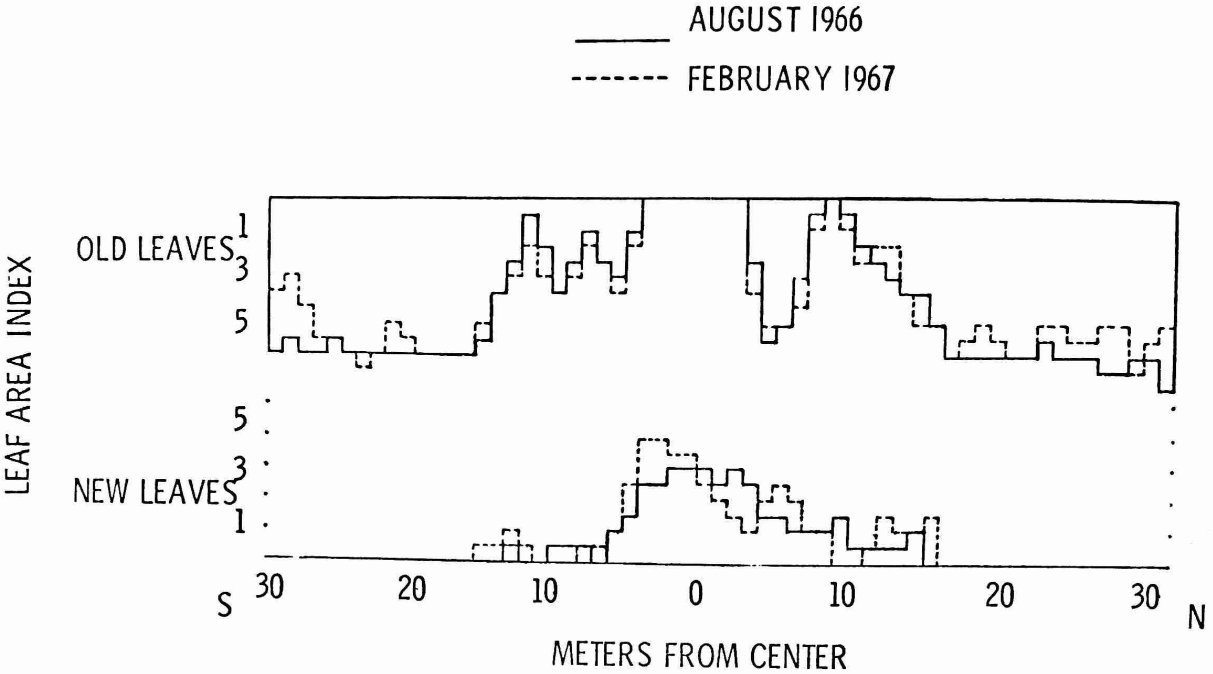

Figure 8. Leaf area indices along the North-South transect of the cut area.

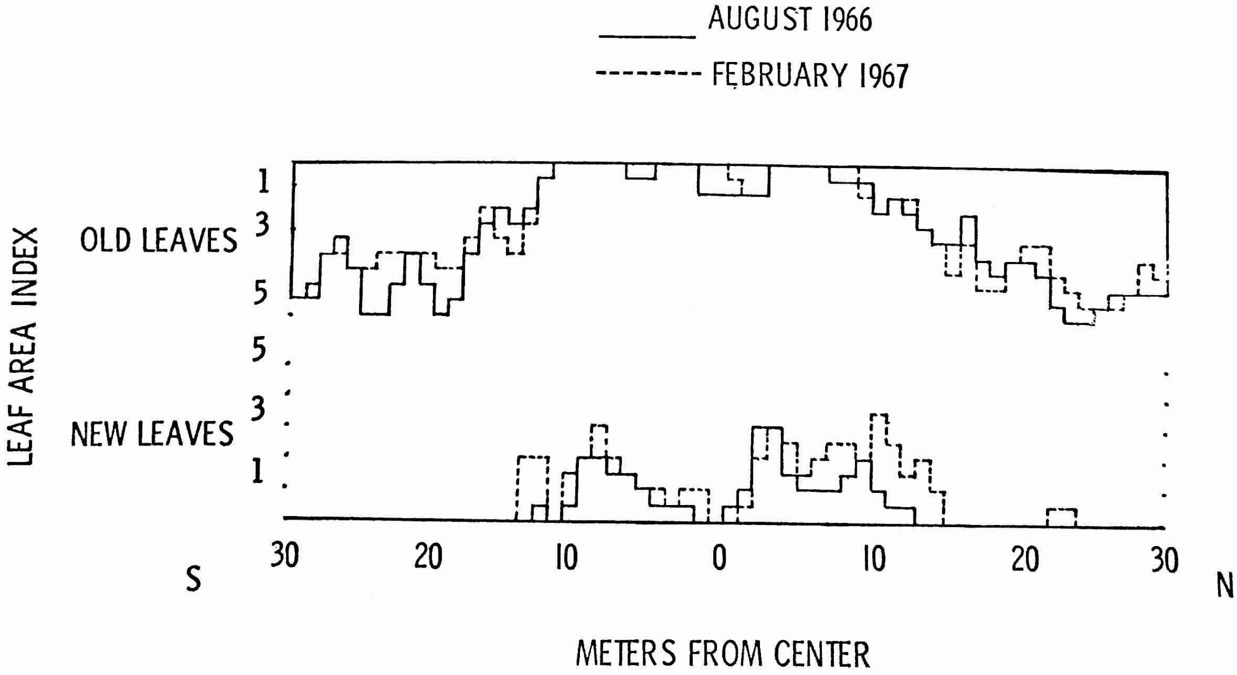

Figure 9. Leaf area indices along the North-South transect of the irradiated area.

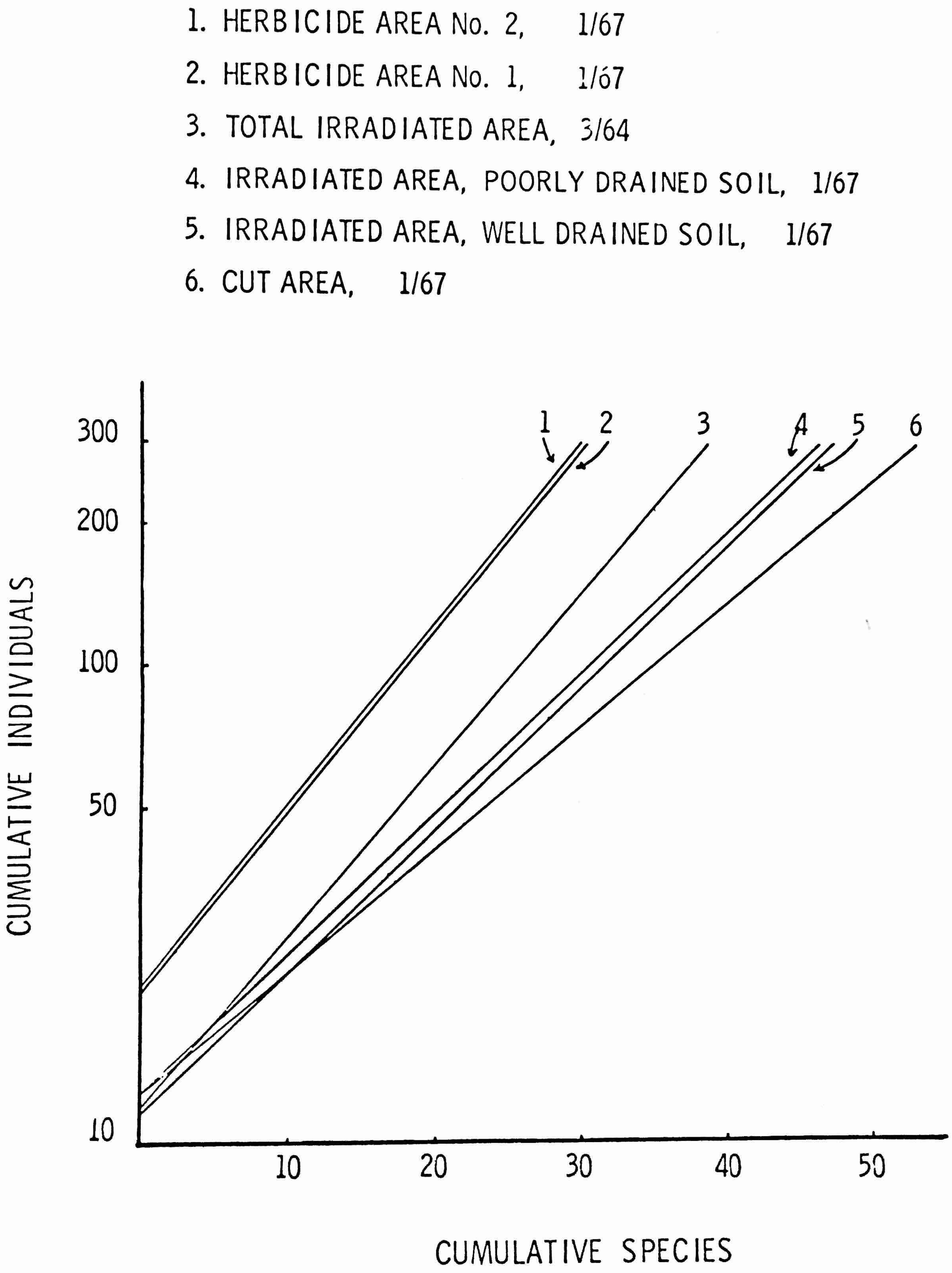

Figure 10. Seedling diversity in the experimental areas.

TABLE 1

Importance Values of Secondary Successional Species in a Tropical Rain Forest

	Irradiated Center				
	Well drained	Poorly drained	Cut Center	Herbicide 1	Herbicide 2
Psychotria berteriana	118*	16	106*	112*	40
Palicourea riparia	27	65	10	52	182*
Tabebuia heterophylla	36	89*	3	12	3
Phytolacca icosandra	9	0	17	18	0
Didymopanax morototoni	45	33	25	47	45
Cecropia peltata	44	7	12	92	33
Heliconia bihai	0	0	61	0	0

*Indicates the most important species in the area.

TABLE 2

Percentage Similarities[1] between Pairs of Experimental Plots

Pairs of Plots	Percentage similarity
Well drained - Poorly drained	51.3
Well drained - Cut	45.7
Well drained - Herbicide plot No. 1	61.0
Well drained - Herbicide plot No. 2	43.9
Herbicide plot no. 1 - Herbicide plot No. 2	49.4
Poorly drained - Cut	30.3
Poorly drained - Herbicide plot No. 1	42.0
Poorly drained - Herbicide plot No. 2	39.2
Cut - Herbicide plot No. 1	42.5
Cut - Herbicide plot No. 2	31.3

[1] A percentage similarity of 100 means that the plots are identical, one of 0 means they are entirely different.

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Electrical Conductivity and Flow Rate of Water Through the Forest Canopy

Phillip Sollins[1] and George Drewry

ABSTRACT

Throughfall, stemflow, and rainfall interception were studied to determine their relative importance as factors in the canopy water balance and the overall nutrient cycle of the forest. A 12-month study of a *Manilkara bidentata* showed that of the incoming rainfall about 50% penetrated the canopy in the form of throughfall. *Dacryodes excelsa* and *Croton poecilanthus* were studied in detail during the relatively wet summer months and showed much less tendency to intercept rainfall (70% throughfall, 1% stemflow) depending, however, on the intensity and duration of the rain.

Conductivity values ranged from 4-40 μmho/cm for rainfall, about 8-100 μmho/cm for throughfall, and 8-1800 μmho/cm for stemflow although in general stemflow was less conductive than throughfall. Low intensity rains were usually accompanied by an increase in throughfall conductivity, high intensity rains (greater than about 0.5 inches/hr) by a decrease in conductivity. Again stemflow showed less such correlation.

Quantitative chemical analysis showed that for rainfall, Na^+ or K^+ and Cl^- were the predominant ions and that for stemflow and throughfall HCO_3- was also important. The literature describing similar work in other tropical areas is summarized and possibilities for future work are suggested.

INTRODUCTION

Tropical montane forests are characterized by the immobilization of metabolites in the standing crop and a relative lack of exchangeable ions in the soil (Greenland and Kowal, 1960; Bartholomew et al., 1953). Cycling of nutrients within the ecosystem is thus indicated and rainfall and litterfall suggested as the two important routes between the canopy and the soil. Rainfall, the subject of this study, is important both as a source of various elements (Na and Cl in particular) and as the means by which various metabolites are leached from the canopy leaves and carried to the soil in the throughfall and stemflow. Although the role of throughfall and stemflow in mineral cycling has often been ignored, various studies both in temperate forests (e.g. Voigt, 1960; Will, 1959; and Madgwick and Ovington, 1959) and in the tropics (Nye, 1961) have demonstrated that (on a kg/ha.-annum basis) the contribution of K and P by

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throughfall and stemflow is comparable to that generally reported for litterfall. Although Na and Cl are not removed from the canopy in significant quantities, they are present in the rainwater in high concentrations. Thus, of the total amount of Na reaching the soil, as much as 90% may be attributed to throughfall and stemflow (Will, 1959).

As part of a general effort to study nutrient cycling and the water balance in the El Verde forest, electrical conductivity measurements were used to establish general patterns of nutrient concentrations and as a check on detailed chemical analyses. Rainfall, throughfall, stemflow, standing water, and runoff were all studied. Quantitative analyses were performed on most of these, and detailed volume measurements made for stemflow, throughfall, and rainfall to determine the relative importance of these as routes through the canopy.

METHOD AND EQUIPMENT

Measurement of Electrical Conductivity

All conductivity measurements were made on an Industrial Instruments Solumeter, Model RA 4 with the factory supplied cell; the range of the instrument was 0-100 μmhos. For samples more conductive than 100 μmho/cm, a 200° ohm resistor was placed in series with the cell resulting in a range of 0-inf. although highly nonlinear, the formula used for converting from this "compressed" scale to μmhos was:

$$C = 100\ C'/(100 - C')$$

where C is conductivity in μmho/cm and C' is observed reading. The instrument contained an automatic temperature compensating circuit which was used during normal operation. For compressed scale readings and later during the continuous recording experiments, the circuit was set at 25°C and not changed. Sample temperatures during preliminary experiments varied from 25°C by less than 3°.

The pH of the samples, as determined on a Beckman Zeromatic Meter, ranged from 4.8 to 7.5, the low values occurring in some of the early throughfall and stemflow samples containing leaves and other organic debris. Since even pH 4.8 results in a conductivity of about 5.5 μmho/cm and since the samples with low pH's were always of high conductivity (>75 μmho/cm), the pH effect was ignored.

Preliminary Survey

A preliminary survey of water present in the El Verde forest, begun by H. T. Odum and Richard Gomberg, was completed and included measurements for streams and for standing water both on the ground and in bromeliads. Sampling was begun in June 1966. Fifty glass jars were placed at regular intervals in both study areas and allowed to fill with leaf drip-off for about a week. Their contents were collected in plastic bottles and their conductivity measured. Figures 1-3 show the locations of the various collection points in relation to the radiation source and the various streams and trails.

Stemflow-Plastic Bag Experiments: The conductivity of water flowing down trunk surfaces (stemflow) was studied in detail and used for calculations of the forest water budget. Plastic bags were attached by string on one side of the bag only, so that they hung partly open and intercepted most of the stemflow in their sector. Occasionally no water was collected, while sometimes, more than 1 1/2 liters accumulated and the bag burst. Also there was no way of determining how much of the water was throughfall, not stemflow, though in a 1/2 liter sample (about average) the proportion was certaily small. Stemflow studies included four species of trees, *Manilkara bidentata*, *Dacryodes excelsa*, *Croton poecilanthus*, and *Euterpe globosa*. These were selected at random in the radiation center (post-irradiation period) although an attempt was made to include trees with widely differing epiphyte densities. Figures 1 and 2 show the locations of the various trees selected.

Continuous Recording Experiments: A system was devised to provide continuous long-range records of conductivity and rate-of-flow of rainfall and throughfall (Figure 4). Another chapter contains a general description of the microclimate station near which all of these experiments were carried out. A catch funnel was mounted atop a 92 ft tower well above the canopy and used to collect rainfall. The water was routed into an 8-inch tipping bucket rain gauge (Green Co., Princeton, New Jersey). During December 1964, a conductivity cell was installed in the rain gauge in such a way that it remained filled with water at all times and desiccation of the electrodes could not occur (Figure 4).

The tipping bucket was removed from a second rain gauge and a conductivity cell mounted in its place. The apparatus was first placed under a young *M. bidentata* alongside an unmodified rain gauge which was used to measure throughfall volume. The outputs from the two functional rain gauges were recorded on two tracks of a Rustrak 4-channel event recorder. The output from the two conductivity cell was recorded on a Leeds and Northrup chart recorder on loan from the U. S. Army Corps of Engineers, Natick Laboratories.

A control system for switching the Solumeter and chart recorders from rainfall (tower) to throughfall (ground) conductivity was built using five relays, timing motor and assorted other components. When 0.01 inch of rain fell at the tower station and the tipping bucket tipped, the system initiated a cycle. For 7.5 min tower (rainfall) conductivity was recorded. The system then switched to the ground cell (originally throughfall) and recorded this for 7.5 min, repeated both steps and then shut off. Time for one complete cycle was thus 30 min. The system remained off until the tower gauge recorded another 0.01 inch. During prolonged rains this occurred immediately, and the system often remained on continuously for several hours.

Continuous Recording Experiments - Stemflow: Water was collected by attaching a 1 inch rubber hose around the tree. A length of wire was threaded through the hose, the hose placed about the tree and tilted so that the joint was lowest, and the ends of the wire twisted together. Parafin was poured between the hose and the tree and molded into a spout at the joint. Water ran along the trough between the hose and the tree, passed from the spout into a funnel and then to a shunt where a small fraction of the water was diverted, filtered and routed to the conductivity cell. All of the water eventually reached the rain gauge where its volume and approximate rate-of-flow was measured. Because of the rapid flow of water past the screen (Figure 4), the filter was self-cleaning and large amounts of debris were never able to accumulate anywhere in the system.

For stemflow measurements, several modifications of the conductivity and volume monitoring devices proved necessary. First, the volumes of water involved were so great that a recording of each bucket tip could not be resolved on the chart record. A stepping switch was added to the circuit so that only every tenth tip of the bucket was recorded. A totalizing counter was also added which responded to each tip of the bucket. During the highest rates-of-flow, the limits of reliable tipping bucket action were reached or exceeded (i.e. when mechanical resonance of the bucket system prevented complete filling).

Because stemflow often persisted a half hour after the rain had ended, the circuitry was later modified so that after the last tower cycle, instead of switching off, the system continued to monitor stemflow conductivity.

Two more unmodified rain gauges were used in conjunction with the stemflow system to obtain simulatenous values for throughfall at different points under the same tree, or under different trees. The outputs from these were recorded on the remaining two channels of the event recorder.

Conductivity data was analyzed by considering those times at which the system switched from ground to tower or the reverse, noting the conductivity at the two cells, and the amount of water indicated on each of the event recorder tracks as having fallen during the previous 7.5 minutes.

Crown Areas: In the process of studying water balances, crown areas of the Dacryodes (De-1) and one of the Crotons (Cp-1) were estimated measured. Several radii were measured taped and the general outlines sketched. This was plotted on graph paper, the figures cut out and weighed, and compared with the weight of a known area at the same scale. De-1 was estimated to have an area of $23.7m^2$, Cp-1 to be $10.5m^2$.

Calibration: Rain gauges were calibrated by pouring water into the gauge until the bucket had tipped a convenient number of times (usually about 80). The water was collected in cylinders provided with the gauges and its volume measured with a ruler also provided with the gauge. Correction factors for the four rain gauges varied from .95 to 1.13. The error is greater at high rates of flow so that the corrections for the trunk-run-off gauge was only approximate.

Capacitance and DC resistance leaks in the conductivity cables were taken into account by observing the meter reading with the cells empty and also the leads detached. Both were comparable for both cells indicating the loss of resistance was in the cables and not across the conductivity cells. Tower values averaged about 4.0 µmho/cm, ground about 4.5 µmho/cm, probably due to much larger length of cable. These values were subtracted from all readings, and in the case of compressed scale, before the conversion formula was applied.

The mean temperature range in the forest is no more than ± 2°C, and temperature effects on ionic mobility were largely ignored. The Solumeter contains a manually adjustable, temperature compensating circuit which was used on regular scale readings during the preliminary and plastic bag experiments. For compressed scale readings, all continuous recording, this was set for 25.0°C.

During December 1965, after the apparatus had been in operation about a year, a test was made to determine the accuracy of the system. A standard KCl solution was prepared and diluted to 5.0 by 10-4N. The conductivity of this should then have been 70.6 µmho/cm. The solution was poured through the apparatus until no change in conductivity could be observed. The tower cell then indicated 70.3 µmho/cm, the ground cell 70.4 µmho/cm, after corrections for cable losses. Since temperature and pH had already limited accuracy to about 10%, the effect of the cell itself was not significant.

Chemical Analyses: Analyses were performed by the laboratories of the Water Resources Division, U.S. Geological Survey, in San Juan through the courtesy of Mr. López, Mr. Murphy, and Mr. Reed. Throughfall water was gathered using stainless steel collecting trays about 4 ft square. The trays were protected by pyramidal aluminum screens which prevented the accumulation of organic debris. A similar tray and screen were placed on the roof of the field station and used to collect rainfall. Water was stored in gallon plastic buckets which were first aged by placing them in the forest for several weeks. Stemflow was collected using the same rubber hose collars employed in the conductivity measurements. Samples were removed from the plastic containers at approximate monthly intervals, the containers emptied and cleaned. Samples of runoff from the Sonadora River and from the bell jar site were also collected for analysis.

RESULTS AND DISCUSSION

Canopy Water Balance

Water balance data is presented in Tables 1-4. Rainfall, throughfall, and stemflow data were totals for each rain, where a rain was defined operationally as beginning when .01 inch of rain had fallen and ending whenever a dry period occurred that was long enough for throughfall and stemflow to approach zero. During several very rainy periods in August 1965, rains (under this definition) lasted 20-40 hours with a total rainfall of as much as 12.0 inches.

In Figures 6 and 7 throughfall is plotted as a function of rainfall, and stemflow as a function of rainfall. Both increase with rainfall and display a linear correlation through most of their range. By combining all the data for each tree, average overall values for percent interception, throughfall, and stemflow were calculated and evaporation determined by difference. These are presented in Table 1. Note that much of the rain evaporated, and that, on a per unit area basis, stemflow is almost negligible.

The results of a year's measurement of throughfall beneath the Manilkara sapling are summarizing in Figure 8. Rainfall and throughfall for all periods for which data was available from both stations was included in the total. Monthly totals were then used to calculate the percent throughfall.

This wide range of values (30-80%) is in agreement with results obtained by other workers in the tropics (Table 2). The explanation of the wide range is not clear. In general, the literature does not mention the types of trees under which the measurements are made (e.g. Nye, 1961 and Hopkins, 1960). However, the limited data available for Croton and Manilkara tends to suggest that this may not be a significant factor. Although the foliage of the two types is very different, much denser on the Manilkara, throughfall for both can be described by almost the same equation (Figure 6).

Some of the variation may be caused by differences in the rainfall patterns. Slow, fine rain rarely penetrates the canopy at El Verde while an intense shower may result in 80% throughfall. In Figure 9, the percent throughfall is plotted against the intensity of the rain. Intensity (in inches of rain/hour) was determined by dividing the total rainfall by the duration of the rain. There is a direct linear correlation. The results are in agreement with the literature summarized in Table 2 with the exception of Friese (1936). Some of the variation may have been due to the condition of the canopy when the rain began, whether it was completely dry with perhaps a saturation deficit accumulated since the previous rain, or thoroughly saturated. Windspeed and temperature probably also affect the rate at which water evaporates during a rain.

The correlation between stemflow percent and rainfall intensity is not very good. This probably reflects the fact that the rainfall affects the upper parts of the canopy while stemflow is measured at the base of the trunk. Any effect of changing rainfall intensity is smoothed out by the time the water reaches the ground. That the tree possesses some storage, and thus integrating capacity, is evidenced by the tendency for stemflow to continue often a half hour after the rainfall had ended (Figure 12).

Conductivity

Preliminary Survey: Results of conductivity measurements are summarized in Table 3. The higher mean for the stream near the field station is probably due to man's presence:detergents, cesspool drainage, etc. Data for the fifty throughfall samples (Table 3) shows means significantly higher than that of the rainfall (45.2 vs 12.5 μmho/cm). However, the variation within the samples was too great to show any comparisons between control and radiation centers.

Plastic Bag Series: Representative results are presented in Table 4 for some individual trees and in Table 5 for the various species. The wide range of conductivities both among and within species is striking. Some of this variation was thought to be due to evaporation of water and leaching of minerals from the organic debris as the water sat in the bags. Although the means for the various species were not significantly different, rank sum analysis showed the Croton and Dacryodes to be different on 2 of the 3 days at better than the 99% confidence level.

It thus seems likely that Dacryodes produce stemflow considerably more conductive than that of Croton. Dacryodes exude a white aromatic resin which could possibly be the cause of this higher conductivity. Stemflow samples collected from Dacryodes often smelled quite strongly of the resin. The stemflow of the Manilkara and Euterpe studied occupies a position intermediate between Dacryodes and Croton.

Continuous Recording Experiments

Throughfall: Figure 10 shows typical results from the 2-month conductivity experiment set up under the *M. bidentata* sapling. These two periods (March 5-6 and 21-22, 1965) were selected because they included both low-intensity, fine rains, and high-intensity squalls in addition to occasional dry periods. No rain fell during the intervals between them. At no point during the 2 months did throughfall conductivity fall below that of the rainfall. In general, peaks in rainfall intensity corresponded to peaks in conductivity. In Figure 11, we see that the change in throughfall conductivity seems to be a function involving the rainfall intensity. High-intensity rains (80 inches/hr) accompany decreases in conductivity while low-intensity rains (.40 inches/hr) coincide with increases in throughfall conductivity. The actual amount of the increase or decrease seems to depend on the immediate prior history of the canopy. For example, in July, a week without rainfall was followed by a period of generally rainy weather. During the first intense squall, throughfall conductivity rose to about 100 μmho/cm; within an hour it had fallen to about 30 and, as the high rainfall rates continued, the conductivity dropped to about 15 μmho/cm.

Throughfall conductivity also depends on that of the rainfall. This averaged 12.5 μmho/cm (Table 6) with sigma = 7.4, but the range (2.8 - 45.0) is a better indication of the extreme variability. In most cases the general level of throughfall conductivity paralleled that of the rainfall (Figure 10). However, the variability of the rainfall conductivity was so great that the sigma/$\bar{x}$ for the difference between throughfall and rainfall conductivity was greater (0.76) than that for throughfall alone (0.50). Average conductivity for *M. bidentata* throughfall and the rainfall corresponding period are included in Table 6.

Stemflow: In Figures 11 and 12, stemflow conductivity for Dacryodes No. 1 and Croton No. 1 is plotted along with the rainfall rate and conductivity for the corresponding periods. A correlation between rainfall intensity peaks and periods of high conductivity is not evident. This lack of correlation is further demonstrated in Figures 13 and 14 in which the change in stemflow conductivity has been plotted.

Also evident in Figures 11 and 12 are the long periods during which stemflow conductivity fell below that of the rainfall. This usually occurred just after prolonged periods of intense rainfall and may well reflect the actual utilization of the leached minerals as well as those present in the rainfall by the epiphytes growing on the tree trunks. These include orchids, bromeliads, ferns, lichens, and bryophytes with the last often forming a mat several centimeters thick. Because numerous observations suggest that stemflow begins

2 or 3 min after the onset of an intense rain, the fact that these periods of negative differences occur after and not during rainfall peaks would seem to indicate that dilution is not a significant factor. Perhaps certain ions are readily leached from the leaves and are present in a large but easily depletable reservoir. Others are perhaps absorbed by the leaves (see results of the quantitative analyses) so that after a prolonged, intense rain none of the exhaustible nutrients remain although absorption of some others may still be taking place. If the leaching normally occurred in the canopy leaves while the absorption was generally characteristic of the epiphytic zone, then stemflow conductivity might easily fall below that of the rainfall while throughfall conductivity would not. Presumable one could postulate a primarily autotrophic zone consisting of the canopy leaves, which provides at least part of the energy requirements for the more heterotropic, epiphytic region beneath.

Chemical Analyses

In Table 7 results of chemical analyses of throughfall, rainfall, stemflow, and runoff are presented. It can be seen that throughfall accounted for the highest concentrations of most ions, rainfall the lowest, with stemflow intermediate. HCO_3- and Cl- were also present in large quantities in the rainfall (3-20ppm.) so that, in terms of nutrients reaching the ground, it ranked by far the highest. NO_3- appeared only in very small amounts, often highest in the stemflow. SO_4- was extremely variable, often completely absent but occasionally present in throughfall in concentrations of 50 ppm. PO_4- was not determined. Of the cations Na-K were the most prominent but at least half of this was attributable to rainfall and not leaching. Small amounts of Mg and Ca were also leached.

Table 8 contains results of a rainfall sampling survey performed by the Water Resources Division, U.S. Geological Survey, at various points throughout the Island. Lago Cidra, the site nearest to El Verde, is about 15 miles downwind from the radiation site. The others are somewhat farther away. The values reported can be seen to be in general agreement with our samples both in variability and magnitude.

GENERAL DISCUSSION

As a result of this study, several general conclusions may be drawn and some suggestion made for further work in this field.

Electrical conductivity appears to be a usable parameter for studies of overall levels of nutrient flow in forest ecosystems. More sophisticated techniques may often be required, but once a reasonable constancy in the ratios of the concentrations of the various ions can be demonstrated for various flow rates, electrical conductivity can be used to monitor the channel over long periods of time. In its cruder forms, the equipment required is inexpensive, requires little maintenance and only occasional calibration.

In terms of the forest ecosystem, several important points might be mentioned. Rainfall is a significant source of nutrient elements. The canopy retains as much as 50% of the rainfall for eventual evaporation. Throughfall provides an important channel between canopy and ground and permits the transfer of large quantities of nutrient material from the canopy to the soil. The actual rate of transfer and composition of the transferred material is a complicated function of several variables including intensity and duration of the rainfall.

Many questions remain unanswered. Variation in rainfall due to microtopographic features such as stands of large trees, ridges, ravines, etc., may explain reports of throughfall greater than 100% (Clegg, 1963, as well as our own data). More measurements of throughfall at more points throughout the forest are needed before an accurate evaluation of water input into the forest system is possible. If its variability and amount with respect to the various species can be determined, then total throughfall could be determined from vegetational structure maps and adequate rainfall data.

The nature and amount of the leachates should be monitors for several individuals of several species over long periods of time. Seasonal changes may become apparent and certainly more extensive and accurate data is necessary before quantitative consideration of nutrient cycles can be made.

TABLE 1

Summary of Canopy Water Balance Results at El Verde in 1965-66

Species and Tag No.	Total Rainfall		Throughfall			Stemflow		Interception		Total Time	Number of rains included
	inches	$1/m^2$	inches	$1/m^2$	% of RF	$1/m^2$	% of rainfall	$1/m^2$	% of rainfall		
Manilkara bidentata No. 1	4.26	117.0	3.12	78.7	73	-	-	38.3[a]	27[a]	12.50	31
Dacryodes excelsa No. 1 (all data)	9.60	242.0	-	-	-	4.10	1.7	-	-	54.88	28
Dacryodes excelsa No. 1 8-6-65	1.10	27.7	.68	17.2	62	.24	0.9	9.6	38	3.25	1
Dacryodes excelsa (August 21-24)	6.83	172.0	-	-	-	3.08	1.8	-	-	33.75	4
Dacryodes excelsa (July 28-Aug. 6)	2.77	68.6	-	-	-	1.04	1.5	-	-	21.13	24
Croton poecilanthus No. 2	.33	8.32	-	-	-	.06	0.7	-	-	4.13	4
Croton poecilanthus No. 1	4.15	104.0	-	-	-	1.09	1.05	-	-	12.8	6
Croton poecilanthus No. 2	1.16	29.1	2.72	20.0	69	.21	0.7	8.9	30	5.63	2

[a] Does not include stemflow.

TABLE 2

Summary of Results of Previous Workers on Interception of Rainfall in Tropical and Semitropical Forests

Location	Interception %	Remarks	Reference
Mauritius	33	Interception decreases with rainfall intensity	Vaughn and Wiehe (1947) in Hopkins (1965)
Brazil	68	Interception increases with rainfall intensity-many replicates - rainfall gauges in tree tops	Friese (1936) in Hopkins (1960)
Uganda (Mpanga Research Forest)	34	All interception with 9.2 m of ground - 43.5 inches annual rainfall - no correlation with intensity	Hopkins (1960)
Belgian Congo (Parc National de la Caramba)	19	Shrubby area during wet season	Noirfalise (1956) in Hopkins (1960)
Nigeria (Olekemiji Forest Reserve)	3	Forest-savana ecotone-much variation between gauges - 48.4 inches annual rainfall	Hopkins (1965)
Puerto Rico (El Yunque)	54 (42-77)	Montane forest, mostly Cyrilla racemiflora and D. excelsa - 130 inches annual rainfall	Clegg (1963)
Ghana (Kade)	16	Ecotone between moist semi-deciduous and moist evergreen -1% stemflow-65 inches rainfall concentrated in rainy season	Nye (1961)
U.S. (Eastern)		Summary of results for eastern hardwood deciduous forest	Helvey and Patric (1965)

TABLE 3

Summary of Conductivity Values of Water in Various Situations Throughout Study Area

Spot checks over 3-month period

Location	Mean (μhmo/cm)	Number of observation days	St. dev. (sigma)
General Survey			
Water in bromeliads	44.1	12	25.4
Water standing in pools	49.3	4	1.9
Rivulets	68.8	3	14.6
Large stream - First towards field station from Sonadora R.	80.4	3	1.9
Large stream - First towards Sonadora R. from field station	121.9	3	11.0
Sonadora River at trail crossing at low water	47.7	5	5.6
Sonadora by upper parking low at low water	48.2	1	-
Throughfall Jars placed at intersections of radials with:			
10 m circle Control center	49.2	12	20.5
10 m circle Radiation center	41.0	10	10.2
3.2 m circle in Control center	30.3	11	7.1
3.2 m circle in Radiation center	55.7	15	20.3

TABLE 4

Plastic Bag Experiment--Individual Trees Representative Conductivity Values for Trunk Runoff

Species	Tag No.	Mean µmho/cm	No. of Observations	Standard Deviation
Euterpe globosa	10091	51.8	2	0.0
Euterpe globosa	19374	30.7	3	8.6
Euterpe globosa	Eg 1	62.6	3	27.9
Manilkara bidentata	763	45.4	3	7.5
Dacryodes excelsa	3177	212.9	3	67.4
Dacryodes excelsa	10393	34.4	4	9.9
Dacryodes excelsa	X-90	104.0	4	51.8
Croton poecilanthus	10123	37.0	4	15.4
Croton poecilanthus	16127	32.6	4	12.9
Croton poecilanthus	2432	33.4	3	2.9

TABLE 5

Results of Plastic Bag Experiments--Data Grouped by Species

	Mean $\bar{X}$ μmho/cm	Standard Deviation sigma	N	Sigma/ $\bar{X}$
Dacryodes excelsa	185.3	335.8	24	1.81
Manilkara bidentata	67.3	46.8	7	.695
Euterpe globosa	48.9	21.6	8	.442
Croton poecilanthus	49.0	36.4	15	.743
*Dacryodes excelsa**	204.6	331.1	24	1.62
*Manilkara bidentata**	101.7	42.5	7	.417
Euterpe globosa	57.7	16.7	8	.290
Croton poecilanthus	58.4	31.1	15	.533

*Data adjusted to allow for differences in conductivity of rainfall

TABLE 6

Results of Continuous Recording Experiments--Summary of All Data Analyzed

	Mean $\bar{X}$	Standard Deviation sigma	Number of data points
Rainfall	12.5	7.4	395
Manilkara bidentata	26.4	11.7	48
Croton poecilanthus 1	17.1	6.3	60
Dacryodes excelsa	31.0	23.2	361

TABLE 7

Chemical Analyses of Water at El Verde Provided by the U.S. Geological Survey at Río Piedras, Puerto Rico. All values in mg/l

Water	Date	Ca	Mg	Na-K	HCO_3	SO_4	Cl	NO_3	Dissolved Solids
RAINFALL	10-26-65	1.0	0.1	3.2	4.0	0.4	3.8	0.1	13
	1-17-66	0.8	2.2	2.1	2.0	0.0	10.0	0.0	16
	3-17-66	0.8	0.5	5.3	3.0	3.0	7.1	0.1	25
	6-16-66	0.6	0.7	3.7	2.4	1.6	6.8	0.0	24
Mean		0.9	0.7	3.6	3.5	1.1	6.5	0.1	22
THROUGHFALL Radiation center-*Dacryodes excelsa* and various understory sp.	10-29-65	2.6	0.9	27.0	6.0	-	7.0	0.1	95
	1-17-66	2.0	0.7	7.6	4.0	0.8	14.0	0.3	28
	3-17-66	1.6	0.7	9.4	7.0	5.1	11.0	0.5	46
	6-16-66	0.7	1.2	-	8.0	1.2	-	0.3	39
	7-8-66	1.2	5.1	2.5	8.0	1.0	6.8	0.5	37
Mean		1.6	1.7	11.6	6.6	2.0	9.7	0.3	49
Tower-*Dacryodes excelsa* and *Sloanea berteriana*	11-1-65	2.8	1.2	31.0	6.0	-	7.2	0.1	96
	1-17-66	2.4	1.2	9.2	6.0	0.8	17.0	0.4	27
	3-17-66	1.6	0.2	8.5	5.0	4.2	10.0	0.5	33
	6-16-66	1.1	1.4	7.6	8.0	4.0	10.0	0.4	39
	7-8-66	2.4	0.2	-	5.0	-	11.0	1.8	68
Mean		2.1	0.8	14.1	6.0	3.0	11.0	0.6	53
Croton poecilanthus No. 1	6-13-66	6.1	1.2	4.6	26.0	0.8	5.0	0.7	37
STEMFLOW *Croton poecilanthus* No. 2	6-13-66	1.0	0.8	5.5	5.0	0.0	9.2	0.6	27
		1.7	0.6	3.9	6.0	0.0	5.9	1.6	24
Mean of 2 samples		1.8	.7	4.7	5.5	0.0	7.6	1.1	26
Dacryodes excelsa No. 1	7-8-66	1.6	1.0	-	2.0	-	-	2.3	82
Mean for all stemflow data both species		1.7	0.9	4.7	3.8	0.0	7.6	1.7	54
GROUND RUNOFF Giant Cylinder site	6-18-66	12.0	1.4	-	52.0	-	7.9	1.2	132
Rio Sonadora	6-13-66	2.0	1.7	5.5	16.0	0.0	7.8	0.1	27

TABLE 8

Chemical Analyses of Rainfall in Puerto Rico
Data Supplied by the U.S. Geological Survey, San Juan, Puerto Rico

All figures are mg/l

Rainfall: USGS Laboratory, Rio Piedras

Date	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)=	Dissolved Solids	Hardness as $CaCO_3$ Calcium magnesium	Non-carbonate	Specific conductance (micromhos at 25°C)	pH Temperature
1/2/64	0.0	0.00	1.6	1.2	-	-	14.0	-	6.8	0.0	0.1	26	9.0	0	41	7.1
1/7/64	0.0	0.00	3.2	1.5	-	-	10.0	-	8.0	0.0	0.0	26	14.0	5.0	46	6.8
2/6/64	0.5	0.00	1.6	1.0	-	-	15.0	2.8	5.0	0.0	0.0	43	8.0	0	44	7.1
3/10/64	0.0	0.00	2.2	1.6	-	-	12.0	0.8	-	0.0	0.2	-	12.0	2.2	76	6.5
3/10/64	0.5	0.02	5.6	2.7	-	-	15.0	0.0	3.1	0.0	0.1	141	25.0	13.0	148	7.3
3/23/64	0.0	0.04	1.2	0.7	-	-	17.0	3.2	5.0	0.0	0.0	25	6.0	0	34	7.3
4/6/64	0.0	0.00	2.0	1.2	-	-	11.0	0.8	8.5	0.0	0.1	15	10.1	1	49	6.9
4/6/64	1.5	0.00	19.0	1.6	-	-	58.0	1.2	16.0	0.0	0.1	86	54.0	6.0	156	7.5
4/17/64	0.0	0.00	0.8	1.0	-	-	9.0	0.0	4.5	0.0	0.0	18	6.0	0	28	6.8
4/17/64	0.0	0.00	2.4	1.5	-	-	12.0	2.4	9.0	0.0	0.0	39	12.0	2.2	52	6.4
4/23/64	0.0	0.00	0.6	1.6	-	-	3.0	2.4	4.5	0.0	0.0	9	8.0	5.5	19	6.1
6/8/64	0.0	0.08	7.4	0.4	-	-	27.0	3.2	1.8	0.0	0.0	43	20.0	0	49	7.6
6/8/64	0.0	0.00	1.0	0.4	-	-	2.0	3.6	1.8	0.0	0.1	22	4.0	2.4	19	5.7
6/18/64	0.0	0.00	2.6	0.9	-	-	5.0	2.0	11.0	0.0	0.2	30	10.0	5.9	56.0	6.3
6/18/64	0.0	0.00	1.4	0.5	-	-	9.0	3.2	5.0	0.0	0.1	19	5.5	0	33.0	7.0
6/30/64	0.0	0.00	1.2	0.2	-	-	13.0	0.8	3.5	0.0	0.1	15	4.0	0	24.0	7.1
6/30/64	0.0	0.00	1.2	0.5	-	-	4.0	1.2	6.8	0.0	0.1	18	5.0	1.7	33.0	6.2
7/2/64	0.0	0.00	0.6	0.2	-	-	9.0	0.4	0.8	0.0	0.0	10	2.5	0	13.0	6.8
7/2/64	0.0	0.00	0.0	0.1	-	-	3.0	0.8	0.5	0.0	0.0	5	0.5	0	4.4	6.3
Rainfall: UPR Mayaguez, 1964																
3/3/64	0.0	0.00	3.6	0.7	-	-	4.0	2.0	5.5	0.0	2.3	14.0	12.0	8.7	45	6.6
5/7/64	0.0	0.00	1.4	0.2	-	-	4.0	0.0	1.5	0.0	0.1	11.0	4.5	1.2	16	7.5
5/7/64	0.0	0.00	1.2	0.5	-	-	4.0	0.8	1.5	0.0	0.0	11.0	5.0	1.7	16	6.0
5/7/64	0.0	0.00	1.0	0.5	-	-	3.0	1.2	1.5	0.0	0.0	15.0	4.5	2.0	16	6.0
6/5/64	0.0	0.00	3.0	0.6	-	-	7.0	2.4	3.2	0.0	0.5	17.0	10.0	4.3	36	7.0
6/5/64	0.0	0.00	2.2	0.4	-	-	5.0	1.6	1.8	0.0	0.4	16.0	7.0	2.9	26	6.1
6/5/64	0.0	0.00	2.4	0.2	-	-	6.0	3.6	1.5	0.0	0.4	15.0	7.0	2.1	26	6.7
Rainfall: Morovis																
5/6/64	0.0	0.00	2.6	0.2		3.0	9.0	1.2	3.5	0.0	0.4	16	7.5	-	31	7.3
6/4/64	0.0	0.00	1.4	0.1		2.1	6.0	.4	2.2	0.0	0.1	11	4.0	-	20	6.4
6/22/64	0.0	0.00	1.0	3.0		3.0	3.0	4.4	1.5	0.0	0.2	11	-	-	14	6.3
7/15/64	0.0	0.00	0.8	0.2		3.0	4.0	0.8	3.5	0.0	0.1	13	-	-	17	6.5
8/6/64	0.0	0.00	2.0	0.5		3.7	8.0	1.2	4.8	0.2	0.1	16	-	-	33	6.9

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