CEER - T-089 TROPICAL RAIN FOREST CYCLING AND TRANSPORT PROGRAM PHASE 1 PROGRESS REPORT TERRESTRIAL ECOLOGY DIVISION CENTER FOR ENERGY AND ENVIRONMENT RESEARCH UNIVERSITY OF PUERTO RICO SAN JUAN, PUERTO RICO JANUARY 1981 CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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1.0. EXECUTIVE SUMMARY

This program was designed to fulfill the clear need for comprehensive understanding of major cycling and transport processes in rain forest ecosystems so that the ecological consequences of potential energy development alternatives can be predicted. As a result of reduced DOE funding for fiscal year 1981, the original program plan (June 1980) has been modified. The basic approach has not been altered, but some tasks have been reduced in scope where the least damage would be done by substituting information available from published sources. Phase I of the two-phase multi-year program is underway and most tasks are on schedule. The first wet season sampling surveys have been completed and substantial progress has been made toward achieving Phase I goals. Unexpected results (e.g. the discovery that one lizard species which is uncommon near the ground is extremely abundant in the forest canopy) and elucidation of the food web by gut content analyses and feeding observations have already demonstrated the value of the phased approach. The integration of these results with the massive body of biological information from the rain forest at El Verde (Odum and

Pigeon, 1970) will provide the needed departure point for investigating energy-related disturbances in this important ecosystem. Four randomly selected plots (1 ha. each) were surveyed and marked in July 1980. A 300 m transect line was subsequently placed diagonally through each plot. A single 300 x 300 m grid (staked at 30 m-intervals) for use in vertebrate surveys has recently been added. Calorimetric measurements have been made on selected animal species. Additional species will be sampled, and vegetation samples will be processed as Phase I is continued. Sulfur content has been calculated for two common species of lizards and estimates for other species are underway.

Other mineral analyses will be added in turn. A new task has been added with the objective of quantifying carbon export from the forested Rio Espiritu Santo watershed. Data from this study can be correlated with rainfall and decomposition information obtained in the study area (which lies entirely within the watershed) to extend our knowledge of this potentially important process.

Vegetation studies are behind schedule as the result of an untimely staff vacancy which developed at the beginning of the field season. Research is now underway on phenology, litterfall, and plot characterization. Decomposition studies are now scheduled to begin during the forthcoming dry season (January-April, 1981). Plot characterization and interplot comparisons are considered important in Phase I so that they may serve as an accurate basis for Phase II investigations. Faunal studies have been emphasized during Phase I because of the need for comprehensive data on the interrelationships among major animal groups in rainforest communities. Initial investigations have already provided significant new insights on abundance, distribution, and feeding relationships among species, and further discoveries are expected when studies are continued into the next field season. The role of phytophagous invertebrates is central to the food web.

Analyses. Their use as prey for larger species is partially known from the literature and from initial gut contents studies, but research on their role as primary consumers has been delayed pending the hiring of an invertebrate ecologist. The position has recently been filled and studies are scheduled to begin in February 1981. Vertebrate studies are on schedule, with the exception of mammal surveys which were delayed because of a potential rabies problem. Key species have already been identified in each class. The tree frog Eleutherodactylus coqui is easily the most abundant amphibian. Three lizard species (Anolis gundlachi, A. evermanni, and A. stratulus) are the most abundant reptiles. Although the bananaquit (Coereba flaveola) is the most abundant bird species, other larger species such as the red-necked pigeon (Columba squamosa) may be key species in terms of biomass. Among mammals, the black rat (Rattus rattus) appears to be the most abundant terrestrial form. Bat species have been collected but studies of their population density are difficult and have not been attempted in phase 1.

Progress at this point in phase I studies has been substantial. Calorimetric and chemical analyses of key species are underway and carbon export research has been initiated. Vegetation studies, although started late, will produce the required data by the end of phase I field studies. Several key animal species have been identified, including one anole which was formerly thought to be uncommon in the forest. The importance of vertical studies for all faunal groups has been demonstrated and will be emphasized as research continues. Initial food studies have produced new information on the feeding relationships and identified some of the major pathways of movement for energy and minerals through the food web. Integration of information from separate tasks is inappropriate at this point, but the preliminary results suggest that new insights into animal community organization in tropical rain forests are likely.

The results are from phase 1 studies.

2.0. INTRODUCTION

The accelerated development of both traditional and unconventional energy resources is impacting ecosystems worldwide. The nature and extent of these impacts are related not only to the type of energy development (e.g. fossil fuel, nuclear, biomass, solar, etc.), but also to the prevailing environmental conditions (e.g. annual temperature fluctuations, rainfall elevation). Therefore, information on temperate ecosystems has limited application in tropical regions.

Potential impacts on temperate zone ecosystems are relatively well known, but tropical ecosystems, particularly rain forests, are understood in far less detail. Their importance in the world carbon cycle and regional significance has been identified, and inputs and outputs have been calculated, but the structural complexity and functional interrelationships of species (e.g. food webs, mineral cycles) are poorly known.

We are therefore investigating cycling and transport processes within a relatively simple moist tropical (tabonuco) forest. Initial studies are being conducted in the rain forest near the El Verde Field Station. Once a comprehensive overview has been obtained through integration of the results of Phase I field studies with the substantial body of published information on the same study area, in-depth studies involving experimental manipulations will be undertaken.

Because the original program plan (June, 1980) was formulated prior to the reduction in funding for Fiscal year 1981, the program has been adjusted accordingly. Basic objectives and overall design have not been altered. Some task elements have been eliminated, and some sampling reduced to a single season where it was felt that sufficient supporting information could be obtained from existing literature. Other task elements have been added on the basis of observations and preliminary data analyses obtained during the first seasonal sampling period. This document presents the modified program design and

Progress as of November 30, 1980, on the Phase I studies is detailed. Methods are included so that this report can also serve as a reference guide for future studies. Due to the preliminary nature of the data, extensive analysis is not possible at this point. Substantial, and in some cases unexpected results have been obtained which have confirmed the value of this phased approach. Results are presented and discussed by task in this report, but due to the incomplete nature of the data sets, no attempt has been made to integrate data from different tasks.

3.0 PROGRAM OVERVIEW

To predict the effects of expanding energy technology on tropical ecosystems, it is necessary to understand the major features of ecosystem structure and function and their response to exogenous environmental variables. Current knowledge of the source-sink role of tropical rain forest biota and the factors which regulate this role is insufficient to foretell the impact of energy development on the mobilization and release of critical elements or the ecosystem's capacity to assimilate elemental inputs. By investigating cycling and transport in a well-studied and relatively simple tropical forest ecosystem, we intend to identify key pathways and major reservoirs of minerals and energy. This will allow relevant hypotheses to be developed and tested concerning potential energy development impacts. Cycling and transport processes are being investigated in the tropical moist (tabonuco) forest at El Verde by conducting a two-phased program. This will establish a firm database and allow for subsequent experimental manipulations. The long history of environmental research in the Luquillo Mountains and the existence of the El Verde Field Station in this forest provide a unique opportunity for this type of research. In the proposed program, we are building on previous work at El Verde to examine the food web structure and identify important factors involved in faunal components of cycling and transport processes.

The following text has been corrected:

The topic has received little attention in temperate ecosystems and even less in the tropics. Phase I studies are focused on obtaining missing information on the forest ecosystem and integrating these data with published information to construct a meaningful model of mineral and energy storage and movement. Faunal components are emphasized in this phase due to the lack of comprehensive food web data for tropical forests, and the wealth of relevant vegetation data for the study area. The objectives of Phase I studies are:

1. To identify the major reservoirs and pathways of minerals and energy in the forest, and

2. To develop hypotheses concerning the potential effects of energy development related disturbances (e.g. inputs of sulfur, carbon, etc.) on cycling and transport.

Each task and subtask will provide information directed towards these goals. The mineral inventory will provide information on the mineral and energy value of each major class of items (fruit, leaves, feces, individual animals, etc.) in each ecosystem compartment. Faunal studies will quantify the number of such items in each compartment, and the rate of movement of these items between compartments. In addition to studies characterizing study plots, the vegetation work will provide a basis to compare the magnitude of elemental flow through compartments with direct movement of primary production to the decomposer compartment via leaf and fruit fall and litter decomposition.

We are attempting to achieve the above-stated objectives by the following steps:

1. Delineation of trophic structure, food webs, and food web segments.
2. Identification of dominant species in each food web or food web segment.
3. Quantification of vertical, horizontal, and temporal patterns of the distribution of identifiable functional units (species, trophic groups, food web segments, etc.) of the forest ecosystem.
4. Quantification of the distribution of key elements among major functional units of the system, taking into account spatial and temporal patterns.

Temporal considerations 5) Development of a refined forest ecosystem model which will permit simulation of cycling and transport processes, and 6) Generation of hypotheses concerning the potential impacts of energy development which are both relevant to tropical forest ecosystems and testable in Phase II. An important result of the proposed study will be a detailed food web in which major aspects of the distribution and transfer of minerals are known. Evaluation of these data is likely to produce useful insights on the relationship of food web complexity to species diversity, and about the influence of rainfall, humidity, soil type,

Nutrient pools, dominant consumers, and food web structure on the overall structure of ecosystems. This information will provide an important conceptual basis for inferring the key points at which perturbations due to energy development are most likely to disrupt natural systems. Phase II will primarily involve the testing of hypotheses, although some Phase I studies (e.g. population turnover rates) will be continued into this phase. Hypothesis testing may take a variety of forms. Direct manipulation of the forest by methods such as the addition of particular elements may be undertaken, as permitted by the U.S. Forest Service. Studies of existing plantations of various ages and managed forest areas may be conducted to gather comparative data on cycling and transport characteristics, including food web complexity. The exact nature and extent of these studies will depend largely on information acquired and synthesized in Phase I and are not considered in detail at this time, although several questions relating to the impacts of energy development on tropical forest can already be posed. Several hypotheses can be generated which involve comparisons between native tropical hardwood (tabonuco) forest and plantations (including those which are managed for energy production). Specifically, one can hypothesize that in the native hardwood forest: 1. Productivity is

Higher,
2. Consumer biomass is greater,
3. Insect pests are less abundant,
4. Food web structure is more complex,
5. Nutrient cycling is more rapid, and
6. The system is more resilient to exogenous disturbances than in plantations on the same soil types and under the same rainfall regimes.

The hypotheses selected for testing in Phase II will be based on information acquired in Phase I and on a realistic evaluation of potential energy-related impacts.

4.0 Phase 1 Methods

A compartmentalized ecosystem model (Figure 1) is being used as a framework for coordinating the various task studies. The focus will be on those ecosystem compartments above primary producers in the food chain for the following reasons:

(1) The importance of higher trophic levels in mineral transport has already been suggested for some forests (Weir, 1969), but the role of fauna in moving energy and nutrients among compartments of terrestrial ecosystems has been largely neglected (Sturges et al., 19745; Burton and Likens, 1975), and

(2) Primary production and elemental cycles have already been studied in the moist tropical forest (Odum and Pigeon,1970).

For these reasons, only a partial measurement of mineral transport in and out of the forest ecosystems will be begun in Phase I of the project. Values needed for the current study will be taken from the literature and/or from the work of visiting and collaborating scientists.

4.1 Sampling Design

The study area (Figure 2) was selected because of its long history of continuous research, beginning with the rainforest gamma radiation studies (Odum & Pigeon, 1970), and its proximity to the established activities at the El Verde Station. Other factors which were evaluated in the study area delineation process were the relationship to U.S. Forest Service research areas and the amount of existing disturbance from previous studies. The overall design is stratified random. Four sampling locations (points) were randomly selected within the study area so that subsequent statistically

Valid analyses can be performed (Green, 1979). Sampling points were selected using a grid technique (Phillips, 1959). The following criteria were used in the selection of random plots: potential confounding factors (e.g., roads, perennial streams, previous destructive sampling) are not present within 50 m of a sampling point.

Figure 1. Generalized Ecosystem Model 10

Figure 2. Scale in meters Rain Forest Study Area

Sample points will be no closer than 200 m to each other so that sampling overlap can be avoided, and reasonable access is possible. The size of the area to be sampled at each randomly chosen point will vary according to the discipline being studied. A one-hectare plot with boundaries marked at 10 m intervals has been established at each sampling point. Plot and plotless methods, transects, and detailed inventory procedures are used in phase 1 investigations. Studies focus on sampling points, but include other portions of the defined study area. Most sampling is being conducted during a minimum of two seasons. Most surveys will occur during the wet and dry seasons, but additional sampling is required for some tasks (e.g., breeding bird surveys). The timing of field surveys is being coordinated to avoid sampling interference yet maintaining close temporal correspondence among field studies.

4.2 Task Methods

Each task is described as a separate entity within the overall phase I sampling design because of the variation in pertinent information already available for different disciplines. The tasks are of varying durations, but all should be completed within 12 to 14 months (see Schedule section). Following the initial phase, the program will be evaluated and some studies continued with modifications (e.g., growth and population turnover of key species). Although the data acquired should be of immediate value, they are also intended to provide a basis for long term in-depth studies continued under phase II of the cycling and transport.

Program. The options will be better defined as phase I approaches completion. Objectives, detailed methods, and results are presented for each task and the significance is discussed. Conclusions and integrated data presentation are not included because of the preliminary nature of the information obtained for some of the tasks.

4.2.1 Physical Phenomena

Basic information on physical aspects of the environment is necessary in order to interpret biological observations and to provide baseline data for phase II studies. Specific objectives are:

- To collect pertinent weather data to be used in evaluating information collected from other tasks.
- To document seasonal and other temporal changes within the study area.
- To record stream flow from the Sonadora watershed in order to evaluate transport from the study area.

Materials:

- Rain gauges (at El Verde Station and tower)
- Thermometers and hygrothermographs (at El Verde Station and four levels at the tower)
- Wind speed and direction recorder (tower only)
- Stream gauging station (at suspension bridges on Quebrada Sonadora within the program study area)

4.2.2 Mineral Inventory and Energy Studies

The fixation of energy from the sun in plant materials is the ultimate driving force for cycling and transport processes in tropical rain forests. Movement of key minerals and energy through the system is being investigated by identifying the major pathways and quantifying movement between major compartments (Figure 1). Because of the important role of tropical forests in carbon cycling, a new task has been added which addresses the role of rainfall events in carbon export from the watershed, which includes the program study area.

4.2.2.1 Mineral Inventory

Sulfur: Material to be analyzed for sulfur is mixed 4:1 with benzoic acid, compressed and oxidized by burning in a combustion bomb under 28 atmospheres of oxygen pressure. The contents of the bomb are subsequently depressurized and rinsed through a coarse, rapid filter with four air.

50 ml.

Portions of doubly distilled water are reduced to 100 ml by evaporation on a hot plate. Standard gravimetric techniques are then used to analyze for sulfate.

Other methods: All other analyses are carried out according to procedures specified in APKA-AMNWA-HPCF "Standard Methods for the Examination of Water and Wastewater". Nitrate is analyzed using the standard amalgamated cadmium reduction, followed by diazo coupling of sulfanilamide and N-(1-Naphthyl)ethylenediamine. The intensity of color is read with a spectrophotometer. Organic and ammonia nitrogen are measured using standard Kjeldahl analysis with titration of indicator boric acid solution trap following digestion and distillation. Phosphate is measured using vanadomolybdate heteropoly acid color development and subsequent readout using a spectrophotometer.

Collections associated with the sediment graph/carbon export correlation are also being used for analysis of export of nitrate, phosphate, and organic nitrogen. The possibility of sulfur/sulfate analysis will also be addressed in the coming months.

Inasmuch as wet weight/dry weight and ash weight analysis of secondary consumers such as

Eleutherodactylid and Anolid species in the forest are not well described, and since ash-free dry weight is important for the description of the calorimetry of these animals, data on ash weight, wet and dry weight are currently being accumulated. The animal's tissue is also burned under controlled conditions (bomb calorimeter) in order to determine the energy storage in the animal compartments of the forest. The residues after burning were rinsed, filtered, and analyzed for sulfur.

Calorimetry: Calorimetric measurements are being made on organisms which are known or suspected of being major components of the rainforest ecosystem.

Dried samples are mixed with benzoic acid burn adjuvant and an accurately weighed sample of approximately 1 gram is burned in the oxygen bomb at 28 atmospheres pressure following moistening with 2 ml of water.

"Drops of a 1% solution of Triton X-100 control the burn. Standards of pure benzoic acid (6,318 cal./g) are run periodically as a calibration for the calorimeter. Temperature differences are read to the nearest thousandth of a degree. All measurements are corrected for unburned fuse wire, and a pre-burn oxygen purge is used to eliminate atmospheric nitrogen from the bomb.

4.2.2.3 Carbon Transport

This task was added subsequent to the development of the original program plan. Carbon transport from the forested upper Rio Espiritu Santo watershed is being quantified. Analysis is based upon a model which gauges sediment export from flow-monitored streams. The Cara del Indio hydrological gaging station on Rte. 966 is an appropriate site for collections of sediments for analysis of the sediment graph during sediment exporting events.

The hypotheses developed are based on the following considerations:

1. Sediment may or may not be associated with the bulk of the carbon exported via the drainage system.

2. Base flow conditions which might be responsible for some inorganic (dissolved) carbon export should not be very significant.

3. Long term storage cycles of carbon (>1000 years) may be responsible for more CO_2 atmospheric buffering than is presently thought.

Our observations consist of surface and bottom water collection during base flow and high water conditions and analysis of the water with respect to inorganic and organic carbon. Organic carbon is measured using a standard sealed vial oxidation technique (c.f. Oceanography International Operating Manual), employing potassium persulfate as the strong oxidant. The vials are scored and broken after the neck has been sealed within a gas carrying system. A surge of nitrogen gas acts as a carrier to bring the liberated carbon dioxide (CO_2) through the infrared sensing system of an Oceanography International total organic carbon analyzer. The detection response is integrated with respect to time electronically and the relative..."

The integrated peak area is related to calibration area curves. Substances used for the calibration of the response curve areas include sodium carbonate primary standard and potassium acid phosphate primary standard. Inorganic carbon is measured by injecting a known volume of sample into a 2M solution of phosphoric acid placed within the nitrogen purge system of the Oceanography International total carbon analyzer. These acidic conditions are sufficient to convert all carbonic acid, carbonate, and bicarbonate forms to free carbon dioxide which is purged with the nitrogen system described above.

4.2.3 Vegetation Studies

Considerable information has been accumulated on the vegetation of the Luquillo Mountains, including the rain forest at El Verde (Odum and Pigeon, 1970). Phase I studies are designed to fill important data gaps (e.g., variability in litterfall, decomposition rates, etc.) which have been identified, and will provide baseline data for experimental studies which are planned for Phase II.

4.2.3.1 Plot Characterization

Several types of information are needed in order to provide a basis for interpreting faunal data and for designing Phase II investigations. Initial characterization techniques are described below.

Structural Analysis: All the vegetation with a diameter at breast height (DBH) of 10 cm or greater will be identified, tagged with species name, DBH measured, and height determined. Between plot comparisons will then be made of: Species composition, species importance, biomass, and standing crop of elements in biomass (Ovington & Olson, 1970).

Topography: Information will be gathered on slope and aspect in each site to add information regarding between-plot variation.

Loose Litter: Variations in the forest floor litter components among plots will be determined by collecting samples at random in each plot each season. The number and size of the samples will be based on plot heterogeneity and prior sampling surveys. The material collected will be separated into the wood and miscellaneous components, dried at 70°C for

Pilot studies were conducted within the study area in April 1980, which indicated that 1 hectare was adequate for phase I vegetation studies. No further work is planned for this phase.

4.2.3.2 Phenology Objectives:

* To identify temporal differences in species' flowering and fruiting patterns within and between plots
* To determine the importance of species' contributions to flower and fruit fall

Methods and Materials:

* Refer to Titterfall for sampling location information
* Flowers and fruits will be separated monthly by species for each basket, counted, dried at 70% for 72 hours, and weighed
* Phenological studies will be limited to the flowers and fruit contributions to litterfall as determined

by basket collection in each plot.

Previous extensive phenological studies in P.R. (Estrada, 1970; Bannister, 1970; Nevling, 1971) indicate that additional studies would be repetitive and of low priority at this time.

4.2.3.3 Litterfall Objectives:

* To determine the seasonal pattern of litterfall as a whole and for individual species
* To detect differences between sites for total and species litterfall

Methods and Materials:

* Twenty two-gallon galvanized hardware cloth baskets lined with 1mm mesh fiberglass screen were placed in each of the four plots
* The locations of four litterfall transects were randomly selected at each site with 10m intervals between potential transect lines. Five baskets were randomly located along each transect (Figure 3)
* Each basket was elevated at least 10 cm from the forest floor (30 cm where possible) and leveled
* Collections of the litterfall are made bi-monthly. The mid-month collection is separated by basket into leaves, flowers, fruits, wood, and miscellaneous items
* The collections at the end of the month are air-dried; separated by species into leaves, flowers, fruits; and sorted by basket into wood and miscellaneous items
* Each component at each collection is counted, dried at 70°C for 72 hours, and weighed. Wet season-dry season samples will be... [text ends here]

Processed by species by plot (some species by transect) for: factor= ic and mineral content.

4.2.2.4 Leaf Decomposition Objectives:
* To determine the seasonal decomposition of freshly fallen leaves
* To compare the between plot rates of leaf decomposition

Figure 3. Randomly Selected Vegetation Sampling Locations Within Study Plot. -19.

* To evaluate the effect of species composition on the decomposition rate
* To determine the change in caloric value and mineral content over time and between major seasons.

Methods and Material:
* Freshly fallen leaves will be collected seasonally from each of the four study plots in order to represent species composition, approximate quantity, and the chemical composition of the leaves in each plot. The leaves will be air dried overnight to remove surface moisture. Twenty grams of air dried leaves will be placed in each 25x40 cm fiberglass screen bag (1mm mesh) for a total of 170 bags/site.
* Eighty bags containing leaves from plot 1 will be placed in plot 1, four near each of the 20 litter baskets. Eighty bags containing leaves from plot 1 will be placed in plot x selected for site homogeneity. Ten bags will be reserved for fresh weight-dry weight conversion.

* The above will be conducted for each of the four plots, thereby detecting any variation in the decomposition rates between plots. By randomly placing decomposition bags from each of the 4 plots in one homogeneous area (plot X), any differences in the decomposition rates, between the plots due to species composition will be determined.
* Ten bags will be collected at random from each site plus 10 bags representing each site from plot X (40 bags total each collection) at 7, 14, 20 days; 2, 4, 8, 16 months. The remaining bags will be considered a field reserve in case of unpredictable bag destruction.
* Caloric values and mineral content will be determined on 3 of the bags from each plot at each collection to determine temporal variations.

4.2.4 Faunal Studies:
The roles of

Animals in ecosystem structure and function can be effectively evaluated by combining energy flow and nutrient cycling studies. Recent work in temperate forest ecosystems has provided valuable information on the roles of animal populations as nutrient "sinks" and as agents of nutrient transport (Weir, 1969; Sturges et. al., 1972).

Because of their potentially high turnover rates at relatively high ambient temperatures, underestimating the importance of organisms with short life spans and low standing crops in cycling and transport processes is even more likely in tropical systems than in temperate systems. The proposed phase I faunal studies are designed to investigate that possibility in the tropical forest ecosystem at El Verde. The major faunal sampling effort is aimed at obtaining information on the food habits and general abundance of animals. From these data emphasizing top carnivores and herbivores, a comprehensive food web will be constructed. Initial food web analyses will attempt to define major pathways rather than focus on parallel food subwebs (Paine, 1969; Gilbert, 1980) which may or may not be important structural units in this insular tropical rain forest. Studies will focus on those intermediate consumers serving as principal diet items for higher order carnivores. Attempts will be made to estimate population turnover rates for key (i.e. abundant, frequently eaten or large) consumers. To some degree, intermediate consumer roles and rates will have to be estimated in a pooled fashion from differences between rates of primary productivity, litter fall, decomposition, and consumption rates of top carnivores. The faunal studies will phase from highly diversified qualitative collection through more selective sampling aimed at relative abundance to highly specialized quantitative sampling, aimed at key species. Relative abundance and absolute abundance data will be combined to refine portions of the food web. Turnover estimates plus metabolic data will be used to quantify flows.

Because of expected seasonality, some types of sampling will be continued throughout the entire period of study. However, with each successive sampling period, more effort will be placed on relative and absolute abundance estimation for key species and species groups, rather than on the identification of new species. Over time, more detailed paths will be able to be delineated and quantified and it will become possible to test whether additional refinement is needed to predict the influence of man-made changes upon these ecosystems.

More specific descriptions of research tasks and methods follow for the major faunal groups.

4.2.4.1 Invertebrates

The invertebrate fauna influences cycling and transport processes in the rainforest ecosystem in three major ways. First, by grazing on photosynthetic and reproductive structures of plants (e.g., phytophagous insects) they affect forest primary productivity and alter plant species composition and diversity (Janzen, 1970, 1973; Mattson and Addy, 1975). Secondly, as decomposers and detritus feeders in the soil and litter, they are responsible for breaking down dead organic matter, making nutrients available to the plant community. This latter function is of great importance to the plants of a tropical forest, which, due to leaching and soils low in nutrient concentrations, must incorporate nutrients at a rapid rate. Thirdly, invertebrates play a role of unknown magnitude as predators, certainly influencing and possibly controlling the density and species composition of selected primary consumers (Hairston et al., 1960). In view of these characteristics of the invertebrate fauna, the importance of their role in the flow of energy and cycling of nutrients in the tropical rainforest becomes evident. Unfortunately, few studies have contributed to the understanding of the different ways in which invertebrates influence the flow of energy and nutrient cycling in tropical terrestrial ecosystems. The majority of invertebrate studies in

The study of tropics has been limited to crude estimates of absolute or seasonal abundance and some biomass determinations. Historically, studies of the dynamics of invertebrate populations have emphasized economic pest species, leading to models of populations that aren't general enough for prediction of randomly selected species (Clark et al., 1967; Gilbert and Singer, 1973). The few detailed studies of invertebrate populations in the tropics, limited to groups of insects such as butterflies of the genera Acraea (Owen, 1971) and Heliconius (Ehrlich and Gilbert, 1973), and euglossine bees (Janzen, 1971), have shown that for these species, population size remains constant over time but turnover rates are high.

If this is true for other tropical forest invertebrates, then because they comprise a large proportion of the faunal biomass, invertebrates must play a major role in tropical ecosystem nutrient cycling and energy flow. It has been shown in temperate forests that invertebrates, particularly phytophagous insects, regulate forest primary productivity (Mattson and Addy, 1975). However, the same has not yet been demonstrated in tropical ecosystems.

Most of the work concerning forest invertebrates in Puerto Rico has been limited to pest species, taxonomic descriptions, and relative abundance and/or food preferences of selected species (Martorell, 1943; De León, 1944; Wolcott, 1940; 1986; 1950; Drewry, 1970). The only studies that have emphasized the role of invertebrates in the rain forest ecosystems were performed during the AEC Radiation Experiment (Odum and Pigeon, 1970) in the tabonuco forest at El Verde. These studies covered the major groups of invertebrates in the tabonuco forest including aquatic communities in bromeliad leaf axils (Macguire, 1970), nematodes in litter and soil (Coleman, 1970), termites (MacMahan, 1970), soil microarthropods (MacMahan & Solins, 1970) and mosquitoes (Weinbren & Weinbren, 1970). However, these studies were fragmentary and conducted during specific periods.

Different seasons and/or years can leave even the basic inventory incomplete. Attempting to study the role of all invertebrates in ecosystem structure and function, and their effect on energy flow and nutrient cycling, is impossible due to the magnitude of the task. Additionally, the taxonomy, autecology, and population dynamics of most invertebrates have not been well studied. For this reason, the scope of this study will be limited to phytophagous insects, their principal predators, and the soil fauna.

Phytophagous insects of both low and high strata of the vegetation will be sampled by means of sweep nets, special enclosures, malaise traps, light traps, and/or a sucking apparatus (De-Vac Sampler). Sampling will be done at each season, both day and night. Environmental variables will be recorded during sampling.

The effect of phytophagous insects on energy flow and nutrient cycling will be evaluated in coordination with related vegetation studies. The intensity of grazing on leaves and fruits will be quantified by means of the relationship between leaf area damaged or consumed and leaf area index through time.

Approximately 90% of forest primary productivity goes to decomposers. Therefore, they will be considered the most important with respect to nutrient cycling and energy transfer. The role of soil fauna will be approached in the same manner as for phytophagous insects.

Because sampling accuracy is of utmost importance in estimating population size, soil litter fauna will be sampled by more than one technique. These techniques will be tailored to the characteristics of the different groups. With the help of expert consultants, the best method will be chosen from the literature. These techniques may include soil coring (for Nematodes), flotation, extraction (using Berlese and Tullgren funnels or high gradient canisters for microarthropods). Direct captures will also be utilized for macroarthropods such as Myriapoda. As with the

Phytophagous insects, dominant species will be identified and future experiments will be designed to investigate their population dynamics. The soil and litter fauna will initially be treated as one compartment, with only prey species being singled out as they are identified from studies of carnivore food habits. As stated previously, for most samples, only information on total numbers or biomass will be secured. However, attempts will be made to determine the relationship at different seasons of the year between numbers of cores (or area sampled) and numbers of recognizable taxa.

4.2.4.2. Amphibians and Reptiles

These poikilothermic vertebrates are conspicuous and abundant components of tropical forests. Considerable data are available on the ecology of some groups (e.g., the genus Anolis), but the information required to determine their importance in cycling and transport through these ecosystems is incompletely known. The basic types of data required are (1) mineral and energy content, (2) status in the food web (food habits and predators), (3) biomass, and (4) population turnover rates. Initial studies will focus on acquiring information of the first three types.

Subtask 1. Species Inventory

Objectives:

- To determine the presence and general abundance of species not readily observed by transect methods.

Methods and Materials:

- Intensive searches at random and selected locations will be conducted periodically throughout the study area, and random observations will be noted.
- Surface debris and litter will be overturned in order to locate secretive and fossorial species.
- The species, location, and general abundance of each species observed will be recorded.

Subtask 2. Presence and Relative Abundance

Objectives:

- To determine the species composition and relative abundance of amphibian (anuran) species within the study area in order to identify important species and to correlate information collected at study plots with more detailed data collected on coquis within the same general area.

Dr. M. Stewart and her colleagues proposed the following methods and materials:

To conduct transect surveys along the same lines as bird and lizard surveys.
1. Walk each transect on three separate evenings during each major season (wet and dry), and record the species, sex (where possible), and the size class of each individual observed along 50 x 2m belt transects.
2. Record the calls of any individuals which cannot be identified in the field.
3. Calculate the relative abundance for each species in each of the four plots.

Subtask 3 is to investigate Anolis food habits.
1. Determine the types of food consumed, frequency of occurrence, and percentages of food items for each species.
2. Collect a minimum of 30 adults of Anolis gundlachi and A. Vermann during each major season (wet and dry).
3. Immediately kill, weigh, and cool specimens in the field.
4. Dissect stomach content out of each specimen and place them in preservative (10% formalin or commercial insect preservative). The contents should be identified as specifically as possible, noting the approximate percentage of total contents for each individual lizard.

Subtask 4 focuses on Anolis population density.
1. Obtain a minimum population density estimate for common species of Anolis in each plot at each season (wet and dry).
2. Obtain a population index and relative abundance estimate for Anolis in each plot.

Methods and Materials:
1. Establish a permanent transect 150m in length beginning at the center of the plot and extending diagonally from it along an existing bird transect in each of the four study plots.
2. Each transect is surveyed by slowly walking the marked line on three separate occasions: morning (0700-1000), mid-day (1000-1400), and afternoon (1400-1800) during the wet and dry seasons.
3. The species, sex (or size class), and distance from the centerline of the transect is recorded for each individual observed.

Relative abundances are calculated for each plot, and minimum population densities are calculated. General references include Sexton (1972).

According to Frye's strip census formula (Overton, 1971):

Term Fi: average perpendicular distance between observed animal and transect centerline
Cr: correction factor for units of measurement
Transect length: area of study site
Estimated population density: number of animals observed on transect

Subtask 5. Anolis Population Turnover and Growth Rates

Objective: To obtain reliable estimates of population turnover and growth rates for the most abundant species of Anolis.

Methods and Materials:

1. Live capture all sizes of Anolis within a designated portion of the overall study area.
2. Mark animals individually, weigh, measure, sex (when possible), and release.
3. Repeat at 1-3 month intervals and extend into phase II.

Subtask 1. Population Density

Objective: To obtain reliable population estimates for each species in all sites studied and to detect changes in population density throughout the year.

Methods and Materials:

1. Grid a 9 ha. area that includes one of the sampling plots (Plot 3). Grid lines will be established at 30m intervals, and intersections marked with numbered fiberglass stakes.
2. Beginning in February, 1981, use modified spot-map methods, mist netting, and systematic observations, to determine population density for each species in the 9 ha. site (see Holmes and Sturges 1975).
3. In each of four 1 ha. sampling plots, establish a 300 m transect line through opposite corners of the plot. Set up a 150 m net lane bisecting each transect line.
4. Visit each site 2 days/month to conduct two transect censuses between 0600-0900 using the method of Emlen (1971). Every third month run four transects in each site between 1500-1800.
5. Compare absolute densities from Plot 3 with data from transect surveys from the same plot.

4.20 3 Birds Synthesis of new techniques and knowledge gained from preliminary field work has resulted in some changes in the original work plan, with a view towards increasing the value of the resulting data. The current methodology for the program is described below.

Calibrate the transect densities to the actual number of birds occurring. Use transect data to estimate population densities in the other three sites. After initial transect counts, sample each site from dawn to dusk for five consecutive days with mist nets, marking all birds captured. Calculate trappable population sizes (MacArthur and MacArthur, 1974).

Subtask 2. Feeding Behavior Objective: To accumulate sufficient observations of feeding to test for differences between species, sites, seasons, and individuals.

Methods and Materials: Observe avian behavior for equivalent periods in each site. Record prey items taken, horizontal coordinates of prey capture, height of prey capture, tree species, type of foraging move, direction and distance of foraging move, substrate attacked, perch diameter, location, time, weather conditions, etc. Data will be compiled and analyzed in a way that will allow comparisons with foraging data taken by C. and S. Kepler in Colorado forest and A. Cruz in pine plantations.

Subtask 3. Diet and Weight Objective: To determine differences in diet and weight between species, sites, seasons, and individuals; to describe food webs for each site.

Methods and Materials: Sacrifice sixty birds of 10 species captured outside study sites, identify stomach contents and freeze for bomb calorimetry. In conjunction with the banding studies in Plot 3, use ground and canopy mist nets to capture as many individuals as possible in this plot. Also, conduct occasional mist netting around the boundaries of the other three plots. Weigh, measure, and mark each individual captured. Sample stomach contents of each individual with antimony potassium tartrate emetic. Identify stomach contents to the lowest taxonomic group possible. Construct a partial food web for each site using data collected and literature sources. Calculate uptake of minerals using feeding rate and bomb calorimetry data.

Subtask 4. Materials Discharge Objective: To obtain reliable estimates of the

The amount of fecal and regurgitated material produced per individual of each species per unit time. Place mist-netted birds in holding cages for 1) one hour during the day and 2) overnight. Collect, dry and weigh defecated and regurgitated material. Determine the average weight of feces and regurgitated material. Bind fecal and regurgitated material to determine mineral content. Using observed rates of defecation in the wild and in bird cages overnight, calculate the amount of material returned to the environment per individual per unit time.

Test for differences between individuals, species, and sites.

Subtask 5. Mineral Content Objective: To obtain reliable estimates of the mineral content per unit weight of 1) whole stomach contents and individual food items, 2) body tissue, 3) feathers and 4) feces and regurgitated material.

Methods and Materials:

1. Capture and sacrifice sixty birds of ten different species.
2. Remove stomach contents, identify and count, dry separately. Combine fecal material from each species and dry.
3. Remove feathers, homogenize and dry feathers and body tissue separately.
4. Determine important food items for each species and collect, homogenize and dry samples of each item.
5. Bind and analyze residue of samples in the following numbers: body tissue, up to 6/species or

until low individual variation is established (minimum 10, maximum 60); feathers, same as body tissue; stomach contents, 6/species (total 60); fecal material, 2/species (total 20); food items, up to 50. Grand total= 150-250 samples.
6. Calculate per item or per event transfer of minerals.

4.2.4.4 Mammals: The role of mammals in the rain forest ecosystems of Puerto Rico is of particular interest because of the low species richness and because the larger species (e.g. black rat and Indian mongoose) have been introduced by man. Studies of this group will be limited in scope, but basic information is needed prior to the implementation of experimental investigations which are planned for phase II.

"# To determine the presence and general abundance of species within the study.

30. Methods and Materials:

Twenty Sherman Tine traps (3x3x9 in) are placed in two lines of 10 traps each at 15n intervals between lines and traps and checked each day for a minimum of three consecutive days. The traps are checked and rebaited (as necessary) daily. Lines were surveyed during mid-November, 1980 and will be surveyed again during the 1981 dry season.

Larger terrestrial mammals are sampled using Tomahawk line traps (6x6x24 in) deployed in a 5x5 trap grid (Nellis, personal communication) with traps spaced at 30m intervals. Traps are checked and rebaited daily for a minimum of three consecutive days.

Bats, the only native mammals presently known to inhabit the study area, are surveyed using horizontal and vertical mist nets erected in selected locations within the study area at intermittent time intervals throughout each major season.

31. RESULTS AND DISCUSSION

5.0 Initial surveys have produced substantial, and in some cases unexpected results. Because these data are preliminary, integrative analyses are not possible at this time. Results are herein reported and discussed by task.

5.1 Physical Phenomena

Daily rainfall and continuous records of relative humidity and temperature fluctuations have been collected at the El Verde Field Station since the radiation studies in the rain forest during the mid-1960s. The tower station was established in July, 1980 and will be maintained throughout the program field studies. Prior to the implementation of phase II studies, a wind (velocity & direction) gauge, rainfall event recorder, and stream flow gauge may be added.

5.2 Mineral Inventory and Energy

5.2.1 Mineral Inventory

A limited number of samples have been analyzed for percent sulfur content. Preliminary results on three species of lizards (Anolis gundlachi, A. evermanni, and A. stratulus) indicate similar values (0.2-0.3%) for all species. Additional individuals will be analyzed and other

The text appears to be discussing the analysis of various faunal species, with a focus on sulfur content and moisture levels. Here is the corrected text:

Faunal species were processed during the remainder of phase 1. Contents of the bomb calorimeter were subjected to sulfate analysis in order to determine the total sulfur content of the samples returned. Much of the experimental work performed was dedicated to testing methodology which appeared to be just adequate for the sulfur levels encountered in the animal specimens. The results and the estimated uncertainty in results prompt us to review methodology and begin examining other alternatives for sulfur analysis; this is particularly necessary for soil sample examination. Results are estimated to be uncertain by as much as 50% in the worst case and the probable uncertainty in other values is likely at least 20%.

Table 1 presents average values of the analyses for organic nitrogen (total Kjeldahl nitrogen), nitrate (WO4), and nitrite (NO2) in 8 samples collected from the surface and bottom of the Rio Espiritu Santo Confluence at Cara del Indio. The organic nitrogen concentration fluctuations appear to be related to those observed for organic carbon, with the highest value reported when the highest observed level of the stream occurred.

Calorimetry wet weight vs dry weight results for the anolid lizards Anolis Gundlach and Anolis evermanni are depicted in Figure 4. It is clear that individuals, whether male or female, all retain about the same amount of labile moisture. By dry weight, we mean the weight of the animal after 36 hours of drying in a convection oven at 80°C. The relationship of wet weight to dry weight for Eleutherodactylus coqui is shown in Figure 5. The individuals of E. coqui apparently retain substantially more labile moisture than the individuals of the anolid species. Approximately 81% of the E. coqui was labile moisture whereas the anolid species contained about 76% moisture by weight.

Heat content of anolid lizard species was determined using bomb calorimetry. The results are tabulated in Appendix A on an "ash-free dry weight" basis. The average heat content...

The calorie content for all anolids was 4322.1 cal/ash-free gm, with a standard deviation of 315.4 cal/ash-free gm.

5.2.3 Carbon Transport

Work has progressed on a new task - the quantification of carbon transport from the forested Rio Espiritu Santo watershed, which includes the program study area. Carbon export from the forest is based on the model for the hydrograph of the Rio Espiritu Santo River, currently under development by a visiting scientist, Dr. Oswaldo Rendón Herrero. This model gauges sediment export and weathering using hourly gaging and sediment collection from a stream with a flow-monitored cross-sectional area calibration.

The following sequence of numbers and symbols appear to be an error and are not legible.

Figure 4 illustrates the Wet Weight/Dry Weight relationships for Anolis vermanni gundlachi.

The following text appears to be in another language or contains typographical errors and can't be corrected without further context or information.

We hypothesize that long-term storage cycles are of limited importance in tropical rain forests. The long-term cycle has a requirement for humus and organic soil formation, which while important to temperate zone forest carbon fixation, is probably of limited significance in the tropical forest. The temperature and humidity in the humid tropics are responsible for rapid decay of leaf material. The 3-4 heavy sediment-exporting rainfall events effectively scour parts of the forest ground surface and the sub-surface soil layer.

Potentially fixable carbon. Stream Chemistry and Gaging: Water samples were collected from the surface and bottom of the Rio Espiritu Santo River confluence, known as Cara del Indio (Indian Face). Samples were processed both before and after either filtration or centrifugation to test the relationship between sediment export and nutrient loss from the forested watershed. Appendix B lists data for five surface and five bottom samples collected on each date. The gaging depths are in USGS units and were taken directly from the depth marker at the USGS gaging station at Cara del Indio on Route 966. The designations F and U refer to filtered and unfiltered samples, respectively. Table 2 shows the average values for carbon analysis of samples collected on each of the four given dates. The inorganic carbon analysis standard deviations indicate that the collection procedure is adequate to ensure homogeneous bulk water samples. Unusually high values of organic carbon observed for bottom samples collected on October 9, 1980, and November 25, 1980, may be artifacts of the sampling procedure, and at least in the case of the November 25, 1980 sampling, a larger number of samples could have provided a statistically valid basis for rejection of the high value. On November 17, 1980, the stream level at Cara del Indio was near base flow condition following a period of very heavy showers during most of the previous 12-hour period. The flushing of labile or available carbon from the watershed may account for the low concentration of dissolved organic carbon observed for the five samples collected on that date. The only data supporting the hypothesis that heavy export of carbon is large.

Table 2. Carbon Concentrations of Samples from Cara del Indio.

Surface Date	Organic	Inorganic	Flow Level	Filtered	Unfiltered	Filtered	Unfiltered (USGS Units)
Oct. 9/80	3.007±1.19	3.794±1.42	5.554±1.28	6.584±1.21	2.82		
Oct. 30/80	5.313±0.49	8.380±0.45	3.634±0.13	3.540±0.06	4.46		
Nov. 17/80	0.584±0.13	0.864±0.21	5.684±0.20	5.440±0.98	2.70		
Nov. 25/80	4.324±1.88						

4.05■2.41■-■-■3.50

Bottom Date	Organic Inorganic Flow Level Filtered Unfiltered Filtered Unfiltered (USGS Units)								
Oct, 9/80	5.56	4.37	3.35	4.76	§.72	4.14	5.88	4.12	2.82
Oct. 30/80	§.48	4.01	8.64	4.05	3.60	4.02	3.67	0.16	4.46
Nov. 17/80	0.45	4.09	0.57	4.01	§.72	4.03	5.08	4.08	2.70
Nov. 25/80	3.90	4.28	4.00	4.37	-	-	3.50		

The data associated with sediment exportation is derived from measurements taken on October 30, 1980 when the stream level was the highest of any of the collection times. The differences in carbon concentration in filtered and unfiltered samples are statistically significant.

5.3 Vegetation Studies

Considerable information has been accumulated on the vegetation of the Luquillo Mountains, including the El Verde rain forest (Odum & Pigeon, 1970). Phase I studies are designed to fill gaps in our knowledge of nutrient flows through the ecosystem and to provide a basis for subsequent investigations in Phase II.

5.3.1 Plot Characterization and 5.3.2 Phenology

Plot characterization and phenology subtasks are being initiated at this time, but preliminary data are not sufficient for analysis. Litterfall and decomposition studies were given priority due to the length of time needed to obtain results and their relevance to overall cycling and transport processes.

5.3.3 Litterfall

Preliminary results give a mean value for October of 1.73 g/m²/day. Plots 1 through 4 varied from 1.76, 1.29, 1.99, and 1.89 g/m²/day, respectively. The leaf fall contributions of the most important species are shown in Table 3. The ranking of the species, from 1 (highest) through §, is based on grams of leaves/m²/day by plot and overall means. Considerable time was required to establish the litterfall baskets in the forest. As a result, only limited data are presently available and no conclusions are possible. The sampling program has been fully implemented and adequate data will be available for analysis in the Phase I final report.

Note

Plots 1 through 4 contributed 0.04,

0.04, 0.002, and 0.09 g/m³ per day for flowers and 0.07, 0.04, 0.06, and 0.05 g/m³ per day for fruits respectively for the month of October, 1980. The species contributing the greatest amount (g dry weight) to the October flower component of litter were: Plot 1, Croton poeeflanthus; Plot 2, Homalium racenosum; Plot 3, Homalium racenosum; and Plot 4, Byrsonena coriacea.

5.3.4 Leaf Decomposition

This task will begin in the 1981 dry season (January-April) and be continued into the following wet season. These methods have been designed to avoid possible errors found in other studies. Weigert (1970) collected litter from the forest floor and oven dried the samples before replacing them in the forest. This method was not used because oven drying the samples before and during the experiment probably killed the decomposers and altered the decomposition rates. Also, samples collected from the forest floor (loose litter) are in all stages of decomposition. The following modifications are expected to yield more relevant information:

* Placing enough bags in the field so that the collected bags would not need to be replaced after drying.
* Using freshly fallen leaves to detect rates of decomposition, caloric content changes, and mineral loss.

Decomposition rates for individual species will not be measured as were done in the studies of Ewel (1976), Weigert and Murphy (1970). It is believed that leaf composites from each plot will yield the site and species interactions characteristics of each plot and therefore give information of any overall site differences in decomposition.

5.4 Faunal Studies

Substantial progress has been achieved in defining major reservoirs and determining principal pathways of nutrients and energy through this rain forest ecosystem. A comprehensive view of the food web organization is emerging which will provide valuable insights into the functioning and complexity of tropical forests. Some of the preliminary results have been unexpected and have caused the redirection of some tasks.

The corrected text is as follows:

It is tempting to integrate our present information, but premature analysis might be counterproductive to program goals and will be deferred until the final report. Individual task results are presented and discussed below.

5.4.1 Invertebrates: Surveys of invertebrates as described in the methods section (4.2) have been delayed because of staffing difficulties. The position has been filled and studies will begin in February 1981. Incidental observations and food analysis suggest that complicated and important interactions occur between larger forms (e.g., spiders and whipless whip scorpions) and small species of vertebrates, mainly frogs, and lizards.

5.4.2 Amphibians and Reptiles: Habitat searches were performed to determine which species were present in the study area. No new species or unexpected observations were made during seasonal sampling. A compilation of observations made during phase 1, and data from literature on the El Verde site will be presented in the report which follows dry season sampling. Species observed in the Study Area during phase I studies are listed in Table 4. Results of the wet season amphibian abundance surveys are presented in Table 5. Eleutherodactylus coqui was consistently the most abundant species, although many of the individuals observed were juveniles and subadults. E.

wightmanae was the next most abundant species and the only one.

Table 4. Amphibian and Reptile Species Observed in the Study Area During Phase I Studies.

Order: Anura
Bufonidae: Bufo marinus
Family: Leptodactylidae
Species: Leptodactylus albilabris
Eleuterodactylus coqui, pottoricensis
Eleutherodactylus hedricki, wightmanae
Family: Ranidae

REPTILES:
Order: Squamata
Suborder: Lacertilia
Family: Gekkonidae
Species: Sphaerodactylus macrolepis, clauber
Family: Anguidae
Species: Diploglossus pleei
Family: Amphisbaenidae
Species: Amphisbaena caeca
Family: Iguanidae
Species: Anolis cristatellus
Suborder: Ophidia
Family: Colubridae
Species: Alsophis portoricensis

2 during 1980 vet: Abundance observed <u 0.3

Bufo marinus and Leptodactylus albi were observed. A 90x gas microscope was used. Surveys were conducted on September 2. Yearly calling was noted in the plot.

Other species were observed along transects in all four plots. E. hedricks was heard calling in all plots, but its densities were such that it was encountered on only two transects. Other species are apparently present at very low densities compared to E. cogui. Similar results have been obtained during dry season surveys by Dr. Margaret Stewart during her studies in the same area, and therefore surveys will not be repeated during the 1981 dry season.

Investigation of food habits of Anolis lizards were begun. The minimum number of lizards was collected for the first seasonal survey, but identification of stomach contents is incomplete. The types and frequency of occurrence of food items from the stomachs which have been examined are presented in Table 6.

Conclusions from initial sampling are only tentative, but seem to indicate that the same insect orders (Coleoptera, Lepidoptera, Diptera, and Hymenoptera) are important prey items of both species. Anolis evermanni appears to consume more Orthoptera than does A. gundlachi which may be a reflection of different habitat use rather than a true food preference. Following dry season sampling, all stomach contents will be re-examined and identified more specifically (where possible). Data will be correlated with insect/invertebrate sampling to detect possible food preferences and energy/mineral flow pathways.

Relative abundance and minimum population density estimates for the two most common lizard species (Anolis gundlachi and A. evermanni) are presented in Table 7. Minimum density calculations show higher population levels in plot 4. Inspection of the data shows that many of the observations were juvenile lizards on understory vegetation beneath forest canopy which was more open than in the other three plots. Anolis gundlachi was found to be the most abundant species observed in all plots, while A. evermanni demonstrated considerable variety.

Variability among plots. This may be a result of the small sample size rather than indicating a real difference. Two additional lizard species were observed along transects, Anolis Stratulus and A. cuvieri. Both species are primarily found in the forest canopy, and this sampling method consistently underestimates their population.

Table 6. Frequency of occurrence of food items in Anolis gundlachi and A. Frequency (2) Food Item Anolis gundiachi>

EE Phylum: Aschelmiethes 7 8

Class: Nematoda

Phylum: Mollusca 4 - as Gastropoda

Phylum: Arthropoda

Class: Arachnida

Order: Araneae - 6

Class: Chilopoda

Scolopendra sp. - 4

Class: Insecta

Orders: Orthoptera - 40

Isoptera - 7 6

Hemiptera - 7

Neuroptera - 2

Coleoptera - 39

Lepidoptera - 30 20

Diptera - 56 76

Hymenoptera - 10 8

Chordata

Reptilia

Order: Squamata - 4

Plant Material - 7 4

Year adults (15 males, 12 females) - 705 adults (12 males, 13 females) 46

om ore at 168 we vee ve 3004 st 960 « 106 vo ore ar ey wt ee 902 o sos act ve ere we 012 yaans uosees 19x Bupanp UT pue *saouepunge ot +o eran “47

Population density. Vertical transect studies, not included here, indicate that Anolis stratulus may be an abundant species in the rain forest study area. The minimum population density estimates are considerably below the absolute estimates calculated by Turner and Gist (1970) for the same area. Relative abundance estimates are also at variance with those presented by Well (1978) for similar habitat at similar elevations near El Verde. Preliminary data from other lizard studies at El Verde suggest that the time of day, weather, and season may all affect the activity and indirectly the observability of species. These questions will receive further consideration during dry season sampling. It is important to note that these data apply only to the lower 4-5m of the rain forest. Vertical transect studies are being conducted which indicate vertical stratification of lizards, and lizard distribution throughout the 18-22m height of the rain forest.

Data from these studies will provide additional information on the relative abundance and distribution of Anolis lizards in the rainforest. The relative abundance and vertical survey for the first wet season have identified Anolis stratulus, A. gundlachi, and A. evermanni as abundant species within the study area. Due to the vertical stratification of these species and since population density estimates have not been obtained for A. stratulus (which may turn out to be the most abundant species), studies of population turnover and growth rates have been deferred until data from dry season surveys have been obtained.

5.4.3 Birds

Initial fieldwork on the avian section of the CEER-DOE mineral cycling and transport study has produced both useful results and a new perspective on the problems of sampling and the appropriate techniques to overcome these problems. Moreover, recent developments in avian censusing methods require a re-evaluation of proposed sampling plans, with the result that more accurate population estimates can be generated. Common and scientific bird names are listed in Appendix C.

Population density information was estimated from transect data. Appendix D contains data from transect censuses taken during July-November 1980. The increased number of observations in October and November over preceding months is the result of an increase in avian activity and the addition of a second observer, who was unfamiliar with the Emlen transect methods. An intensive training program since that time has reduced the amount of inter-observer variability to acceptable levels.

The outstanding feature of the data is the dominance of all plots by a single species, the Bananaquit. The Red-necked Pigeon and the Puerto Rican Tody are the next most abundant species in each site, although their relative position changes in different sites. The proportion contributed by each species to the total number of observations remains relatively constant for most species in all sites during.

July-November, a notable exception is the Red-necked Pigeon, where the number of observations in any month is determined by the occurrence of fruiting trees around which these birds aggregate. In months where a food tree was in fruit near a transect line, observations of this species would be relatively high. Table 8 gives the total number of observations of each species in each site during the period July-November 1980. The data are corrected for differences in the number of transects and in the total time spent in each plot. Most species show very similar values for all four plots. Six species (Ruddy Quail-Dove, Zenaida Dove, Puerto Rican Emerald, Stolid Flycatcher, Stripe-headed Tanager, Puerto Rican Bullfinch) are twice as common in Plot 4 as in any other plot. Plot 4 is more disturbed than the other three plots, but until vegetation analysis is completed, any explanation for the increased abundance of these six species in Plot 4 is only speculative. Fifteen of the 21 species observed were found in all plots. Those species found in fewer than four plots were either migrants or very rare residents. With increased observation time, species list for each site are expected to approach complete congruence. Data from mist-net samples in each plot are shown in Table 9. In almost two weeks of netting, only half the species occurring in the sites were caught.

Table 9. Number of captures and capture rate for Plot 1-4

	Plot 1	Plot 2	Plot 3	Plot 4	Total
Ruddy Quail-Dove	9	6	6	3	
Puerto Rican Emerald	2	2	2	2	8
Puerto Rican Tody	0	2	7	1	10

(Note: The text following "the sites were caught." is incomplete and doesn't make sense. This is the best my AI could do with the provided context.)

"Pearly-eyed Thrasher: 1, 2, 2, 5; Red-legged Thrush: 1; Mack-throated Blue Warbler: 2, 2;

Ovenbird: 1, 1, 2; Bananquit: 3, 2, 1; Stripe-headed Tanager: 1, 1; Puerto Rican Tanager: 6. Total Captures: 85. Number of sets: 2. Number of days: 3. Captures/net-day: 0.45, 1030.70, 0.37.

Birds were captured. This result is consistent with other sites in the wet tropics, where vertical stratification makes some species difficult to catch. The only species caught in numbers was the Ruddy Quail-Dove, a ground feeder. These results suggest that estimation of population densities with marked birds will require the use of canopy nets to capture some species.

Figure 6 presents data on the height of occurrence of seven species. Data were collected during transect surveys and are summed for all four study plots. Figure 6 compares heights of species in two different foraging guilds. Both nectarivores (Puerto Rican Emerald Hummingbird and Bananaquit) and large frugivores (Ruddy Quail-Dove and Red-necked Pigeon) show little overlap in their vertical distribution. The former guild may show more overlap in the canopy, but insufficient data are available at this time to test this hypothesis.

Sixteen birds of six species have been collected and their stomach contents preserved. The weights of these birds and other individuals captured during mist netting for Task 1 are summarized in Table 10. Insufficient observations are available to begin the construction of preliminary food webs; however, literature sources have been identified that will contribute much of the information on diet needed for this task.

Nineteen of 60 birds have been captured and are being processed for orb calorimetry. A detailed protocol for processing bird parts has been developed. Fecal material, food items, and stomach contents are being accumulated as the other tasks progress. Difficulty in capturing two species (Red-necked Pigeon and Puerto Rican Woodpecker) may result in these species being omitted from the analysis."

Mammals: No mouse-sized mammals were trapped in 80 trap nights in the lines of Sherman line traps, and none have been observed in or near the study area in the recent past. The trapping surveys will be repeated on a larger scale during dry season surveys.

Table 10: Mean weights (in grams) of seven species caught in mist nets.

Ruddy Quail-Dove: 38.6
Puerto Rican Emerald: 16
Puerto Rican Tody: 32.03
Pearly-eyed Thrasher: 96.7
Red-legged Thrush: 80.5
Bananaquit: 7
Puerto Rican Tanager: 33.07

Larger terrestrial mammals had not been surveyed as of November 30, 1960, but the Indian mongoose (Herpestes auropunctatus) and black rat (Rattus rattus) have been observed within the study area. A semi-permanent grid, as described in the methods, will be established at plot 3 in the near future. This segment of field surveys has been delayed until field team members were immunized against rabies, as it's a major reservoir for this disease in Puerto Rico (The Indian mongoose, Jerkel et.al., 1952).

Horizontal nets placed in the rain forest (plots 1 and 2, at the Sonadora suspension bridge, and near the field station) and a vertical net erected at the field station captured three species of bats: Artibeus jamaicensis, Stenoderma rufum, and Monophyllus redmani. All three species have previously been reported from the area (Tamsitt and Valdivieso, 1970). The first two species are frugivorous and the third is nectarivorous. Insectivorous species have not been observed in the rain forest, although some species (e.g. Pteronotus fuliginosa) may forage in openings and above the canopy.

6.0. PHASE I SCHEDULE

Field sampling began in July, 1980 following the selection of sample plots. In spite of the late starting date for some tasks, all phase I field work is scheduled for completion by August, 1981. A final status report which summarizes and integrates material from all tasks is scheduled for completion by September 30.

1981 - Due to the late start of some tasks, the submission of this report may be slightly delayed. An important part of the report will be an outline of projected phase II research, including continued investigations of key organisms and pathways, and an outline of planned experimental studies. Seminars and presentations based on work accomplished in phase 1 are scheduled to start by May 1981 following the completion of dry season field work. The workshop that was originally planned has been postponed indefinitely. It is anticipated that several scientific publications, based on individual task studies, will result from this phase. Manuscripts will be prepared simultaneously with the final report. Papers of a more integrative nature will be written immediately following the preparation of the final report and will be given priority over routine project work.

7.0 ORGANIZATION AND MANAGEMENT

The Terrestrial Ecology Division is a unit of the Center for Energy and Environment Research operated by the University of Puerto Rico for the Department of Energy. Field studies are conducted in the Caribbean National Forest from CEER's El Verde Field Station. Chemical analyses and other laboratory investigations are performed at the Terrestrial Ecology Division's facilities in Rio Piedras. The principal investigator is responsible for program coordination but also has specific task responsibilities. Each major task is supervised by a division scientist. A figure presents the overall program organization. Collective decisions are made regarding the program execution by all members of the scientific staff including the Terrestrial Ecology Division head, and Ecology Section Head. Ultimate responsibility within CER rests with the director of CEER Dr. Juan A. Bonnet, Jr. who responds directly to the President of the University of Puerto Rico, Dr. Ismael Almodovar.

Unfortunately, the text provided in the last paragraph is unclear and seems to be scrambled or encoded. Could you please provide a correct version of it?

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APPENDICES 63

Appendix: Calorimetry Data on Anolis Lizards. Species and Dry Roof calories per Sex Weight Ash ash-free gm.

Appendix: Carbon Analysis of Stream Samples Collected from Cara del Indio (On October 9, 1980, 10:47 AM, Flow Level: 2.82 USGS Units.)

Surface Bottom Carbon Concentration in mg/l Carbon Concentration in mg/l Organic Inorganic Organic Inorganic

Carbon Analysis of Stream Samples Collected from Cara del Indio on October 30, 1980, 10:45 AM. Flow Level: 4.46 USGS Units.

Surface Bottom"

Carbon Concentration in mg/l Carbon Concentration in mg/l Organic Inorganic Organic Inorganic F v r v F v Fou 5.24 8.7 353 362 5.46 8.56 3.57 3.58 6.08 8.66 3.56 3.56 5.25 9.62 3.28 3.46 3.38 8.00 3.58 3.46 5.76 8.50 3.60 3.69 4.71 1.19 3.66 5.50 8.18 3.65 3.80 5.08 8.75 3.85 3.49 5.46 8.35 3.90 3.85

Appendix 8 (Cont'd) Carbon Analysis of Stream Samples Collected from Cara del Indio on November 17, 1980, 11:00 AM. Flow Level: 270 USGS Units.

Surface Bottom Carbon Concentration in mg/l Carbon Concentration in mg/l Organic Inorganic organic Inorganic F v F v r v Fr v 0.806 1.142 5.80 5.89 0.573 0.808 5.41 5.23, 0.546 0.859 5.70 6.08 0.417 0.670 6.23 5.70 0.457 0.951 5.36 5.47 0.483 0.447 5.80 5.62. 0.561 0.717 5.73 6.05 0.460 0.473 5.64 5.72 0.569 0.616 5.82 3.73, 0.396 0.433 5.92 5.15

Carbon Analysis of Stream Samples Collected from Cara del Indio on November 25, 1980, 10:45 AM. Flow Level: Surface Bottom Carbon Concentration in mg/l Carbon Concentration in mg/l Organic Inorganic Organic Inorganic r v F v F v Y v 3.51 3.35 3.01 3.49 2.76 3.88 2.30 2.20 7.66 2.22 3.37 2.30 = = 8.87 10.62

Red-tailed Hawk Buteo jamaicensis
Ruddy Quail-Dove Geotrygon montana
Zenaida Dove Zenaida aurita
Red-necked Pigeon Columba squamosa
Puerto Rican Lizard Cuckoo Saurothera vieilloti
Puerto Rican Emerald Chlorostilbon maugaeus
Puerto Rican Tody Todus mexicanus
Puerto Rican Woodpecker Melanerpes portoricensis
Stolid Flycatcher Myiarchus stolidus
Pearly-eyed Thrasher Margarops fuscatus
Red-legged Thrush Turdus plumbeus
Puerto Rican Vireo Vireo latimeri
Black-whiskered Vireo Vireo altiloquus
Black-and-white Warbler Mniotilta varia
Louisiana Waterthrush Parkesia motacilla
Bananaquit Coereba flaveola
Blue-hooded Euphonia Euphonia musica
Stripe-headed Tanager Spindalis zena
Puerto Rican Tanager Nesospingus speculiferus
Puerto Rican Bullfinch Loxigilla portoricensis

Latin names according to Bond, Jane: Collins, London. 256 pp. 1979. Birds of the West Indies.

I'm sorry, but the text you've provided appears to be scrambled or encrypted. It's unreadable in its current form and cannot be corrected without knowing the original intended message.

Apologies, but the text provided is largely nonsensical and unrecognizable. It seems to contain random characters, symbols, and numbers. I would need more context or a clearer message to provide any meaningful assistance.