PRNC-103 GENERAL, MISCELLANEOUS, AND PROGRESS REPORTS (TID - 4590) PUERTO RICO NUCLEAR CENTER THE RAIN FOREST PROJECT ANNUAL REPORT FY-1967 Jerry R. Kline, Carl F. Jordan, George E. Drewry, and Project Technical Staff OPERATED BY UNIVERSITY OF PUERTO RICO UNDER CONTRACT NO. AT (40-1)-1833 FOR U.S. ATOMIC ENERGY COMMISSION ---Page Break--- TABLE OF CONTENTS ---Page Break--- 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. ---Page Break--- TERRESTRIAL ECOLOGY PROGRAM | 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 P. 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 ensure 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 that 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. Fil 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. ---Page Break--- 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 rainforest, 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 on May 9, 1965, 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 traveling 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 1Ce, 137Cs, 58Co and 90Sr were plotted as a

function of time on a sentlogerithmic 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. ---Page Break--- 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 is noted 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, therefore it 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. A fully adapted chemical procedure to investigate tropical plant material for this nuclide has been developed. The procedure involves collecting samples from plant tissue with dilute solutions, and precipitation of strontium as the phosphate in the presence of ferric ions for strontium holdback carrier. At the end of the soaking period, the solution is filtered and counted in a low background counting system. The samples are routinely checked for radioactivity. Assumptions run by the most recently modified process indicate statistical error with the 64.8 hour half-life of Sr-90. More than 70 samples of forest material have been analyzed thus far. Standardization procedures using calibrated 3067 scintillation detectors 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 85Sr, 137Cs, and Syn has begun in January 1966, in cooperation with Dr. I. 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 137Cs 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 rainwater 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 a 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 controlled. Areas in the forest have been prepared to study water movement through soils using tritiated water. The first experiment was carried out on February 8, 1967, when 20 mCi of THO diluted to 1 liter were applied to a square plot which was equipped with lysimeters, runoff collectors, and air samplers. Data is shown in Appendix A. ---Page Break--- nL 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, A Tropical Rain Forest. 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 Olsen for the purpose of demonstrating the proper installation of lysimeters to be used in studies of nuclide movement in soils. ---Page Break--- Dr. H. T. Odum remained as a consultant to the project after his termination of employment and had 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. Drewry, G. E., Factors Affecting Activity of Rain Forest Frog Populations as Measured by Electrical Recording of Sound Levels. Kline, J. R., Cycling of Fallout Radionuclides in Tropical Forests. Kline, J. R., and H. T. Odum, Comparisons of the Amounts of Fallout Radionuclides in Tropical Forest. Mercado, N., Report on Leaf Fall in the Radiation Center. Murphy, P. G., and J. McIntyre, Tree Growth at the El Verde Site. Odum, H. T., The AEC Rain Forest Project in Puerto Rico. Odum, H. T., Forest Metabolism and the Giant Cylinder Experiment. Odum, H. T., and A. Lugo (presenting), Metabolism of Forest Floor Microcosmos from the Rain Forest. Odum, H. T., A Functional Theory of Rain Forest Classification Based on Transpirational Control of Root Numbers, Height, Retention of Radioactive Fallout, and Energy. Jo, Venutor, R., and F. K. B. Koo, Cytogenetic Effect of Gamma Radiation on Palicourea riparii. Watson, H., Report on Stem Growth in the Radiation Center. ---Page Break--- Of the papers presented at the Ecological Society of America meetings, 411 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 Soil. 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 Forest (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 Radiecology 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: Kline, J. R., Radionuclide Behavior and Distribution in Tropical Forests (later issued by Battelle as I0CS Memorandum BMI-1, Nov. 1, 1966, 20 p.). Odum, H. T., Hydrogen Budget and Compartments in the Rain Forest at El Verde, P. R., Pertinent to the Consideration of Tritium Metabolism.

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APPENDIX A REPORT ON UNFINISHED PROJECTS

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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 are 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 90Y as the phosphate. After 2 weeks of ingrowth, the 90Y 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/m²/month. It was independently calculated from 90Sr deposition data, published in "Radiological Health Data and Reports," that the probable retained input was of the order of 0.26 nCi/m²/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 137Cs 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 137Cs 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 137Cs are considerably shorter than those for 90Sr and imply a less

effective retention mechanism for 13/cs. The estimate of 568 days obtained for canopy half-life approaches an 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 13/cs was about 0.04 nCi/m². From the previously cited deposition data for 137Cs and the 13Cs/90Sr ratio of 1.4, it was calculated that the actual input deposited on leaves by intercepted rainfall was 0.37 nCi/m²/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 from 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 40 g/m²/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 occurring constantly. The leaves which are lost have the average contaminant burdens of radionuclides while those which replace them have relatively 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 40 g/m² of leaves fall and then are replaced with a like amount of new leaves. This

process is described in Equation 1. (Lo = Wo @ or WL) x oy = Cy @) where: W = Average canopy biomass (g/m²) ---Page Break--- v L = Average weight of fallen leaves = average weight of new leaves (g/n²) = Content of radionuclide in canopy leaves before dilution (pCi/s) 1 (pCi/g) GrLye = KC @ ; : “eg +g a (au) (2) xq +6 © Where n = the number of repetitions (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/m² (derived from the data of Odum et al.) and 40.5 g/m² for leaf fall and replacement during one cycle. The calculated nuclide residence half-life 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 nKy Kz D to the left-hand side of the equation, where D is the total average deposition of the nuclide per month, Kp is the average rainfall interception efficiency, Ky 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 July 2, 1966, at El Verde. The most prominent nuclides were 99Zr-95Nb and 134Cs (Figures 4 and 3). Prior to the test, the effective half-life for 95Zr was about 61 days, while after the fresh ---Page Break --- input it was 44 days. The corresponding environmental half-life 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 M4ce 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. ---Page Break--- re 20.0 10.0) 5 g 50 ° 1” 30020 9001080 June 64 June 65 June 66 Time, Days Figure 1. Environmental residence time of 90Sr in freshly fallen leaf litter in the rain forest. 20.0 10.0 Bes, pcilgm Lo 100200 300 400 500 Time, Days Figure 2. Effective residence times for 137Cs in freshly fallen leaf litter, canopy leaves, and understory leaves in the rain forest at El Verde. ---Page Break--- 20 woo Mes, cig Figure 3. Figure 4, Expected Residence Time of Cs in Forest Canopy Based on

Dilution Analysis vo = Time, Days Computed residence time of 137Cs in rain forest canopy based on dilution analysis of canopy leaves. mo imo 5.0 oo Ans done 6 Fever Time, Days Behavior of 95Zr after input of China 1966. Nb in rain forest leaves nuclear debris produced on May 9, ---Page Break--- a. Canopy Average ‘ce pcilgm a, Time, Days Figure 5. Behavior of 137Cs in rain forest canopy leaves and forest 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 137Cs of Fallout origin in Various Rain Forest Compartments Environmental Leaf biomass 37a Buddens Compartment half-life (days) (g/m² dry) ct /at canopy 588 859 5.8 Understory 937 ‘oe Leaf fall no 40.5e8 O.2ee Leaf Litter - 124 12 ND = Not determined, Included in canopy estimate. ‘Average per month, ---Page Break--- 22 Tracer Experiment planned to determine whether the relatively high levels of fallout radionuclides in the El Verde forest could be accounted for by uptake by trees, a tracer experiment involving 137Cs was established in Senesey. 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 m², were completely encircled with secured aluminum garden edging to a depth of 3 inches, and roots to that depth were cut to prevent export of nuclides to trees outside of the plots. Two of the plots were stripped of all litter and to 1966, prior to the application of nuclides, on January 6, 1986, approximately 1 mCi/m² each of 137Cs, 89Sr, and Dyn 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 plot. This material was dried, 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, instinctive since no clear pattern of uptake kinetics was established after 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 ---Page Break--- 23 4m 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 5x

10°3 to 0.62 for 124¢e and from 0 to 4% for Sin 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 49Gb Plot is instructive. These values range from 0.006 to 1.77 for Mice and from 0.074 to 7.85 for “Mn and indicate, in general, a greater recovery of Syn. This might be expected since Mn is known to be an essential nutrient for plants in trace amounts. Thus it appears that 13ce 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 85sr 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 material. Freshly fallen leaf litter in the plots which were originally stripped of litter was found to be radioactive at the end of the experiment. Total activity in litter accounted for up to 3% of the original 3acg and 4% of the Syn (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 134cs remained relatively constant throughout the duration of the experiment while Syn values tended to decline. Clear conclusions are difficult because greater than anticipated variation was found. ---Page Break--- 24 cimigm Rates of

Radionuclide loss from organic litter originally sprayed with radioactive solution is shown in Figures 5 and 6. The data indicate 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.

4800, PLANTS FROM 0-1 FT TALL
4000 at 3200 Mies
——— tn 2400 1600 00

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

---Page Break---

25 PLANTS MORE THAN 3 FT TALL
Bley 0 Bs 0 54Y & z 3 m0
PLANTS 1-3 FT TALL

Figure 2. Uptake of 14Ce, 85Sr, and 4A through roots of understory plants (forest litter in place).

14, — Bes PLANTS FROM 0-1 FT TALL

Figure 3. Uptake of 14Cs, 85Gr, and 54Y through roots of understory plants (forest litter removed).

---Page Break---

26
1600 MORE THAN 3 FT TALL
C/M/gm
1200 1-3 FT TALL

Figure 4. Uptake of 14Ce, 85Sr, and 54Y through roots of understory plants (forest litter removed).

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TABLE 1 Total uptake of 14Cs and 54Y in Plot 1 by understory plants after 1 year (litter removed).

Species Name Height (inches) Plant 14Cs (x10^6) 54Y (x10^7)
Banisteria laurifolia 10 Seedlings 0.06 0.49
Dryopteris deltoidea 10 Fern 0.66 1.0
Dacryodes excelsa 10 Seedlings 0.03 0.38
Bugenia stahlit 10 Seedlings 0.03 0.04
Eugenia stahlit 10 Leaves 0.57 0.04
Branches 0.34 0.50
Guarea trichiliodes 10 Seedlings 0.08 0.07
Meliosma herbertii 62 Leaves 0.62 4.55
Branches 1.56 57.43
Philodendron krebsii ground Vine 0.22 0.90
Rourea glabra 10 Leaves 0.16 1.37
Branches 0.71 0.10
Balsamifera 10 Seedlings 0.13 0.15
T. balsamifera 25 Leaves 0.07 0.00
Branches 0.34 0.50
Leaf Litter - - 169.00 659.70

---Page Break---

28

TABLE 2 Uptake of 14Cs and 54Y in Plot 2 by understory plants after 1 year (litter removed).

Species Name Height (inches) Plant 14Cs (x10^7) 54Y (x10^3)
Eugenia stahlit 10 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 46 in, whole 30.57 19.76 Plant. 1. balsamifera 15 ft. Leaves 117.56 2258.93 Branches 16 175.09 Trunk 21.87 726.64 Intermediate Trunk 129.71 4360.46 Ground level 1, balsamifera 10 tn, 2.49 16.66 1. balsamifera 30 in, Leaves 0.44 8.24 Branches 4.08 201.09 Leaf Litter - 3069.14 4038.26 SEE ---Page Break--- 29 eee TABLE 3 uptake of 134Cs and “Yn on Plot 3 by Understory Plants After 1 Year (Litter in Place) sss Part of Percent Uptake Species Name Height Plant —Cs(x105) Hn(x103) Dacryodes excelsa 10 in. Seedling 0.19 3.55 Guarea trichiliodes 10 in. a 3.00 1.66 Inga laurina 10 in. o 7.29 3.18 Myreia leptoclada 18 in. Leaves 0.81 0.84 Branches 0.58 0.60 Myreia leptoclada 15 ft. Leaves 37.28 73.06 Branches 27.89 314.93 Trunk 202.74 4093.67 Rourea glabra 36 in. Whole Plant T. balsamifera 10 in, Seedlings

2.23 7.38 Dead stem 15 in, old stem 1.76 11.3 ---Page Break--- 30 a TABLE 4 uptake of 134Cs and Yn on Plot 4 by Understory Plants After 1 Year (Litter in Place) ee Part of Percent Uptake Species Name Height Plant Cs(x105) Hn(x103) Banisteriopsis laurifolia 10 in. Seedling 0.25 0.86 Inga Laurina 10 in, Seedling 1.07 1.30 Mantikara nitida 10 in, Seedling 1.78 1.26 Mantikara nitida 12 in. Leaves 1.70 0.39 Branches 18.16 4.26 Mantikara nitida 17.5 in. Leaves 166.22 8.22 Branches 656.05 0.00 Branches 265.90 0.00 Trunk (Top) 35.88 0.00 Trunk Intermediate 80.79 0.00 Trunk 128.26 0.00 Ground Level Meliosma herbertii 1 in, Leaves 7.18 17.91 Branches 6.48 45.27 Meliosma herbertii 7. Leaves 1.42 2.37 Branches 361.83 1374.94 Myreia leptoclada Whole Plant 2.39 1.78 Myreia leptoclada 16 in, Leaves 9.26 8.78 Branches na 3.69 Neorudolphia volubilis 3 ft. Vine 17.89 18.00 Ocotea Leucoxylon 10 in, Seedling 1.35 2.69 Rourea glabra 10 ft, Seedling 11.22 0.88 1. balsamifera 30 in, Leaves 0.53 2.37 Branches 2.78 29.7% 1. balsamifera 10 in, Seedling 0.48 1.54 Leaf Litter 2053.78 9371.70 ---Page Break---

TABLE 5 134Cs and *n in soil surface (CPM/g) March 17, 1966 June 7, 1966 January 26, 1967 134Cs 2636 + 41 2677 + 19% 2246 + 40% Shannas + 551 517 475% 305 + 39% CMI gms 0 ma TIME, DAYS Figure 5. Rate of change of Ce, 85Sr, and 3H in forest floor leaf litter (plot 4). 3 ---Page Break--- 32 Climbing 10,000 1,000 100! Figure 6. Rate of change of 134Cs, 85Sr, and 3H in forest floor litter (plot 3). 200 300 400 500 Time, Days and 3H in forest floor ---Page Break--- 33 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 (T2O) 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 rainwater 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 x 10^7 count/min/ml for a total application of 1.45 x 10^10 count/min. The specific activity on the plot after application of the 500 ml rinse was then 0.97 x 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

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 that 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 ---Page Break--- cpm/mt 35 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. 1400 1200 1000 800 600 as note 20 4 60 80 100 120 140 160 180 200 220 240 Time, Hours Figure 1. Average tritium activity in atmospheric water collected at ground level from four stations upslope and to the side of the experimental plot. ---Page Break--- 36 Time, Hours 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. ---Page Break--- 2300 200 Figure 4. coming 8 88888 Figure 5. 13,000 Time, Hours. Tritium activity in atmospheric water collected 6 meters downslope from experimental plot at ground level. Time, Hours Tritium activity in atmospheric water collected 2 meters downslope and 1 meter above ground from experimental plot. ---Page Break--- 38 Figure 6. Figure 7. Tritium activity in atmospheric water collected 2 meters downslope from experimental plot and at varying distances above ground. ---Page Break--- y Fraction (x10) 1.0 3 Lixie Coy 100 200 300 400 500 600 700 Time, Hours Figure 8. specific activity fraction of tritium in surface runoff water. SAF © (cpa/nl) runoff/ (cpa/al) original. ---Page Break--- 40 SS TABLE 1 Tritium Recovered in Surface Runoff Water Date Collected Volume Percent calculated c>M/nl_- Collected, ml —Recovery — 25/67 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 oat 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 un 0.001 2/23/67 3:00 PM 7,290 2,100 0.01 2/24/67 4:00 PM 5,491 3,000 oat 2/21/67 10:00 am 3,629 20 0.001

anyer 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 vs 0.001 Cumulative recovery for 1 month 1.3%, ---Page Break--- TABLE 2 Recovery of Tritium in Percolating Soil Waters by a Lysimeter Buried 5 Inches in the Soil Volume Percent Date Collected cre /mt Collected, ml Recovery 2/16/67 13,315 29 0.16 2/17/67 24,716 130 1.36 2/26/67 18,424 n 0.55 3/1/67 41,238 315 5.43 3/2/67 41,239 7 1.00 3/6/67 45,598 99 1.89 3/27/67 21,550 vs st Cumulative recovery after 6 weeks 11.94 a ---Page Break--- 42 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/%) for each of the nine elements in the ash of freshly fallen leaf litter collected at one time from coefficients of variation range from 35.6 for Mn to ‘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 2x2 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 43 main effects or interactions, thus establishing that the elemental composition of leaves. The time x location interaction for iron was statistically significant at the 0.95 level (Table 2). 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. No significant radiation had no effect on 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 of 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, it is concluded that the stratification described in this section is not particularly instructive. ---Page Break--- x (qs 001) = 09 cx'98 es SSE BTN 68"yy or'ss 60°99 usr = earey est £700" 0800" One" cer eve zeze"t 690° 6220" as emt 9€€0" caso" 9669" 9°96 sses"t 40698 yy" = zat as Gigaveet 990" 6ST" vost = Ga)STZ ©—gzeB'Z~—TOST"ET. © ozes* nace (us) ween "9 oa HW wy uz aH "9 x 4 Usy Uy aueceTs oor oaang Ta 28 aso20g upey 242 UT suOTaVag YoF329TT09 3891 OF BOI YY J¥OT Jo UoTaTsoduo] TeaUDUOTE aya UE uOTIeTIEA 1 atv ---Page Break--- Teteration tees for Lene Liceer Aah nefor » Pe center ete 33 1.06 108 ma Lot 1.09 DO Aecer avery 3.7 Las 2.38 an 139 233 3.02 oO am efor Radiation 36,22 39.27 a6 (Control Bae 3.8 a pverase 35.03 34.33 >» MD o seme Radiation a 2.7% 1.93 Control oa Dery 73 average 233 » re center Averane Radiation 028 048, Control ‘ose 038 “080 averaze 045 033 P) cu (Pm) Center Before ever verens Radiation Ww 0 100 Control 108 5 16 average a2 104 ©) za (Pm) center netore After svarage Radsation 700 785 ma Control 700 380 195 average 700 a » MD fore Average 5.49 2.50 4.00 18.48 295 10:70 1.97 203 D ma Before After Average Radiation 5 a 8 Control 65 136 vo avoray 70 8 ---Page

Break--- 46 (s6") asi x - s : : : e - aro . , epeys nan 991 "0 eT"OwaTTT ez wy tort YO “ - Pi apeus 9 = 00 TO 98S ore twty tee TT 1e"O Ps uns nex % 900 *O-HTOT BOE_zety ete aT P ung PIO or 0°06 eae tey tet BLT RO = PT norkdd 9E2 UKE PNY wEEE HOT ye at soyoods. ‘oopy oazeng ‘epz9a 13 6033 seyseds 9821 Tw10A95 UF Ys Jo YoSaysoduoy TwausEaTS pus adKI J¥OT FO dTysUOTIBTON > wave - : = 6s = se - - - (s6"0) as set eo ETO LOD zet SS teL ware ‘weOaeTs saTTIAE at o'0 oto Stree tee BT'S SOT. wr'z sO ‘am TIed TITS sz soo e970 89 OE OE EST SEO aeyTesrq woUECTS: Ott co'0 v0 eS eae wHZ BIT. Ose Tew wpe zo 00 esz est cs azto are aT no-Kdd 942 OKT NZ UZKad BHT HO, AL ae sopoads eV Uy sauaWeTs oyu oazeng tp20A 13 280N s9021 Jo sofo0ds snogieA wor3 YBy 3e97 Jo Wos2}seduo9 [wiuamaT oeseAy ceva, ---Page Break--- a7 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 29 $g/m^2/day$ in the summer months to slightly more than 1 $g/m^2/day$ in the winter months. The annual monthly average was 40.5 $g/m^2/month$. 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 indicate 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. ---Page Break--- 48 wh can't see you in a 2 30 taste ete. ‘Meters from center & —-— 0-0 z°° —— v-» a ue Ne - Lo 0 mm © % 10 1m 1M 10 10 20 Z~ 20 20 2 300 30 June July Aug Sept Oct Nov Dec Jan Feb Mar Apr co field site during June 1, Leaf fall in the El Verde, Puerto Rico for the period June 1966 to April 1967. oo ee ae Fe a Oo 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 ---Page Break--- 20 4“ A Sete FX. A sean vege — ormeis ari oe Katee goa » o © m wm Ww m0 0 mm x 30 June July Aug Sek Oct-Nov Dec dant Agr ay Fruit fall collected in 55 stations during the period September 1966 to April 1967, at the El Verde, Puerto Rico site for 5 species. ~~ Shane etrane Duerotes cela. enitara nia =x 3 * 20 ‘ Figure 3. oe a Bo i Sas a Figure 4. Distance from Source Total increases in tree circumference during the period June 1966 to April 1967, in the irradiation center. ---Page Break--- 50 Productivity Study in Irradiated Area A study of total net productivity in the area surrounding the source, location has been initiated. A 900 m² grid has been laid out in 1 m² 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. ---Page Break--- 46 47 49 50 32 33 35 56 58 59 60 a 63 65 66 oa cy 70 n 2 a 26 28 38 40 4s 48 st 37 n st Job Code Skip Sample date Skip New (Nt) or old (0) vegetation Skip Species Skip Tre 8 (G), Phytolacca (P), or skip Sprout (8) or not (Ni) Skip Coordinates of grid Skip Drainage, Well (W) or Poor (P) Skip Inches Sixteenths Basel Diameter One hundred twenty eights, or skip Inches Sixteenths Dia. 30 cm One hundred twenty eights Tree skip (new) Inches: Sixteenths Dia. 4.5 ft One hundred twenty eights skip Length skip Percent coverage of quadrat skip. Percent coverage in growth area Skip crase Max. height, cm skip Average ht., ca Skip Coverage Skip Inches Sixteenths One hundred twenty eights Dia. Phytolacca skip Inches Dia. 4.5 ft Old trees Tenths skip Percent canopy remaining Figure 1, Format for computer cards for plants within the radiation study ---Page Break--- 52 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 Linoctera domingensis, 76% of 58 old leaves remained. At 45 feet in Inga lsurina, 100% of 28 young leaves and 86% of 7 old leaves remained. Further monitoring of the leaves will be done. Percent of Young and Old Leaves of Manilkara bidentata Heights that Remained for 5 1/2 Months Percent of Percent of No. of tagged tagged young No. of tagged old leaves leaves remaining on 3/26/67 10/11/67 3/28/67 3 re 8 B 38 45 28 100 3 1 a 30 100 23 87 2 6 100 2 100 36 7 100 uv 100 3 2 100 2 100 30 7 100 u 8 — Aa ---Page Break--- 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 No. of Percent of tagged young tagged tagged old leaves remaining, 3/67 leaves remaining, 3/67 Species Leaves 11/65 11/66 Manilkara bidentata 33 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 Average measured change (cm) Manilkara bidentata 10 +26 Dacryodes excelsa 8 -19 ---Page Break--- 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 were 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/m²/hr) than those measured on a tree of the same species at the giant cylinder site (152 gC/m²/hr). Psychotria berteriana, a successional species growing at the radiation center, had higher maximum photosynthetic rates than the climax species, found to have a maximum rate somewhat higher than Dacryodes. Both are climax species. P/R RATIO Metabolism data from two climax species (Dacryodes) indicate that the photosynthesis to respiration ratio may fluctuate (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. Tupoy A. Photosynthetic Studies on Rain Forest Seedlings. 2. Ings, Cecropia peltata, Anthocephalus cadamba, Dacryodes excelsa, and Erythrina berteroana, Master's thesis University of Puerto Rico, 196 --Page Break--- SSS TABLE 1 Summary of Maximum Rate of Net Photosynthesis: Three Species Being Studied SS Maximum Rate of Net Photosynthesis Species gC/m² Phe P/R Ratio gC/m² Dacryodes excelsa Old sun leaves,

giant cylinder site 0.152 8.33 and P/R Ratios for Dactyodes excelsa: Young, immature leaves (bright green), same tree as above 0.18 1.76 Tree #2660, old sun leaves, 18 meters from source 0.098 7.67 Facing source meters from source Manilkara bidentata Tree #2730, old leaves, 18 meters from source 0.181 7.5 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 0.218 475 a 35 ---Page Break--- 56 DONE, VERY YOUNG LEAVES (HEZORTCREBK), clan CYLINDER SITE TOMER oma ABBA = 3.43 x 10° ca ALA? ar rm or rmmoetton 0.92 «2 //oav msrmucio 0.53 ec //oax (am se) caer oe 6 o 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. ---Page Break--- 37 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 nm 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 nm, and a peak of maximum transmittance around 800 nm, 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. ---Page Break --- 58 100 10 Microwatts / cm² / nm 350 500 650 800 950 1100 Wavelength in millimicrons Figure 1. Radiation spectrum above the canopy, March 29, 1967, 12:55 PM ---Page Break --- 10.0 1.0 Microwatts / cm² / millimicron 0.1 350 Figure 2. TRANSMITTED THROUGH LEAF 500 650 800 950 1100 Wavelength in millimicrons Quality of radiation transmitted through a leaf of Manilkara bidentata, March 29, 1967, 1:40 PM

PM 39 ---Page Break--- 60 em? / millimicron Z| 10.0 ° ee 350 500 650 800 950 no Wavelength in millimicrons Figure 3. Radiation spectrum below the canopy, March 29, 1967, 12:45 PM, ---Page Break--- 6 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-inch seamless steel troughs with a mechanism for collecting 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 matter 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, the “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^2, and with an open top, was constructed of 1-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 tes ---Page Break--- 62 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 m2, 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 ceased to move through the lysimeter. The collection

bottles for Terres cetes! and runoff were emptied, and then reconnected, and the UtEMGausee were emptied. Rein continued intermittently through SRE heavy rains. The team assured that the soil remained saturated throughout the night until the next morning when measurements were taken. Water moving through the soil was calculated by rerouting runoff from rainfall reaching the soil surface. All sections were converted to square meter basis. The volume of water created by lysimeters was divided by the total volume of percolate to represent the percentage of percolate collected by lysimeter. The percentage closely resembled the percentage obtained by dividing the top area of the lysimeter by 1's? (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 six rain gauges, 5 feet long by 2 inches wide by 8 inches deep is - while there is 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 approximately the same amount 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 graded and donated by the Ecology Section, Brookhaven National Laboratory. ---Page Break--- 6 rejected and quite porous. During heavy rains, water should move through this porous zone. Below 10 inches the soil aggregate starts to disappear, and the soil is clay with very little, or no sand. Thus considerably less water might be expected to move below 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.

Lysimeters in this soil collected much more water than lysimeters in any other location. A hypothesis for this phenomenon, 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, 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 Cole, D. W. 296, 1958. ‘Aluminum Tension Lysimeter, Soil Science 85: 293-2. Jordan, C. Fe, A Simple, Tension-Free Lysimeter, Soil Science, 1968, in press ---Page Break--- 66 a ‘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 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 3 5 inches 2 2 inches Total cry 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 6261 cat Top area of lysimeter 154.831 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%

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TABLE 3
Water Balance Data from Field Plots, Dec. 23, 1966

	Plot No. 1	Plot No. 2
1. Rainfall (Liters/a)	65.500	102.000
2. Runoff (Liters/n)	11.907	4.500
3. 1-2 (percolate)	53.593	97.500

Percolate collected in lysimeters (liters): 905 - 990
& ry (percent): 1.67 | 1.01
6. Area of lysimeter (percent): 1.54 | 1.54
One square meter

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ose asc § wet ory oc rae O'TE 9" orders 1105 20 O'% $0" $9" 9 gy ost Zoot deep s9youy YT ‘xeaen 293007841 20 9T so" ze" to ort ast Lotz 9288) doap sousur ¢ ‘regen x0300y 847 z0 60 so" 26 OT eer $0 00°S (T8388) doap sayouT ¢ ‘2938a 293207847 tO YT Sov By TO ot tet ort 00'T 302377 AoTTEYS: ‘a030n 92007847 BO LS Ser OTe 20 OT BET ows SET 39335 deap ‘xoaem 303005847 zO0 WE SOT eT TO OT LTT sto Osco Joan 200TH Uw 8 uz Kt, x a Hd ordues waa 1961 ‘6 Azenuer uo 30204 poaeypesar ay xe0u wox3 voxeL soTén0s sapea3xG T}0S pur ‘2020 eayy ‘2020 1OI0uTS4T UF sauOUETT Jo Woyl”I3U209 » aTEvL

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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/mL
Water collected directly from lysimeter No. 1: 232 c/nLg
Water passing through resin column on lysimeter No. 2: +15 c/a/s
Resin column on lysimeter No. 2: 2.44 c/a/g of water that passed through column
Water passing through resin column on lysimeter No. 3: +09 c/a/e
Resin column on lysimeter No. 3: 5.42 c/m/mL of water that passed through column

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70
Centimeter
18 | 16 | 4 | 2
Rainfall above Canopy
Rainfall reaching forest floor
* One standard deviation of rainfall reaching forest floor.

10 | 2 | 27 | 6 | 13:20 | 27 | 3:10
Dec 66 | Jan 67 | Feb 67 | Mar 67 | Apr 14 | 20 | 2 | 6 | 13 | 24

Figure 1: Rainfall above

canopy, and throughfall, in the experimental forest near El Verde. ---Page Break--- Volume, ml 42 2 6 2B 2 Dec 66 mn —— __ysimeter No. BEN —e— Disc Lysimeter eeeeee Overflow 10 2 27 6 132 27 3 10 Jan 67 Feb 67 Mar 67 Apr ---Page Break--- >, ml Volume, 0.1 14422 6 1B 24 Dec 66

Figure 3, Lysimeter No. 10 20 27 6 13.20 27 3 Jan 67 Feb 67 Mar 67 Apr Lysimeter collections, 14-inch depth, control area. 10 ---Page Break--- Volume, ml S. 01 Lysimeter No. 2 1420 2 6 13° (4 10 2 27 6 132% 273 10 Dec 66 Figure 4, Jan 67 Feb 67 Mar 67 Apr Lysimeter collections, 5-inch depth, tritium area, ---Page Break--- 7% Volume, ml —— Uysimeter No. 6 " a T = " uo 8 0 10° 10 1 1420 2 6 13 24 0 076 BAA 3 10 Dec 66 Jan 67 Feb 67 Mar 67 Figure 5. Lysimeter collections, 5-inch depth, cesium area. ---Page Break--- Volume, ml Figure 6. —— _Lysimeter No. 9, 2 inches deep 10 Lysimeter collections, 2- and 5-inch depths, Lysimeter No. 10, 2 inches deep Lysimeter No. 11, 5 inches deep Lysimeter No. 12, 5 inches deep 2 27 6 13 2027 3 10 Feb Mar Apr cesium area. 75 ---Page Break--- w 10! ww = g So? 10 Overflow 1 b 01 420 2B 6B 2@ 0 076302 3 10 Dec 65 = Jan 67 Feb Mar Apr Figure 7, Lysimeter collections, 5-inch depth, above bell jar. ---Page Break--- Volume, ml 104 10° 0? 0 1 01 2% 10 02 6 132 2 3 10 Jan Feb Mar Apr 1967 Figure 8, Volume of water falling upon an area of ground equal to the top area of a lysimeter (154.8 cm^2), ---Page Break--- 78 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 Berlese 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 Puerto 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 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 a or damage to diagnostic structures of the specimens. ---Page Break--- 79 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 all 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 Drevry, Eusebio Diaz Pagan, Joaquin Molinari, Dr. David Walker and the mosquito collecting team of the PRNC Terrestrial Ecology II program under Dr. Poul Weinbren. Abbreviations used in the checklist are as follows: Collection Method L = station lights Lr = Light traps within the forest = 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 sn = 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 a = has as a synonym ---Page Break--- 80 Checklist of Insects Collected at El Verde Field Station Classification Remarks Subclass order # Fam. ‘Suborder Determined (Det.) by Family Subfamily Genus species subspecies collection —other method remarks, Subclass Apterygota 20 sp. Order Thysanura ~ bristletails 1 ep. Family Machilidae - jumping L sp. bristletail 1 sp. = undetermined ST, BF Order

Collenbola - springtails. Family Poduridae 2 sp. 1 sp. ~ undetermined St, BF Family Entomobryidae 16 sp. 14 sp. ~ undetermined St, BF Family Sminthuridae 3 sp. 3 sp. - undetermined St, BF Peerygot: Order Ephemeroptera - mayflies 1 sp. Family undetermined Lisp. 1 sp. ~ undetermined L, Order Odonata - dragonflies, damselflies 3 Fam. 4 sp. Suborder Anisoptera - dragonflies Det. in progress - Oliver S. Flint Jr. USM Family Aeshnidae 2 sp. 2 sp. ~ undetermined L, 8 Family Libellulidae 1 sp. = undetermined y Suborder Zygoptera - damselflies Det. in progress - Oliver S. Flint, USI Family Coenagrionidae 1 sp. Order Orthoptera - grasshoppers, etc. 8 Fam. 44 sp. Det. Ashley Gurney USDA, except noted Family Acrididae - short-horned grasshoppers 1 sp. Schistocerca colombiana (Thunberg) Family Tettigoniidae - long-horned grasshoppers 1 sp. Subfamily Phaneropterinae - bush katydids ---Page Break--- Microcentrum triangulatum Brunner 1, Turpilia rugosa Brunner 1, Anaulocomera laticauda Brunner 1. Subfamily Copiphorinae - cone-headed grasshoppers Neoconocephalus triops (Linn.) 1, Erioloides species 1. Subfamily Agraecinae 1 sp. = new genus, new species Subfamily Conocephalinae - meadow grasshoppers Conocephalus cinerius Thunberg 1. Family Gryllctidae - cave crickets, etc. 1 sp. Subfamily Gryllacridinae - leaf rolling grasshoppers Abelocephala species 1. Family Gryllidae - crickets 1 sp. Subfamily Gryllinae - field crickets Amphicaste caribea Saussure 1. Subfamily Tettigoniinae - sword-bearing bush crickets Gytoxipha gundlach Saussure 1. Anaxipha species 1. Subfamily Eneopterinae - brown bush crickets Gryllacris vaginalis Saussure 1, Gryllacris terebrans Saussure 1, species 1, Gryllacris species 4, Laurepa krugii Saussure 1. Family Gryllotalpidae - mole crickets ("changas") 1 sp. Seapteriscus vicinus Scudder 1. Family Phasmatodea: walking sticks Det. incomplete Phibalosoma adumbratum (Saussure) 1 common in coastal forest, Phibalosoma adumbratum (Saussure) 1.

Lamponius species a 3 sp. - undetermined H Family Mantidae - mantids Gonatista grisea (Fabr.) L Family Blattidae - cockroaches 14 sp. Panchlora sagax Rehn & Hebard L new species Gariblacte craticulata Hebard Bj Cariblatta plagia Rehn & Hebard = Cariblattoides suave Rehn & Hebard L Neoblattella boringuensis Rehn = L, & Hebard 1 sp. ---Page Break--- 22 voner Rehn & Het ‘species a new species species b poss, new species ipha coriacea Rehn 8 Pseudosymplocs LW Pseudosyaploce species L prob. new species L, a L, Epilampra wheeleri Rehn He Euryeotis species Plectoptera infulata Rehn & Hebard L, H Order Isoptera ~ termites 2 Fam, Family Rhinotermitidae - subterranean termites Tenuirostritermes discolor Banks L, ST, H new species

Femily Termitidae - comejen Nasutitermes costalis Holmgren L, ST, H Order Dermaptera - earvige 2 Fem, Panily Labiduridae (Psalididae) Carcinophora americana (Palisot de Beawois) L Family Lebiidae 1 sp. 1 sp. = undetermined st Order Enbioptera - web spinners Lvam, 1 sp. Panily undetermined 1 sp. 1 sp. ~ undetermined st poss. Oligotone saunderess Order Psocoptera - psocids, bark lice 7 Fam. 10 sp. Suborder Trigonorpha Family Lepidopsocida Lop. 1 sp. undetermined ST, LT, L Suborder Troctonorphe Family Pachytroctidae 1 sp. 1 sp. ~ undetermined L, st Family Liposcelidae - booklice 1 sp. Liposcelis divinatorus (Muller) Suborder Eupsocida Family Epipsocida 3 8p. 3 sp. - undetermined uw L sp. > undetermined ur 2 sp. = undetermined ur ALtidae 2 ep. pretiosus Banks = LT T sp. = undetermined ur order Thysanoptera - thrips +3 Fem, #0 Families undetermined about 10 sp. - undetermined st order Hemiptera - true bugs 10 Fam. 25 sp. Family Belostomatidae - water bugs 1 sp. Det. Jon. L. Herring, USDA Belestoma subspinosum Palisot de Beauvois = B. boscii L. & S. Family Schizopteridae = jumping ground bugs 3 ep. 3 ap. ~ undetermined ST ---Page Break--- 83 Family Miridae - plant bugs 6 sp. Det. J. Maldonado Capriles, UPR Itacoris trimaculatus Maldonado LT Antiue min: Lr 00% ur ur Dagbertus species L (Distant) L idae

~ unique-headed bugs 1 sp. 1 sp. ~ undetermined Pantly Nabidae - damsel bugs 1 sp. Det. R. C. Froeschner, USKM Neogorpis neotropicalis (Barber) L Family Lygacidae - cinch bugs 4 sp. Det. J. Maldonado Capriles, UPR Ozophora atropicta Barber ST, L, LT, # Ozophora subimpicta Barber or Ozophora ‘species or Pachybrachius species or Family Coreidae - leaf-footed bugs Det. Jon L. Herring, USDA 1 sp. Phehia rubropteta (Westwood) L Family Cydnidae - burrower bugs 1 sp. Det. J. Maldonado Capriles, UPR Amnestus species L prob. A. pusio Family Scutellaridae - shield bug Det. J. Maldonado Capriles, UPR Pachycoris fabricius (Linn.) # Family Pentatomidae - stink bugs Det. J. Maldonado Capriles subulatus (Thunberg) H Horvath Acrosteroum marginatum Palisot — L, de Beavois cornuta Burmeister L parvinule Barber st. inor (Vollenhoven) st Order Homoptera Sram, 66 sp. Family Cicadidae - cicadas Det. George B. Drevry, PRNC Borencona aguedilla Davis a, L, LT Family Cicadellidae - leafhoppers 16 sp. Det. Janes P. Cramer USDA, det. incomplete Cicadulina tortilla Caldwell st Hortensia similis (Walker) L Krisna insularis Oman L Deltocephalus flavicosta Stal or Protalebrella brasilensis Baker LT Tylozygus fasciatus (Walker) L ---Page Break--- 84 Protalebra species Xestocephalus species Empoasca species Balclutha species Osbornelius spect Graminelle species Xestocephalus species b Family Fulgoridae - planthoppers L st, Lt ST, UT st, LT st, LT L L 45 8 Det. George E. Drevry, PRNC; Checked Janes P. Grammer, USDA Subfamily Cixtinae Bothriocera undata (Pabr.) Cubana tortriciformis Muir Subfamily Delphacinae Gedusa species Subfamily Achilinae cinerea Osborn dorsivittata Caldwell arida Caldwell Quadrana punctata Caldwell Subfamily Tropiduchinae jella nepalita Caldwell Ladella or Neurotmeta species Subfamily Flatinae Petrusa marginata Brunnich pivota Caldwell rorus Caldwell Focquensis Caldwell Flatormenis pseudomarginata Muir Flatormenis nefuscata Caldwell st, Lt, st, L St, Lr, st, LT, st, Lr, st, LT, st, LT, st, Lt, Lr or st, Lt st, LT, ST, Lt,

st, Lt, L peeeee L L undescribed species undescribed species poss. color type of C, ciner undescribed species ---Page Break--- virginfe Caldwell L eillerum (Kirkaldy) 1 (Caldwel1) Q, u, u magna Caldvell ides albu: Subfamily Issinae Thionia boringuensis Dozier st, L Neocolpoptera puertoricensis Dozier ST, L Subfamily Aconaloniinge Caldvell ‘Acanalonie agilis (Melichar) st Acanalonia vivida (Fabr.) L Family Peyllidae - 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 ete. Sram. 9 sp. Det. Oliver S. Flint Jr., USN Family Mantispidae - mantispid files 2 sp. Mantispa specie ST, L near M. sayi or 4. gracilis Climaciella species L near C. brunnea Family Nemerobiidae - brown Lacewings le Nusalalia cubana (Hagen) st, L Family

Chrysopidae - common Lacewings 4s Chrysopa collaris Schneider L Chrysopa species a L near ¢._cubana Ghrysopa species b L jew species Nodita sp. L Family Ascalphidae - ovl flies Loy Ululodes species Ty Coniopterygidae - dusty-wings L ep. Systematics uncertain - Oliver S. Flint Jr., USNM 1 sp. - undetermined Order Coleoptera ~ beet 34 Fam, 101 sp. Det. in progress - 8 specialists USDA and USI Family Carabidae - ground beetles 1 sp. 1 sp. ~ undetermined st, L Pantly Histeridae - hister beetles 1 sp. Ormalodes speci H Family lydrophilidae - water scavenger beetles 1 sp. 1 6p. = undetermined st Family Silphidae - carrion beetles 1 ep. 1 sp. ~ undeterained st Fantly Stephylinidae - rove beetles 7 8p. 7 sp. - undetermined st Family Pselaphidse - ant loving beetles 4 op. 4 sp. ~ undetermined st Family Scydnaenidas ant like stone beetles 1 sp. ---Page Break--- 1 sp. - undetermined st Family Cantharidae - soldier beetles ‘Tylocerus barberi Leng & Mutchler ST, H Family Lampyridae - fireflies Calopisma borencona Leng & Mutchler H Diphotus triangularis (Olivier) # Photinus vittatus Olivier 4, LT, L Leng & Mutehler 4H, LT, L Photinus species 4, LT, L Family Lyeidae - net winged beetle Oy 4 sp. =

undetermined Family Dermestidae - dermestid beetles 1 sp. ~ undetermined Family Cleridae - checkered beetles 1 sp. ~ undetermined Family Elateridae - click beetles 5 sp. Dicrepidius ranicornis Palisot de Beavois 1. Pyrophorus luminous Illiger 1. Platyerepidius species 2 sp. - undetermined 1. Family Throscidae - pseudo click beetle 1 sp. ~ undetermined Family Dascillidae - soft-bodied plant beetles 3 sp. 1 sp. - undetermined Family Dascillidae - soft-bodied plant beetles 3 sp. 3 sp. - undetermined Family Ptilodactylidae - soft-bodied plant beetles 5 sp. - undetermined Family Eluidae - rifle beetles 1 sp. ~ undetermined Family Rhizophagidae 1 sp. ~ undetermined Family Cryptophagidae - silken fungus beetles 1 sp. - undetermined Family Cucujidae - flat bark beetles 1 sp. - undetermined Family Endonychidae - handsome fungus beetles 2 sp. ~ undetermined Family Coccinellidae - ladybird beetles 1 sp. Gurinus sp. Family Colydiidae - cylindrical bark beetle 1 sp. - undetermined Family Euglenidae - euglenid beetles 1 sp. - undetermined Family Oedemeridae - oedemerid beetles 1 sp. - undetermined Family Mordellidae - tumbling flower beetle 1 sp. - undetermined Family Melandryidae - bark beetles 1 sp. ~ undetermined Family Lidae - betsy beetles renatus MacLeay Family Scarabaeidae - scarabs, dung beetles, etc. Det. L. Cartwright, USN. Strategus oblongus Palisot de Beavios Phyllophaga portoricensis Say Phyllophaga species a Phyllophaga species b Phyllophaga species c Phyllophaga species d Chalepides a (Pabr.) Canthocelle parva Chapin Canthochilus borinquensis Mathews Canthochilum histeroides (Harold) 2 palm rhinoceros beetle Det. Eric Matthews UPR Det. Eric Matthews UPR Det. Eric Matthews UPR Family Cerambycidae - long-horned wood-boring beetles Det. George B. Vogt USNM, some in progress Stenodontes exserta Olivier Callipogon proletarius Laneere Parandra cribrata Thomson Derancistrus thomae Linn.

Chlorida festiva Linn. L L L L, # LH Neocledus species: ¥ L L L H L, Leptostylus species Qreodera species ‘Typanidius species Batocera rubus Linn, @ sp. ~ undetermined Family Chrysomelidae - leaf beetles Diabrotica species L 2 sp. - undetermined 51 Family Brentidae - primitive weevils Belophorus species H Family Curculionidae - snout beetles, weevils Rose Warner Spillman, USDA Det. in prog: Diaprepes abbreviata Linn. Ly B Compus species L, 7 sp. - undetermined L, st i, ST probably 0. glauca Linn. Family Scolytidae - bark beetles, timber beetles, ambrosia beetles 8 sp. - undetermined ST, L 87 1 sp. 0 ep. 4 sp. 3 sp. 1 sp. 9 sp. ---Page Break--- Order Trichoptera - caddisflies 6 Fam. 8 6p. Peer® ~ det. George E. Drevry, PRNC, to be checked Oliver S. Flint, Jr, Pantly Rhyacophilidae - primitive caddisflies ‘Atopsyche species uw poss. A. trifida Denning Family Philopotamidae - finger-net caddisflies 2 sp. ‘Chinarra maldonado Flint Ur, L ly Psychomyidae ~ tube making caddisflies 2 sp. Polycentropus zaneta Denning uw ‘Atopsyche tubicola Flint ir Family Wysropsychidae ~ net-spinning caddisflies Lap. eriden protea (Denning) ce Family Caloceratidae

Phylloicus species w prob. Pe pulehrus Flint Family Helicopsychidae Lisp. Heliocopsyche minina Siebold uw order Lepidoptera = 25 Fam. 246 sp. Family Pieridae - sulfurs 5 sp. Disnorphie pio (Latreille) x Phoebis sennae (Linn.) x Phoebis philes (Johansson) x Phoebis species N Eurena species x y Satyridae - satyrs Lop. isto nubile Lathy " Family Nymphalidae - fritillaries, etc. 4 sp. Prepona antinache Pruvost —H Marpesia petreus (Fabr.) x Heliconius charithonia (Linn) Tsp. undetermined x x x L sp. prob. P. argante (Fabr.) ks 2 sp. Family Lycaenidae - blues and hairstreaks Thecla species Thecla species b Family Hesperiidae - skippers layers ‘Panoquina nero (Pabr.) Perichares phocion (Pabr.) Choranthus vittelinius (Fabr.) Family Sphingidae - Sphinx (Johannson) Exinnyis alope (Drury) Pholus fasciatus (Sulzer) 9 sp. = Protoparce sextus ‘Aellopos L Aellopos ‘species L Tsp. ~ undetermined L Family

Anatidae (Ctenuchidae) - ctenuchas Det. William D. Field, USI Cosmosoma auge (Linn.) L, LT ---Page Break--- Cosmosoma achenon (Pabr.) (Dewitt) ‘terminalis (Walker) yridele chalesope Hubner Euceron species undescribed sp, near E. pice Wiki Family Arctiidae - tiger moths Det. William D. Field, USI 8 op. Eupseudosoma involutum Sepp L Epantheria icasia (Cramer) L Epantheria species ‘Utethesia ornatrix (Linn.) ‘Phegoptera bimaculata (Dewitz) Tricypha proxima Grote Lonomia negripuncta Hampson LT Family Noctuidae (Phalaenidae) - noctuid moths 58 sp. Det. Edward L. Todd, USDA, some in progress: Blosyris aycerina (Pabr.) Ophisma tropicalis Guenee Gonodonta sicheus (Cramer) Gonodonta ineurva (Sepp) ‘diffluens (Guenee) megas (Guenee) Prodenia pulchella Herrich- new record for P, Re Schaffer Prodena rubrifusa Hampson Prodenia Heliothis virescens (Pabr.) Eulepidotis addens (Walker) Heterochroma berylliodes Hampson Heterochroma species undescribed species Ephrodes Guenee Sylectre sryeats (Cramer) Condica cupentia (Cranes) Hesselia obvertens (Walker) Specropia scriptura (Walker) Mastigophorus iis Moschler Phlycteina irregularis (Hochler) Manestra soligens Moschler Gonodes liquida Hochler Netalectra analis Schaus Lascoria phormisalis Walker Anespischetos porrectalis (Pabr.) ‘Anespischetos sactatalis (Welker) Phalacnophana eudorealis (Guenee) Garteris oculatella (Hochler) Gallipistra floridensis (Guenee) Callipistra jamaicensis (Hochler) Plusia adnoneng Walker CPR OD CODE pee ---Page Break--- 90 Aracoptera vilhelmina Dyar Afrida tortrociformis Moschler ‘ysbis garnoti Guenee Blepeina Blepting species b Aneibiens species Diomye species species b species cles species Lascoria species Disphragis species Zale species 5 ep. ~ undetermined Family Nolidae Det. Edward L. Todd, USDA Nola bistriga (Hochler) ly Geonet rid: Det. in progress Microgonia vesulia (Cramer) 26 sp. - undetermined Family Pericopidae Ctenuchida virginalis Herrich Schaffer Hyalurga vinosa (Drury) Family Notodontidae - prominents L, Lt L, Lt L > measuring worms,

loopers Béward L. Todd, USDA Det. Edvard L. Todd, USDA Rifargia distinguenda (Walker) Proelymnfotie aequipars (Walker) Disphragis ina (Schaus) Disphragis species Panily Megalopygidae - flennel soths Hegelopyge krugit (Dewitz) Family Pyralidae Det. George E. Drewry, PRNC, Det. in progre Pachysorphus subductellus Moschler Gataclyste miralie Moschler Gataclyate species Fabr. ‘Argyrie diplomachalis Dyar L L L L L, ot L L, ur L, Lt L L, ur W. Hodges, USDA Z. f4etilie (Guenee) 1 sp. 27 8p. 4 ep. Lop. Ronald ---Page Break--- 2 Syngamta florella (Cramer) bur Diaphania costata (Pabr.) L Lr Disphanie flegia (Cramer) ” Diaphants Iyetitats: (eine. Lar Diaphania nitidalis (Cramer) Ly ur Diaphania species . Naruca ‘Cestualie’ (Geyer) Sarageia gigentalie Guenee Terastia weticulosalie Guenee Sylepte elevata (Crabs.) Sylepta silicalis (Guenee) Sylepes apecises Sylepta species b Sylepta species ¢ Bulepte concordalts jubner Azochis rufidiscalie Hanpson Azochis spect Desnia ufeus (Cramer) Desnia species Eyrausta cerata (Pabr.) Exyrausta cardinalis (Guenee) Phostria huneralis (Guenee) Phostria species « Phostria species > 38 sp. = undetermined tur Family Pterophoridae = plume moths 5 ep. Oidaenatophorus basalis (Moschler)

L, LT Peerophorus species Sep. - undetermined L = many-plumed moths 1 sp. ur copes ur ir Lr Pree noe Family Olethreutidae - codling moths, etc. 2 sp. Bactra species L 2 sp. Family Cossidae - carpenter moths Lsp. Peychonoctua personalis Grote L, ut Family Gelechiidae Lp. Dichoneris species L, ut Family Ethmiidae Ethmia notatella (Walker) L Family Acrolophidae - borrowing webworms 15 sp. 15 sp. = undetermined L, LT Family Tineidae - clothes moths, etc. Tiquadra aeneonivella (Walker) = L Tsp. - undetermined L Family Gracilariidae - leaf miners 1 sp. 1 sp. - undetermined L L sp. 2 sp. ---Page Break--- 92 Order Diptera - flies Suborder Nematocera - long horned flies Family Tipulidae - crane flies Subfamily Tipulinae Det. George E. Drewry, PRNC Dolichopeza puertoricensis Lt, L Brachyprenna unicolor Osten Sacken 1 Subfamily

Linoniinae Det. Alan Stone, USDA Heliu: (Osten Sacken) LT Limonia diva (Schiner) L, ur Livonia gövdeyi Alexander ur Limonia cinereinota Alexander ur tibialis (Loew) ur Limonia myersiana Alexander ur ur ur ur ur uw species hh ur Allistoniana Alexander LT, L i (Alexander) Lr, L ‘species aa ur hoffmani Alexander ur divisa Alexander ur Erinitatis Alexander ur Species t ur ur Atarba species s ur olynere geniculate pallipes Alex. LT Hexatoma species a Hexatoma species b L Psiloconopa portoricensis (Alexander) ur Patloconopa caliptera (Say) Lr Teucholabis species eg, ur Gononyia pleuralis (Williston) ur Gononyia puer Alexander ur Gonomyia subterminalis Alexander LT Trentepohlia ur Trentepohlia specic ur Shannonomyia leonardi ur Shannonomyia species p ur 2 Lr ‘Shannonomyia speci Family Psychodidae - moth flies 36 Fem. 454 ap, 38 8p, poss. nev, near domestica poss. new, near domestica poss. nev, near will: new, near L, cartbea Alex. new, near L. caribea Alex. new, near A. angustipennis ‘Alex. undescribed species undescribed species poss. T. portoricana Alex. poss. new, near Leonardi Prob. undescribed Det. in progress, Alan Stone, USDA 37 sp. ~ undetermined = midges ST, LT Det. in progress, Willis W. Wirth, USDA ---Page Break--- 93 Family Geratoponidae = Diting midges, punkies 36 ap. Det. Willie W. Wirth, USDA, most in progress Monohel johannseni Wirth Lr © A Prost Gorscotdes species a st Falpoeyia species = a Keriehapogon, 3 species undetermined st, Stilobezzia, 3 species " undetermined st, ut Dasyhela, 3 species undetermined ST, LT Forcipomyia, 22 species undetermined ST, LT Family Simuliidae ~ black flies 2 op. 2 sp. ~ undetermined La Family Culicidae - mosquitos and phantom midges Det. Brooke Worth, Rockefeller Foundation 12 (Theobald) st, LT. Lr species ¢ ST Aedes mediovittatus (Coquillett) LT, L, H_ Det. Brooke Worth, RF Aedes taeniorhynchus (Wiedemann) LT, H Det. Brooke Worth, RF Aedes seri LT, H Det. Brooke Worth, RF Culex nigripalpus Theobald LT, H Det. Brooke Worth, RF Culex quinguifasciatus Say LT, H Det.

Brooke Worth, AF Culex species ur Det. Brooke Worth, RF Wyeomia species LT, H Det. Brooke Worth, RF Uranotaenia species ir Det. Brooke Worth, RF Mansonia flaveolus (Coquillett) LT Det. Brooke Worth, RF Family Dix dixid midges Dixa species ur prob. D. hoffmani Lane Family Seatopeidae ~ minute black scavenger flies Rhegmoclema species ST Aldrovandiella species ST Family Mycetophilidae - fungus gnats 28 sp. Leia species st Manote species st Platyura, 5 species undetermined ST, LT Megophthalmida species st Boletina (incompleta Curran) ST, LT Boletina species st prob. undescribed Neompheria species ur Zygonyia, 4 species undetermined ST, LT Exechia, 5 species undetermined ST, LT. Rhymosia species ST Hycetophilia, 6 species st poss. new genus undetermined 1 sp. - undetermined st poss. new genus Family Sciaridae - dark wing fungus gnats ---Page Break--- 94 33 sp. - undetermined st, LT, L Family Cecidomyiidae ~ gall midges 30 sp. - undetermined st, LT, Suborder Brachycera - short horned flies Family Stratiomyidae ~ soldier flies Det. W. W. Wirth, USDA, some in progress Hermetia illucens (Linn.) LT, St, # Nothonyia nigra Janes LT, sp. = undetermined St, Lt Family Tabanidae - horse flies Det. Alan Stone, USDA Brunettsi (Bequaert) Family Bibionidae ~ dance flies 6 sp. = undetermined ST, LT Family Dolichopodidae - long-legged flies Det. George C. Steyskal, USDA Gondylostylus graenicheri (Van Duzee) LT. Condylostylus sp. st. Condylostylus sp. LT prob. undescribed Gondylostylus species ST, LT prob. undescribed Pelastoneura species ST prob. undescribed Neurigonia species LT Thrypticus species st poss. T. fraternus (White) Chrysotus flavohirtus Van Duzee ST Chrysotus species a st. prob. undescribed Chrysotus species c st. prob. undescribed Chrysotus species b st. prob. undescribed Chrysotus species d ST, LT prob. undescribed Chrysotus species 3 st 1 ST Chrysotus species 2 sp. ~ undetermined ST Family Phoridae - hump-backed flies Det. in progress, Willis W. Wirth, USDA 65 sp. - undetermined ST, LT Family Syrphidae - flower

flies Det. Willis W. Wirth, USDA (@revry) x ‘besa (Fabr.) N cubensis Macquart L, 6 Baccha capitata Loew L Baccha Tatiuscula (Loew) N Family Otitidae - picture-winged flies Euxesta thonae Loew L, st Euxesta species L Family Trypetidae - fruit flies ‘Anastrepha species Family Lonchaeid: Lonchaea species st, L L 65 sp. 5 sp. ---Page Break--- 95 1 sp. ~ undetermined ur Family Lauxanidae 6 sp. Det. George C. Steyskal, USDA Pseudogriphoneura albovittata st, Lr ‘Ceowy Pseudogriphoneura octopunctata (Wiedemann) st, ur Pseudogriphoneura species ur poss. undescribed Neogriphoneura sordida Giustenmne) st ovctlominettia pietiegrats : Goauitiett) st apronyes spectes Lr not §, vitigern Family Micropezidae - stilt-legged flies ce Det. George B. Deewry, PRNC bap. Taentaptera lascive (Fabe-) rs ° Taenlapters species i Systellaphe sesree tnderlein St Syatellaghe Spates ES aaily Weriidae’= neriid flies dep. 3 ap. = undetermined Pantly Sepsidae = Black scavenger flies Lop. et. George c. steyskal Palacosepeis hemorrhoidal EL chines) Pantly clustidee dep. ap. = undetermined st, ur Family Agromyzidae - leaf miner flies 2 sp. Det. Curtis W. Sabrosky, USDA & George C. Steyskal, USDA Odinta biguttate Sabrosky st. Melanagronyza species st. Family Milichiidae (Phyllomyzidae) - phyllonyzid flies 2 ep. 2 sp. - undetermined Family Drosophilidae - small fruit flies, pomace flies 8 sp. Drosophila, 3 sp. undetermined st. Aulacigaster species ST @ sp. undetermined ST Family Chloropidae - fruit flies, eye gnats 2 sp. Det. Curtis W. Sabrosky, USDA imella lutzi (Curran) ST Pentanotavlax species ST undescribed species Family Sphaeroceridae (Barboridae) - dung flies sp. 4 sp. - undetermined ST 20 sp. Family Tachinidae - tachinid flies Det. in progress, Curtis W. Sabrosky, USDA Euphas{opteryx dominicana (Townsend) L, st Eucelatoria armigera (Coquillett) L, ST ---Page Break--- 96 Tachinophyto species st, 8 Ths 17 sp. - undetermined st Family Calliphoridae - blow flies Lop. Det. R. J. Gagne, USDA Phaenica rica (Shannon) ST, LW ily Sarcophagidae - flesh flies

Det. in progress, R. J. Gagne, USDA Paraphrissopoda capitata (Aldrich) ‘ST Sarcophage species a ST a st TI sp. - undetermined St Family Muscidae - horse flies, etc. 12 op. Det. George C. Steyskal, USDA L, ST op: iportus Snyder ST, L Neodexiopsis discolorisexue Snyder ST Neodexiopsis crassicrurus Snyder LT Neodexiopsic maldonadoe Snyder Order Hymenoptera ~ bees, ete. 24 Fam. 140 sp. Suborder Apocrita Family Ichneumonidae - ichneumonid wasps 4 op. 4 sp. - undetermined st, L Family Braconidae - braconid wasps 8 sp. Det. Carl F. W. Musebeck, USI Apanteles carpatus (Say) st. Heterospilus species st Xenarcha species st. Eephylus species st. Orthostigma species st. Spathius species st. Macrocentrus species ur Clinocentrus species ur Family Mynaridae - fairyflies 13 sp. - undetermined Panily Trichogrammatidae 3 sp. - undetermined st Family Eulophidae 14 sp. ~ undetermined st Family Encyrtidae 7 sp. ~ undetermined sT Family Eupelmidae 1 sp. - undetermined st Family Agaontidae - fig wasps Blastophaga species st Family Cynipidae - gall wasps Det. Carl F. W. Musebeck, USIM ---Page Break--- hypolethria species st Kleidotona species st 2 sp. = undetermined St Family Ceraphronidae 7 11 ep. Det. Carl F. W. Musebeck, USI Geraphron, 5 sp. undetermined st ‘Aphanogmus, 4 sp. undetermined ST 2 sp. ~ undetermined st Panily Diapriidae 12 sp. = undetermined st Family Scelionidae 17 sp. ~ undetermined st Panily Platygastridae 9 sp. - undetermined st Family Bethylidae ~ bethylid wasps 4 sp. ~ undetermined st Family Formicidae ~ ants Det, William L. Brown, Jr., Cornell Univ. Strumigenys rogeri (Emery) st Strumigenys eggersi (Emery) st ‘Strumigenys gundlachi st Paratrechine species st (Ilyander) species 0 st Doringuensis ST st, Solenopsis geminata (Fabr.) st Solenopsis corticalis Forel st Tetranorius guineense (Fabr.) x Dndontonachus bauri st, Iridomyrmex melleus Wheeler st ‘Gyphonyrnex Fimosus (Spinola) st Hononorium floricola (Jerdon) st ‘Camponotus st, Trachymyrmex st yrnelachiste st, Tapinoma littorale Wheeler st Brachymyrmex

heeri Forel st, uw ‘Ablyopone spect Family Scoliidae - scoliid w undescribed sp. Lop. Det. George E. Drewry, PRNC (Pabr.) 1" Campsomeris er wasps Family Vespidae Det. Polistes crinitus Felton Mischocyttarus cubensis (Saussure) W " 2 ep. George E. Drewry, PRNC ---Page Break--- 98 Family Pompilidae spider wasps Det. George E. Drewry, PRNC Pepsis ruficornis (Pabr.) Family Sphecidae - sphecid wasps Ammobia ichneumonides (Linn.) N 2 sp. - undetermined NL Family Dryinidae - dryinid wasps 1 sp. ~ undetermined st. Family Apidae - bees Xylocopa brasilianorum (Linn.) " Family Halictidae - miner bees 2 sp. - undetermined # ADDENDA AND NOTES FOR INSECT CHECKLIST 1, Additional insects reported ‘Teiacanthagyana septima (Selys) Gynacentha nervosa Ranbur Family Libellulidae Erythrodiplax unbrata (Linn.) Family Coenagrionidae Enallegna coecum (Tagen) " Order Neuroptera Family Mantispidae Climactella cubana (End.) L Above Det. Oliver S. Flint, Jr., USI we (instead of ¢. 1 op. 3 sp. 1 sp. 2 sp. October 1, 1966 species) ---Page Break--- 99 LITERATURE CITED 1, Borror, D. J., and D. M. DeLong, An Introduction to the Study of Insects, Rinehart and Co., New York, 1030 p., 1954, Caldwell, J. S., and L. F. Martorell, Review of the Auchenorynchous Homoptera of Puerto Rico, Part I Cicadellidae, Part II The Pulgoroidea Except Kinnaridae, J. Agr. Univ. P. R. 3421-269, 1950. 3. Curran, C. H., and W. T. M. Forbes, W. Schaus, W. P. Comstock, E. By Klots, H. Osborn, and H. G. Barber. The Insects of Porto Rico and the Virgin Islands, New York Academy of Sciences, New York, Scientific Survey of Porto Rico and the Virgin Islands, Vols. 11, 12 (parts 1-4), 14 (parts 1-3), 1928-39, 4, Flint, O. S., The Caddisflies of Puerto Rico, Univ. P. R. Technical, paper 40:1-77, 1964. García-Diaz, J., An Ecological Survey of the Fresh Water Insects of Puerto Rico, J. Agr. Univ. P. R. 22:43-97, 1938. 6. Martorell, L. P., A Survey of the Forest Insects of Puerto Rico, Parts I and II, J. Agr. Univ. P. R. 29:69-608, 1945. 7. Medina Gaud, S., The Thysanoptera of Puerto

Rico, Agr. Expt. St Univ. P. R. Technical paper 32:1-159, 1961. Wolcott, G. Ne, The Insects of Puerto Rico, J. Agr. Univ. P. R. 32:1-975, 1948. ---Page Break--- 100 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 - Residuum 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 horizon roots tend to form a mat at the surface. Salt or alkali - None Stoniness - Abundant stones and boulders on surface 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 is waterlogged; very strongly acid; clear wavy boundary, BL 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 ---Page Break--- Bal B3 cL 13-24" 24-35" 35" + lol 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 Al material, patchy clay

films; numerous thick earthworms; very strongly acid; clear wavy boundary. 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. Saprolite - very highly weathered volcanic rocks that can be crushed between fingers, with variegated colors. ---Page Break--- 102 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 feet 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 soil the root distribution is normal Salt or alkali - None Stoniness ~ None Soil Profile; Undecomposed and partially decomposed leaves and twigs B1 0-15" 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. B2 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. 60" + Saprolite - highly weathered volcanic rock that retains rock structure but which can be easily crushed between fingers. ---Page Break--- 103 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 Groundwater - Deep Moisture - Moist Climate - Tropical humid Root Distribution - Abundant on surface and deep Salt or alkali ~ None Stoniness - Abundant on surface Soil Profile ho 1 Consists of partially decomposed and undecomposed leaves and twigs with depth aL O-1" Yellowish brown (10YR 5/4) silty clay loam; weak fine granular structure; slightly sticky and slightly plastic; very strongly acid; abrupt wavy boundary. Bal 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. 322 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. ca 19-27" Yellowish brown (10YR 5/8) silty clay loam; massive japoritic material, ee ---Page Break--- 104 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 DBR. ---Page Break--- 105 (oxd poz 103) seBprapton “y “1 30 poqzen 943 02 Suspzo29" 3e0x0y ops0n TH aua Jo 215024 POzTTHOPT oy eantra 13M WwoldouLens 31I40¥d G3zNvaai 09! O148Nd- 1S3404 FGA 13 ---Page Break--- 106 TABLE 1 Species Symbols for Idealized Profile of El Verde Forest, Puerto Rico Symbol 1. Euterpe globosa z 2. Croton poeeilanthus cr 3. Dacryodes excels Da 4. ce 3. sh 6. Manilkare Man 7. Miconia tetandra Mit 8. Micropholis garciniaefolia Mig 9. Inga vera Tev 10. ‘Alchorneopsis portoricensis Alp 11. Matayba domingensis ad 12. Inge lavrina TnL 13. Quararibaea Turbinara 0 14. Ormosia krugii or 15. Didymopenax morototoni Di 16. Gyrille racemiflora y 17. Gallycogonium squamulosun ca 18. Alchornea latifolia all 19. Linociera domingensis L 20. Tabebuia heterophylla T 21. Sapium levrocerasus sa 2. c 23. oc ---Page Break--- ‘Smmon Tobe species tn the th verde Pos 107 wo, 8 Transecte Latin Name ‘ane on oy wo wo “oo ~ : ee si BO Eat 3 3 cacao moet es ak a0 a8 aga 8 3 OR ili we ow mk ake » we seo Gog 3 1 uv ‘Queraribace, ” a “ ormosie krugti tune 2 & SCpcepenst trotont oo Bot " on st ne oo 5g 12 Alehornen Lattfolia % sas woe 8 31a balbat'tcorontta ae ok Bt 2 7 Guarea trichiliodes iM 8 % 5 cme SS q BRN Sg 2 3 ‘Loses herbereit ‘oss lg > eI HE Bl Bot a 3 it 6B 3 3 2 Eoeate om es x 5 eeepc Sob} x : wee z t sig 1910 $ oy o » 1 Kietelle cugose: 008 eee ated taneecte ut at nen © 2 na vadnortnt Aledo i 3 olstee patie see a i estes ie 3 1 MeiseayiseSeetacon Feaute $ 2 steered, Palo de cabee 8 Feat ae Cg ema ene ttn et eat a a ---Page Break--- 108 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 ---Page Break--- 109 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 paper tape inputs. 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 ground 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 steady wind speed during the months of September and October 1965, which is seemingly related to an increase in average temperature during this same period; this may be due to a reduction in average ventilation. There are generally higher wind speeds at ground level than in the canopy, which is reflected in the temperature pattern also, with slightly higher temperatures in the canopy. ---Page Break---

TABLE 1 Weekly Total Rainfall Record El Verde, Puerto Rico Begin End Date/Time Date/Time Rainfall 7/8/64 7/23/64 7/23/64 7/28/64 7/31/64 8/7/64 8/7/64 8/14/64 8/21/64 9/9/64 0 9/16/64 9/16/64 0 9/23/64 9/23/64 0 9/30/64 9/30/64 8:50 10/7/64 10/7/64 9:30 10/14/64 10/14/64 9:36 10/21/64 10/21/64 9:07 10/28/64 10/28/64 3.0" 11/4/64 11/4/64 0.8" 11/8/64 11/8/64 0.8" 11/25/64 11/25/64 2.16" 12/2/64 12/2/64 0.1" 12/9/64 12/9/64 1.0" 12/16/64 12/23/64 12/23/64 0.5" 12/30/64 12/30/64 1.67" 1/6/65 1/3/65 1/13/65 1/20/65 1/20/65 1/27/65 1/27/65 2.74" 2/4/65 2/4/65 2.1" 2/18/65 2/18/65 2.25" 2/25/65 2/25/65 3/1/65 3/1/65 3/8/65 3/8/65 3/15/65 3/15/65 3/22/65 3/22/65 3/29/65 3/29/65 4.75" 4/5/65 4/12/65 4/2/65 4/19/65 4/19/65 4/26/65 4/26/65 5/4/65 5/4/65 5/11/65 5/11/65 5/18/65 5/18/65 5/25/65 5/25/65.

6/1765 6/8/65 6/8/65 6/15/65 ---Page Break--- TABLE 1 (Continued) => Begin : Date/Time rainfall

EN 6/22/65 6/29/65 7/6/65 7/16/65 7/3/65 7/20/65 8/3/65 8/10/65 8/10/65 8/17/65 8/17/65 8/24/65 2.76 9/7/65 9/15/65 9/2/65 9/22/65 9/29/65 10/6/65 10/13/65 10/13/65 10/20/65 10/20/65 10/23/65 10/28/65 11/4/65 11/4/65 11/12/65 11/9/65 11/19/65 11/26/65 11/26/65 12/3/65 12/3/65 12/10/65 12/10/65 12/18/65 12/24/65 12/31/65 1/7/66 1/14/66 1/21/66 1/21/66 1/28/66 1/28/66 2/4/66 2/11/66 2/4/66 2/8/66 2/24/66 3/3/66 3/10/66 3/24/66 4/7/66 4/21/66 4/16/66 4/21/66 4/28/66 4/28/66 5/5/66 5/12/66 5/12/66 5/20/66 5/27/66 ---Page Break--- Temperature, deg. C 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. ---Page Break--- 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. ---Page Break--- 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. ---Page Break--- 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 0 0 2 0 0 1 0 2 2 4 3 2 0 0 2 0 5 6 5 3 0 0 0 3 2 8 8 6 7 0 6 7 2 1 6 6 6 16 ESE 9 9 4 8 7 6 1 8 0 3 0 0 0 SSW 2 3 1 0 4

5 & 0 sw, 6 o 0 5 5 3 2 ws o 1 ot o 0 2 2 4 12 w nr) o 0 30205 3 ae o 7 4 oo 4 6 & os ww 2 6 2 o 0 320% 6 mw 2 6 2 0 0 4 3 68 9 ‘Based on 10 days or less for the month, ---Page Break--- APPENDIX B MANUSCRIPTS SUBMITTED This section includes manuscripts which have been completed during FY-197 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 I0CS 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. ---Page Break--- u7 Comparisons of the Amounts of Fallout Radionuclides in Tropical Forests J. R. Kline and H. T. Odum f 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 40K, 137Cs, and 90Y. 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 legumes and forest litter indicated an apparent accumulation of 14Xe, but not of 137Cs in the litter of all of the forests examined, with traces of 90Zr-Nb in both leaves and litter. The one exception, a forest in Mexico, showed an

average of 3.5 pCi/g in the leaves and 10.3 pCi/g in litter, been received as a result of the monitoring. 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 Cs levels up to 25 pCi/g in leaves, although the last U.S. and USSR atmospheric weapons tests occurred in late 1962. Rainwater samples taken in 1965 indicated undetectable amounts of 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 for us 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. Trees were sampled from primarily understory growth because of the difficulty in climbing to canopies in forests where no equipment was available.

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 oven-dried 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 (Tl) crystal enclosed in a Cd-Cu lined lead cave with 4-inch walls. The crystal was connected to a 400 channel THC pulse height analyzer calibrated to 10 keV/channel. At the end of the 100 minute counting runs, backgrounds were subtracted and the data 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 fitting the spectra. 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 40K, 137Cs, 54Mn 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 is 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 seasons shown later in this report. The levels of M4ce, 17/cs, and seers generated at the common latitudinal position show a significant decrease from north to south. This is consistent with the findings of Lockhart et al. (4) in the 80° 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 increasing 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 eastern 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 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 *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 Yoore 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 mechanisms 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. 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 epiphytic plants on leaf surfaces. These plants obtain their mineral nutrients by interception of canopy drip or rain and may also intercept aerially injected radionuclides. The relationship between fallout isotopes and epiphytic plants has been shown by Briscoe and Briscoe (1). They showed that leaf scrapings, which include the surface epiphytic 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 correlates with rainfall which was ---Page Break --- 122. The forest litters show a considerable accumulation of 134Cs and 137Cs over the levels found in the forest trees (Table 5). This is not the case, however, for 90Sr. 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 134Cs in leaves.

Liggers is the result of the fact that Cs is not a plant nutrient and Ma 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 Cs in litters is probably due to the fact that Mn is an element required by plants in only trace amounts. As the originally intercepted Cs 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 Cs/Mn ratio. The apparent failure of 137Cs 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 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 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 Cs reaches the forest floor. These two factors may combine to produce a more rapid recycling of 137Cs in the forest and hence an apparent lack of accumulation in the litter. 95Zr in Canopies and Litters Page of the solution of simultaneous equations for the complex spectra 95Zr-99Nb 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 95Zr-99Nb were found in both leaves and forest litters. The results for this site show an accumulation of 0.5 ib in the forest litter as was previously shown for Cs and Syn. 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 95Zr-99Nb 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 Mo-140 and Cs-134 are also present.

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123 ‘CONCLUSIONS: The average levels of contamination of tropical forests with fallout radionuclides are related to the latitudinal position of the forest area, with the region from 18° north to 9° north being the most highly contaminated. This is consistent with recent sewage of the 60° meridian sampling network, where a sharp increase in nuclide content of air is shown to occur south of the equator at around 10° 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. 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 the binding of intercepted nuclides, in the recycling of nuclides, or in tree-epiphyte associations. Comparisons of forest litters and canopies showed that Cs-137 and K-40 were accumulating in the litter of all of the forests examined. Results were not so clear.

for 13Cs since some forests showed apparent accumulations and others showed apparent depletions in the litter. The accumulation of 14Ce is suggested to be due to negligible recycling of this element in plant communities while that of 137Cs is probably the result of low rates of recycling and high isotopic dilution. The variable results for 137Cs 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 groundwater or is rapidly recycled back to the trees. Measurements of 95Zr-95Nb showed detectable but low levels of these isotopes in most of the forests 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 content carried out with reasonable economy by selection of samples might be indicators of the general canopy burden. Values from leaf litters tend to overestimate Na and K levels in leaves but give approximately the same values for 13Cs. Epiphytic plants such as bromeliads and mosses are often easily obtainable from forest understories and tend to give maximum estimates for canopy burden: — 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 soil. Extensive surface roots. Bromeliads and epiphytic 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 epiphytes 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. Central America: Costa Rica, Panama, Mexico. Turrialba site, Evergreen montane rain forest with trees to 90 ft. Soils residual over igneous rocks. Surface roots similar to El Verde. Sarapiquí site. Evergreen rain forest with trees to 150 feet. Soils residual over igneous rock. More deeply rooted than El Verde. San Lorenzo site. Evergreen rain forest with trees to 100 feet. Soils residual over igneous rock. Deeply rooted, few epiphytic plants. Uxmal, Yucatan site. Seasonal rain forest with trees to 70 feet. Soils residual over igneous rock. ---Page Break--- -popet2uy 200 Aarouossoede Kex-mauet uy 830333 “kaytyqeyaea oqdmes 20; HY x reuze3 10223% 9-0 F 10 soz 1 Fors wot uwavama ‘Te0xn) 091%9% 2-0 $ S-0 co 5 0 Foe 6 eae £10 F siz 60 TE e's Sou (iabydexes) easy P2800 10 ¥ 2°0 20 F OF TE for (eqtes2ani) voTy 23809 wopaouy 1923099 cor 60 Ft 10 F9"9 oot ot Pepruay LoF CLF 56 OF EET oot St eoyurmod spueqsr 29420 vedo o's Forse F sro oz a vista 8:0 F 62 $2 F251 Fest set tnt opx0n Tz 90 ¥ 6° $0 62 Fey oot ia ovoT abit 10 ¥ 0-0 Loree Fee o tet suoaseuT1 oon eazeng &, (S/r04) °9, (soyout) epnazaeT gaesoa * ue, mm Tregurey Tenwy veoK voyaoy qer3u99 pur w¥9aasse9 a2 Jo sases0g Two}dox1 OT UO3T #MAHOT UT 819407 Ug z stew PUP SD ¢1 ‘yyy eBEIOAY ---Page Break--- 27 soqdues oTSurs* se > 9t oros - “'se ise - 9781 sured ero = 19 sorz- 6-19 sTit- 8°22 920k 46 - 6°8

rati= 0°88 sity - Te perrowoag eee = TT $6” = TOT 695 - E21 seavol 202d asozog U331E ol sv6e L761 sured go - Be Srey = €°92 6:02 = "ST perqouora Te - 20 ane = 9°85 ese = 02 sonra 90a1 epx9A 12 970 s'ot us sured 42 6:21 oe apeyrouord we = 10 ws <9 v6 = tT soavo7 9031 oosaeH er 10 oe - 91 as eT senvoT 9931 389303 9u03 900} Wye ero) yo asa20a Le sisea0g weoyy o330nd uy sadKy aueTg Jo UoFIeUTWEIUCD 30 soBuLY © arava ---Page Break--- 128 TABLE 4 Mice, 137¢5, Syn Levels in Leaf Litter from Caribbean ‘and Central American Forests Fee 1375 Forest Mice (pci /gram) in ee Puerto Rico Limestone 8.0 43 1.2 Maricaot : - - EL Verde 18.3 8.9 3.3 Elfin (E1 Yunque) 45.4 16.4 10.8 Other Islands Dominica 34.6 12.9 7.3 Trinidad 11.6 47 2.0 Central America 5.6 1.3 0.7 Costa Rica (Sarapiqui) 5.2 17 Lg Panama 40 1.6 0.7 Mexico ld 06 NDA * Litter sample not collected ** ND = Not detected ---Page Break--- 129 TABLE 5 Relative amounts of M4ce, 137c5 and Sin in Leaves and Litter from caribbean and Central American Forests 144 137 34 Ce Leavesss Cs Leavestit Mn _Leavestrit Ta By % Forest Ce Litter os Litter Mn Litter Puerto Rico Limestone 0.6 0.6 Maticaok a H El Verde 0.8 o.9 Elfin 0.6 0.7 Other Islands Dominica 0.4, 0.7 0.4 Trinidad 0.6 0.8 0.2 Central Anerica costa Rica (Turrialba) 0.5 0.9 0.7 Costa Rica (Sarapiqui) L7 4.0 1.3 Panana (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 ‘*e*Population not different from one ‘Population 1 at 97% confidence level (AL tests Wilcoxon signed rank). ---Page Break--- 130 TABLE 6 95z¢-95xy Levels in Forest at Yucatan, Mexico, as Compared with Other Central American and Caribbean Forests Leaves 95 95. Forest zx- Nb (pCi/e) Litter uxmal, Yueatan, Mexico 3541.7 Gentral American forests (and Trinidad) 0.3 4 0.1 Island forests 120.2 *Single sample LITERATURE CITED

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rates of leaching of 19Cs and >*Yn from forest canopies. The accumulation of fallout isotopes in epiphyllous plants rather than leaves themselves, and the probable high rate 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 (4,556). 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 14Cs 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 'achieve Scientist 1 and Director, Terrestrial Ecology Project, PRNC. former Director, Terrestrial Ecology Project, Puerto Rico Nuclear Center, now Professor of Biology, University of North Carolina, Chapel Hill. former Director, Puerto Rico Nuclear Center, ---Page Break--- as a result in increased loss of the isotopes from the forest canopy. To explore this problem, comparisons of radioisotope 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 litter 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 137Cs and Sr 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 (Tl) 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 (Tl) 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 levels of 137Cs and 90Y 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 ---Page Break--- 133 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 rainforest are not known. Data for freshly fallen leaves is given for 137Cs and 90Y in Figure 1. The data is given in the form of the following ratios 34, ‘un (Ra) ng ‘cs (Rad) >44n (Con) Wes (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 90Y ratios showed no apparent deviation from the expected value of one either before or after the irradiation experiment. The 137Cs ratios indicate that the radiation center originally had greater levels of 137Cs 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 137Cs from the control center for that month. Actual 137Cs 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 137Cs and 90Y 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 rainwater 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 isotopes 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 rainforest and it is currently undergoing further investigation.

TABLE 1 Pre- and Post-Irradiation Values of 137Cs and 54Y 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
137Cs	7.7	1.3-28.0	5.1	2.0-9.4	10.3	4.3-18.9	7.6	3.2-12.9
54Y	2.1	0.165-5.6	2.7	0.64-5.6	2.1	0.8-5.5	1.3	0.66-2.2

A "t" test at 0.99 confidence level shows no significant.

differences between irradiated and control centers either before or after irradiation, LITERATURE CITED 1, Briscoe, C. B., and G. A. Briscoe, Beta Counts from the Luquillo National Forest. In: A Tropical Rain Forest, H. T. Odum, ed. 2, Elder, R. L., and W. Moore, Jr., Comparison of Cesium-137 Binding Characteristics in Pangola Hay and Spanish Moss, Radiological Health Data, 6(10):586-589, Oct. 1965. Kline, J. R., and H. T. Odum, Comparisons of the Amounts of Fallout Radionuclides in Tropical Forests. In: A Tropical Rain Forest, H. T. Odum, ed. ---Page Break--- 5 135 Tukey, H. B., Jr., H. B. Tukey, and S. H. Wittwer, Loss of Nutrients by Foliar Leaching as Determined by Radioisotopes, Amer. Soc. Hort. Sci. 71:496-506, 1958. Tukey, H. B., and J. V. Morgan, The Occurrence of Leaching from Above Ground Plant Parts and the Nature of the Material Leached, Proc. XVI Int. Hort. Congr. Brussels, 153-160, 1962. Tukey, H. B., and H. B. Tukey, Jr., The Loss of Organic and Inorganic Materials by Leaching from Leaves and other Above-Ground Plant Parts. In: Radioisotopes in Soil-Plant Nutrition Studies, International Atomic Energy Agency, Vienna, 289-302, 1962. Tukey, H. B., Jr., and J. V. Morgan, Injury to Foliage and its Effect Upon the Leaching of Nutrients from Above-Ground Plant Parts, Physiologia Plantarum, 16:557-564, 1963. Tukey, H. B., R. A. Mecklenburg, and J. V. Morgan, A Mechanism for the Leaching of Metabolites from Foliage, Isotopes and Radiation in Soil-Plant Nutrition Studies, International Atomic Energy Agency, Vienna, 371-385, 1965. Witherspoon, J. P., Jr., Cycling of Cesium-134 in White Oak Trees, Ecological Monographs 34(4):403-420, Autumn 1964. ---Page Break--- 136 4a, aat/*HeCon) (con) 13%, aaa 7, 2.0 Figure 1. Ratios of Y- and Cs-137 in irradiated and control centers: Average Period" save 1.0 Was 13 aod dD AS ON DG FM ROMS SAS OW DOF oes! 16 voncn see obtained from monthly collections of freshly fallen leaf litter. ---Page Break--- 137 OCS MEMORANDUM BMI=1 Bur ~ 930.01 BIOENVIRONMENTAL AND

RADIOLOGICAL-SAFETY FEASIBILITY STUDIES ATLANTIC-PACIFIC INTEROCEANIC CANAL RADIONUCLIDE BEHAVIOR AND DISTRIBUTION IN TROPICAL FORESTS November 1, 1966 BATTELLE MEMORIAL INSTITUTE Columbus Laboratories 505 King Avenue Columbus, Ohio 43201 ---Page Break--- 138 Battelle Memorial Institute - correspondences 505 KING AVENUE COLUMBUS, OHIO 43201 OCS Memorandum BAT=1 File: 94T-830.01 SUBJECT Radionuclide To: SEE DISTRIBUTION behavior and Distribution in Tropical Fore [ARCA CODE 614, TELEPHONE 299-3151] CABLE ADDRESS: Battelle November 1, 1966 Enclosed is OCS Memorandum BAT=830.01 dated November 1, 1966, prepared by Dr. Jerry R. Kline of Puerto Rico Nuclear Center, San Juan, Puerto Rico, under Purchase Order No. 3-346 for Battelle-Columbus Laboratories: Rsb/tiw Ene. (1) DISTRIBUTION: Chan, ccc lige, ‘NVOO (2) Chan, Cratering Characteristics Gp Chan, Ground Shock Gp Chan, Radioactivity Gp Sandia Corp. Dir, Nos FD, O1CS (6) Pot (2) TAK Dix, DPNE ENGTEM ‘RN BUT-Northwest ‘under AEC prime Contract No. AT(26-1)-171. x LEX mech Rs S. Davidson Manager Bioenvironmental Program cofengrs (4) Divéngr, SAD (2) OTs DA ESSA, Las Vegas ESSA, Silver Spring aso Fld Mgr aPtcsc Site, wv00 ‘Asst igrop, NVOD RNC wR Us Gay wows Torre WS v. Fla. ---Page Break--- 139 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)-1633. by Jerry R. Kline ---Page Break--- ABSTRACT found Fallout radionuclides in forests of Darien, Panama, 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 that 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 that 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 124Cs, 85Sr, and 54Mn 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 attributed to nuclides through roots but accounted for on the basis of recycling or more likely the result of interception on surfaces from rainfall, ---Page Break --- at 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 the 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 2 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 ---Page Break--- 142 in tropical communities. Under the long-term objectives of the Terrestrial Ecology program, a series of tracer experiments were planned to study the Battelle aided in the entry of nuclides into forest trees via root systems; the acceleration of these plans by partially funding the first experiment in the series which involved a study of the uptake of Cs, Sr, and I 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. 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 litter, 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: A site near sea level about 1/4 mile along the graded road which forms a loop near the camp; an area of no apparent recent logging activity. Santa 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. ---Page Break--- 3 Mangrove. Samples were collected from the mangroves immediately adjacent to the camp on the downstream side. Pidiaque. Collections were made from the top of two small ridges 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 Jes 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 ---Page Break--- 146 measurements on a sample which gave in excess of the standards. Repeated 100,000 detected gamma rays per 100 minutes indicated that all of the reported nuclides could be determined with a precision of 5 percent of the n. 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 percent. 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, 1906, 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 acres 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 relides by wrapping with plastic bags or with aluminum foil. The nuclides 14C, 89Sr, and 54Mn were applied in carrier-free aqueous

mixture in the form of a spray delivered from a hand-pumped garden sprayer. Approximately one µCi/n? of each nuclide was applied directly to the soil. Within 24 hours after the application of the spray, the plants were uncovered. ---Page Break--- Leaf samples were collected from small (G+1 {t), medium (13 ft), and large (>3 ft) plants 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 fitted by counting standards of each simultaneous equations which were for 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 40K, 137Cs, and 234U in leaves and litters collected from Darien, Panama, are presented in Table 1. in lowland forests. 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 40K and in the Panamanian forests are consistent with 137Cs with lesser amounts of 234U. The low levels of nuclides findings of the 60th meridian survey where it was reported that fallout levels normally decline sharply near the equator relative to the northern ---Page Break--- 146 TABLE 1, Levels OF 40K, 137Cs, and 234U IN PLANTS OF SEA LEVEL FORESTS OF DARIEN, PANAMA May 375 54 location ___Plant Type 0 Ig Circle Road Trees (ave) 0.51 0.70 0.08 Culpo fruit 1.27 0.112

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 Roads Cut Over Site Trees (Ave) 0.57 0.22 0.05 Litter aise ons 0.15 Banana Farm Trees (Ave) 1.36 0.38 0.07 Litter oraz 0.20 ona Banana 0.30 0.07 0.03 Platano 0.25 0:05 0.15 Mangrove Red Mangrove 0.15 0.05 0.05 Moss 421 0.59 0.07 Mora ora 0.8 on17 Lichen un 143 ons Salt Water Fern 0.20 0.154 Not Detected ---Page Break--- 147 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 134Cs and 137Cs but not of 40K, 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 partially assumed that the increases with altitude shown here are at least explainable on this basis although no rainfall data are available for the 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 same 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 OJun(2) the mosses which hang from limbs in the Panamanian Elfin forest are most highly contaminated, and the 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 ---Page Break --- 148 37¢s AND S4un IN PLANTS TABLE 2. LEVELS OF 144ce, 137cs OF MOUNTAIN FORESTS OF PANAMA Pidiaque (1000 ft) 0.13 a ea Cerro Azul Trees (Ave) 0.43 Spiny epiphyte 0.19 Cerro Jefe Trees (Ave) 2.84 Elfin forest (3600 feet) Mixed bryophytes (trunks) 6.35 a (ground) 10.42 Mosses (tree canopy) 31.13 Lycopodium (edge) 5.57 — ae peu os ue oe ee 0.91 2.81 5.39 0.97 0.05 a 0.72 1.00 0.85 1.60 0.26 0.10 2.28 ---Page Break --- ro) been burned. The Cyrilia Ps 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 a 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 equal to that of surrounding old vegetation after only six months of growth. Foods were

collected in Panama by workers 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. ---Page Break--- 150 Table 3. Levels of 14Ce, 137Cs, AND Pu IN POUNDS OF DARIEN, PANAMA a Mean 1376 Shown Food i 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 Oats 0.01 0.01 0.08 Yuca 0.01 0.01 0.01, Water 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

0.08 The data in Table 4 indicate levels of fallout nuclides in forest litter in the Canal Zone. These litters of some sites are included as a rough index of comparison of the amounts of nuclides between Canal Zone sites and Darien sites. 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 14Ce, 137Cs, and Pu IN LITTER AND LEAVES OF CANAL ZONE FORESTS a 1écg __137Cs___ SAD Litter (Ft. Clayton) 1.28 0.77 0.16 Litter (Barro Colorado) 0.105 0.47027 Palm leaves (Barro Colorado) 2.15 1.98 (+19 cm) ---Page Break--- 151 Measurements of radionuclides in soils were generally uninformative due to the fact that fission products were obscured by the natural radioactive nuclides which were present. This is residual material from limestone of the lowlands which were formed on the 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 226Ra daughters or of 40K. 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 226Ra daughters in soil. Tracer experiment uptake of 134Cs, 85Sr, and 1s 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 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/nm² of each of three nuclides. The large fluctuations in nuclide concentrations in the plants from 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 50% of the spray solution reached the plant. ---Page Break--- 182 ACTIVITY, C/M/CH 100 10 226Ra DAUGHTERS 226Ra DAUGHTERS 04 0.8 12 16 20 ENERGY, MeV FIGURE 1. RADIUM DAUGHTERS IN SURFACE SOIL TAKEN FROM A BANANA FARM IN DARTEN, PANAMA, ---Page Break--- cIMIg PLANTS FROM 0 - 1 FT TALL FIGURE 2. UPTAKE OF 134Cs, 85Sr, AND 1s THROUGH ROOTS OF UNDERSTORY PLANTS (FOREST LITTER REMOVED). 153 ---Page Break--- 154 cIMIg 1200 PLANTS MORE THAN 3 FEET TALL 800 —-— 400 PLANTS 1- 3 FEET TALL 800 400 FIGURE 3. UPTAKE OF 134Cs, 85Sr, AND 1s THROUGH ROOTS OF UNDERSTORY PLANTS (FOREST LITTER REMOVED). ---Page Break--- cIMIg 155 PLANTS FROM 0 - 1 FT TALL 4800 4000 3200 2400 UPTAKE OF 134Cs, 85Sr, AND 1s THROUGH ROOTS FIGURE 4. OF UNDERSTORY PLANTS. (FOREST

LITTER IN PLACE). ---Page Break--- 156 PLANTS MORE THAN 3 FEET TALL 400 °CIMIG FIGURE 5. UPTAKE OF 14Cs, 85Sr, AND IN THROUGH ROOTS (OF UNDERSTORY PLANTS (FOREST LITTER IN PLACE). ---Page Break--- 157 Surface. Even though the plants were covered during the spray process, the surfaces in this amount of the spray liquid could have formed 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 uptake; however, these plants than in the smaller plants. The ratios 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 the 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 Tracer Teaser 3.8 34429 79.2 21354 48.9 7387 ---Page Break--- 158 levels in the fallout contaminated experiment. The data show that nuclide levels in plants are approximately the same for litter and 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 such activity must be in the form of surface deposition which were intercepted from rainfall. Measurements of environmental half-lives of fallout radionuclides periods are very long in tropical forests by

Kline(1) indicates that these were determined for nuclides of probable stratospheric origin. 'Experiments of the type described here will enable assessment of the tracer 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 surfaces are relatively short in comparison to the radioactive half-life of this form. 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. ---Page Break--- 159 ACKNOWLEDGEMENTS These contributions to the preparation of this work are: Dr. H. Te Odum, formerly Director, Terrestrial Ecology, Puerto Rico Nuclear Center. Dr. H. B. Tukey, Jr., consultant to the Terrestrial Ecology Project on leave from Cornell University. Consultation and field work relating to the establishment of the tracer experiment. Mr. Nelson Mercado, arch assistant. Gamma ray spectrometry. 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. LITERATURE CITED 1. Kline, J. R. Cycling of fallout radionuclides in tropical forests.

Int A Tropical Rainforest. In preparation. J. R. and Odum, H. T. Comparisons of the amounts of fallout radionuclides in tropical forests. In A Tropical Rainforest In preparation. Lockhart, Luther B., Robert L. Patterson Jr., Allen W. Saunders, Jr., and Robert W. Black. Atmospheric radioactivity along the 60th meridian (west). In Radioactive Fallout from Nuclear Weapons Tests. Alfred W. Klement, Jr., Ed. AEC Symposium series 5. 477-436. 1965. 4. Martin, William E. Interception and retention of fallout by desert shrubs. Health Physics 111 1341-1354, 1965. - Kin 3. ---Page Break--- 160 Vegetative Sprouting Following Irradiation of a Tropical Rain Forest Carl F. Jordan. 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. Recovery of a forest... In a general survey of the area, it was found 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 = [Po] 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 latitude. 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 the 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. Sprouting was the sole means of forest recovery in Davson County, and 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 were of sprout origin. Of the 86% which originated from seed, 89% were tree species, and 11% were vines, herbs, and ferns. In considering 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. In extended periods of irradiation of temperate forests such as the one at Brookhaven, it would eventually kill back-sprout growth even though roots are protected (Sparrow and Woodvell, 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 or further than 18 meters. On the 48th of November 1966, the range for that distance was 5 x 1 ---Page Break --- 163. 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

Confidence level Total number Number of protected Percent at which percent Species of sprouts sprouts protected differs from 48%

Sloanea berteriana 338 321 95

Meliosma herbertii 22

Palicourea riparia 125
Dacryodes excelsa 134 118 88
Inga laurina 67 52 7
Rourea glabra 26
Other species 263 189 2

---Page Break ---

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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

Percentage of sprouts Level of confidence on the side of the tree at which percentage Species facing the source differs from 50%
Sloanea berteriana 63 99
Meliosma herbertii 97
Palicourea riparia 6 99
Dacryodes excelsa 36 83
Inga laurina 35 37
Rourea glabra 3 99
Other species 70 99

---Page Break ---

TABLE 3 Distances of Sprouting Trees from the Gamma Source

Average distance one standard of tree from source deviation from Specie (meters) the average (meters)
Sloanea berteri 14.6 3.6
Meliosma herbertii 15.3 25
Palicourea riparia 12.9 4.0
Dactyodes excelsa 13.3 43
Inga Lauri 12.3 2.7
Rouréa glabra 12.5 46
24 other species 13.6 2.6
---Page Break---
TABLE 4 Number of Sprouting Trees in Concentric Rings Around the Source
Meters from source Number of sprouting trees
0-5, °
5-10 25
10-15 17
15-18 8
at 18 °
SO
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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.
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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 the 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 Tebonuco (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. ---Page Break--- 167 The "cut center" was treated in the spring of 1965. There 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

ri time (Smith, 196). ‘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. Dover, personal communication). At approximately the same elevation, the mature forests surrounding all study areas appeared to be similar. A grid of 900 one-square meter squares was laid out with nylon cord surrounding the source location in the irradiated area. 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 1 m^2 squares were run out to 30 m in the four cardinal directions. At every corner of the grid squares, the 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 3 m^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: the number of sprays of leaves through which the line of sight passed was assumed that a spray of leaves averaged one leaf. While there was no difficulty in counting sprays when it was counted, in thickness, ---Page Break --- 168 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 0.82. 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 axis. To determine the 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 measurement: 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. ---Page Break--- 169 Quantity of vegetation in this study originated since April 1965. In the irradiated area, production of new vegetation was wide (Figure 1). It was suspected that soil conditions might be varied, so approximately 100 soil cores were inspected: In some areas, the soil's upper layer exhibited yellow color (7.5 Y 8/6/8) (Munsell, 1956) from the surface down to 12 inches, while in other areas it was dark brown (10 YR 4/3) at the surface grading to dark gray (10 YR 4/1) at 12 inches: Richard (1957) states that the reddish-yellow color of the soil, formed under conditions of unimpeded 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 £1 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 the 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 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 (HeCormick, 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). ---Page Break--- 170 When leaf-area index measurements of new vegetation were being made in the irradiated area, a notation was made as to whether leaves that touched 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 measurement: 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 the 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, 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, Seuragesia formed dense patches in one herbicide area, and a grass 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. As 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. Bowler, 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. ---Page Break--- Species diversity clustered significantly between the herbicide-sustained and the poorly-drained plots, and between the well-drained areas. Differences between all other areas were none significant at the 0.05 level of confidence (Figure 10). Species diversity did not. 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 the presence 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.

Relatively small forest openings are directly dependent on the size of canopy openings. The canopy opening in each herbicide area 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 the size of the 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 low species diversity were the most recently disturbed, while the irradiated area, with intermediate diversity, was delayed in recovery because of trampling. ---Page Break--- 173 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 tracked 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 portoricoensis, and Linociera domingensis occurred in the irradiated sere in January 1967, but their importance values were usually less than one.

CONCLUSION

Slight differences in the 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 effects. The only difference that was uniquely a radiation response was the sprouting of trees near their base where they were shielded from radiation. The primary conclusion of this study is that recovery of a tropical rainforest damaged by gamma radiation closely resembles secondary succession following other types of disturbances in the tropical rainforest of Puerto Rico.

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17% METERS SOURCE 0 METERS 0-09 10-19 20-29 30-39 40-49 >49
Figure 1. Map of leaf area indices of new leaves, irradiated area, August 1966.

---Page Break---

METERS
10 us
POORLY DRAINED
WELL DRAINED
POORLY DRAINED
15 10 5 ° 5 METERS
Figure 2. Map of soil drainage in irradiated area

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176 O° NY
METERS
0-09 10-19 20-29 30-39 40-49 >49
Figure 3. Map of leaf area indices of new leaves, irradiated area, February 1967.

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

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v8 METERS
Map of leaf area indices of old leaves, irradiated area, February 1967.
Figure 5.

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LEAF AREA INDEX
LEAF AREA INDEX
1 OLD LEAVES
5 5 3 New LEAVES
Figure 6.
AUGUST 1966 FEBRUARY 1967
30 2 0 0 0 2 0 METERS FROM CENTER
Leaf area indices along the

East-West transect of the cut area AUGUST 1966 FEBRUARY 1967 OLD LEAVES 3 B 5 3 NEW LEAVES, METERS FROM CENTER Figure 7. Leaf area indices along the East-West transect of the irradiated area. ---Page Break--- 180 AUGUST 1966 ~ FEBRUARY 1967 LEAF AREA INDEX New Leaves: 30 2 10 0 10 2 30 (METERS FROM CENTER) indices along the North-South transect of the area. Figure 8. Leaf cut area, AUGUST 1965, FEBRUARY 1967 LEAF AREA INDEX NEW

LEAVES 5 3 1 METERS FROM CENTER Figure 9. Leaf area indices along the North-South transect of the irradiated area. ---Page Break--- CUMULATIVE INDIVIDUALS 1. HERBICIDE AREA No. 2, 1/67 2. HERBICIDE AREA No. 1, 1/67 3. TOTAL IRRADIATED AREA, 3/64 4. IRRADIATED AREA, POORLY DRAINED SOIL, 1/67 5. IRRADIATED AREA, WELL DRAINED SOIL, 1/67 6. CUT AREA, 1/67 1 2 3 5 6 300 by 200 100 50 10 10 20 30 4 59 CUMULATIVE SPECIES Figure 10. Seedling diversity in the experimental areas. ---Page Break--- 182 TABLE 1 Importance Values of Secondary Successional Species in a Tropical Rain Forest Well Drained Poorly Drained Center Herbicide 1 Herbicide 2 Paychotria berteriana 116 16 40 Palicourea riparia 27 65 10 52 182 Tabebuia heterophylla 36 89 3 2 3 Phytolacca icosandra 9 0 18 Didymopanax morototont 45 3 25 47 45 Cecropia peleata 4 7 2 92 33 Heliconia bihai 0 6 'Indicates the most important species in the area. TABLE 2 Percentage Similarities between Pairs of Experimental Plots Pairs of Plots 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 Cut = Herbicide Plot No. 1 Cut - Herbicide Plot No. 2 44 percentage similarity of 100 means that the plots are identical, one of 0 means they are entirely different. ---Page Break--- 183 LITERATURE CITED 1.

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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 forms in the soil (Gremlamd and Koval, 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 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 were 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 Soluneter, Model RA 4 with the factory supplied cell; the range of the instrument was 0-100 ymhos. For samples more conductive than 100 ymho/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 ymhos was: $\phi = 100 c'/(100 - c')$ where ϕ is conductivity in ymho/cm and c' is the 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 marly throughfall and stemflow samples containing leaves and other organic debris. Since even pH 4.8 results in a conductivity of about 5.5 ymho/cm and since the samples with low pH's were always of high conductivity (>75 ymho/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 186 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.

Stenflow-Plastic Bag Experiments: The conductivity of water flowing down trunk surfaces (stenflow) 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 stenflow 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 certainly small. Stenflow 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 conductivity cell mounted in its place. The apparatus was first placed under a young M. bidentata alongside an unsodified 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 cells 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 recorder from rainfall (tower) to throughfall (ground) conductivity was built using five relays, a 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 minutes, tower (rainfall) conductivity was recorded. The system then switched to the ground cell (throughfall) and recorded this for 7.5 minutes, repeated both cycles, and then shut off. Time for one complete cycle was thus so cue and remained off until the tower gauge recorded another 0.01 inch; during prolonged rains, this occurred immediately, continuously for several hours. The system often remained 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. Paraffin 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 with each tip of the bucket. During the high 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 half an 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 simultaneous 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. ---Page Break--- 188 Ground Areas: In the process of studying water balance, the Dacryodes (De-1) and one of the Crotons (Cp-1) were estimated and measured. Several radii were measured, taped, and the general outline 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 23.7 m², Cp-1 to be 10.5 m². Calibration: Rain gauges were calibrated by pouring water into the gauge until the bucket had tipped.

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 0.95 to 1.13. The error is greater at high rates of flow, so that the corrections for the trunk-run-off gauge were 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/em, ground about 4.5 µmho/em, probably due to much. These were subtracted from all readings on a 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 Soluneter contains a manually adjustable temperature compensating circuit which was used on regular scale readings during the preliminary and plastic bag experiments. In scale readings, all continuous recording, this was 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/em. The solution was poured through the apparatus until no change in conductivity could be observed. The tower cell then indicated 70.3 µmho/em, the ground cell 70.4 µmho/em, after corrections for cable loss. 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 sequence through the courtesy of Mr. Lépes, Mr. Murphy, and Mr. Reed. Theough all water was gathered using stainless steel collecting.

trays about 4 € square, “The trays were protected by pyramidal alovines aceon which prevented the accumulation of organic debris. ‘A steilae ceay ---Page Break--- 189 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 Sonedora 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 summarized in Figure 8. Rainfall and throughfall for all periods for which data was available from both stations were included in the total. Monthly totals were then used to calculate the percent throughfall. A wide range of values (30-80%) is in agreement.

with results Theduned by other vorkere Sn the tropics (fable 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., tye, 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). ---Page Break--- 190 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 99.7%

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. 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. ---Page Break--- 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 rain, and high-intensity rainfall 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 (0.40 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 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 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 ---Page Break --- 192

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. Presumably one could postulate a primarily autotrophic zone consisting of the canopy leaves, which provides at least part of the energy requirements for the more heterotrophic, epiphytic region beneath. Chemical analyses in Table 7 present the results of chemical analyses of throughfall, rainfall, stemflow, and runoff. 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 (32 dppm), 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 and 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 were 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 suggestions 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 ---Page Break--- 193 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 micro-topographic 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 monitored for.

several individuals of several species over long periods of time, regional a sequence apparent and certainly more extensive and accurate. A more quantitative consideration of nutrient cycles can be made. ---Page Break--- ---Page Break--- 5 (e961) st230a paw Keaton, (196) ean (e961) 88919 (5960) surxdou (og61) surtdon ur (S61) 9871232108 (0961) suradon (0961) suridont uy (9E6D) e80r24 (6961) supidon ur (e761) 242 5H pur wyeHeA 380203 snonpy2ap poonpzey uzezeve 303 e2qneea Jo Azmuns ayes uy poae2zussu09 soysuy <g-no1zw9as I~ ‘yuos 8Tou wpenaaq 9002097 qyeyuyes yenuue soysus OCT = veqe0xo <q pur ex0qsuoDe e1t1a49 Atas0m ‘380203 oueau0H voTaeTzeA yavs-389308 ‘9m Susanp woxw Aqgnays Axysuequy yan voraetesze9 ou = TT9sUTeX enue s9qauy ¢°¢y - punoa’ jo ‘m 2°6 Ya3A Uoadeoz03uy TTY sdoa 9023 uy soSne8 yresuyex - soze9s {dor ‘aes kaysuowy T1egUyes apa s9s003907 voyadeo020T Aaysuaauy Tresuyes ata soeee399p uoyadeor0q01 ou en ¥s ec (oxeasea) 3° (opex) eueus (enbung 13) ooFY oaz0nd (eazesou asoz0d Ff5m999T0) PHA98TN (oe ‘eT 9p TwuoTaeN 92¥g) 0810 (aseaeg yozeaseu eBuedn) vpvesn zee enyapanen a9us29399 syaeuay sasexog TwoydoraqHos puP % woradsoz0q0T u0}38907 jwosdoas uy T1ejUTeH 30 voyadaoseaUT VO sx9qIOH snoTAe2E 30 FTRERY 30 Krvmng z mTevE ---Page Break--- 196 TABLE 3 Summary of Conductivity Values of

Water in Various Situations Throughout Study Area Spot checks over 3-month period Number of Mean observation st. dev. Location (ubino fen) days (signa) General survey Water in bromeliads 44.1 12 25.4 Water standing in pools 49.3 4 Le Rivulets 68.8 3 14.6 Large stream - First towards field station from Sonadora R. 80.4 3 Le Large stream - First towards Sonadora R. from field station 121.9 3 1.0 Sonadora River at trail crossing at low water 47 5 5.6 Sonadora by upper parking lot at low water 48.2 1 - ‘Throughfall Jars placed at intersections of radials with: 10 m circle Control center 49.2 2 20.5 10 m circle Radiation center 41.0 10 10.2 3.2 m circle in Control center 30.3 n m 3.2 m circle in Radiation center 5507 3 20.3

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TABLE 4

Plastic Bag Experiment--Individual Trees

Representative Conductivity Values for Trunk Runoff

Species No. of Observations Standard Deviation

Euterpe globosa 10091 51.8 2 0.0

Euterpe globosa 19374 30.7 3 8.6

Euterpe globosa 102.6 3 2.9

Manilkara bidentata 763 45.6 3 1.5

Dacryodes excelsa 3177 212.9 3 67.4

Dacryodes excelsa 10393 9.9

Dacryodes excelsa 104.0 4 51.8

Croton poecilanthus 10123 37.0 4 15.4

Croton poecilanthus 16127 22.6 4 12.9

Croton poecilanthus 2432 33.6 3 29

---Page Break---

TABLE 5

Results of Plastic Bag Experiments: Data Grouped by Species

Standard Deviation

Species Mean Conductivity Standard Deviation N

Dacryodes excelsa 185.3 335.8 2 1.81

Manilkara bidentata 67.3 46.8 7 6.35

Euterpe globosa 48.9 21.6 8 4.02

Croton poecilanthus 49.0 36.4 15 7.43

Dacryodes excelsa 206.6 331.1 2 1.62

Manilkara bidentata 101.7 42.5 7 8.7

Euterpe globosa 57.7 16.7 8 2.90

Croton poecilanthus 58.4 31.4 15 9.33

Data adjusted to allow for differences in conductivity of rainfall

TABLE 6

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

Standard Mean Deviation Number of Data Points

Rainfall 12.5 1 395
Manilkara bidentata 26.4 1.7 4
Croton poecilanthus 1 63 6
Dacryodes excelsa 31.0 23.2 361

---Page Break---

TABLE 7
Chemical Analyses of Water at El Verde Provided by the U.S. Geological Survey at Rio Piedras, Puerto Rico.
All values in ng/L water

Date 10-26-65
Sample 1.0 0.13 2 0.4 3.8
Sample 2 0.8 2221 0.0 10.0 0.0 16
Date 3-17-66
Sample 53 30 20 7 on 28
Sample 166 0.6 0.7 3.7 24 0.68 0.0 2
Sample 9 0.7 3.6 35 0.65 0.0 2
Deerosee excelsa 10-9-65 2.6 0.9 27.0 6.0 + 7.0
Sample 95 0.7 766 40 0.8 1.0 0.3
Date 8-17-66 0.7 84 7.0
Sample 05 4 166 0.7 2
Sample 2 6 2 68
Mean 6.6 20 9.7 0.3 8 12
m0 60 = 72 on 96
Sample 24 12 9.2 60
Dar 16 0.2 HS 5.0 42 100 0.5 39 166 0.0 76 8.0 40 100
Croton poecilanthus No. 1 1362 6 26.0 50 0.7 37
Croton poecilanthus No. 2 1266 1.0 0.8 5.5 50 0.0 9.2

0.6 27 17 06 3.9 60 0.0 5.9 16 26 mean of 2 samples Le 7 47 55 00 726 La 2 Decomposition exceeded no, 1 86S LE LO Ow mean for all stations of both species 17 09 47 28 0.0 16 17 5 Gaon ‘plant Cylinder site G86 10 Le = 0 ea ‘io Sonadore G06 2.0 17 5.5 16.0 0.0 7.8 On 27 ---Page Break--- 200 been types of inn sm Rest Bow ‘data Supplied" to ver Scbginl rv, Same Toate Rice ? ii =e Wis 0.0 0.0 26 02 30 90 12 35 00 Od WTS OHO (Wt 00 000 14 0 21 60 of 22 00 Od 4 = be Walls 0.0 0.0 1.0 30 50 50 4k 4S 09 OR OM = BY TWis/et 0.0 0.00 0.8 0.2 30 40 08 55 09 Or 1) = = 6S wei 0.0 0.00 20 05 37 80 12 48 02 Ot = = aD ---Page Break--- 201 LITERATURE CITED 1 10, mn 12. Be 4. Bartholonew, W. V., J. Meyer, and H. Laudelout, Mineral Nutrient Immobilization Under Forest and Grass Fallow in the Yanganbi (Belgian Congo) Region, Publ. de L' Etude Agron. du Congo Belge, Number 57, 27 p-, 1953. Clegg, A. C., Rainfall Interception in a Tropical Forest, Caribbean Forester 24(2):75-79, 1963. Helvey, J. D., and J. H. Patric, Canopy and Litter Interception of Rainfall by Hardwoods of Eastern U.S. Water Resources, Res. 1:193-205. Hopkins, B., Rainfall Interception by a Tropical Forest in Uganda, East African Agric. Journal 25(4):255-258, 1960. Hopkins, B., Vegetation of the Olokemiji Forest Reserve, Nigeria III., The Microclimates with Special Reference to Their Seasonal Changes, J. Biol. 53(1):125~138, 1965. Junge, C. E., "Atmospheric Chemistry" in Advances in Geophysics, Vol. 4, Academic Press, N. Y., 1958. Madgwick, H. A., I. and J.D. Ovington, The Chemical Composition of Precipitation in Adjacent

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