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PROGRESS REPORT

ECOLOGICAL BEHAVIOR AND EFFECTS OF ENERGY RELATED POLLUTANTS

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15 Month Report

June, 1976 - August, 1977

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Fiscal Year November 1, 1976 - October 31, 1977

CONTENTS: 15 MONTH REVIEW

H. L. Ragsdale is replacing Robert B. Platt as Principal Investigator for the next Fiscal Year. As such, he has had the primary responsibility for preparation of this progress report.

INTRODUCTION

This past year was the first of a three-year program commitment, and was also the twenty-first year of continuous AEC-ERDA support. Over these years, the program has undergone substantive changes with each 3-5 year period. This last has concentrated upon the behavior and effects of energy related pollutants and reflects the present day urgency for scientific as well as public information on the ecological aspects of energy related pollutants in the environment.

The accompanying renewal proposal for the next year is a continuation of our thrust toward energy related pollutants, such as SO_2, and away from our earlier studies which focused primarily on radioactive energy related pollutants. While the field and laboratory work with SO_2 has begun, all of field work associated with radioactive materials has been terminated and continuing analyses of the three year data base are leading to published papers.

In order to expedite the efforts of reviewers, we are submitting four kinds of information. First is a brief summary of accomplishments. Second is a listing of the materials prepared during this period which include 14 refereed publications, 17 published abstracts, 2 manuscripts submitted for publication, 6 other presentations, and 6 special reports, primarily for the nuclear industry. Third is a set of 17 abstracts of papers which were presented in 1976-77, 14 for the Ecological Society of America, one for the Health Physics Society of America, one for the Association of Southeastern Biologists, and one for a Limnology Symposium. Fourth is an evaluation for each of the sub-projects with brief summary presentations for the concluding sub-projects and longer, detailed reports for the non-radioactive pollutant sub-project in the renewal proposal.

All published materials during the 15-month period are included as part of this report.

BRIEF SUMMARY OF ACCOMPLISHMENTS

Our program had two primary thrusts for this year, the analysis of SO_2 effects on population, community, and ecosystem processes, and the publication and analysis of results from our earlier program on ^{137}Cs flux in the Lower Three Runs Creek Watershed. Since these studies are at different stages and deal with different energy related pollutants, the accomplishments are summarized separately below.

SO_2

This research was designed to assess the impact of SO_2 on the survival and stability of plant populations and communities. The results to date have an important bearing on the adequacy of current permissible ambient air levels for SO_2.

1) Atmospheric SO_2 concentrations at near permissible levels have a significant adverse effect on sexual reproduction processes, which results in a reduced number of viable seeds, in all 8 populations tested.
2) Although all plant populations were adversely affected, populations of Lepidium collected from the highly stressed, SO_2 environment of the Copper Basin were less affected (greater number of viable seed) than those Leipdium populations collected from environments outside the Copper Basin.
3) Fertility, as measured for the Geranium populations collected from outside the SO_2-stressed Copper Basin, decreased dramatically between 0.6 and 0.8 ppm SO_2 (9 hours) and adverse effects were produced from fumigations one and two days after flowering.

The doses we used are near-permissible levels and our results showed lethality in the critical sexual reproductive phase of the life cycle of these plant populations. Similar effects occurred in plants with and without visible leaf damage. Hence, we describe our near-permissible SO_2 concentration doses as "lethal" with "invisible" effects. Such lethal effects may not be detected as leaf damage or as metabolic rate alterations but could be observed in agricultural fruit harvest and through assessments of fruit viability in studies such as we have conducted.

Implications of the observed reduction in number of offspring are, that some local populations are forced to undergo an evolutionary change (adaptation to SO_2 stress) and those not able to adapt are diminished in importance or eliminated altogether. This latter significance is of concern for both natural and agricultural plant populations. For example, few of the agricultural plant species undergo natural selection at a given site and we could continually suffer significant losses of fruit production without a compensating adaptation to the SO_2 stress.

There is also an ecological implication of the "invisible effect" of fruit and seed mortality. The life cycle of many insects and the trophic relations of numerous animals depend, at least in part, on fruit production by trees and shrubs. Hence, there is a potential for disruptive effects on ecosystem level processes.

Lower Three Runs Creek Watershed

Our 1973 paper, Floodplain Transfer and Accumulation of ^{137}Cs, based on our earlier surveys of Lower Three Runs Creek (SRP) led to the definition of four systems-oriented studies within the Lower Three Runs Creek Watershed to examine ^{137}Cs transfer processes in ecological systems characteristic of the Southeastern Coastal Plain. We have carried out these studies within the stream and its floodplains, within floodplains along the stream gradient, in upland aquatic systems (Carolina Bays), and in the upland scrub-oak forest system.

Our initial hypotheses regarding the Lower Three Runs Creek Floodplain System are intact and have been extended and refined through these studies. Additionally, specific mechanisms of stream-floodplain material exchange and within floodplain material cycling have been documented and quantified. The documentation of 12% of the fallout ^{137}Cs in the above ground biomass of the upland scrub-oak forest was related to high ^{137}Cs uptake by the root system coupled with slow release of ^{137}Cs in the organic layer of the sandy soils. Although our conclusions remain tentative until the final data have been synthesized, we have found both high and low bioaccumulation in ecosystems throughout this watershed. The bioaccumulation and retention of ^{137}Cs appears to relate strongly to the soil parameters, potassium availability, and the specific microtopographic features of a given landscape system. These systems parameters and the processes of material transport within and through such watersheds are a function of this coastal plain land region.

PERSONNEL

Personnel directly contributing to the program are listed below. Those receiving personal support from this contract are marked with an asterisk. All personnel share in our basic facilities, as we share in those of other departments, particularly Geology, Biometry, and Physics.

*Dr. Harvey L. Ragsdale, Principal Investigator, Systems Ecology
*Dr. Robert B. Platt, Professor of Biology, Systems Ecology
*Dr. W. H. Murdy, Professor of Biology, Biosystematics
*Dr. D. J. Shure, Associate Professor, Systems Ecology and Animal Ecology
*Dr. George E. Taylor, Jr., Assistant Professor of Biology, Population Genetics
*Mrs. Agnes Hargrove, Research Assistant
*Marlin Gottschalk, Graduate Student Research Assistant
*Dennis Creech, Graduate Student Research Assistant
Dr. W. D. Burbanck, Faculty Advisor, Animal Ecology
Dr. Willard Grant, Faculty Advisor, Geochemistry
Dr. . H. Rohrer, Faculty Advisor, Radiation Physics
Dr. Wm. A. Rhoads, Colleague, Nevada Test Site Program
Dr. John M. Palms, Faculty Advisor, Radiation Dosimetry
Dr. Paul G. Mayer, Hydrology, Georgia Institute of Technology
Dr. Charles Ray, Faculty Advisor, Population Genetics
Dr. Buell Evans, Faculty Advisor, Director of Computing Center
Dr. Elmer Hall, Faculty Advisor, Chairman of Biometry & Statistics
Albert L. Tate, Graduate Student
John Schalles, Doctoral Student
Wendell Cropper, Doctoral Student
John Hay, Doctoral Student
John Gladden, Doctoral Student
R. N. Coleman, Nuclear Instrumentation
John Croom, Doctoral Student
B. K. Tanner, Sample Processing and Analysis

INTERACTION WITH OTHER LABORATORIES, GOVERNMENT AGENCIES AND INDUSTRY

Six years ago a close continuing relationship was established with Georgia Power Company, in connection with their proposed nuclear reactor on the Altamaha River at Baxley, Georgia. During this time we have had several joint conferences with personnel from Georgia Power Company and its parent company, Southern Services, and Emory University. This relationship has continued.

In 1969, a close working relationship was established with Allied-General Nuclear Services, by a consulting agreement in which our personnel agreed to assume primary responsibility for the development and implementation of an environmental monitoring program for their nuclear fuel reprocessing plant, now constructed adjacent to the Savannah River Plant at Barnwell, South Carolina. This has been a particularly fruitful relationship, for it has provided us an opportunity to develop monitoring procedures from ecological perspective and to test the applicability of an ecological approach to such problems. Our program is primarily based on a change from monitoring systems of the past which concentrated on direct food chains to man to an ecological approach based on the distribution and fate of radionuclides and their ecological effects through terrestrial, aquatic and atmospheric pathways. The association with Allied-General Nuclear Services resulted in a new relationship with the Savannah River Plant and its numerous research and technical sections. This association also contributed significantly to the development of our research program along Lower Three Runs Creek on the Savannah River Plant site.

Through our own activities among the departments of Physics, Geology, Biometry and Biology, as well as through associations with industry, close working relationships have been developed with the following state and federal laboratories, regulating agencies, and academic institutions.

- The Southwest Research Institute
- ERDA Savannah River Operations Office and Laboratory
- ERDA Savannah River Plant Contractor, E. I. duPont Nemours and Company
- ERDA Savannah River Ecology Laboratory
- U. S. Geological Survey
- U. S. Army Corp of Engineers
- U. S. Environmental Protection Agency
- Georgia Institute of Technology
- The Boyce Thompson Institute of Plant Research, Inc.
- The University of Miami School of Marine and Atmospheric Sciences
- U. S. ERDA Lawrence Livermore Laboratory
- New York Operations Office Health and Safety Laboratory
- U. S. ERDA Battelle Pacific Northwest Laboratory
- U. S. ERDA Oak Ridge National Laboratory
- Regulating Agencies within the state of Georgia and of South Carolina
- EPA's National Air Pollution Laboratory

PUBLIC INFORMATION

We are continuing to bring informed ecological analyses of energy related pollutants to the public. This has included presentations to state and federal regulatory agencies through special seminars and legislative hearings; seminars and talks to citizens groups, schools and laboratories; participation in planned forums between industry and academia; and appropriate news releases.

Public service activities by the investigators in the area of conservation have included work with the Highway Department, State Parks Department, U. S. Forest Service, Council on Environmental Quality, and the Advisory Council on Science and Technology.

TRAINING ACTIVITIES

Training activities have been much broader than those reflected in the list of publications, as well as by the very few graduate student research assistantships provided by the ERDA contract. Approximately 12 to 15 graduate students (half of our graduate students) are in the ecology program. However, most of their tuition and stipend support has come from other sources. Those doctoral students who have been closely associated with the ERDA contract have been particularly successful in finding professional positions commensurate with their career goals. For example, one has become an ecologist with Texas Instruments Environmental Divivion, one has accepted a 1-3 year appointment as visiting professor of Biology at The Federal University, Rio de Janeiro, Brazil, and a third has accepted a National Research Council and EPA "Research Associate Fellowship" to pursue SO_2 - plant physiology studies at the EPA National Ecological Research Laboratory in Corvallis, Oregon. These three students are broadly dispersed into responsible and meaningful positions in our society where their training and experience from our ERDA supported research will be fully utilized.

During recent years we have held a weekly interdisciplinary seminar among graduate students and faculty of several departments.

This has involved presentation and analyses of faculty and graduate student research, visits by guest investigators from other laboratories and universities for one to three days, systematic studies of pertinent new monographs and areas of study, and throughout a particular emphasis on the interaction between ecology and the problems arising from man's activities. The orientation is always on how to utilize the unique responsibility of the university to conduct basic research, and the needs of the society which require solutions to specific problems.

I. REFEREED PAPERS

1976. Ragsdale, H. L., R. N. Coleman, B. K. Tanner, and J. M. Palms. In Situ Analysis of Gamma-Emitting Radionuclides in Southeastern Ecosystems. Tenth Mid-year Topical Symposium. Natural Radioactivity in Man's Environment. The Health Physics Society, Northeastern New York Chapter. October 11-13, 1976. Saratoga Springs, N. Y. p. 477-487. Rensselaer Polytechnic Institute. Troy, New York 12181.

1976. Shure, D. J. and M. R. Gottschalk. Cesium-137 dynamics within a reactor effluent stream in South Carolina, p. 234-241. In Radioecology and Energy Resources, C. E. Cushing, Jr. (ed.). Dowden, Hutchinson and Ross, Inc. (Ecological Society of America, Special Publication #1).

1976. Platt, R. B., J. M. Palms, H. L. Ragsdale, D. J. Shure and P. G. Mayer. The interpretative role of ecological concepts in radiological monitoring, p. 2-17. In The Utilization and Interpretation of Environmental Radiation Data. NRC and EPA publication volume.

1976. Schalles, John F., and Thomas E. Wissing. Effect of dry pellet diets on the metabolic rates of bluegill (*Lepomis macrochirus*). Journal of Fisheries Research Board of Canada 33: 2443-2449.

1977. Platt, R. B., J. M. Palms, H. L. Ragsdale, D. J. Shure, Emory University; and P. G. Mayer, Georgia Institute of Technology. The Interpretive Role of Ecological Concepts In Radiological Monitoring. Published in EPA and ERDA proceedings: The Utilization and Interpretation of Environmental Radiation Data. March 1-3, 1976. Orlando, Florida.

1977. Hay, J. LuVall and Harvey L. Ragsdale. Patterns of ^{137}Cs Distribution Across Two Disparate Flood Plains. Environmental Chemistry and Cycling Processes Symposium. SREL. April 28-30, 1976. (in press)

1977. Croom, John and H. L. Ragsdale. ^{134}Cs Dynamics in Untreated and Poisoned Turkey Oak Leaf Litter Bags. Environmental Chemical and Cycling Process Symposium. SREL, April 28-30, 1976. (in press)

1977. Ragsdale, Harvey L., B. K. Tanner, R. N. Coleman, and J. M. Palms. In Situ Measurements of The Gamma Radiation Fields in Scrub-Oak and Old Field Ecosystems of the Southeastern Coastal Plain. Environmental Chemistry and Cycling Processes Symposium, April 28-30, 1976, Savannah River Ecology Laboratory. (in press)

1977. Coleman, R. N., J. M. Palms, O. H. Puckett, B. K. Tanner, R. E. Wood, and H. L. Ragsdale. A Technique for In Situ Measurement of the Natural Radiation Field and the Associated Dose Exposure Rate in the Southeastern United States. Environmental Chemistry and Cycling Processes Symposium. April 28-30, 1976. Savannah River Ecology Laboratory. (in press)

1977. Harwell, Mark A., Wendall P. Cropper, Jr., and Harvey L. Ragsdale. Nutrient Recycling and Stability: A Reevaluation. *Ecology* 58:660-666.

1977. Shure, Donal J., and Harvey L. Ragsdale. Patterns of Primary Succession on Granite Outcrop Surfaces. *Ecology* (in press).

1977. Shure, D. J. and M. R. Gottschalk. Radiocesium transfer through aerial pathways in a South Carolina floodplain forest. *IN* Environmental Chemistry and Cycling Processes, D. C. Adriano and I. L. Brisbin, Jr. (eds.). ERDA Publication Series (in press).

1977. Lund, A. C. and W. H. Murdy. Ethnobotany of Urban Plants of Atlanta, Georgia. Bull. Ga. Acad. Sci. 35:24-41.

II ABSTRACTS

1976. Creech, D. B. and H. L. Ragsdale. Urban Forest Lead Dynamics. Emory University, Atlanta, Georgia. AIBS: May, 1976.

1976. Hay, J. DuVall and Harvey L. Ragsdale. Accumulation of ^{137}Cs in Forested Floodplains by Basidiomycetes. Bull. Ecol. Soc. Amer. AIBS: May, 1976.

1976. Ragsdale, H. L., R. N. Coleman, B. K. Tanner, and J. M. Palms. In Situ Analysis of Gamma-Emitting Radionuclides in Southeastern Ecosystems. Tenth Mid-year Topical Symposium. Natural Radioactivity in Man's Environment. The Health Physics Society, October 10-13, Saratoga Springs, N. Y.

1976. Shure, D. J. and M. R. Gottschalk. Vegetation analysis and litter dynamics in a South Carolina floodplain forest. Bull. Ecol. Soc. Am. 57:52 (Presented at AIBS meeting).

1976. Langley, A. K. Jr. and D. J. Shure. The Influence of Loblolly Pine Plantations on Small Mammal Populations. Bull. Ecol. Soc. Am. 57:29 (Presented at AIBS meeting).

1976. Gladden, J. B., S. L. Bell, and D. J. Shure. Population and Radiocesium Dynamics of Anurans in a Contaminated Floodplain Forest in South Carolina. Bull. Ecol. Soc. Am. 57:20-21. (Presented at AIBS meeting).

1976. Schalles, J. F. and D. J. Shure. Limnology of Carolina Bays of the Savannah River Plant area in South Carolina. Presented at Amer. Soc. of Limno. and Ocean. Meetings in Savannah, Georgia.

1977. Croom, J. M. and H. L. Ragsdale. Structure and Production in a Sandhills Turkey Oak (Quercus laevis) Community. Bull. Ecol. Soc. Amer. 58:56.

1977. Croom, J. M. and H. L. Ragsdale. Root Uptake of ^{134}Cs and ^{137}Cs Burden in Turkey Oaks (Quercus laevis). Bull. Ecol. Soc. Amer. 58:56.

1977. Cropper, W. P., Jr., and H. L. Ragsdale. Lead Distribution in Canopy Tissues of Ailanthus altissima. Bull. Ecol. Soc. Amer. 58:8.

1977. Harwell, Mark A., Wendell P. Cropper, Jr. and Harvey L. Ragsdale. Stability Analysis of Linear Nutrient Cycling Models. AIBS Meeting, East Lansing, Michigan. Bull. Ecol. Soc. Amer. 58:50.

1977. Taylor, G. E., Jr. Physiological Factors Affecting Leaf Susceptibility to Sulfur Dioxide. Abstract published and paper presented at the ASB meeting. ASB Bull. 24:89.

1977. Gladden, J. B. and D.J. Shure. Patterns of variation in production and structure of an emergent macrophyte community. Bull. Ecol. Soc. Am. 58:21. (Presented at AIBS meeting).

1977. Gottschalk, M. R. and D. J. Shure. Soil Characteristics and Plant Community Structure Across the Floodplain of a Southeastern Coastal Plain Stream. Bull. Ecol. Soc. Am. 58:21 (Presented at AIBS meeting).

1977. Schalles, J. F. and D. J. Shure. Primary Production in a Shallow Carolina Bay Pond at the Savannah River Plant, South Carolina. Bull. Ecol. Soc. Am. 58:27-28. (Presented at AIBS meeting).

1977. Gladden, J. B. Annual Changes in Chemical and Structural Parameters of Stream Margin Soils. Bull. Ecol. Soc. Am. 58:20 (Presented at AIBS Meeting).

1977. Schalles, John F. and Donald J. Shure. Water chemistry and primary producer dynamics in a Carolina Bay pond. Workshop in Aquatic Ecology in the Southeast, Southeastern Section of the Ecological Society of America. Augusta College, Augusta, GA. October 14-15.

III MANUSCRIPTS SUBMITTED FOR PUBLICATION

1977. Harwell, Mark A., Wendell P. Cropper, Jr. and Harvey L. Ragsdale. Analyses of Transient Characteristics of a Nutrient Cycling Model. (Submitted to Ecology).

1977. Taylor, G. E. Jr. An Organizational Framework for the Analysis of the Response of Foliage to Sulfur Dioxide Stress. (Submitted to Phytopathology).

IV PRESENTATIONS NOT OTHERWISE REPRESENTED

1977. Ragsdale, Harvey L. The Emory Program of Ecological Research. A presentation at The First Annual Topical Meeting on Savannah River Environmental Programs. May 3-5, 1977. Aiken, South Carolina.

1977. Shure, D. J. Ecological Impact of Small Mammals. A book review in BioScience 27:128.

1977. Ragsdale, Harvey L. In Situ Measurement of Gamma-Emitters in Southeastern Coastal Plain Ecosystems. Seminar presented to School of Biology, Georgia Institute of Technology, Atlanta, GA.

1977. Ragsdale, Harvey L. Biological and Ecological Aspects of Nuclear Facilities. Seminar presented at the School of Nuclear Engineering, Georgia Institute of Technology, Atlanta, GA.

1977. Ragsdale, Harvey L. Lead in Urban Atlanta, Georgia,Forests and Trees. Seminar presented at Fernbank Science Center, Atlanta, GA.

1977. Murdy, W. H. Environmental Ethics Seminar at Fernbank Science Center, Atlanta, GA. Jointly sponsored by AAAS and Fernbank Science Center.

V. REPORTS

1976. Mayer, P. G., J. M. Palms, R. B. Platt, H. L. Ragsdale, and D. J. Shure. The Environmental Monitoring Program for the Allied-Gulf Nuclear Fuel Reprocessing Plant: Interpretation of Environmental Data for the Period from June 1, 1975 to May 31, 1976. EMP-113, Addendum III.

1976. Mayer, P. G., J. M. Palms, R. B. Platt, H. L. Ragsdale, and D. J. Shure. Environmental Radiological Monitoring, Operational Phase, Compliance Sampling Program for the Barnwell Nuclear Fuel Plant. EMP-116, Addendum I, Revision II.

1977. Ragsdale, H. L. and A. J. Ruttenber. Fluoride Concentrations in Vegetation and Soil Around the Barnwell Nuclear Fuel Plant. EMP-105, Addendum I. 41 p.

1977. Ragsdale, H. L., B. T. Ragsdale, J. D. Hay, and M. A. Harwell. The BWELL System computerized storage, retrieval, and reporting of environmental data. EMP-130. 136 p.

1976-77 Mayer, P. G., R. B. Platt, J. M. Palms, H. L. Ragsdale, and D. J. Shure. Sample Processing and Analysis Reports 9, 10, and 11 for the Barnwell Nuclear Fuel Plant.

1977. Coleman, R. N., J. M. Palms, H. L. Ragsdale, B. K. Tanner, and R. L. Wood. In Situ spectrometric analysis of gamma-emitting nuclides of the natural radiation and fallout field and the associated dose exposure rates in the vicinity of BNFP. EMP-112, Addendum 2.

ABSTRACTS FOR 17 PAPERS

PRESENTED JUNE, 1976 - SEPTEMBER, 1977

NOTE: These abstracts correspond with the Abstract Titles in Section II of the comprehensive listing of publications.

CREECH, DENNIS B. AND HARVEY L. RAGSDALE. EMORY UNIVERSITY, ATLANTA, GEORGIA, Urban Forest Lead Dynamics.

Quantitative lead burdens for the soil, selected vegetation, and litter compartments of an urban forest ecosystem were documented. Total soil lead showed an inverse relationship with soil depth and distance from an adjacent roadway. Exchangeable soil lead was also measured. Lead accumulations over distance and time (May through September, 1974) for both understory (*Carya tomentosa* Nutt.) and upper canopy (*Quercus rubra* L.) trees were determined for branch and leaf tissues. Rates of litter decomposition and lead loss were estimated over a 12 month period for leaves of the same tree species.

Bull. Ecol. Soc. Amer. 57:22. 1976.

HAY, J. DUVALL AND HARVEY L. RAGSDALE, Emory University, Atlanta, GA

Accumulation of ^{137}Cs in forested floodplains by basidiomycetes.

Basidiomycete samples and their associated substrate were collected from an upstream and a downstream location of Lower Three Runs Creek, a radioactively contaminated Upper Coastal Plain stream draining a portion of the Savannah River Plant, near Aiken, SC. The results showed that the upstream site had 10X higher concentration of ^{137}Cs. Upstream values ranged from 18 to 14,000 pCi/g-d, mean 1052± 190; while the downstream range was 3 to 4,700 pCi/g-d, mean 108± 39. The uptake ratios were similar between sites, 1.5 to 52X upstream and 1.2 to 45X downstream.

Bull. Ecol. Soc. Amer. 57:21. 1976.

Paper No. 027A

In Situ Analysis of Gamma-Emitting Radionuclides in Southeastern Ecosystems

H. L. Ragsdale,* R. N. Coleman,
B. K. Tanner, and J. M. Palms

Departments of Biology* and Physics
Emory University, Atlanta, GA 30322

ABSTRACT

In situ and laboratory gamma-ray spectroscopy measurements were taken in 34 locations, primarily scrub oak forests and old fields, in the South Carolina Coastal Plain. Generally there was good to excellent agreement between laboratory and *in situ* results and forests were juuged to be superior *in situ* sampling systems. We conclude that *in situ* technology applied to forested regions can provide accurate results. In addition, we conclude that *in situ* methodology may be used in a precise manner to provide early warning of low level gamma-emitter increases in the natural environment.

10th Mid-Year Topical Symposium. Natural Radioactivity in Man's Environment. The Health Physics Society.

SHURE, DONALD J. and MARLIN R. GOTTSCHALK, Emory University, Atlanta, Georgia,
Vegetation analysis and litter dynamics in a South Carolina flood plain forest.

Flood plain forest composition and litter dynamics were analyzed in a 1.5 ha area along a reactor effluent stream in South Carolina. Phytosociological studies indicated that ash is the dominant flood plain species. Willow is also important along the stream bank and sweetgum, blackgum and red maple remain subdominant species from bank to upland terrace. Water oak is dominant on the upland terrace. Annual litterfall (600-800 $g/m^2/yr$) patterns are somewhat varied in different topographical locations. Litter decomposition is very rapid within flood plain areas and habitat, species and yearly decomposition rates are strongly influenced by seasonal flooding processes.

Bull. Ecol. Soc. Am. 57:52. 1976.

LANGLEY ALBERT K., JR. and DONALD J. SHURE, Emory University Atlanta, Georgia. The Influence of Loblolly Pine Plantations on Small Mammal Populations.

Small mammal populations were analyzed over a yearly cycle in four contrasting but similar-aged habitats of the Georgia Piedmont. An abandoned pasture and a broomsedge field were sampled monthly in conjunction with similar habitats containing Loblolly pines which were planted at the time of abandonment. Cotton rats (<u>Sigmodon hispidus</u>) were the only small mammal species captured. Population densities were significantly greater and population composition remained more stable in the natural versus managed habitats. Discriminant function analysis was employed to determine habitat variables accounting for population differences. Significant variables included foliage height diversity, plant biomass and litter.

Projection equipment needed - 2 x 2 slide projector

Time requested - 20 minutes

Mailing address - Albert K. Langley, Jr.
Biology Dept.
Emory University
Atlanta, Georgia 30322

Poster session not requested

Bull. Ecol. Soc. Am. 57:29
(Presented at AIBS Meeting)

GLADDEN, J.B., S.L. BELL AND D.J. SHURE, Emory University, Atlanta, Population and radiocesium dynamics of anurans in a contaminated floodplain forest in South Carolina.

The radiocesium dynamics of anuran populations were analyzed in a contaminated floodplain forest system in South Carolina. Population analyses using mark-recapture techniques indicated that *Rana pipiens* and *R. clamitans* were the major species while *R. catesbiana* was lower in numbers and biomass. *Rana clamitans* populations had the highest mean 137-Cs concentrations (36 pCi/g-d). Radiocesium variations in anurans showed little correlation with organism size, topographic location, or season. Laboratory studies suggested a 3 week biological half-life of radiocesium in these anurans. Radiocesium flux through the field population was estimated from these data.

Bull. Ecol. Soc. Am. 57: 20-21, 1976.

LIMNOLOGY OF CAROLINA BAYS OF THE SAVANNAH RIVER PLANT AREA IN SOUTH CAROLINA. J. F. Schalles and D. J. Shure, Emory University, Atlanta, Georgia.

Carolina Bays occur as topographically constrained, shallow upland depressions throughout the coastal plain of Georgia and the Carolinas. Comparative limnological studies were performed in six Carolina Bay ponds of the upper coastal plain in Barnwell County, South Carolina. Major limnological parameters, including cation analysis, were measured at six permanent stations in each pond every two months to enable spatial and temporal comparisons over an annual cycle. A more comprehensive ecosystem analysis is underway in one of these systems.

Macrophytic communities within these systems exert a strong influence over physical and chemical phenomena. Although the waters are quite soft (normal TDS < 20 ppm), acidic pH's (normal range of 4-5) are very constant seasonally and appear to be regulated biologically. Concentrations of dissolved materials are variable and are most strongly correlated with water level fluctuation. Herbaceous vegetation cover greatly restricts physical mixing, and striking O_2 and temperature stratifications are frequently observed in these shallow waters (maximum sampling depth 1.3m). Two of the Carolina Bays have been perturbed by adjacent construction activities and offer good contrasts with undisturbed sites. Higher TDS levels and pH's and lower DOM levels are found in the disturbed areas.

Published in: Program of the Thirty-ninth Annual Meeting, American Society of Limnology and Oceanography, Inc 1976

CROOM, J. M., and H. L. RAGSDALE, Texas Instruments, Buchanan, N. Y., and Emory University, Atlanta, GA. Structure and production in a sandhills turkey oak (Quercus laevis) community.

Community structure and soil description for a sandhills turkey oak community in the coastal plain of South Carolina are presented along with analysis of growth and production of turkey oaks, the community dominant. Thirteen species of trees and shrubs have been identified from this sandy, nutrient poor system; 93% of the stems are turkey oak. Unit-area estimates of turkey oak wood and leaf components, net turkey oak wood production, leaf litter composition by species and standing litter are presented. A brief discussion of ecosystem strategy is developed from community structure and production.

Bull. Ecol. Soc. Amer. 58:56

CROOM, J. M., and H. L. RAGSDALE, Texas Instruments, Buchanan, N.Y., and Emory University, Atlanta, GA. Root Uptake of ^{134}Cs and ^{137}Cs Burden in Turkey Oaks (Quercus laevis).

Bioaccumulation of radio-cesium in southeastern U. S. ecosystems has received much attention. Low clay content and cation exchange capacity of soils increased availability of radio-cesium for plant uptake. A soil plot in a sandhills turkey oak community was tagged with 25 nCi cm^2 of ^{134}Cs in spring. Stratified soil samples and vegetation samples were taken during the growing season. Samples for ^{137}Cs in soil and vegetation were taken away from the tag area. In September, 92.5% of the tag was in the 0-5 cm soil layer, 5% below 5 cm and 2.5% in above ground plant tissues. Comparisons are made between unit-area soil and vegetation burdens of ^{137}Cs and ^{134}Cs tags.

Bull. Ecol. Soc. Amer. 58:56

Cropper, W. P., and H. L. Ragsdale. Emory University, Atlanta, GA.
Lead Distribution in Canopy Tissues of *Ailanthus altissima*.

The concentrations of lead in leaf and branch tissues of 13 *Ailanthus altissima* trees, collected in Atlanta, Georgia, were measured during the 1975 growing season. Lead determinations were made by AAS, and background absorption measurements and lead additions indicated no significant matrix interference. Lead in exposed leaflet and bark samples was highly concentrated (up to 180 micro-g Pb/ g dry wt), and highly variable. Lead in composited wood samples ranged from 0.48 to 4.42 ppm. Phloem lead concentrations, 1.00 to 10.27 ppm, were generally greater than those of wood samples from the same branches.

Bull. Ecol. Soc. Am. 58:8 (Presented at AIBS Meeting)

HARWELL, MARK A., WENDELL P. CROPPER, JR., and HARVEY L. RAGSDALE, Emory University, Atlanta, GA. Stability analysis of linear nutrient cycling models.

Relative stability analyses of linear, donor controlled ecosystem nutrient cycling models have been equated to analyses of the parameters of the second order damped oscillation equation. However, direct experimental perturbations of the models and the second order approximation show that the terms said to measure the resistance and resilience components (ω and ζ respectively) do not reflect the actual response of either stability component. Ecosystem resilience and resistance rankings based on the linear models are assigned according to observed temporal response.

Bull. Ecol. Soc. Am. 58:50

TAYLOR, G. E. JR., Emory University, Atlanta, GA. Physiological Factors Affecting Leaf Susceptibility to Sulfur Dioxide.

The study of plant response to sulfur dioxide has experienced a shift in emphasis from descriptive symptomology to physiological explanations and ecological ramifications. Physiological investigations of sulfur dioxide-induced morbidity have focused on the primary and secondary sites of altered leaf metabolism and structure. These studies range from organismal physiology-transpiration, respiration and photosynthesis, to biochemistry of membrane integrity and enzyme activity, and each has provided insight to how sulfur dioxide effects chronic and acute leaf damage. This report attempts to provide an organizational framework for these diverse investigations by utilizing Levitt's revision (1972) of the stress phenomenon in plants. The result is a logical scheme of alternative factors mediating the response of plant foliage to sulfur dioxide.

ASB Bull. 24:89

Gladden, J.B. and D.J. Shure, Emory University, Atlanta, Ga.,
Patterns of variation in production and structure of an emergent macrophyte community.

Biomass and morphological changes were monitored in a stream margin emergent macrophyte community over a five year period. Earlier augmentation of stream discharge in this reactor effluent stream modified stream morphology and currently the vegetation community reflects a successional mosaic with Polygonum spp. in areas most frequently inundated. Peak Polygonum biomass and community area normally occur in late summer or fall. However, peak standing crop and community area varied as much as 50% over 5 years. The annual patterns of biomass increase, peak standing crop and community area were all modified by annual variations on stream discharge.

Eqioment needed: 2 x 2 slide projector

Time requested: 20 minutes

Mailing address: John B. Gladden
Biology Department
Emory University
Atlanta, Georgia 30322

Poster session: opposed

Bull. Ecol. Soc. Am. 58:21

(Presented at AIBS Meeting)

GOTTSCHALK, MARLIN R. and DONALD J. SHURE, Emory University, Atlanta, Georgia, Soil characteristics and plant community structure across the floodplain of a Southeastern Coastal Plain stream

Soil samples were collected across the floodplain of a South Carolina stream to determine which edaphic properties were associated with changes in plant community structure. Significant differences existed in exchangeable Ca-Mg-K-Na, cation exchange capacity (CEC), % organic matter, particle-size distribution and Cs-137 content at different depths within the soil and at different distances from the stream. Nutrient cations, CEC and Cs-137 distribution were correlated with percent silt-sized particles and organic matter. Micro-topography and stream history were quite significant in soil-type distribution.

Equipment needed: 2x2 slide projector

Time requested: 20 minutes

Mailing address: Department of Biology
Emory University
Atlanta, Georgia
30322

Poster session opposed

Bull. Ecol. Soc. Am. 58:21

(Presented at AIBS Meeting)

SCHALLES, JOHN F. and DONALD J. SHURE, Emory University, Atlanta, Ga., Primary production in a shallow Carolina Bay pond at the Savannah River Plant, S.C.

Above-ground macrophyte biomass in a softwater, acidic Carolina Bay pond averaged 120 g dry wt/m^2 during 1975 and 1976. Root to stem-leaf ratios varied from 3:1 in September to 10:1 in February. Mean periphyton biomass was 29 mg Chl a/m^2 (range 19 - 35). Chlorophyll extractions revealed an unexpectedly large fraction of photosynthetic bacteria (average biomass of 17.5 mg Bact Chl a/m^2 from provisional equations). Annual macrophyte net production estimates were 140 and 120 g dry wt/m^2 for stem-leaf and root components. Results of two completed diurnal oxygen curves during late growing season yielded mean gross primary periphyton production and community respiration rates of 8.4 and 10.2 g O_2/m^2/day.

Equipment needed: 2 X 2 slide projector

Time period requested: 20 minutes

Poster session: opposed

Mailing address: John F. Schalles, Department of Biology,
Emory University, Atlanta, Ga. 30322

Bull. Ecol. Soc. Am. 58:27-28

(Presented at AIBS Meeting)

Gladden, J.B., Emory University, Atlanta, Ga., Annual changes in chemical and structural parameters of stream margin soils.

Soils were collected quarterly from stream margin communities along a reactor effluent stream in South Carolina. Soils were analyzed for particle size, organic matter, cation exchange capacity, pH, 137-Cs and exchangeagle cations (137-Cs, K, Na, Mg, Ca). Significant correlations occurred among all soil cations. Highest correlations occurred among cations and parameters related to the soil cation exchange complex (cation exchange capacity, silt, organic matter). Cation concentrations and cation exchange capacity were highest in late Fall and decreased through the following growing season.

Equipment needed: 2 x 2 slide projector

Time requested: 20 minutes

Mailing address: John B. Gladden
Biology Department
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Atlanta, Georgia 30322

Poster session: opposed

Bull. Ecol. Soc. Am. 58:20

(Presented at AIBS Meeting)

Water chemistry and primary producer dynamics in a Carolina Bay pond. (John F. Schalles and Donald J. Shure, Emory University, Atlanta, Ga.)

Carolina Bays contain the only abundant natural lentic systems of the coastal plain of Georgia and the Carolinas. These systems afford a number of interrelated problems concerning their origin, ecological history, hydrology, community structure, and productivity. We have intensively studied the major components of an undisturbed, shallow 6 ha Carolina Bay pond at the Savannah River Plant, S.C. Water chemistry resembles that reported for other softwater, acid systems in the region. Macrophytes make the greatest contribution to primary production (NPP of roots and shoots 360 mg C/m^2/day). Calculations from 4 sets of diurnal oxygen curves yield a mean periphyton NPP of about 160 mg C/m^2/day. Photosynthetic bacteria apparently maintain a biomass that could support production at least equivalent to the algal fraction.

Workshop in Aquatic Ecology in the Southeast. Sponsored by the Southeastern Section of the Ecological society of America. Augusta College, Augusta, Ga. Oct. 14-15, 1977.

PROGRESS REPORT

SUB-PROJECT I. The Distribution and Movement of Radionuclides in Southeastern Coastal Plain Ecosystems

SUB-PROJECT I-A Radiocesium Cycling in the LTRC Floodplain Forest

D. J. Shure and M. R. Gottschalk

INTRODUCTION

The major objective of this study has been to quantify the pathways of ^{137}Cs cycling within the Lower Three Runs Creek (LTRC) floodplain forest at Donora Station. Radiocesium additions to LTRC during earlier production reactor operations were partially redistributed along contiguous floodplain areas. Thus, we have been interested in determining the amount of ^{137}Cs within different floodplain components and the percentage of ^{137}Cs cycled annually between various compartments. This information should enable an assessment of the role of particular pathways in long-term radiocesium cycling within the LTRC watershed.

METHODS

Studies have continued since August 1973 within a 1.5-ha area of floodplain forest along LTRC at Donora Station (Fig. 1). Sampling has largely been conducted parallel to LTRC at the bank, 30m, 60m and 90m (upland terrace) transects. Earlier studies (1973-1975) involved a unit-area assessment of ^{137}Cs levels in soil, litter-humus, and feeder-root compartments. The existing vegetation was analyzed at each transect and grab samples of leaves and branches were obtained at several intervals over the growing season to determine

^{137}Cs concentration in major plant species compartments. Efforts have been proceeding to determine the unit-area burdens in the vegetation at each transect and their annual fluctuation over a 4-year period.

Aerial pathways have been studied in detail to assess their importance in overall ^{137}Cs dynamics in the floodplain system. Polyurethane collars were established on twelve ash trees of varying size for stemflow collections. Throughfall collectors were set up (6/transect) at bank 30m, 60m, 90m and control (open-clearing) locations. Precipitation studies were initiated in the spring of 1974 and stemflow and throughfall samples have been collected at monthly intervals thereafter. Litterfall collections were initiated in September 1973 with samples obtained from 12 litter traps (0.25m^2 hoops) at each of the bank, 30m, 60m and upland transects. Litterfall was collected monthly (every two weeks during the Fall) from all traps, separated into species components, and biomass and ^{137}Cs content determined. Litterfall collections were used in litterbag studies of mixed (1974) and major species (1975) decomposition rates at each transect.

Additional studies have been aimed at determining the inflow and outflow of particulate matter and ^{137}Cs within the study area. Drift traps were positioned at input and outflow channels along the floodplain and large particulate organic matter periodically obtained during annual flooding. Paddle wheel samples were also positioned within the input-output channels to monitor fine particulate matter and sedimentation dynamics. Extensive soil sampling was also conducted during the summer of 1976 to determine the physical and chemical properties of the soil and their potential importance in sedimentation and recycling processes. A detailed topographic survey was also made in order to assess the relationships between flooding frequencies and existing soil structure (Fig. 2).

RESULTS-PROGRESS

a. Vegetation Analysis

Phytosociological studies have been completed for the woody vegetation present within the study area. Importance values were determined for each species present at the four transects using relative density, relative basal area and leaffall production (Fig. 3). All trees were analyzed in twenty, 150m^2 quadrats (5/transect) which included 20% of the overall study area. Bray and Curtis (1957) ordination techniques reflect the degree of differences in vegetation community structure across the floodplain and at the upland terrace (Table 1). Tree heights have also been estimated for 242 trees in order to determine height-DBH relationships and eventually to generate biomass estimates (Carter et al. 1973) for the major tree species at each location.

Additional studies conducted during the past year have included a comparison of ^{137}Cs concentrations in branch and bole tissues of the major floodplain species. The branch/bole ratios should enable a more realistic assessment of ^{137}Cs burdens in floodplain trees since only branch and leaf samples were obtained during past growing seasons. Radiocesium analysis of all branch, leaf and bole samples should be completed by late 1977.

Increment borings were obtained from 40 ash trees of different sizes in July 1977. The resulting analysis of tree ring data should provide an understanding of the age distribution within the floodplain and the influence of past SRP activities on forest dynamics.

b. Soil Analysis

The soil, litter-humus and root samples collected monthly from August 1973 through August 1975 are still under analysis for ^{137}Cs content. The final data sets on these parameters should be completed in early 1978.

The physical-chemical analysis of soil samples obtained during Summer 1976 is essentially completed (Fig. 4 - 7). The results indicate a sandy substrate at the bank, 30m and upland areas. Silt and clay content of the soil increased at 60m. The sand content generally increases at greater depths at each floodplain location. Soil pH decreased across the floodplain and was higher in deeper strata. Organic matter and cation exchange capacity (CEC) both increased across the floodplain and were always highest in the upper soil strata.

Cation concentrations in the soil were varied. Calcium concentrations were particularly high at all floodplain locations and strata. Magnesium and potassium concentrations increased across the floodplain with significantly higher Mg and K levels at the surface.

Radiocesium levels were also considerably higher in the upper soil strata. Cesium-137 levels were generally similar across the floodplain and dropped sharply at the upland terrace. In contrast, sodium concentrations showed almost no pattern of change at any location.

Correlation analysis has been used to compare the results for various soil parameters and plant community ordination (Table 2). The plant differences across the floodplain were more closely correlated with topographical features (distance and elevation) and soil pH. High plant community correlations with ^{137}Cs and Ca concentrations probably reflect past deposition patterns of these elements along elevational-flooding gradients.

c. Aerial Pathways

The first year's data on the relative importance of particular aerial pathways (litterfall, throughfall, stemflow) on ^{137}Cs recycling have been summarized in an appended manuscript (Shure and Gottschalk 1977, in press). Additional litterfall data have been completed for almost a two-year period. Stemflow and throughfall results are nearing completion for the three-year study (April 1974-April 1977). The results of these studies should enable interesting comparisons of spatial and temporal changes in ^{137}Cs fluxes through these aerial pathways.

LITERATURE CITED

Bray, J. R. and J. T. Curtis. 1957. An ordination of the upland forest communities of Southern Wisconsin. ECOL. MONOGR. 27:325-349.

Carter, M. R., L. A. Burns, T. R. Cavinder, K. R. Dugger, P. L. Fore, D. B. Hicks, H. L. Revells and T. W. Schmidt. 1973. Ecosystem analysis of the Big Cypress Swamp. USEPA-904/9-74-002.

Shure, D. J. and M. R. Gottschalk. 1977. Radiocesium transfer through aerial pathways in a South Carolina floodplain forest. IN Environmental chemistry and cycling processes, D. C. Adriano and I. L. Brisbin, Jr. (eds.) ERDA Publication Series (In press).

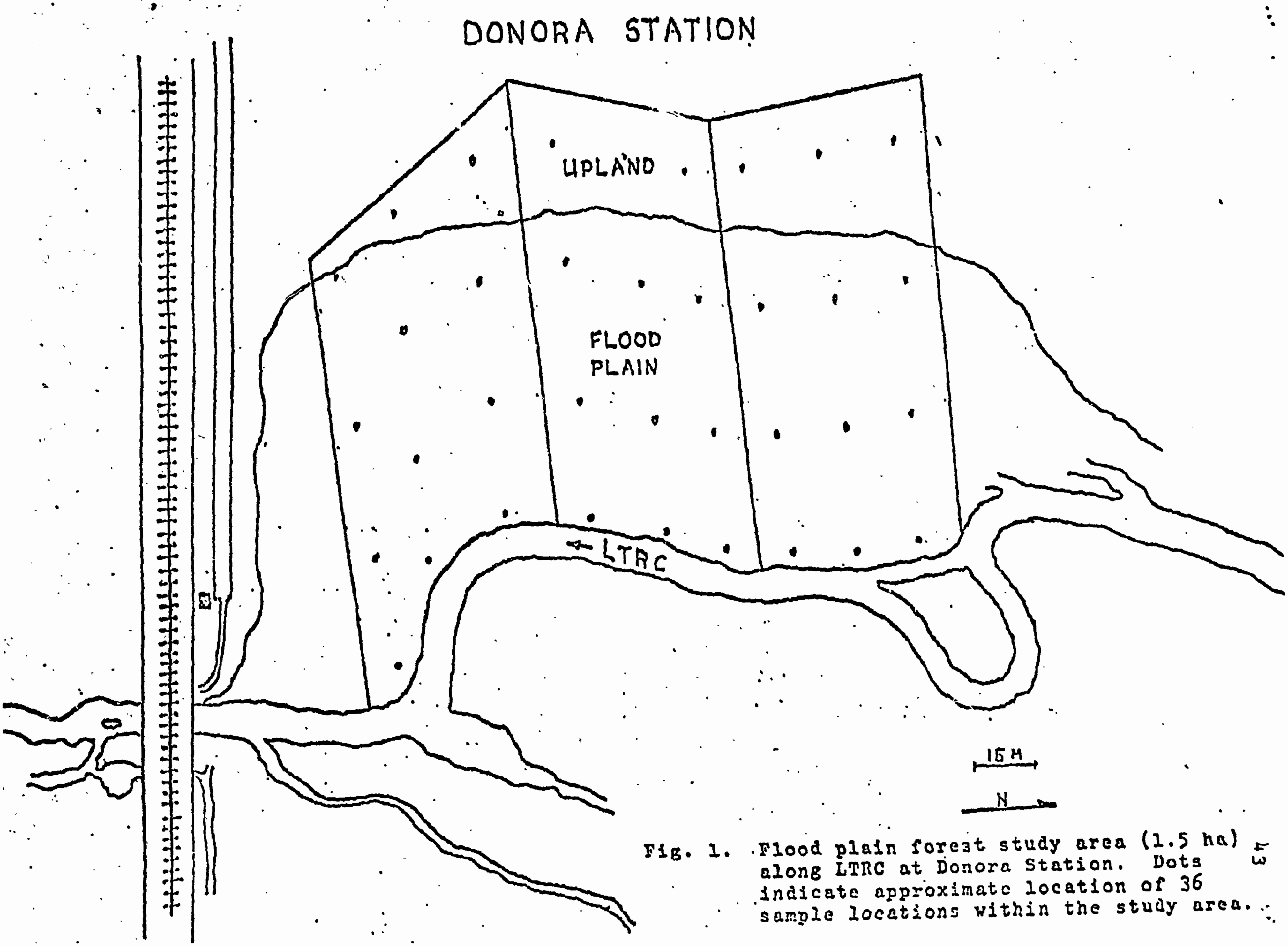


Fig. 1. Flood plain forest study area (1.5 ha) along LTRC at Donora Station. Dots indicate approximate location of 36 sample locations within the study area.

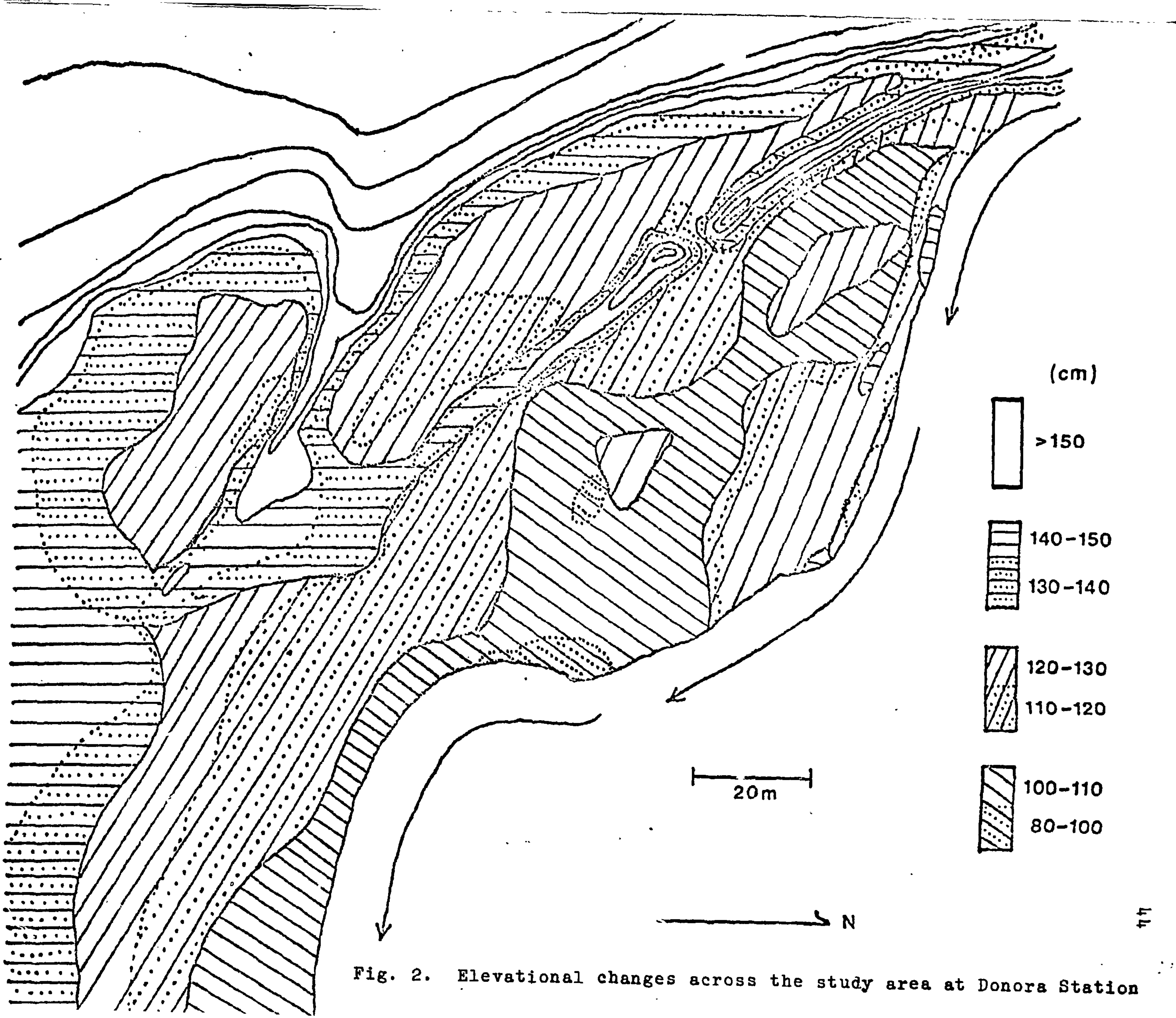


Fig. 2. Elevational changes across the study area at Donora Station

Fig. 3. Importance values for the major tree species present at each floodplain transect.

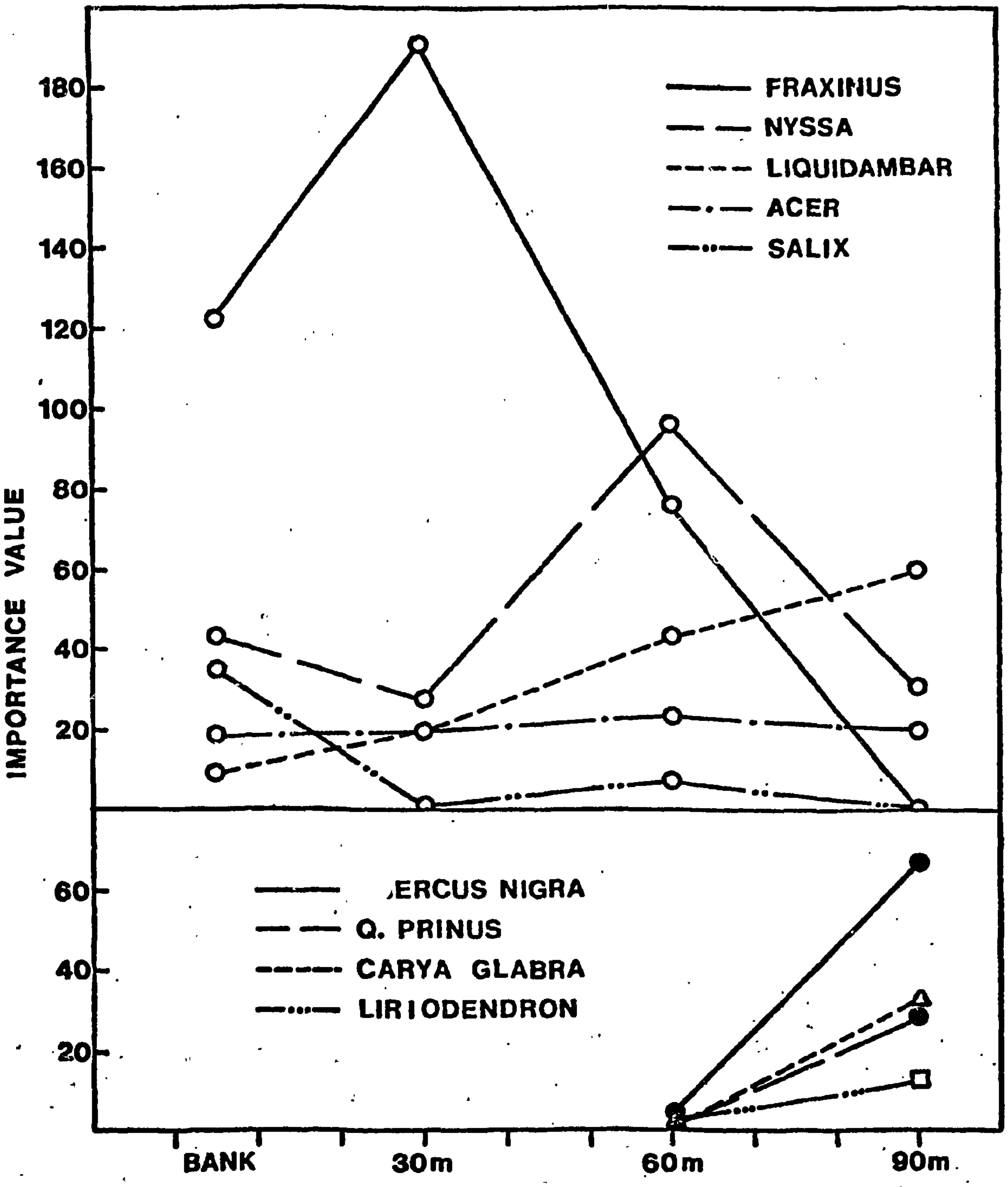


TABLE 1. PLANT COMMUNITY ORDINATION

	Dissimilarity[a]			
	BANK	30 M	60 M	90 M
BANK	xx	.172	.271	.620
30 M	.678	xx	.331	.594
60 M	.579	.519	xx	.483
90 M	.231	.256	.368	xx
Ordination Values	.620	.571	.438	0

a : Dissim. = 0.85 - Coeff. of Comm.

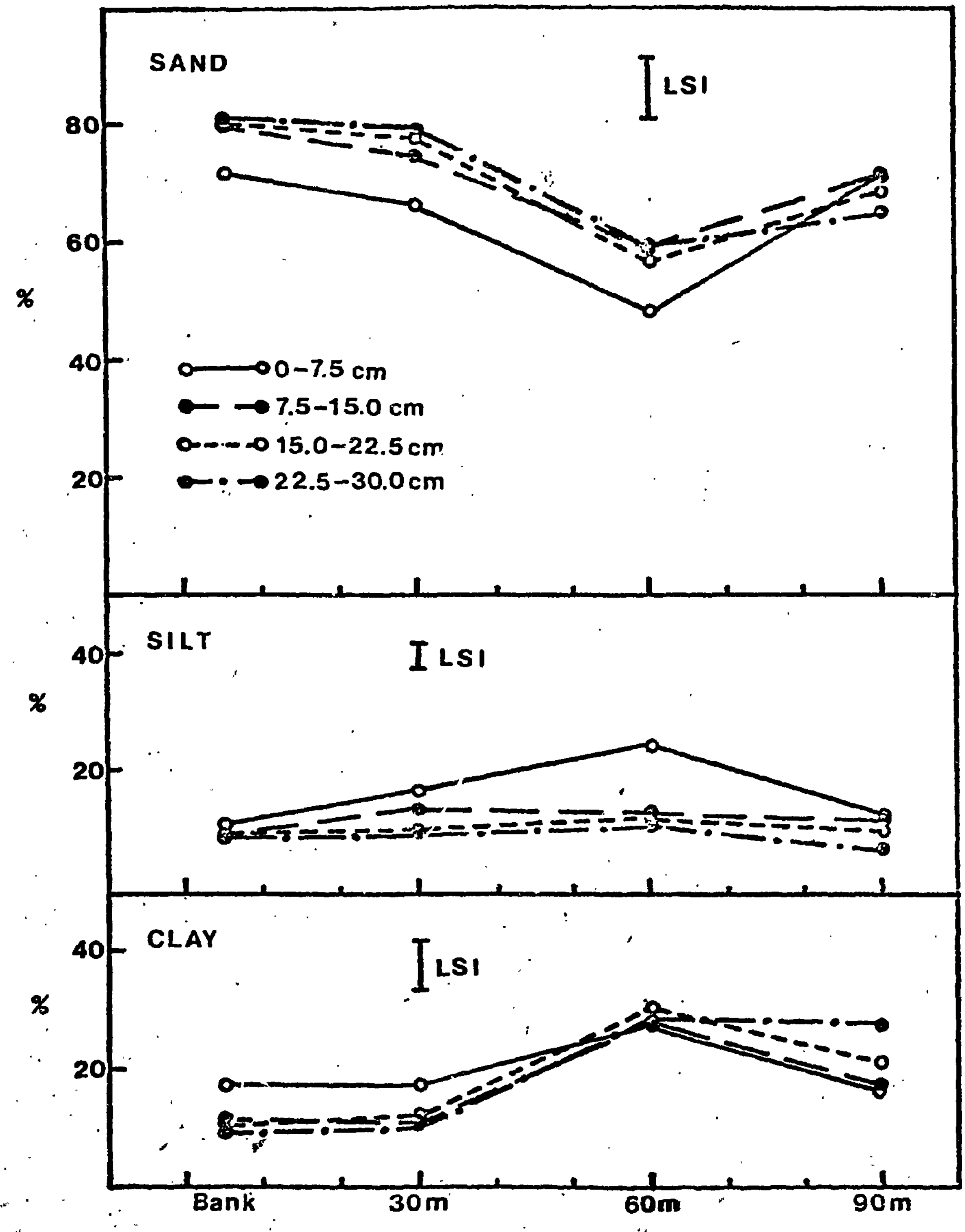


Fig. 4. Percent sand, silt and clay concentrations in soil samples collected at different locations and depths along the flood-plain. Least significant intervals (LSI) apply for all means (N=9) in each data set.

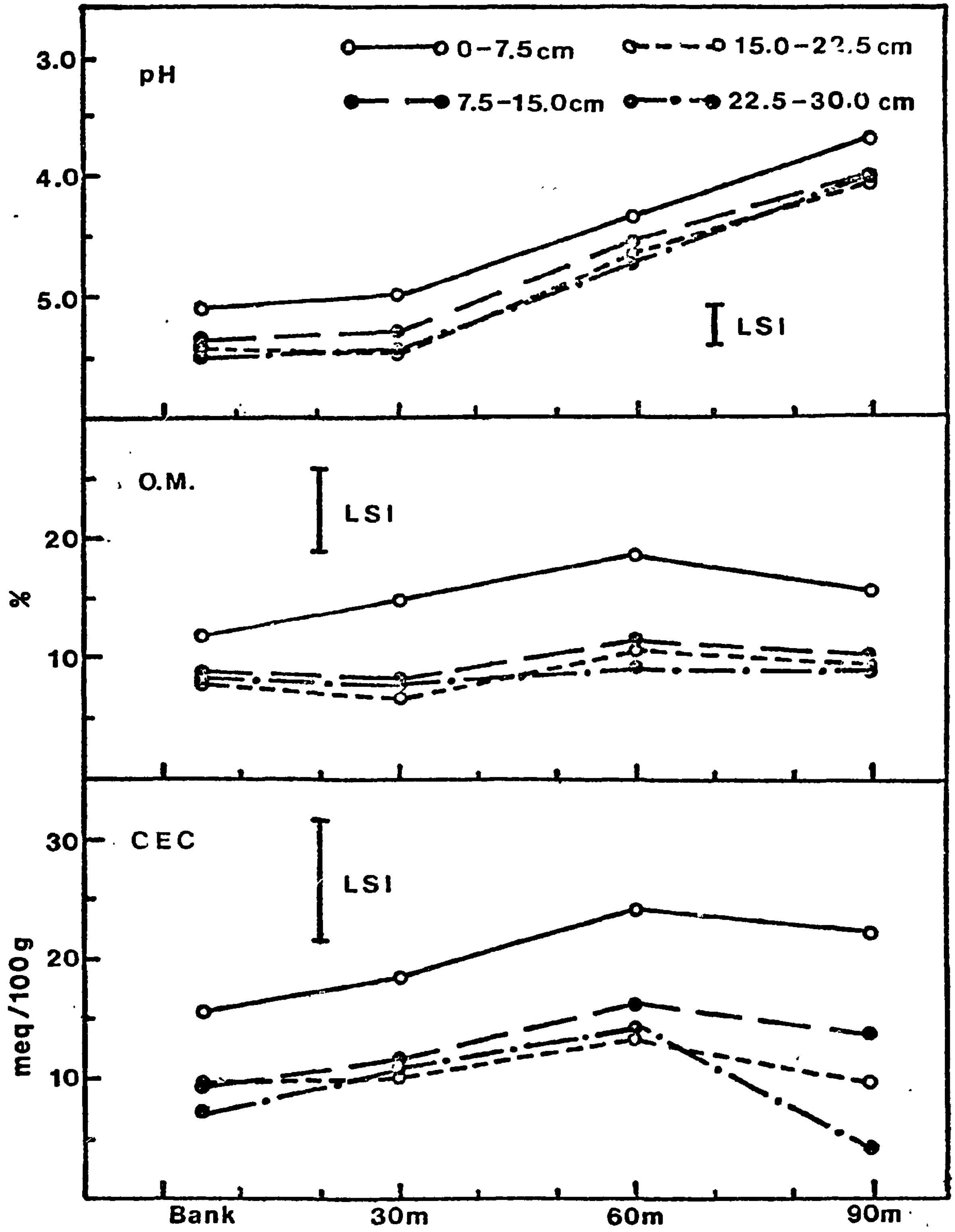


Fig. 5. Soil pH, organic matter content (O.M.) and cation exchange capacity (CEC) at different locations and depths within the study area. Least significant intervals (LSI) apply for all means (N=9) in each data set.

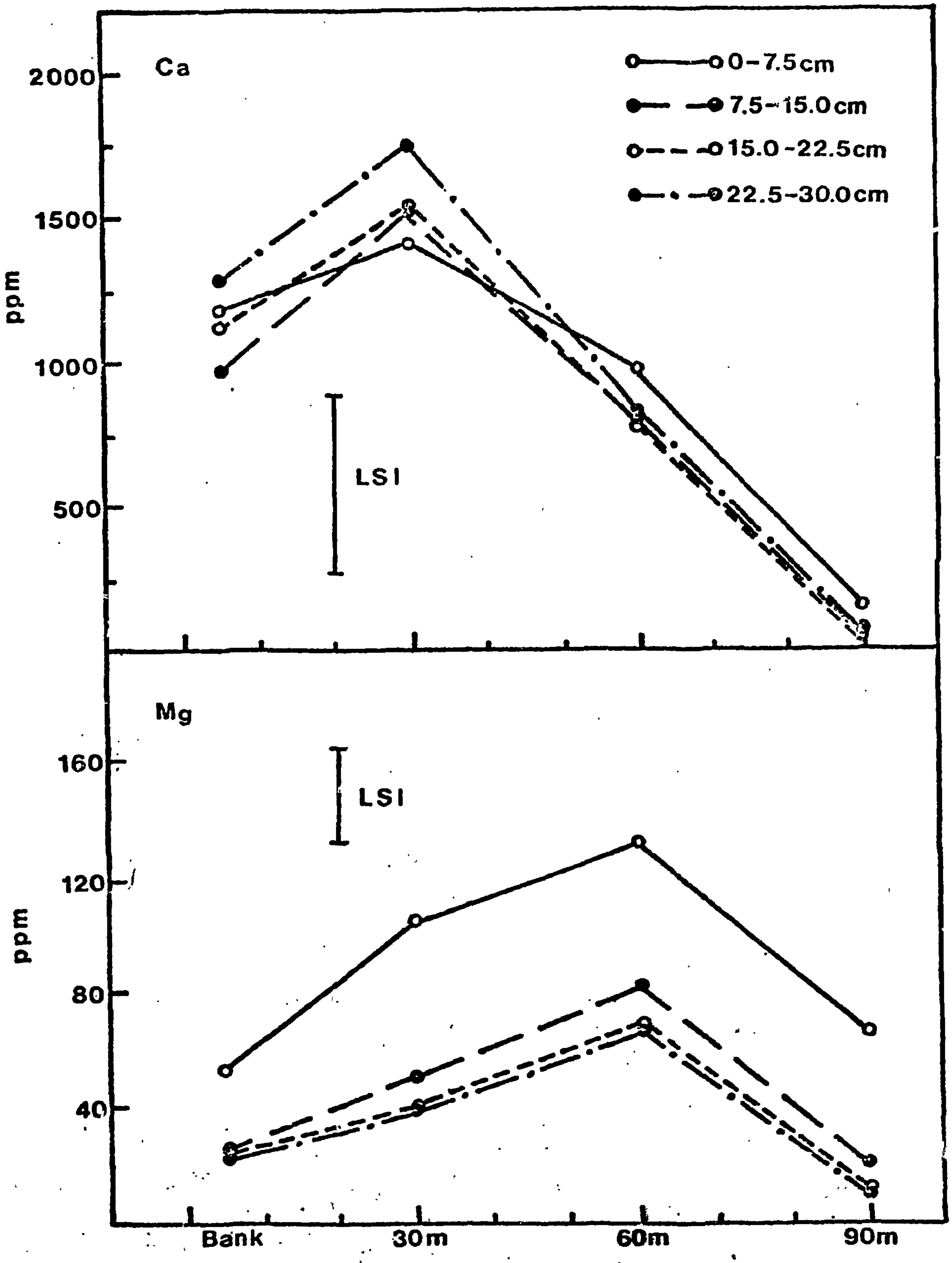


Fig. 6. Calcium (Ca) and magnesium (Mg) concentrations at different soil depths and locations within the study area. Least significant intervals (LSI) apply for all means (N=9) in each data set.

Fig. 7. Cation and ^{137}Cs concentrations at different soil depths and locations within the study area. Least significant intervals (LSI) apply for all means (N=9) in each data set.

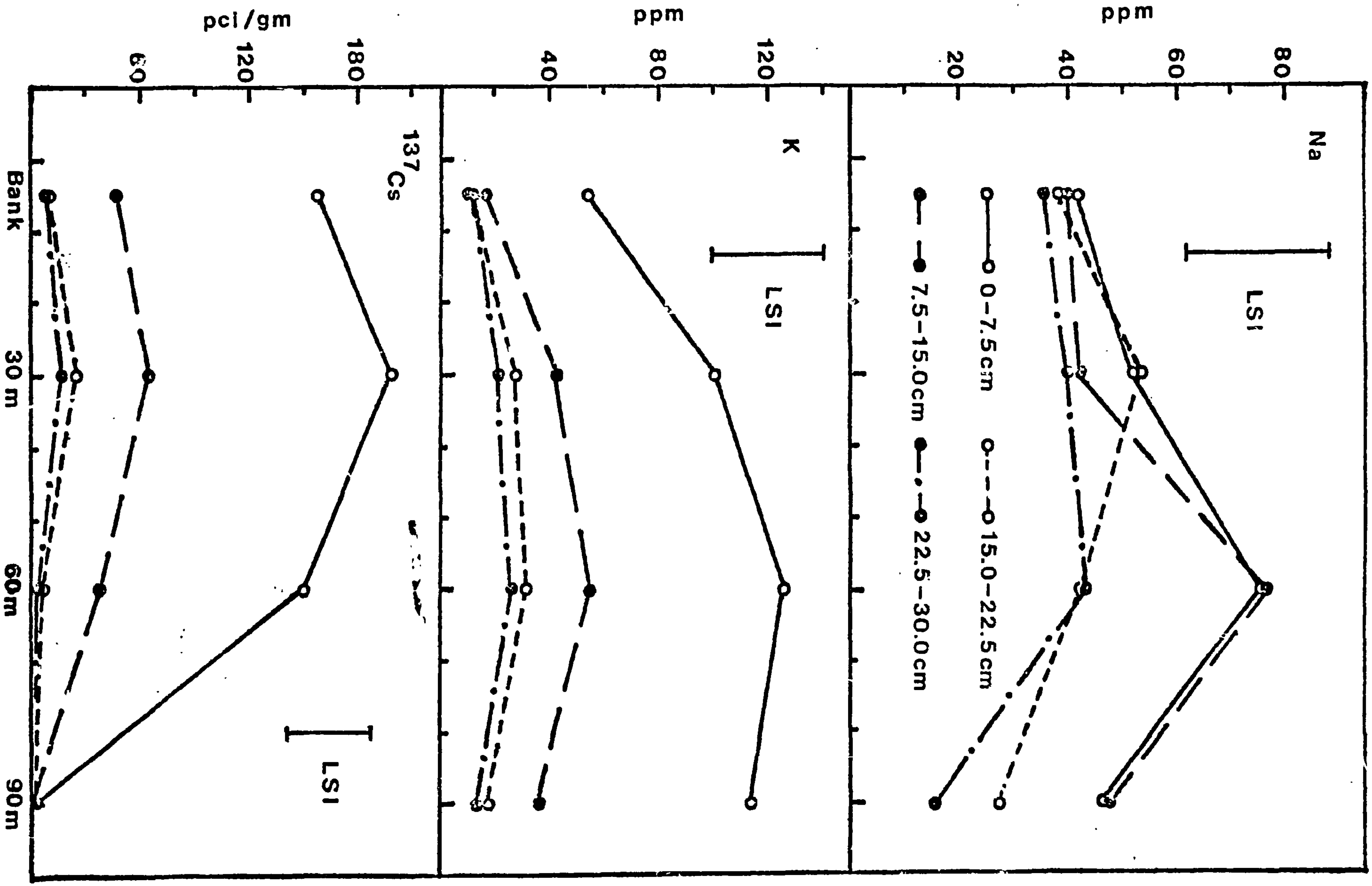


TABLE 2. Soil Correlations with Plant Community Ordination

	r		r
Mg	.317	O.M.	.512
Ca	.931	Clay	.428
Na	.419	Silt	.170
K	.271	Sand	.299
^{137}Cs	.944		
CEC	.136	Dist.	.925
pH	.956	Elev.	.996

SUB-PROJECT I-B

TITLE: RADIOCESIUM EXCHANGES BETWEEN A BLACKWATER CREEK AND FLOOD PLAIN FOREST SYSTEMS.

AUTHORS: J. B. Gladden and D. J. Shure

INTRODUCTION

This report represents a further analysis of the role of the stream margin emergent vegetation community in ^{137}Cs exchanges in Lower Three Runs Creek. Previous reports have examined annual changes in stream-emergent zone-floodplain ^{137}Cs transfers and burdens. Generally, those results have shown that stream hydrology is the dominant factor controlling ^{137}Cs movements. Structural properties of the emergent zone plant community significantly affected ^{137}Cs accumulation and retention through modification of sedimentation-erosion processes, however. This report examines primary production and community changes in the emergent zone and the changes in emergent zone soil properties.

METHODS

Emergent zone plant community analyses were conducted from September 1972 to September 1976. Above - and below-ground vegetation was harvested from eight randomly selected plots (0.25 m^2) on each sampling date. Vegetation was gently washed to remove sediment and oven-dried (100 °C; 24 hr.) for biomass determinations. Community area maps were constructed at the beginning and end of each growing season (April and September) during the study period. Emergent zone surface soil samples were collected in December 1974 and May, July and September 1975 for analysis of soil parameters. Fifteen samples were collected in December and May and 30 samples were collected in July and September. Oven dry soils (70 °C) were analyzed for percent organic content (loss on ignition: 450 °C, 24 hr.), percent sand, silt and clay and cation exchange capacity. Exchangeable soil cations (K, Na, Mg, Ca) were analyzed after 24 hr extraction in 1 N ammonium acetate (pH = 7.0) on a Perkin Elmer model 306 Atomic Absorption Spectrophotometer. Exchangeable and total soil ^{137}Cs concentrations were determined on a Packard Model 5012 Gamma spectrometer. PH was measured on fresh soils wetted to the "sticky-point".

RESULTS

Emergent vegetation forms the second largest community type in the stream-floodplain forest complex. Only the mature floodplain vegetation covers a larger area. Two emergent macrophytes, Polygonum punctatum and P. densiflorum, form extensive, monotypic communities in both upstream and downstream study sites (Fig. 1). Other stream margin areas are covered by mixed herbaceous species and young hardwood species dominated by Salix nigra and Platanus occidentalis.

Biomass changes in the Polygonum community were monitored from September 1972 - September 1976 (Fig. 2). Polygonum biomass normally shows minimum values in early spring and maximum values in September. However, both the patterns of biomass increase and the peak standing crop varied considerably among years. Peak standing crop ranged from 480 g/m^2 in 1975 to 1105 g/m^2 in 1976. The differences in biomass accumulation appeared to be related to differences in annual stream discharge patterns (Fig. 3). Low Polygonum biomass occurred in years of high stream discharge and high biomass during low discharge. Graphical and regression analyses confirmed that elevated stream discharge reduced shoot and total Polygonum production (Fig. 4).

The Polygonum community is somewhat unique because the location of the stream-side edge of the community changes considerably from year to year. Polygonum community area mapping in April and September showed that stream discharge also effects community area changes (Fig. 5). Under normal conditions community area appears to increase from Spring to Fall. However, the extremely high streamflow in Summer 1973 resulted in a continuous reduction in community area from September 1972 through April 1974. Only 1976, a year of low stream discharge, was the community area greater than in the previous years.

Production estimates incorporating concurrent changes in biomass and community area can deviate significantly from production estimates based on unit area biomass alone. Two standard techniques for estimating production were compared against a method incorporating the change in community area (Table 1). After standardizing the result to percent biomass increase from April-September, methods A and B gave very similar results. Method C, which incorporates the changes in total community area, shows that the standard techniques overestimate production in 1973 and grossly underestimate production in 1974. These area changes would also affect the estimation of soil-plant ^{137}Cs movement because Polygonum radiocesium concentrations (pCi/g) vary little from year to year.

We have also examined annual changes in emergent zone soil characteristics and nutrient concentrations. Soil organic matter (25%, Fig. 6), sand (49%), silt (39%) and clay (12%) had no significant variation from December 1974 to September 1975. Similarly, sodium, total ^{137}Cs and exchangeable ^{137}Cs did not vary significantly (Fig. 7). Soil cation exchange capacity (CEC), potassium, magnesium and calcium concentrations all decreased significantly (Fig. 8) while soil pH increased (Fig. 6). Soil cation decreases are restricted to biologically-essential cations and are believed to result from both plant uptake and nutrient leaching during flooding. The high CEC of these soils is due primarily to high organic matter. The decrease in CEC from December 1974 to July 1975 must have resulted because of changes in the nature of the organic matter since total organic matter percentage does not change.

Correlation analyses of soil structural and chemical parameters showed strong relationships among soil CEC, organic matter, silt and sand (Table 2). Soil pH and clay content were poorly correlated with other soil parameters. Total soil ^{137}Cs consistently has the highest correlations with other soil cations (Table 3a). Potassium, sodium and magnesium are very highly correlated among the stable elements. Soil calcium generally has the lowest correlations with other soil cations, possibly because of the high concentrations of calcium relative to other cations.

Total ^{137}Cs and exchangeable calcium had the highest correlations with soil structural and chemical properties (Table 3b). Calcium concentrations were most strongly related to soil CEC and organic content. Cesium-137 was more closely related with the soil silt fraction. Soil pH and clay content showed little relationship to soil cation concentrations.

Canonical correlation analysis of soil cation concentrations against soil structural and chemical properties extracted three significant variate pairs (Table 4). The first variates included exchangeable ^{137}Cs and calcium (variate 1) and silt and sand (variate 2) as the most important variables. This variate pair indicates the importance of deposition of stream-borne materials and areas of accumulation in the emergent zone. Radiocesium accumulations are largely a result of deposition of stream-borne silt and high soil calcium concentrations occur in areas of detritus accumulation. High proportions of silt occur in areas where deposition exceeds resuspension, resulting in long-term accumulation of materials. The second variate pair extracted included Mg-Na-Ca and silt-pH-organic matter. The second variate probably describes the soil sorption complex which appears to be dominated by silt and organic matter. Divalent cations, Mg and Ca, would be particularly important in a soil dominated by organic matter. The relationships described by the third pair of variates is not clear.

This analysis of vegetation and soil characteristics generally supports our earlier hypotheses that the dynamics of the emergent zone are largely determined by stream flow factors, and the timing and magnitude of stream flow exert a strong regulating influence on <u>Polygonum</u> production and community area. Nutrient accumulation, including ^{137}Cs, appears largely determined by silt deposition patterns and the accumulation of emergent zone and floodplain detritus.

TABLE 1. COMPARISON OF THREE TECHNIQUES FOR ESTIMATING PLANT PRODUCTION.*

$$\% \text{ Biomass Change} = \frac{\text{Biomass Change}}{\text{Initial Biomass}} \times 100$$

Biomass Change: A = final - initial (g/m^2)

B = sum of positive increments (g/m^2)

C = final - initial ($g/m^2 \cdot$ area)

Method	1973	1974	1975
A	120.88	202.63	105.28
B	128.90	205.55	105.28
C	78.47	346.38	131.90

*Results were standardized to percent biomass increase from April crop to September peak crop.

TABLE 2. CORRELATIONS AMONG SOIL STRUCTURAL AND CHEMICAL PARAMETERS.*

	pH	CEC meq/100g	Percent Organic	Percent Sand	Percent Silt	Percent Clay
Mean	6.63	45.97	23.34	49.10	38.90	12.00
S.D.	0.34	19.99	9.33	21.44	20.53	4.69
pH	1.000	.327	.313	-.362	.410	-.143
CEC		1.000	.939	-.886	.886	.174
% Org.			1.000	-.907	.904	.193
% Sand				1.000	-.976	-.300
% Silt					1.000	.085
% Clay						1.000

P(.05) = 0.250   P(.01) = 0.327

*Samples from July and September, 1975, were pooled (n=60).

TABLE 3a. CORRELATIONS AMONG SOIL CATION CONCENTRATIONS.*

	K ug/g	Na ug/g	Mg ug/g	Ca ug/g	XCs pCi/g	TCs pCi/g
Mean	65.51	33.31	76.03	3307.98	11.36	87.73
S.D.	26.98	16.70	31.37	2274.05	6.16	50.80
K	1.000	.807	.762	.592	.679	.761
Na		1.000	.824	.412	.655	.712
Mg			1.000	.531	.659	.716
Ca				1.000	.599	.669
XCs					1.000	.949
TCs						1.000

*Samples from July and September, 1975, were pooled (n=60).

TABLE 3b. CORRELATIONS AMONG SOIL CATIONS CONCENTRATIONS AND SOIL STRUCTURAL AND CHEMICAL PARAMETERS (n=60).

	K	Na	Mg	Ca	XCs	TCs
pH	.115	.117	-.126	.327	.190	.228
CEC	.654	.519	.608	.854	.789	.828
% Org.	.675	.599	.673	.845	.778	.850
Sand	-.602	-.536	-.575	-.772	-.788	-.853
Silt	.656	.581	.583	.790	.838	.883
Clay	-.114	-.092	.076	.072	-.068	.033

P(.05) = 0.250 P(.01) = 0.327

TABLE 4. CANONICAL CORRELATION ANALYSIS OF SOIL CATION CONCENTRATIONS AND SOIL STRUCTURAL AND CHEMICAL PARAMETERS.

Canonical Variables	Soil Cations var./coeff.	Structural and Chemical var./coeff.	
	exCs/ 0.530	silt/ 1.21[illegible]	
	Ca/ 0.509	sand/ 0.841	r = 0.959
Set 1	K/ 0.078	CEC/ 0.447	
	Mg/ 0.016	OM/ 0.321	X^2 = 185.73:25 df.
	Na/ 0.004	pH/-0.129	
	Mg/ 1.888	silt/-0.976	
	Na/-1.147	pH/-0.929	r = 0.634
Set 2	Ca/-0.450	OM/ 0.804	
	exCs/-0.253	sand/-0.547	X^2 = 47.97:16 df.
	K/ 0.050	CEC/-0.062	
	exCs/-1.194	silt/-3.176	
	Ca/ 1.109	OM/ 2.395	r = 0.423
Set 3	Na/ 0.916	sand/-1.413	
	K/-0.733	CEC/-0.750	X^2 = 19.99: 9 df.
	Mg/ 0.094	pH/ 0.609	

*Total ^{137}Cs was eliminated to put all cations on an exchangeable basis and % clay was eliminated because of matrix considerations: July and September, 1975.

Figure 1. COMMUNITY MAPS OF UPSTREAM AND DOWNSTREAM STUDY AREAS AT DONORA STATION. THE LOWER AREA BEGINS ABOUT 100m DOWNSTREAM FROM THE UPSTREAM SITE.

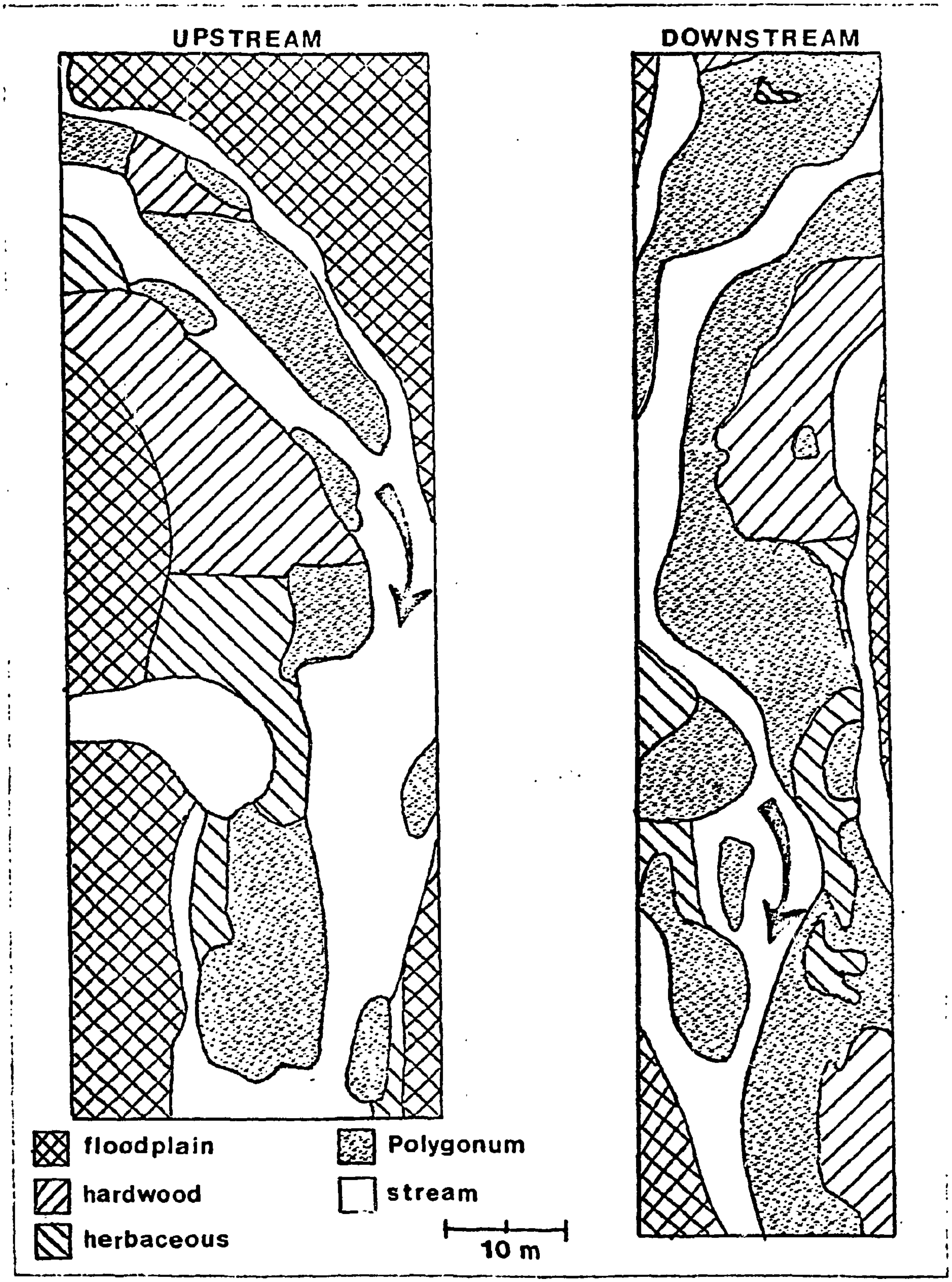


Figure 2. Polygonum shoot (leaf + stem) and total (shoot + rhizome + root) biomass changes from September 1972 to September 1976. Mean and std. error are presented for each sample date (n=8).

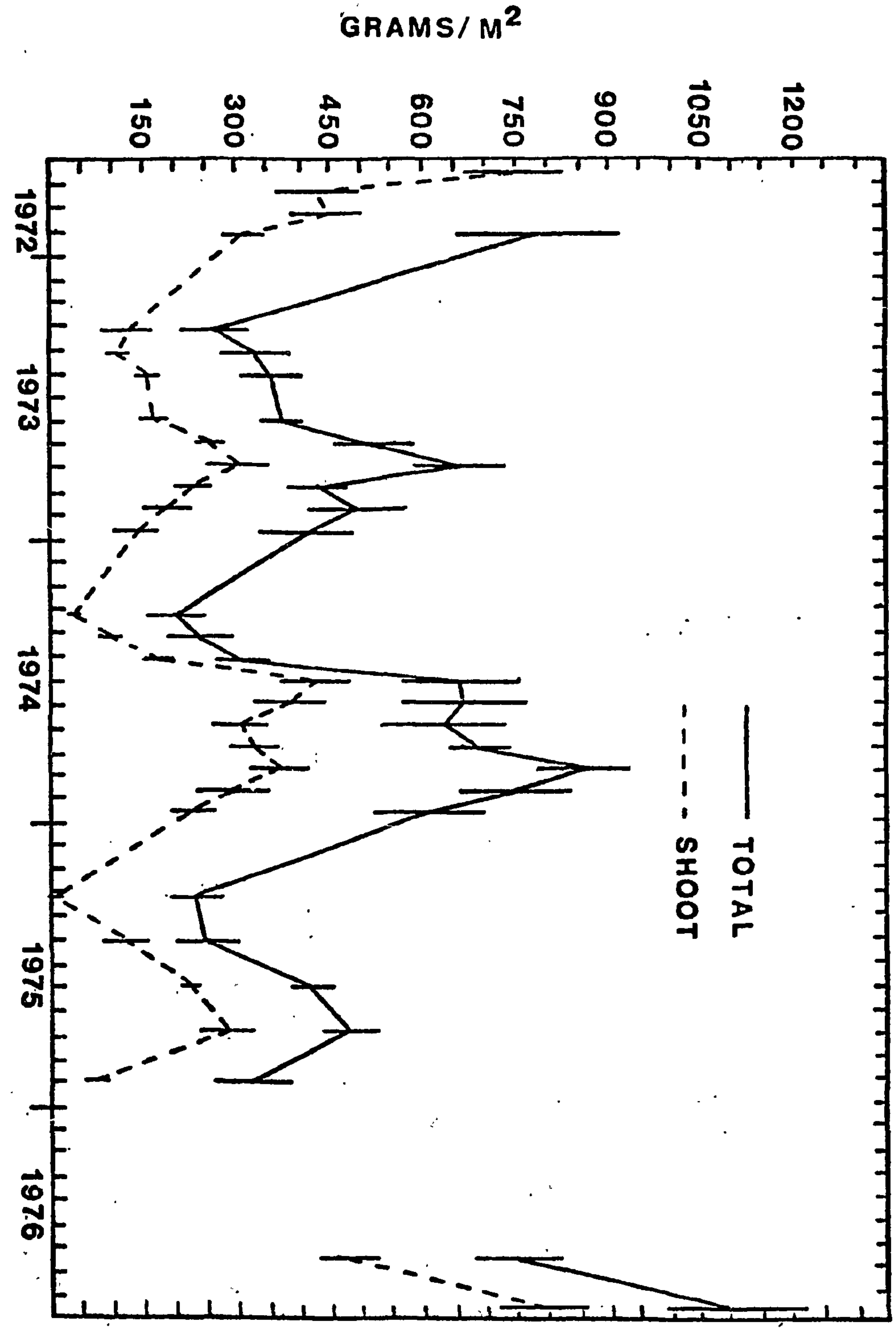


Figure 3. LTRC stream discharge from 1972 to 1976. Weekly mean stream discharge was calculated for a USGS recording station at Patterson Mill.

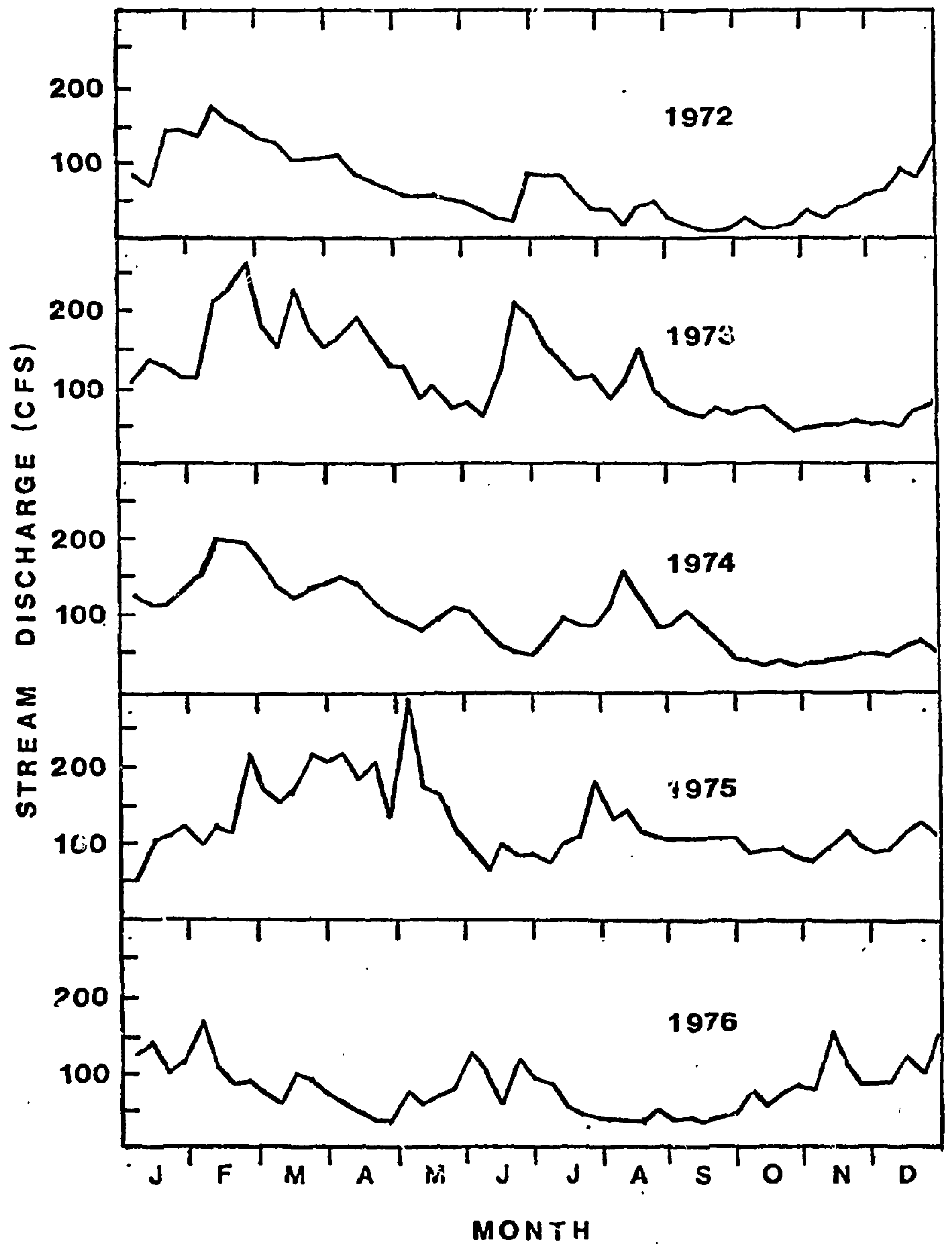


Figure 4. Regresson of Polygonum shoot (top) and total (bottom) production (log $(g.m^{-2}.d^{-1}+ 5)$) and mean stream discharge (log MSD) during sampling intervals in growing season.

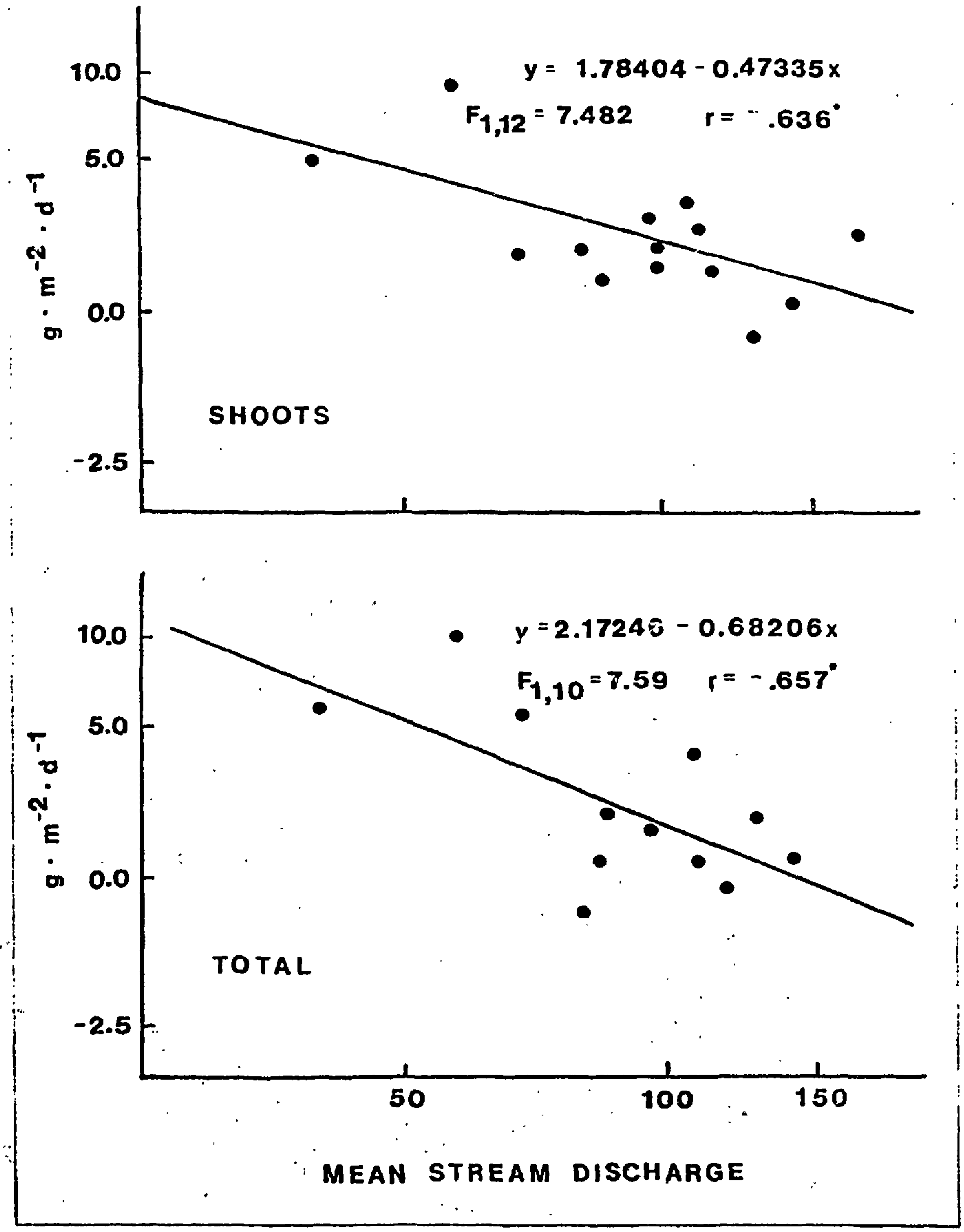


Figure 5. Polygonum community area in upstream and downstream areas calculated from maps constructed in April and September of each year. Dashed lines indicate changes between peak crops and solid lines indicate changes between annual peak crops.

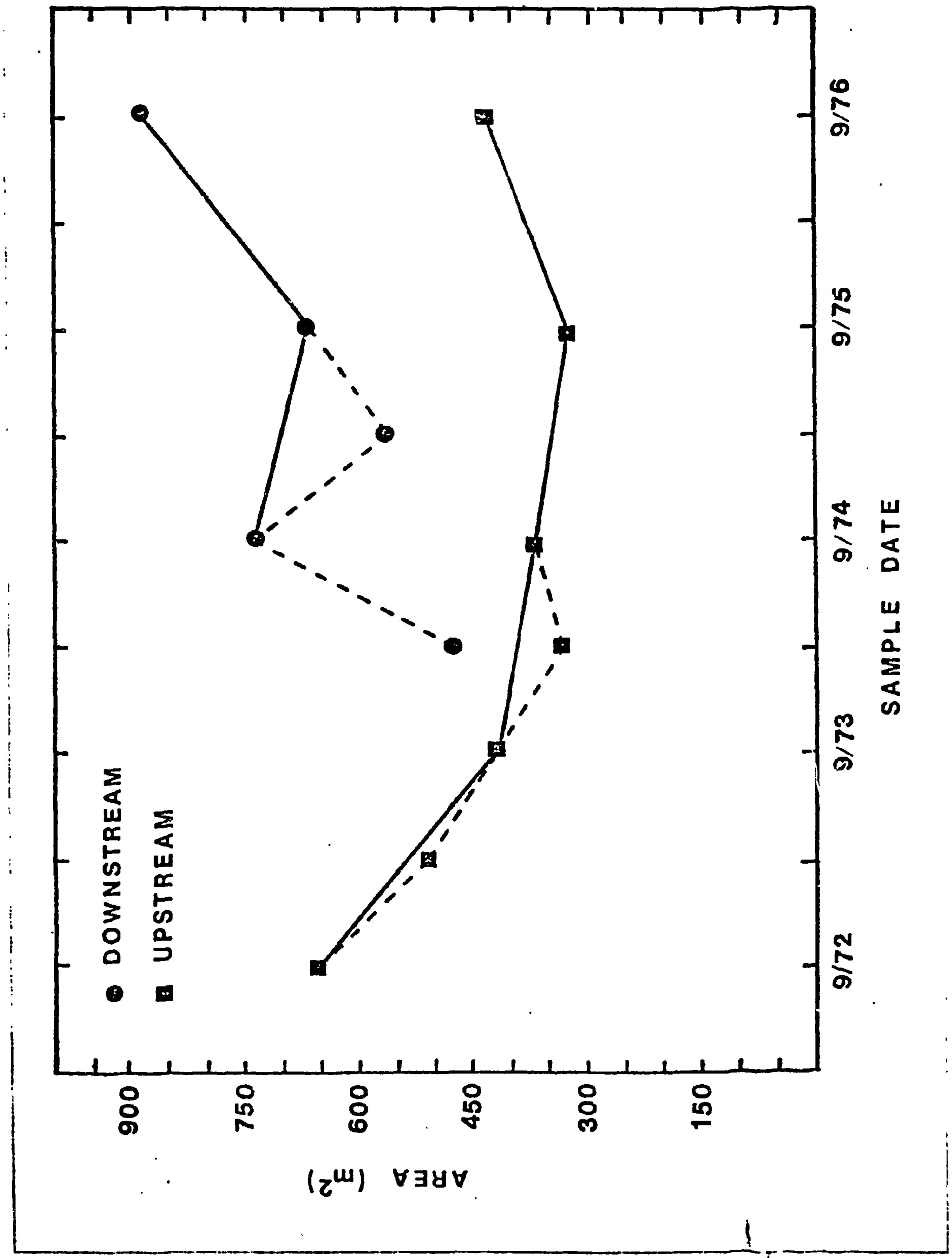


Figure 6. Changes in soil organic matter, cation exchange capacity (CEC) and pH from December, 1974 to September, 1975. Means sharing the same symbol (',*) are not significantly different (p=0.05).

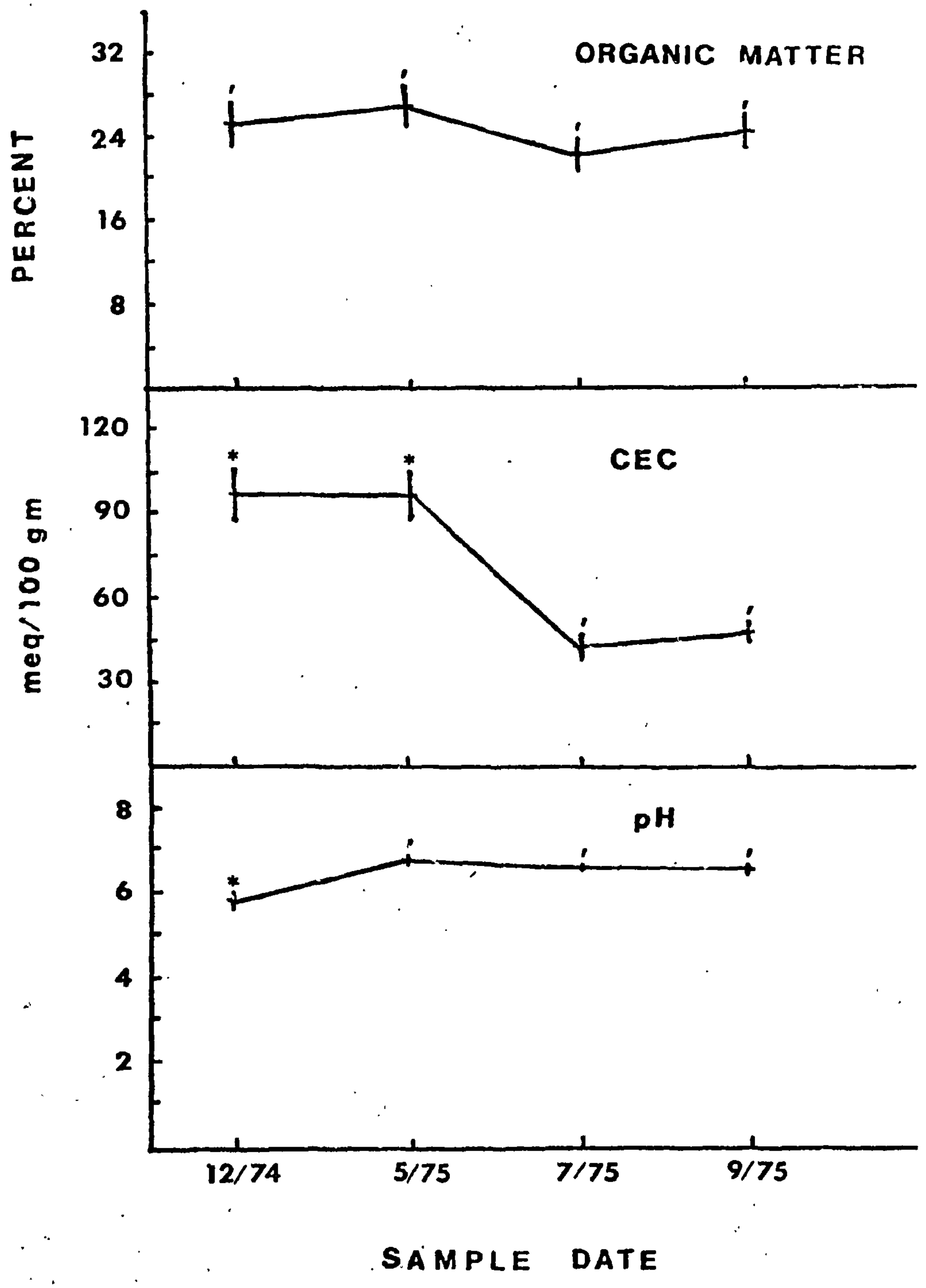


Figure 7. Changes in exchangeable soil sodium, ^{137}Cs and total ^{137}Cs. Neither element had significant changes over the sampling period.

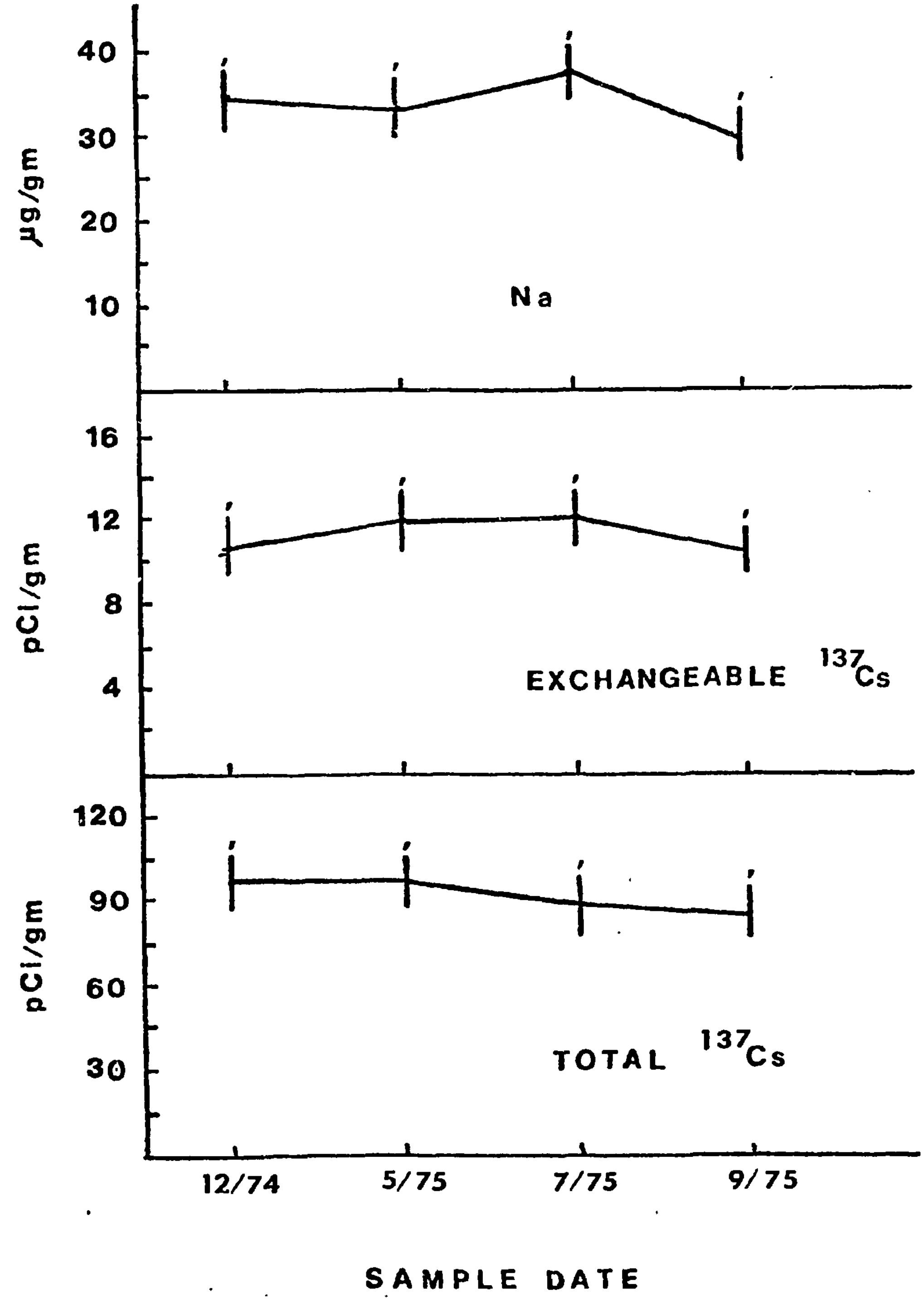
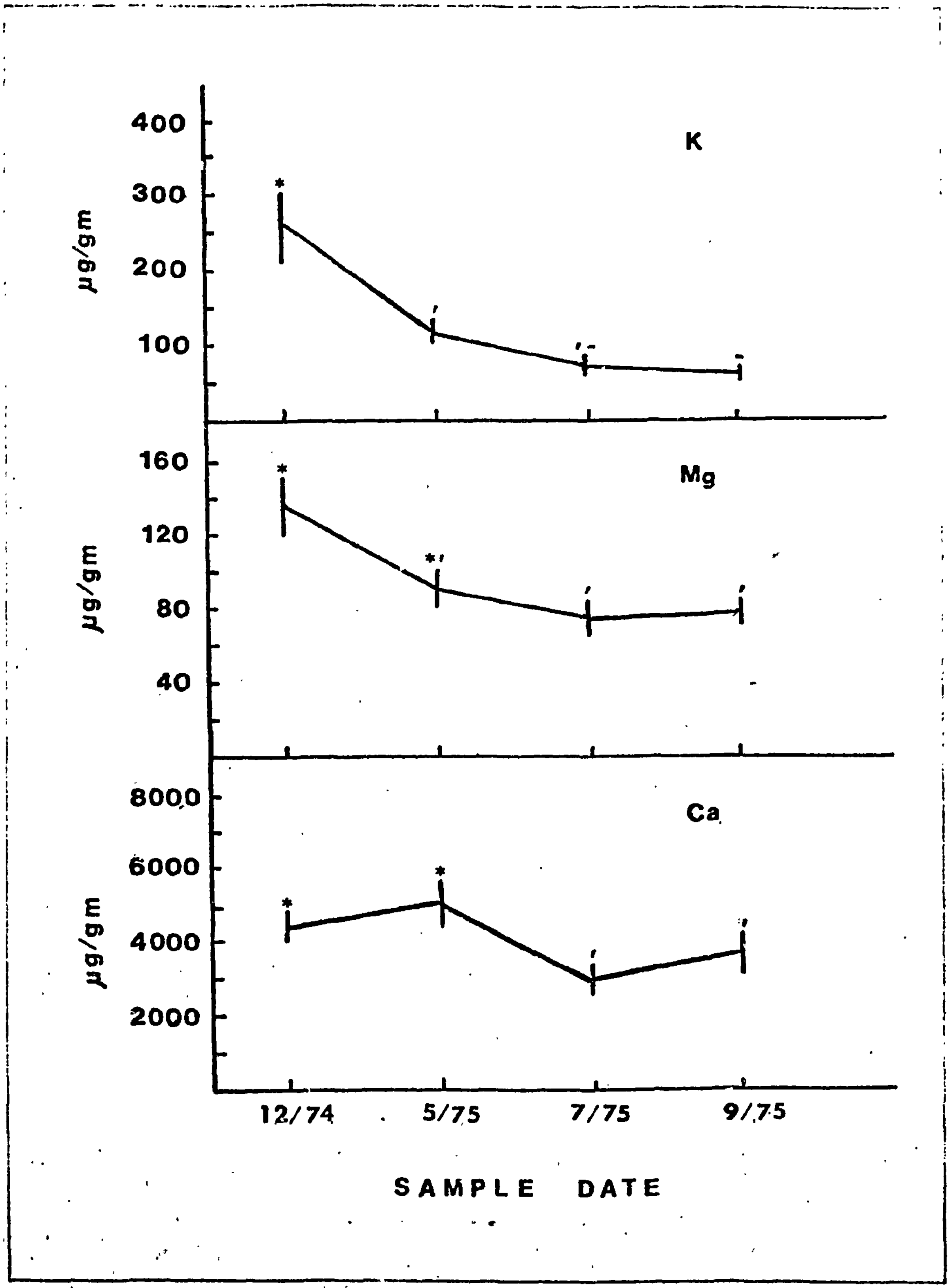


Figure 8. Changes in exchangeable soil potassium, magnesium and calcium concentrations. Means sharing the same symbol are not significantly different (p=0.05).



SUB-PROJECT I-C

TITLE: AQUATIC ECOSYSTEM STUDIES OF CAROLINA BAYS

AUTHORS: J. F. Schalles and D. J. Shure

INTRODUCTION

Carolina Bays are a conspicuous but poorly-studied landscape unit of the Atlantic Coastal Plain in Georgia and the Carolinas. Wetland areas ranging from grassy savannahs to swamp forests and ponds occupy the centers of these naturally occurring, shallow depressions. The studies reviewed in this report have involved a comparative limnological survey of six Carolina Bay ponds and a more intensive ecosystem-level analysis within one of these areas. Several dozen additional bays have been visited in South Carolina and North Carolina to gain further impressions of their ecology.

The geological significance of the depressions was addressed in a series of papers during the mid 1900's (Smith, 1931; Melton and Schriever, 1933; MacCarthy, 1937; Cooke, 1940; Johnson, 1942; Prouty, 1952; Legrand, 1953; and Shockley, 1956). The mode of origin of the bays has not been agreed upon. A solution-collapse sequence or simultaneous creation from a meteorite shower are the two most tenable hypotheses. Frey (1953) estimated the age of the bays at 40,000 to 100,000 years while Wells and Boyce (1953) assembled evidence indicating ages as great as 250,000 years. If the above estimates are correct to order of magnitude, then Carolina Bays are remarkably old for such shallow depressions. Fire appears to prevent organic accumulations from completely filling the bays (Buell, 1946; Wells and Boyce, 1953).

Frey (1949) studied the limology of 5 large Carolina Bay lakes in North Carolina. He found these lakes to be acidic, with soft waters and high but variable levels of brown color. Eyles (1941), Buell (1946), Kelley and Bateson (1951), and Porcher (1966) have described vegetational composition in differing bay types while others have examined various faunal groups (Hubbs, 1946; Gross, 1955; Golley et. al, 1965; and Gibbons, 1970). The degree and timing of inundation appears to be the primary physical variable controlling community structure and function within the depressions. In addition to supporting aquatic communities, Carolina Bays provide important habitat for migratory waterfowl and for the reproductive activities of terrestrial amphibians, and they serve as upland watering holes for wildlife. The abundance of Carolina Bays at the Savannah River Plant and their proximity to commercial operations at the Barnwell Nuclear Fuel Plant and Chem-Nuclear sites increases the relevance of identifying and quantifying basic ecological processes in the bay pond ecosystems.

Methodology

The six bays (Fig. 1) used in the comparative survey were sampled at two-month intervals between August 1974 and August 1975 and at less-frequent intervals since then. Physical and chemical parameters were determined on each date for six permanent stations in each bay. Sediment and macrophytic vegetation samples were collected on four dates for fallout Cs-137 comparisons.

Several approaches have been used to study Bay 4 (Fig. 2), which we have designated Thunder Bay. Samples were collected within a 1 ha area (Fig. 2) at approximately 6-week intervals from May 1975 to May 1977. Standing crop estimates of the major organic components were obtained by collecting the materials enclosed within a 0.25 m^2 galvanized cylinder. Periphyton production and community respiration within the water column have been measured on four dates using a 24 hr oxygen curve technique (Odum and Hoskin, 1958). Hydrology of the Thunder Bay site has been studied with water level recordings of the pond and of four shallow wells, two placed upslope and two downslope of the bay.

Results and Discussion

A. Comparative limnology

Distinct seasonal and interbay differences are found in the chemical parameters monitored. Although not all samples and data have been analyzed, several conclusions are possible. Bays 2 and 5 have been affected by altered surface drainage at the Barnwell Nuclear Fuel Plant. These bays have less acid pH values, lower levels of dissolved organic matter, and greater levels of dissolved solids (TDS). The TDS change is apparently the result of elevated Ca^{++} concentrations (Table 1). Bay 2 is the only site where there is no significant, negative correlation between conductivity and water level, reflecting the considerable flushing by BNFP drainage ditches. Bay 1 is adjacent to a highway and its bottom profile suggests marked past disturbance. The water chemistry at this site is intermediate between disturbed (Bays 2 and 5) and undisturbed Carolina Bays (3, 4, and 6). Bays 1 and 3 dried up during the fall of 1974, causing a pronounced concentration of dissolved materials. Potassium concentration seems to be a sensitive indicator of biological conditions in the ponds, with decreasing levels observed as the growing season progresses. Sharp increases in K^+ occurred in Bays 1 and 3 after drying out, perhaps reflecting vegetation death and release of this very labile element.

B. Thunder Bay studies

Field work is largely completed in this part of the study. Surface and well water level recordings will be extended into 1978. Results from several components of the enclosure collections are complete. The biomass structure of the aquatic community is dominated by the root mat of the macrophytes. About 92% of the root biomass is concentrated in the upper 10cm of sediment. Above-ground stems, leaves and reproductive parts form the more conspicuous macrophyte structure and exert strong control over water column and air - water interface processes. The distribution of above-ground biomass of the four most-abundant aquatic plant species is closely correlated with water depth (Fig. 3). The floating leaf species, *Brasenia schreberi* and *Nymphae odorata*, dominate the deeper water while the grasses *Panicum* sp. and *Leersia hexandra* are the major components of the shallow, emergent vegetation zone. Signicant increases in *Brasenia* and Panicum and decrease in Leersia between the two study years demonstrate the dynamic nature of the community in response to cyclical water-level fluctuations. An average of 143 g/m^2 dry wt was produced in the above-ground macrophyte component over an annual cycle. The net production of Brasenia, Panicum, Nymphae, and Leersia was 60, 43, 17, and 12 g/m^2 respectively when averaged over the 1 ha sampling area. An overview of macrophyte dynamics is presented in Figure 4. Root to shoot ratios varied from a low of about 4:1 in early fall to 14:1 in midwinter. Root production begins only after the shoot production starts to peak. New production is evidently stored from late summer to late fall directly in the roots along with translocated shoot materials. The decrease in root biomass during the winter reflects maintenance expenses and the energy required for new shoot tissue produced in this period. The net primary production of dry matter for the macrophytes (maximum-minimum standing crops) is 260 $g/m^2/yr$.

Chlorophytes and diatoms dominate the periphyton community of Thunder Bay. Chlorophyll extractions were used to estimate standing crops of this component. The extractions revealed a bacterial chlorophyll a absorbance peak, and this peak was used as an index of the abundance of purple photosynthetic bacteria. Mean unit-volume and unit-area estimates of algal and bacterial chlorophyll a estimates (Fig. 5) indicate the photosynthetic bacteria sometimes approach or exceed the algal fraction. No seasonal trends are discernable, although the unit-area algal values decline over the study.

The four 24-hr oxygen curves (average values) exhibit variation between dates (Figure 6). The September curve was run on a cloudy day and the remainder on clear days. All evidence suggests that the periphyton are a light-limited, shade-adapted community. The average gross primary production for the four oxygen curves is 1.15 g O_2/m^2/day. Using conversions from Likens (1975), the annual net productions for the macrophytes and periphyton are calculated to be 131 and 87 g $C/m^2/yr$, respectively. The production of the photosynthetic bacteria is not detected by the oxygen curve technique. It is possible that this fraction might be as productive as the algae.

The Thunder Bay system is low to moderately productive compared to other littoral zones. However, the production level is greater than might be expected on the basis of water chemistry, which fits an oligotrophic or dystrophic classification.

The hydrology work on Thunder Bay suggests that the pond has a slow but continuous discharge downslope and some seasonal recharge from a shallow aquifer upslope and north of the bay. This latter condition may be important since the Barnwell Nuclear Fuel Plant site could be in the line of flow of this water prior to surfacing in the bay (James Cahill, USGS, personal communication). The overall relation of Carolina Bays to near surface groundwater movements on the coastal plain is a subject that merits much greater attention.

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Table 1. Summary of selected chemical parameters for the six Carolina Bays used in the study (mean values, n=6 except cations where n=5).

					Cations (ppm)			
Bay	pH	Tot. Alk. (ppm)	DOC (ppm)	TDS (ppm)	Ca	Mg	Na	K
1	4.5	8.3	22.7	40.4	2.1	1.2	1.3	2.5
2	6.2	13.4	5.0	38.0	9.9	1.0	1.4	1.3
3	4.3	2.6	16.7	21.7	0.7	0.4	1.3	1.6
4	4.3	2.0	9.0	9.8	0.8	0.4	0.9	0.3
5	6.0	17.5	6.3	51.0	13.5	1.4	1.7	1.4
6	4.4	1.7	13.6	13.0	0.7	0.4	1.0	0.4

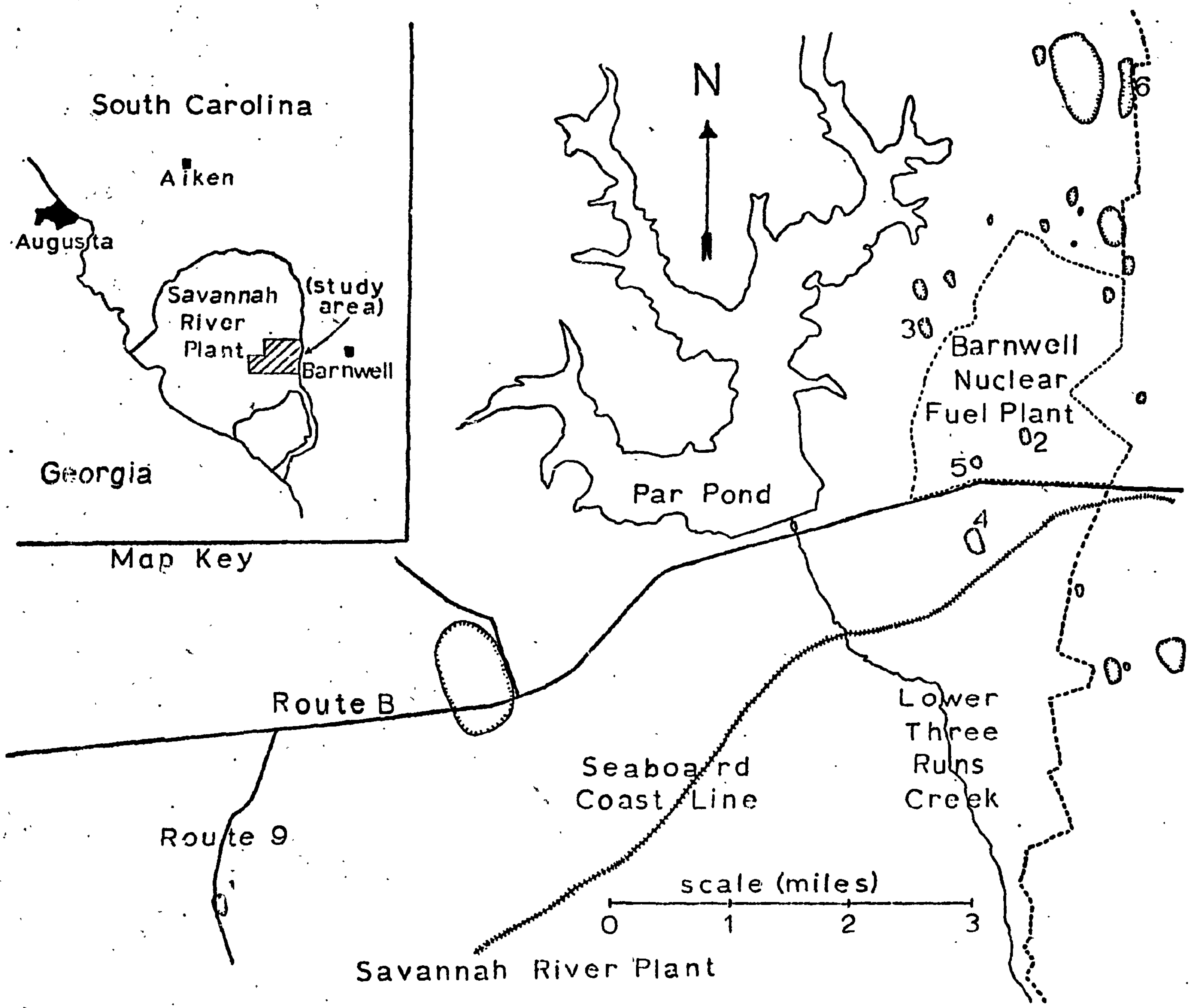


Figure 1. Location of the six Carolina Bays selected for study.

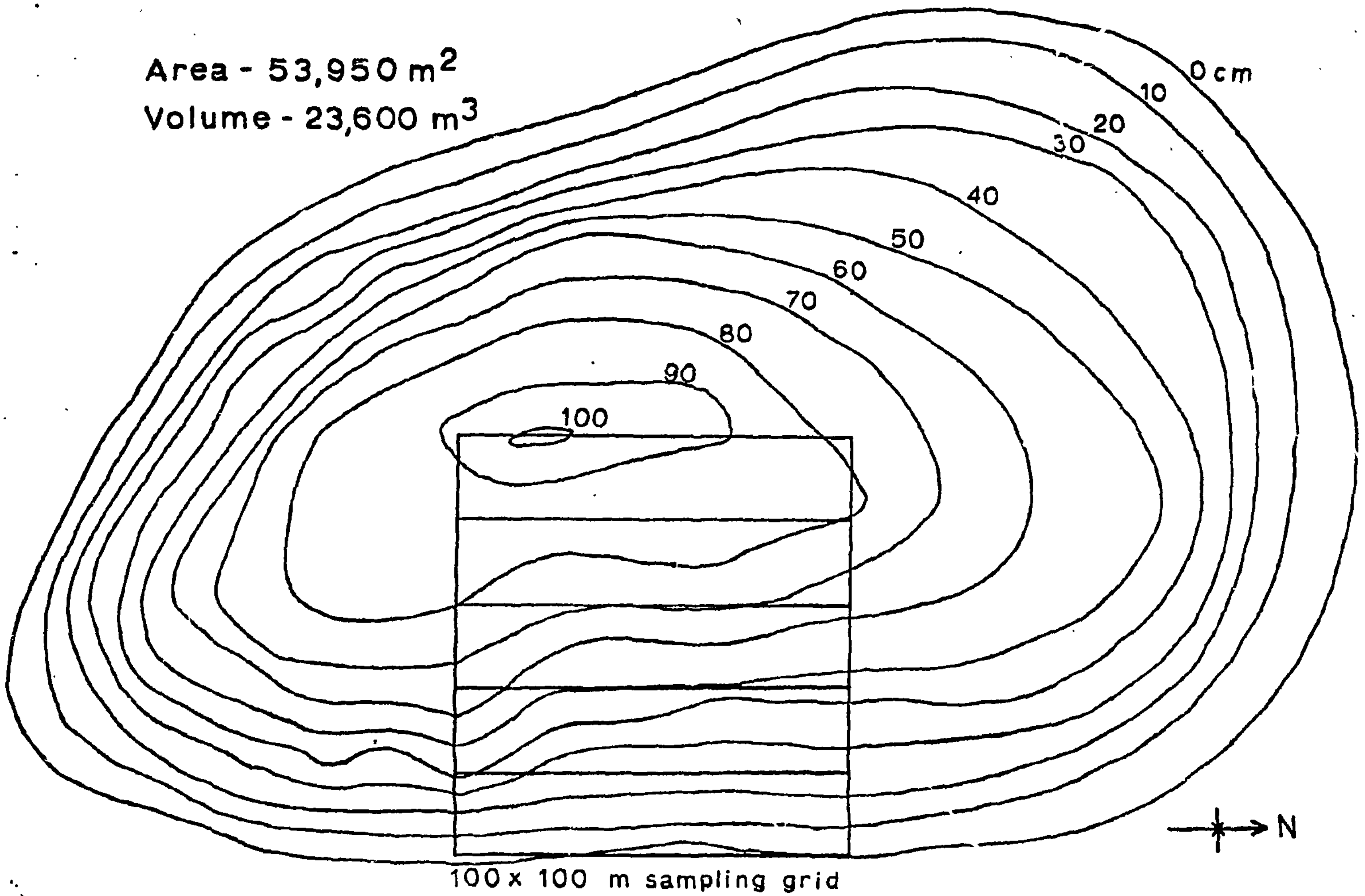


Figure 2. MORPHOMETRY OF THUNDER BAY
SAVANNAH RIVER PLANT, SOUTH CAROLINA

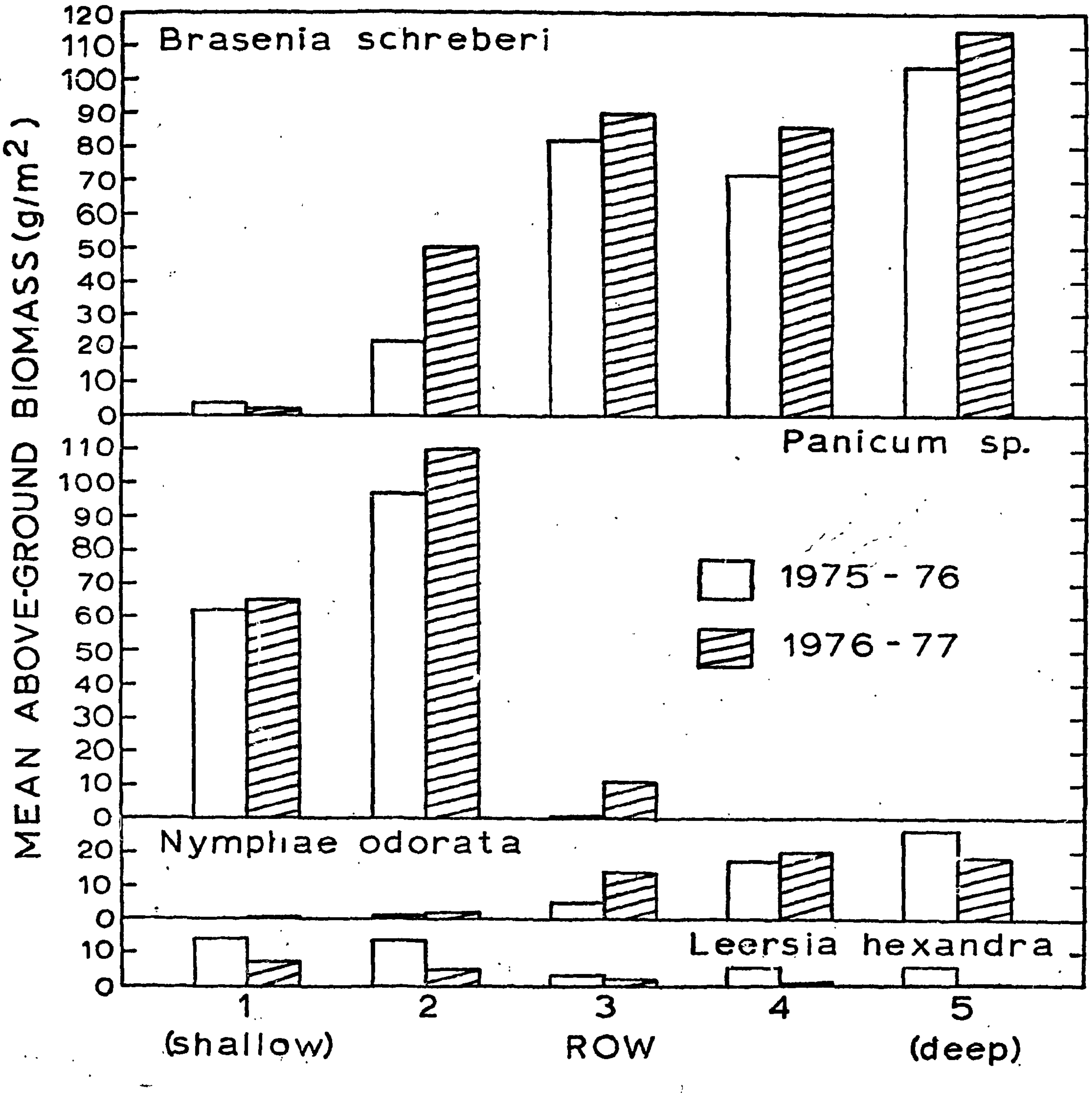


Figure 3. Distribution of aboveground biomass across the five sampling rows for the four most abundant macrophytes.

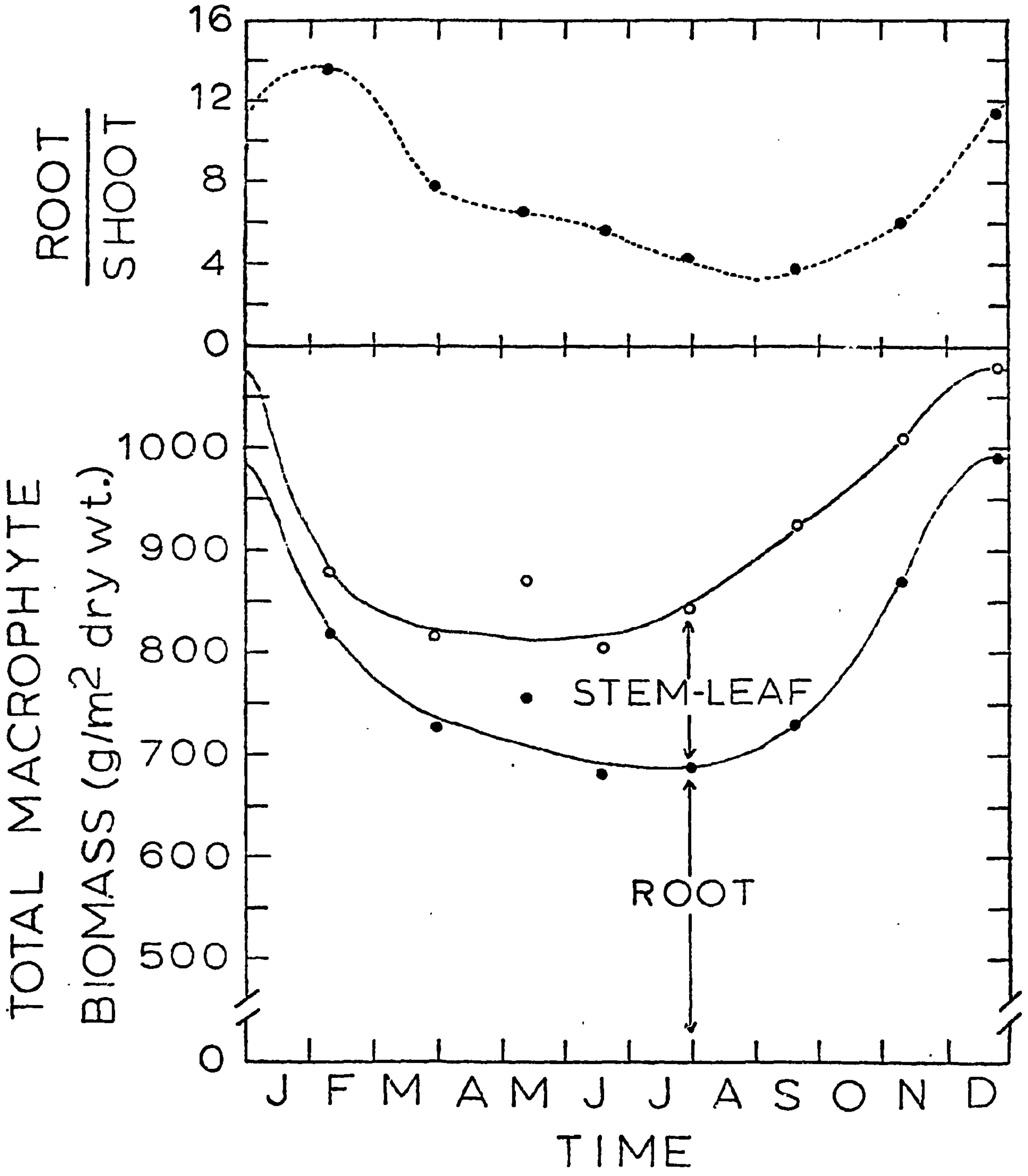


Figure 4. Summary of averaged standing crop of root and shoot components over an annual cycle.

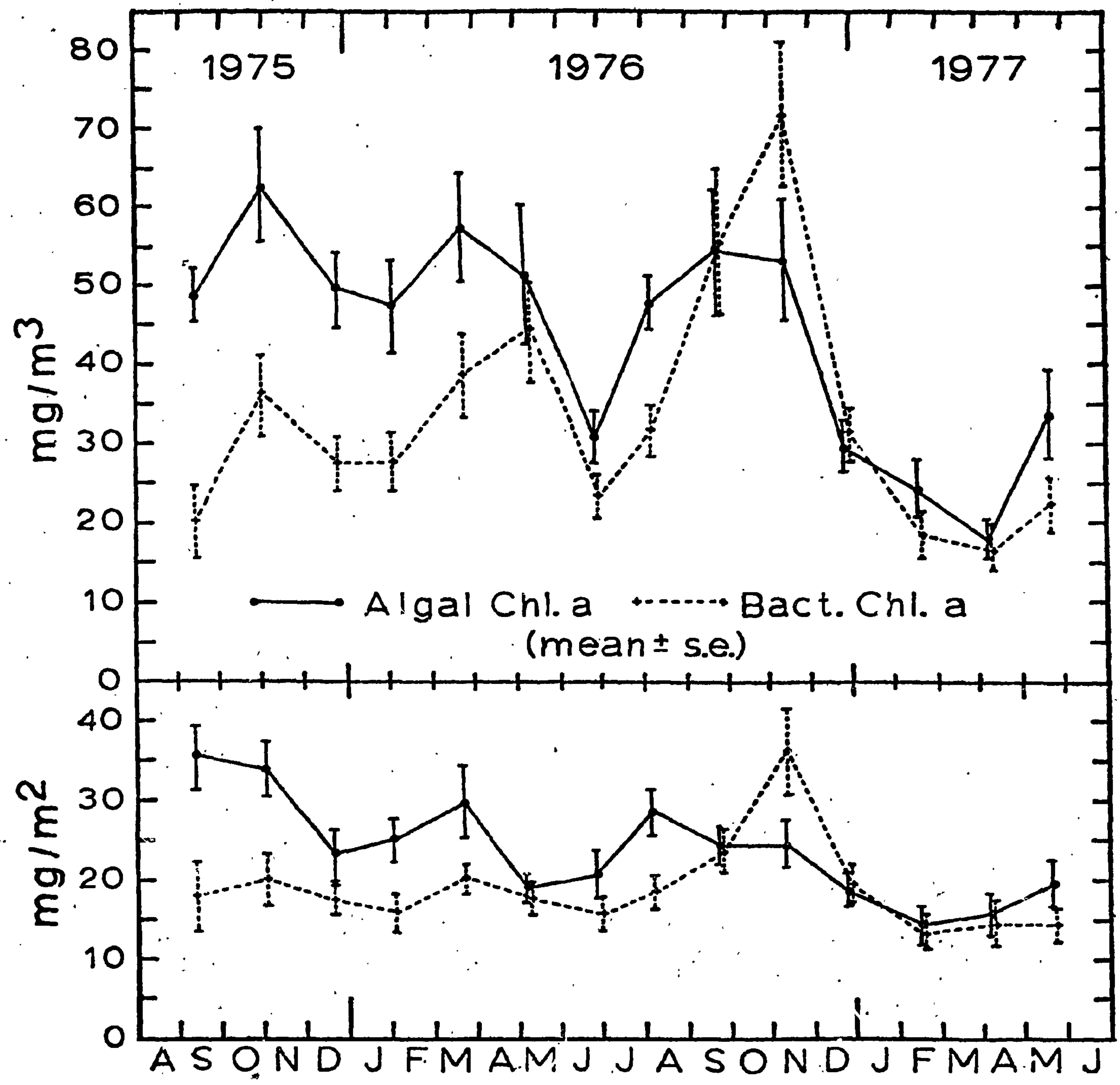


Figure 5. Means of algal and bacteria chlorophyll a densities for each sampling period ($\overline{X}$ ± s.e.).

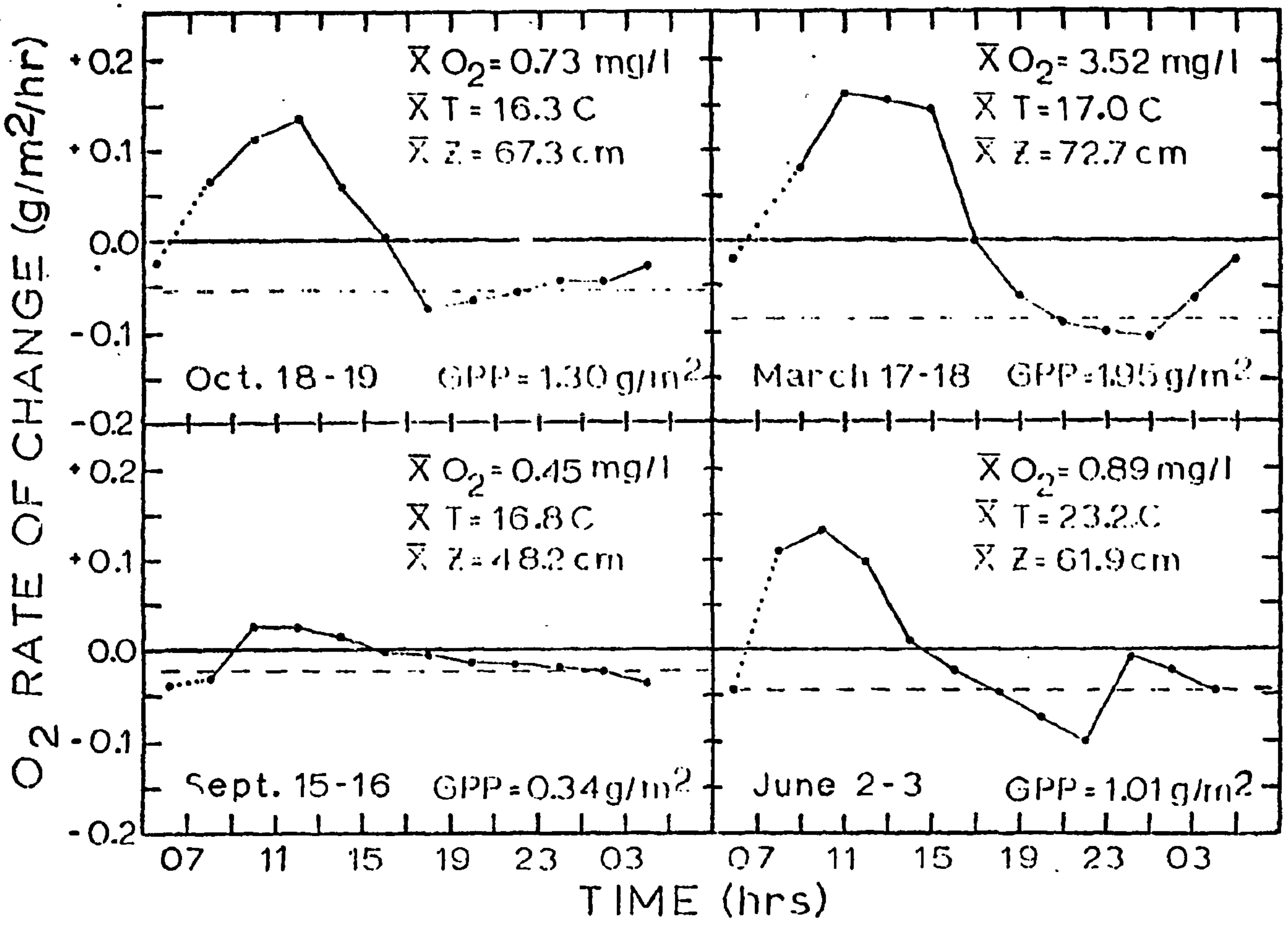


Figure 6. Results of the four sets of diurnal oxygen curves. Each data point represents the mean for 10 stations. The dashed line shows average night time respiration. Also shown are the means for all stations of oxygen, temperature, and depth over the 24 hr sampling period.

SUB-PROJECT I-D (Concluding Report)

TITLE: SOIL-VEGETATION INTERACTIONS IN FLOOD PLAIN FORESTS

AUTHORS: Harvey L. Ragsdale, John DuVall Hay, and Wendell Cropper

INTRODUCTION

This research program was initiated to understand a previously documented upstream-to-downstream gradient of decreased ^{137}Cs cycling and bioaccumulation in the forested floodplain of the nuclear reactor effluent stream, Lower Three Runs Creek. In this context two 100 hectare sites, representative of the upstream-downstream gradient of Lower Three Runs Creek, were established as sampling units. Contrary to the usual atmospheric pathway for fallout ^{137}Cs input to ecosystems, the Lower Three Runs corridor ^{137}Cs burden resulted from the stream water. Given that the initial ^{137}Cs burden in the floodplains resulted from stream water flooding of the flood plains and that there was a downstream gradient of decreasing ^{137}Cs bioaccumulation, we initiated a research program focused on the soil-plant root zone as the critical pathway for initial ^{137}Cs uptake and for subsequent recycling of ^{137}Cs. Our sampling program focused on analysis of soil parameters, ^{137}Cs recycling inputs to the forest floor, and flood plain geomorphology.

METHODS

A detailed description of the methods used in this study were reported earlier.

RESULTS SUMMARY

FLOOD PLAIN FORESTS

Soil - - In alluvial floodplains, soil is subjected to a cyclical pattern of wet and dry cycles throughout the year. In the southeastern coastal plain, the late spring through early winter is generally the period of low water levels, but at no time is the water table far from the soil surface. The water table was higher downstream, and the proximity of the water table to the soil surface alters pedogenic processes by producing anaerobic conditions and changing the physico-chemical properties of the soil. Soil pH was also related to the seasonal variation in water level. The highest acidity was in October, when the water table was the lowest. The higher water table downstream also produces a slowdown in the rate of organic decomposition which helps to explain the accumulation of soil organic matter at the downstream site.

Soils at the downstream site were acidic, had higher cation exchange capacity, exchangeable hydrogen, silt and clay content; while the upstream site had higher bulk density and sand content. These edaphic differences were consistent and permitted separation of these upstream to downstream floodplain sites by statistical techniques. As is common with floodplains in the coastal plain, the argillaceous component of the soil was not well developed and most of the clay size particles were fine quartz grains. There was a change in morphology of the statistical distribution of edaphic characteristics. At the upstream site, the edaphic parameters generally had a leptokurtic distribution, while downstream their distributions tended to be platykurtic. Subsurface soils reflected the patterns in surface soils, but generally had lower ion exchange capabilities and an increase in coarseness. It was also possible to distinguish between the surface and subsurface soils on the basis of their edaphic characteristics.

Flood Plain Sedimentation - - A method of floodplain growth, albeit slowly, is through sediment deposition on the floodplain surface. This accretion of sediment occurred at both sites, but was greater at the downstream site. Sediment deposition onto the floodplain is aided by tree bases, fallen branches and holes acting as sieves which strain the water column of floating organic debris and slow the water column, thus producing sediment deposition. These fine particulate surficial sediment deposits do not persist in the subsurface soil. This is reflected by the increase in bulk density in the subsurface soils.

Vegetation - - The arborescent vegetation component changes gradually along LTRC, both for the species encountered and the relative importance of the species sampled. The density of trees also decreased with increased distance along LTRC. This gradient is probably related to the increased water level downstream which limits the growth of some species. The herbaceous component of these floodplains was similar along LTRC, but qualitative differences in density occurred.

Leaf Litter - - Leaf fall was similar in timing and quantity at both sites. There was no area of highest leaf fall at either site. Leaf litter decomposition followed a logarithmic pattern at both sites; and the net effect of litter fall at both sites was accumulation of soil organic matter since the turnover time of leaf litter was greater than one year. Most of the weight loss in leaf litter is caused by fragmentation after the litter is the water column rather than by rainfall induced leaching.

Roots - - The root system of floodplain tree species is concentrated in the surface layers of soil, especially in the top 5 cm and can be exposed to air in upland areas of these floodplains. Sediment deposition onto the surface reduces the volume of root to soil, but regrowth through the newly deposited sediment layers is rapid. The root mat acts as an effective, dynamic floor for the floodplain, preventing windthrow of trees by the anastomosing and intergrafting pattern of root growth.

Fungi - - Fungi were collected from the major habitats present at each floodplain. The number of fungi present varied seasonally, with maximum numbers in summer and early fall. This was due to the environmental factors. Higher water levels in the winter and spring inhibit growth, and elevated temperatures in the summer and fall provided a favorable environment for fungal growth.

Soil Respiration - - Soil respiration also had a seasonal pattern with maximum values in the late summer and early fall, when temperatures were high and the water table was low. The downstream site had a greater amount of soil organic matter for utilization as substrate by soil microorganisms and this was reflected by higher soil respiration values.

^{137}Cs IN THE FLOODPLAIN FOREST

^{137}Cs Concentrations - - The Cs-137 concentrations of these floodplain systems generally was higher in biota upstream and higher in soil downstream. In the soil, Cs-137 was the major nuclide; and Co-60, K-40, U-series, and Th-series Isotopes were also detected. The downstream soil had a higher average concentration of Cs-137, but there was a wider range of Cs-137 concentrations upstream. The edaphic parameters most highly correlated with soil Cs-137 concentration were soil organic matter, cation exchange capacity, and clay content. In general, bulk density was the best predictor of soil Cs-137 .

The vertical profile of Cs-137 concentration in the soil was not similar to previously described patterns, since a linear regression provided the best fit for the data. This is probably a function of the pedogenic processes that occur during soil development in floodplains. Since floodplains can have soil deposition, soil particles with adsorbed Cs-137 had a greater probability of being incorporated into deeper soil layers. Subsurface soils at both sites had the same pattern for important correlates with soil Cs-137 concentration.

The Cs-137 concentration in leaf litter at both sites had a similar seasonal pattern, but the upstream site was consistently higher (5X). The ratios of Cs-137 concentration in roots:litter were similar along LTRC; but the absolute magnitude of Cs-137 present was different. This difference reflected the amount of Cs-137 taken up by root system. The mean Cs-137 burden in root material at the upstream site was 21 x higher than downstream, reflecting a decreased uptake of Cs-137 downstream. The difference in root Cs-137 concentration was consistent enough to be the best factor in separating these floodplain ecosystems with a multivariate analysis procedure. Within sites, the yearly mean Cs-137 concentration in branches and "other" tree components was similar to that for leaves, but the burden input was lower due to the lower amount of branch and "other" litter input to the floodplain surface. As for leaf litter, Cs-137 concentration in "other" litter was approximately 5 X higher upstream than downstream. Upstream, there was no across-or along-stream pattern for Cs-137 input via leaf fall, but downstream there was a tendency for Cs-137 concentration to increase with along-the-floodplain distance.

Most fungi present at these floodplains accumulated Cs-137. This was the major nuclide in the fruting bodies of the fungi, but Cs-134 and K-40 were also detected. Agaric fungi fruting bodies had the highest concentration of Cs-137 on these floodplains, and the maximum values recorded were higher than any previously reported sample from LTRC. Upstream, fungi or the soil-litter interface had the highest Cs-137 concentration, while downstream fungi collected from prone logs had the highest average Cs-137 concentration.

^{137}Cs DYNAMICS IN THE FLOOD PLAIN SYSTEM

Generally, in a downstream direction, floodplains tend to broaden and flatten, and this occurred along LTRC. The microtopographic variation upstream was greater than downstream, reflected on both the overall magnitude of elevational difference and in the change between adjacent points. The difference in microtopography probably was a reflection of preceding water flow at these sites. The upstream floodplain was dissected by several subchannels of the main stream channel which contained water flow throughout the entire year while the downstream site had intermittent channels that only had water flow during flooding conditions. The difference in water flow onto these floodplains also produced a different sediment deposition pattern at each site. Upstream, there was an increase in sediment deposition with a decrease in microtopographic elevation. Downstream, there was a decreasing sediment load deposited across the floodplain with the greatest material deposition on the higher areas nearest the stream channel.

There was not a strong correlation between microtopographic elevation and soil Cs-137 concentration on a point-to-point basis, but for areas of similar microtopographic elevation a predictive relationship was obtained. This relationship was a downward opening parapolic pattern which supports and extends a previous hypothesis about Cs-137 deposition onto these floodplains.

The microtopographic effect in these floodplains basically influenced the soil and sediment components since there was no microtopographic effect on the amount of leaves collected at either site, or in the Cs-137 concentration in the collected leaves. Also, the Cs-137 concentration in fungi collected from the soil-litter interface was not correlated with their relative microtopographic elevation. However, once leaf litter was deposited onto the floodplain surface there was a microtopographic effect. Litter deposited on more upland areas tended to remain in place; while litter deposited on lower areas was moved by flood waters. Upstream, the microtopographic placement of litter bags on the floodplain surface was negatively correlated with the overall amount of weight loss, but not the overall mean Cs-137 concentration. Downstream, there was no correlation between microtopography and weight loss or Cs-137 content. At both sites, litter immersed by floodwater lost more weight than litter only exposed to rainfall leaching.

The seasonal movement of Cs-137 into the leaf component was similar between sites, but the upstream site had consistently higher concentrations than downstream. The spring period had the highest accumulation with a secondary peak in the late fall, which agrees with previous results on Cs-137 uptake by trees. There was an apparent constancy between years in the amount of Cs-137 input to the floodplain forest via leaf fall, which indicated a stable cycle of Cs-137 in both floodplain forests. Tree uptake of Cs-137 apparently occurred through surficial root absorption since there were defineable differences in Cs-137 concentration of roots collected at the soil surface versus roots collected from subsurface soil. Once the

Cs-137 was present in trees along the LTRC corridor, within tree cycling was similar. Floodplain tree species apparently can effectively retain Cs-137 in their tissue since there was no correlation between the amount of rainfall and the Cs-137 concentration in leaf litter or a reduction in the Cs-137 content of leached components.

Leaf litter deposited on the floodplain surface initially had a decrease in Cs-137 content, and then increased in Cs-137 concentration while losing weight. This was due to the fragmentation of the leaf litter with the subsequent increase in sites for sorption of Cs-137. The final Cs-137 concentration in leaf litter on the floodplain surface was equivalent between upstream and downstream, even though the initial concentrations were 5 X different, the upstream pattern of Cs-137 concentration in leaf litter was dynamic, with uptake and release of the nuclide; while downstream only uptake of Cs-137 occurred after initial leaching. Upstream, the soil organic matter can act as a nutrient exchange surface for Cs-137 because of low potassium concentrations; but downstream, potassium in the soil and groundwater were exchanged; and Cs-137 was absorbed to ionic exchanges surfaces of the litter.

Fungi at both sites also cycle Cs-137, and several samples were collected with Cs-137 concentrations higher than previously reported for these sites. The fungi show a seasonal pattern of Cs-137 uptake and have their maximum concentration in the fall period, their period of maximal growth. Generally, the substrate had a lower Cs-137 concentration than the fungal fruiting body, indicating accumulation of this nuclide from the environment; but there was not always a correlation between fungi and substrate Cs-137 concentration. Since fungi can release bound potassium from soil minerals, it is possible that fungi on the soil-litter interface at the upstream site are releasing Cs-137 that is bound to soil particles in this low potassium environment. At the downstream site, the abundance of potassium inhibits the uptake of Cs-137 from the substrate or the release of absorbed Cs-137 from soil minerals. The Cs-137 uptake ratios varied with the type of fungi collected, but uptake ratios were similar between types and between sites. Within sites, bracket and agaric fungi had the same pattern of uptake from different habitats but had different patterns between sites.

IMPLICATIONS FOR Cs-137 CYCLING IN COASTAL PLAIN FLOODPLAINS

Our results suggest that a complex interaction of biotic and abiotic factors control Cs-137 dynamics in the floodplain forests along southeastern coastal plain streams. Differences in Cs-137 cycling, from upstream flux through the biota to downstream accumulation in the soil, can be related to a series of gradients (Fig. 1). A major difference was the microrelief of the floodplain forest. As floodplain microrelief decreased in a downstream direction, the predictability of edaphic characteristics in these floodplain soils increased. In a downstream direction, the surface soils became enriched in organic matter and fine particles which provided more exchange surfaces in the soil. The concentration of soil K also increased in a downstream direction. Subsurface soils at both locations reflected surface soils, and were distinguishable from surface soils on the basis of their edaphic characteristics. These gradients are probably reflective of similar ones to be found in other southeastern coastal plain streams.

A Cs-137 input to the upstream section of a coastal plain stream would be incorporated into the floodplain vegetation through its feeder foot system since low potassium levels in soil and groundwater would not inhibit Cs-137 uptake. Once into the vegetation, Cs-137 is cycled through previously defined cycling pathways. Since the density of plant feeder-roots is highest near or on the floodplain surface, Cs-137 recycling input to the forest floor, via throughfall or litter leachate, has a high probability of contacting exposed roots because the large microtopographic variation at the upstream site precludes sediment deposition onto all areas of the floodplain. Cycling of Cs-137 in upstream floodplains may also be aided by fungi which accumulate Cs-137 from various organic substrates. Therefore, Cs-137 present in vegetation at the upstream site, can be maintained at relatively high levels in the biota through the direct nutrient recycling pathways of shoot-(leaf, litter)-root-fungi or shoot-(leaf, litter)-root-shoot. Upstream, the recycling pathways by-pass the soil matrix.

Downstream, Cs-137 can also be incorporated into the vegetation component, but the quantity is reduced compared to upstream locations. This results from the higher potassium concentration in the soil and groundwater downstream. Once within the plant, Cs-137 distribution and within-plant cycling processes are similar to upstream areas. However, Cs-137 that is recycled within the downstream forest floor has a higher probability of being intercepted by organic and inorganic cation exchange surfaces of the soil rather than by a surface root mat. The reduced microtopographic relief downstream effects a uniform sediment deposition across the entire floodplain surface, which results in virtually complete and continuous coverage of the root mat. The fungal component downstream also is effective in accumulating Cs-137 but the concentrations are lower than those of fungi in upstream flood plain forests. Therefore, the Cs-137 cycled in downstream biota must follow the indirect nutrient cycling pathways of shoot-(leaf, litter)-soil-root-shoot or shoot-(leaf, litter) -soil-root-shoot. Both of these recycling pathways involve the soil matrix.

SUB-PROJECT II (Concluding Report)

TITLE: CHEMICAL ELEMENT CYCLING IN TURKEY OAK COMMUNITIES

AUTHORS: Harvey L. Ragsdale, John M. Croom, Wendell P. Cropper, Dennis Creech

SUMMARY-INTRODUCTION

This project was begun in 1973 to study the material flux patterns, particularly radionuclides, of the edaphically restricted and moisture constrained Turkey Oak - Sand Hill Ecosystem of the Southeastern Coastal Plain.

Environmental monitoring for the effects of atmospheric releases of chemicals should provide ecologically sound appraisal of the long term effects of these effluent releases to the atmosphere. Such effects in terrestrial systems are usually demonstrable in terms of specific chemical concentration rather than biological damage. This is increasingly true as release levels of both radioactive and stable elements generally have been lowered over the past few years. While atmospheric releases are subject to numerous fates, some of these materials wash out of the air and into natural terrestrial ecosystems where they become part of the chemical element cycling patterns of the terrestrial system and subject to the large watershed patterns of chemical element flux. It is the natural terrestrial ecosystem which provides long term integration of effluent releases which wash out of the atmosphere. Hence, natural terrestrial ecosystems theoretically can be used as "long term effects" monitoring stations to test for environmental accumulation and gradients from point and non-point sources. However, the use of naturally occurring ecosystems as long-term integrators of energy related effluents releases requires a basic understanding of the systems in functional terms of material flux dynamics.

Since our study of the Turkey Oak Ecosystem was initiated, we have progressed through site selection species identification, biomass determinations and the development of biomass predictor models, fallout ^{137}Cs and burden determinations, experimental system labeling with ^{134}Cs, and stable cation determinations. Monthly determinations have been conducted to identify material flux pathways and rates.

Two parts of this extensive project are summarized in this report. Part I is an analysis of structure and production of the Turkey Oak community in which we propose that these systems have attained "maximum persistent biomass" with nutrient conservation in the organic pool (40% of total organic structure) of litter and soil organic matter. Part II is a comparison of radiocesium burdens in Turkey Oak communities and our results show about 13% of the fallout ^{137}Cs burden in the vegetation. Turkey Oak uptake of soil applied ^{134}Cs suggested that the high annual rate of 2.5% uptake occurred in the 5-25 cm soil depth as opposed to the 0-5 cm soil depth. This analysis suggests that the root uptake can be the major mechanism for cesium bioaccumulation in Turkey Oaks.

RESULTS

Part I: Analysis of Structure and Production in a Turkey Oak (*Quercus laevis*) community

Community Structure

Fifteen species of trees and shrubs and 10 species of herbaceous plants have been identified as components of the turkey-oak community. The predominant tree species is the turkey oak, *Quercus laevis*. The only shrub is *Vaccinium* spp. (mostly *Vaccinium corymbosum*, the high bush blueberry). *Vaccinium* mostly occurs in thickets where tree stems are rare. The ground cover consists of the bracken fern (*Pteridium aquilinum*, ~1 m^{-2}) which occurs in rather uniform density in large patches, and root sprouts of *V. corymbosum* which occur in great density throughout the study area. Table I lists densities of trees and shrubs and their seedlings. Turkey oaks compose 87.6% of tree and shrub basal area.

Biomass of individual turkey oaks was best predicted (least squares sense) by the equations

$$\text{Wood wt} = 0.908 + 0.015\,(D30)^3 + 0.131\,(Ht)^2 \quad (r^2 = 0.984)$$

$$\text{Leaf wt} = 0.142 + 0.01534\,(D30)^2 + 0.004\,(Ht)^3 \quad (r^2 = 0.961)$$

where

D30 = stem diameter 30 cm above ground

Ht = tree height

These polynomial equations were developed by step-wise linear regression to identify the tree structural measurements (or their powers) best estimating the known dry weights of 13 trees and their components (branches, stems and leaves). Bole diameter 30 cm above ground was the key structural measurement in biomass prediction of both leaves and wood; in both equations it contributed more than 90% of the regression sum of squares.

Above ground biomass was estimated from the above equations and 330 live turkey oaks from six 10 x 10 m plots. Below ground biomass (roots) were estimated by sieving soil from 0.5 m^2 pits down to a depth of 1.5 m. Litter on the ground surface was estimated from 0.5 m^2 quadrat samples. Unit area biomass in the study area is summarized in Table II.

Production and Decomposition

The same turkey oaks used in the above biomass estimates (that were still living) were remeasured 2-1/2 years later and unit area biomass determined again. The net biomass increase was +1.0% or about 0.4% per year.

Litter production in the turkey oak community is ~400 g y^{-1} dry wt. Turkey oaks contribute ~85% of the total litter while Vaccinum and pines together contribute 10-12%. The other incidentally occurring trees contribute the remaining 3-5%. Turkey oak leaf litter is persistent on the forest floor where approximately 35% of the total litter standing stock decomposes each year. Microflora and fauna contribute ~15% to the total decomposition process.

Precipitation

Rainfall in the study area averaged 107.2 mm y^{-1} over the 2-1/2yr that data were collected. Through-fall averaged 90.8% of rainfall; it is that portion of rain that falls through the tree canopy to the forest floor. Stem flow averaged 4.2% of rain; it is that portion of rainfall that strikes leaves or branches, runs along a branch to the tree stem and then downward to the ground. Interception was the difference, 5.0%, between through-fall + stem flow and rainfall.

In 1975, O'Neill et al. proposed that ecosystems "attain maximum persistent biomass" in a paper entitled "A Theoretical Basis for Ecosystem Analysis with Special Reference to Element Cycling". Turkey oaks in the study area have apparently reached maximum biomass as net production is very low (<0.5% y^{-1}). 40% of this organic pool (litter and soil organics) is dead thus requiring no maintenance metabolic energy. The soil organics can perform the role of nearly absent cation-binding days. Hay (1976) demonstrated this phenomenon in a southeastern flood plain. The heavy litter layer reduces the rate at which rain water reaches the soil surface, hence reducing leaching rate of cations. We propose that this nutrient-poor, turkey oak community maintains maximum persistent biomass in an energy conserving strategy and that this strategy is coupled with nutrient retension and nutrient conservation.

TABLE I

DENSITIES AND PERCENT COMPOSITION (%) OF TREES AND SHRUBS

Species	Common Name	Mature Individuals stem/100 m^2 (%)	Seedling/stem m^2
Quercus laevis	Turkey Oak	55.0 (63.7)	0.49
Q. laevis (dead)	Turkey Oak	9.8 (11.3)	----
Vaccinium spp	---	17.0 (19.6)	42.81
Q. incanta	Blue Jack Oak	1.7 (2.0)	0.07
Q. alba	White Oak	0.5 (0.6)	0.01
Pinus palustris	Long Leaf Pine	0.3 (0.3)	<0.01
P. taeda	Loblolly Pine	0.3 (0.3)	<0.01
Prunus serotine	Wild Black Cherry	0.7 (0.8)	<0.01
Sassafras albidum	Sassafras	1.3 (1.5)	0.09
Total stems 100 m^{-2}		86.6 (100.1)	

TABLE II

UNIT-AREA BIOMASS OF TURKEY OAK STAND

Component	Wt (kg. dry)	% of Total
Leaves	0.51	39.4
Wood	4.44	
Litter	1.22	9.7
Soil Organic matter	3.90	31.1
Roots		
0 - 25 cm	1.72	
25 - 50 cm	0.50	19.8
750 cm	0.26	
Total	12.55	100.0

Part II: Root Uptake of $^{134,137}Cs$ Burden in Turkey Oaks (Querus laevis)

METHODS

^{134}Cs bioaccumulation by root uptake was estimated from a soil tagging experiment. A 5 x 6 m area containing five turkey oaks was raked clean of litter. Approximately 25 nCi/cm^2 of ^{134}Cs was applied in early April. Leaf litter was then replaced. Soil samples of 5 cm intervals down to 25 cm were taken during the growing season for estimates of soil activity. Branch and leaf samples from the upper and lower canopy of each tree in the tagged area provided estimates of changing ^{134}Cs burden from root-uptake.

Weights of individual trees were calculated from polynomial regression equations (Table I) of their wood and leaf components. Unit area turkey oak biomass was estimated from measurements on trees from six 10 x 10 m quadrats. The polynomial regression equations were developed by a step-wise regression program for leaf and wood components of 13 turkey oaks of different sizes. A series of structural measurments were made on each tree before harvesting, weighing and wet to dry weight determination.

Radiocesium determinations were decay and background corrected. Soil ^{137}Cs determinations were made on a GeLi system. Soil ^{134}Cs and all plant radiocesium determinations were made on well-type NaI detectors.

Unit-area soil burden estimates were corrected for density at the different sample depths. Concentration factors were calculated as per gram ratios of plant cesium concentration to associated soil cesium concentration.

RESULTS AND DISCUSSION

Cesium-134 concentration in turkey oaks increased during the growing season while ^{134}Cs distribution changed in both soil layers (Figure 1). The ^{134}Cs burden below 5 cm decreased while above ground plant burden increased as did the ^{134}Cs burden in the upper soil layer. We propose that root uptake decreased the ^{134}Cs burden below 5 cm where most turkey oak roots occur. Subsequent leaching from leaves by rain water and production of plant litter moved a portion of the translocated ^{134}Cs from the canopy to the soil surface. This resulted in a net gain of ^{134}Cs in the surface soil. By mid-September 2.52% of the ^{134}Cs applied to the soil had become incorporated in turkey oak tissues. Most of the ^{134}Cs remained in the upper 5 cm as reported in ^{137}Cs surveys of Gamble (1971) and McHenry and Richie (1975). Concentration of ^{134}Cs below 5 cm was negatively correlated ($r = -.542$) (sig. alpha = 0.1) with observed increases in plant tissue concentrations (Table II). This correlation is consistent with conclusions of Croom, Creech and Ragsdale (1975) that ^{137}Cs concentrations of turkey oaks and loblolly pine were related to the ^{137}Cs concentration of the 5-25 cm soil layer but not the ^{137}Cs concentration in the 0-5 cm soil layer. Also the majority of turkey oak roots are located between 5-25 cm soil depth.

Radiocesium concentration factors of turkey oaks as indicated by mean plant activity to mean soil activity are different for ^{134}Cs and ^{137}Cs, (Table III) and ^{137}Cs concentration factors are high in comparison to those compiled by Dahlman et al (1975). In Table III, concentration factors are listed for ^{134}Cs and ^{137}Cs for three different soil layers. When activity in the 0-15 cm soil layer is considered (Garten et al., 1975), the ^{137}Cs concentration is higher than for any trees they reported from a contaminated flood plain. Absolute radiocesium concentration is higher in leaves than branches for both ^{134}Cs and ^{137}Cs (Table IV). But a larger percentage of the unit area burden above ground is in wood (80%) rather than leaves (20%) and is not different for ^{134}Cs and ^{137}Cs (Table IV) ($\alpha = 0.05$).

From Table V it is evident that radiocesium burdens in turkey oaks, ~2.5% for ^{134}Cs and 12.9% for ^{137}Cs, differ. The ^{134}Cs burden represents one growing season accumulation from root uptake and is probably not different from the 2.8% transfer rate reported by Cummings et al. (1969). Both rate constants estimate growing season root uptake by vegetation on the experimental plots. Extrapolations per gram vegetation uptake rates from the experimental plot to community standing crop estimates of turkey oaks results in a unit area uptake rate of ^{134}Cs of ~8%.

Above ground ^{137}Cs burden in turkey oaks was estimated to be 15.87 nCi/m^2 or approximately 12.9% of the total ecosystem unit area burden of 122.97 nCi/m^2 which is consistent with the average watershed activity of 123.9 nCi/m^2 reported by McHenry and Richie (1975). Activity in both leaves and branches 26 months after applying ^{134}Cs to the soil, was about two times greater than activity 2 months after the tag (Table 6). If uptake during the remainder of the growing season equals that of the growing season after tagging, above ground

^{134}Cs burden will be ~15%. But uptake of ^{134}Cs by turkey oaks obviously changes over time as evidenced by the change in its distribution in the soil column. Activity below 5 cm is more than 2.5 times greater 26 months after tagging, than it was 2 months after tagging. If rates of uptake had remained constant over time, ^{134}Cs distribution should not have changed so dramatically.

We hypothesize that this high ^{137}Cs vegetation burden resulted from an equally high soil to plant cesium transfer rate as measured by ^{134}Cs uptake. Root uptake, then, can be the major mechanism for cesium bioaccumulation in turkey oaks rather than foliar absorption as concluded by Dahlman et al. (1975), who estimated that only 10-30% of vegetation cesium burden was the result of root uptake. The high rate constant of ^{134}Cs uptake by turkey oak roots that we have found is plausible because of

(1) absence of strongly fixing clays in the soil column - the soil column is only ~3% kaolinite.

(2) acidity of the soil - pH~4.5 which increases the availability of all cations in the soil column.

(3) slow leaching rate of radiocesium (and perhaps all cations) through the soil column because of its retention in the upper soil layer perhaps by organic material.

On the basis of our analysis, we conclude the following.

(1) Concentration of ^{134}Cs in turkey oaks is related to ^{134}Cs concentrations in the 5-25 cm soil layer but not the 0-5 cm soil layer where most of the ^{134}Cs remained.

(2) Radiocesium concentration factors in turkey oaks are different for tag ^{134}Cs and fallout ^{137}Cs. Compared with literature concentration factors of ^{137}Cs, both are quite high.

(3) Approximately 2.5% of the applied ^{134}Cs had become incorporated in above-ground plant tissue by growing season end. This high cesium transfer rate is hypothesized to account for the high vegetation burden, 12.9%, of ^{137}Cs calculated for a sand hills community.

TABLE I

POLYNOMIAL REGRESSION EQUATIONS FOR

PLANT COMPONENT WEIGHT ESTIMATIONS

$$\text{WOOD WT} = -0.908 + 0.015\ (\text{D30 cm})^3 = 0.131\ (\text{Ht})^2$$

$$R^2 = 0.984$$

$$\text{LEAF WT} = -0.142 + 0.01534\ (\text{D30 cm})^2 + 0.0040\ (\text{Ht})^3$$

$$R^2 = 0.961$$

TABLE II

CORRELATION COEFFICIENT OF PLANT CONCENTRATION AND SOIL LAYER CONCENTRATION OF 134-Cs AT GROWING SEASON END

SOIL LAYER	R
0-5 cm	+0.173
>5 cm	-0.542

TABLE III

RADIOCESIUM CONCENTRATION FACTORS FOR DIFFERENT SOIL LAYERS

MEAN PLANT (LEAVES AND STEMS) gm^{-1}/MEAN SOIL gm^{-1}

SOIL LAYER	134-Cs	137-Cs
5-25	190.9	25.7
0-25	10.4	12.3
0-15 (AS GARTEN ET AL, 1975)	5.9	7.9

TABLE IV

PLANT COMPONENT CONCENTRATIONS OF RADIOCESIUM AT END OF GROWING SEASON

	134-Cs	137-Cs
LEAF:pCi/gm	6975	6.52
%	17.1	21.1
BRANCH:pCi/gm	4125	2.82
%	82.9	78.9

TABLE V

COMPONENT BURDEN OF RADIOCESIUM IN THE TAGGED PLOT AT GROWING SEASON

COMPONENT	^{134}Cs % of Total	^{137}Cs	% of Total
VEGETATION	2.52	15.87 nCi/m^2	12.9
SOIL	97.48	102.88 nCi/m^2	84.5
LITTER		3.22 nCi/m^2	3.6
TOTAL BURDEN		122.97 nCi/m^2	100.0

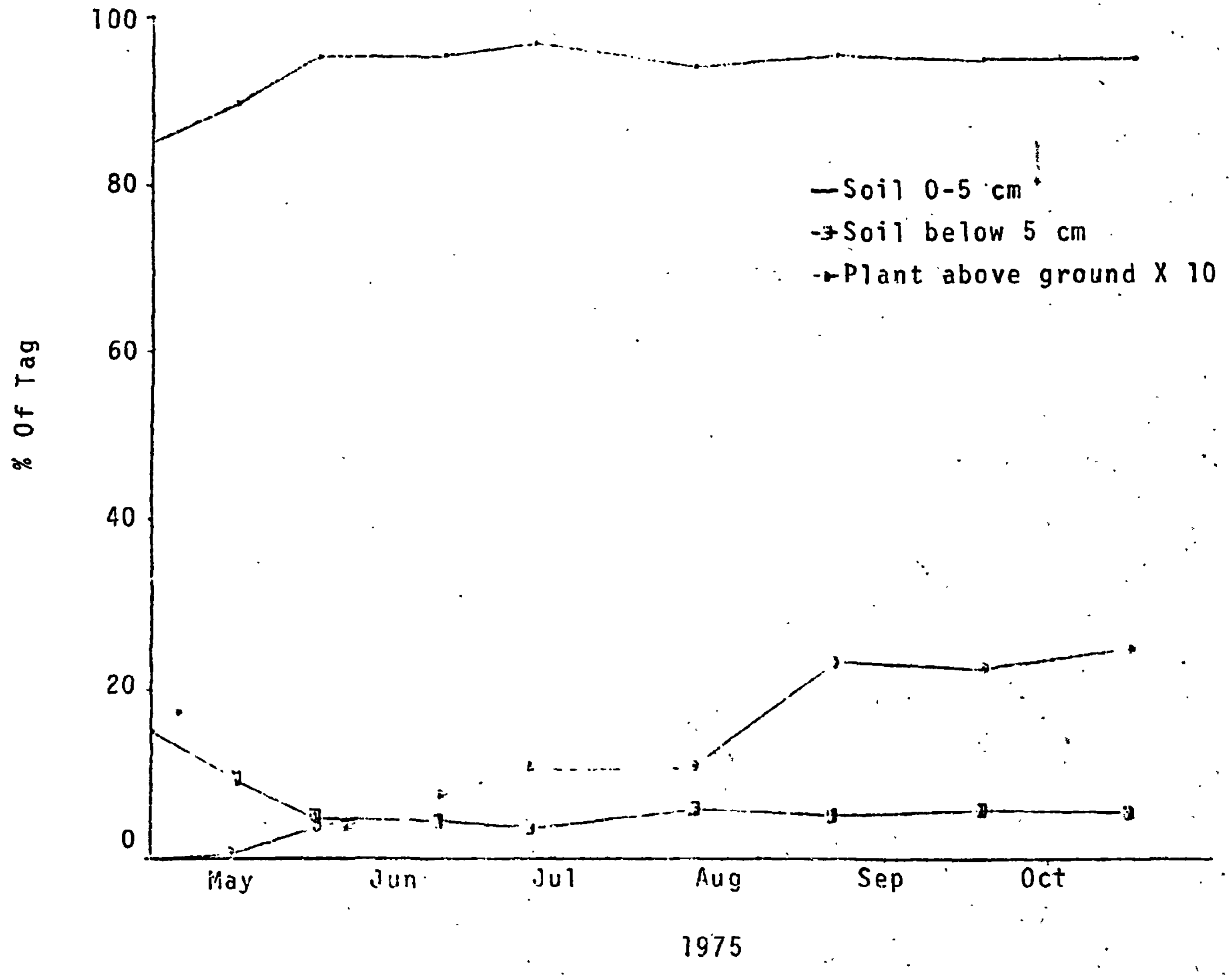
TABLE VI

^{134}Cs ACTIVITY AND DISTRIBUTION IN TURKEY OAKS AND SOIL 2 AND 26 MONTHS AFTER TAGGING

	JULY 1975	JULY 1977
ACTIVITY (pCi g^{-1})		
LEAVES	2300	5100
BRANCHES	1700	3000
RELATIVE DISTRIBUTION		
SOIL 0-5 cm	95.4	88.4
SOIL BELOW 5 cm	4.6	11.6

Fig. 1

ROOT UPTAKE OF ^{134}Cs



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SUB-PROJECT III ADAPTATION OF NATURAL PLANT COMMUNITIES TO CHRONIC, LOW-LEVEL SULFUR DIOXIDE STRESS.

W. H. Murdy

INTRODUCTION

This project was initiated to assess the impact of chronic, low level SO_2 on natural plant communities. Research on SO_2 effects on plants has involved mostly a study of individual plants of agronomic or ornamental importance from the standpoints of morphology, physiology and yield. Most SO_2 studies with plants have dealt with damage to vegetative parts. However, it is unlikely that the levels of SO_2 are high enough in the Copper Basin or elsewhere to alter significantly plant communities solely by differential damage to vegetative parts.

Sulfur dioxide as an environmental stress factor may differentially influence the survival of species and thereby cause changes to occur in plant communities and entire ecosystems. Also, SO_2 may serve as a selection agent to induce the evolution of SO_2-tolerant populations within species not inherently tolerant of SO_2. Natural communities within the Copper Basin of Tennessee have experienced SO_2 as an environmental stress factor for the past 75 years. Thus, the Copper Basin is a principal source of many of the populations used in this project.

The completed experiments described below deal with SO_2 effects on sexual reproduction. There is considerable evidence from *in vitro* studies to suggest that phases of sexual reproduction, such as pollen germination on exposed stigmas and pollen tube growth. are highly susceptible to injury from air pollutants at concentrations below national ambient air standards and below those which cause obvious damage to vegetation. Sulfur dioxide induced injury to sexual reproduction may not affect the survival of contemporary individuals, but may lower their reproductive potential and thereby affect the survival of populations.

Dose-response experiments have been carried out using two species, Geranium carolinianum, a ubiquitous, weed species, which does not occur in the Copper Basin, and Lepidium virginicum, also a ubiquitous, weed species but one that thrives in the Copper Basin, in order to test the following hypotheses:

1) Species whose reproductive processes are susceptible to SO_2 injury may be excluded from a region, like the Copper Basin, subject to prolonged SO_2 stress.

2) Species which thrive in a region of prolonged SO_2 stress are able to do so because their reproductive processes are tolerant of SO_2 in:
   a) all members of the species (a species specific trait); or
   b) only populations of a species which occur in the region of an SO_2 stress (an ecotypic adaptation).

METHODS

Populations of 4 species (*Lepidium virginicum*, *Plantago lanceolata*, *Daucus carota*, and *Melilotus officinalis*) have been sampled from inside and outside of the Copper Basin. Sampling consists of collecting a minimum of 50 mature seeds from an average of 22 plants chosen without bias at a particular site. For example, sampling in the case of *Lepidium virginicum* involved 158 individuals from 7 populations inside of the Copper Basin and 217 individuals from 9 populations outside of the Copper Basin.

Experimental subjects are grown from seed under uniform conditions. Experiments are performed within a fumigation chamber when plants are at anthesis. The chamber consists of a 3-square-meter, air tight acrylic box equipped with lights, fan, inflow and outflow ports and an opening for a monitoring probe. Sulfur dioxide is bled into the chamber from a SO_2-permeation tube placed within a tube holder, which is in turn submerged in a constant temperature water bath. Concentration is regulated by the size and wall thickness of permeation tubes and by water bath temperature. The concentration of gas within the chamber is monitored continuously with a Beckman 906A, SO_2 analyzer.

Authorization to purchase the SO_2 analyzer was not given until the first of the year. Delays in shipment and a necessary period of "shake down" to get it in good working order meant that experiments could not begin until April, 1977. Thus, the results given below involve only about 5 months of w

Before experiments were performed on the effects of SO_2 on sexual reproduction in Lepidium virginicum and Geranium carolinianum, it was necessary to determine the nature of sexual reproduction in these species as it relates to: floral morphology, sequence of anthesis, potential for self and/or cross pollination, and sequence of fruit and seed development. The results of observations and experiments on these two species are given in Appendices 1 and 2.

Lepidium virginicum

Experiments with this species, which grows successfully inside and outside of the Copper Basin, show not only that SO_2 has an adverse effect on sexual reproduction, but that the effect is greater in populations from outside of the Copper Basin than in those from inside. Such findings suggest that in the Copper Basin region of SO_2-stress, populations of Lepidium virginicum have evolved, which tolerate SO_2 during sexual reproduction better than conspecific populations in regions lacking SO_2 stress.

Lepidium inflorescences are racemes in which new flowers are continuously produced at the tip while fruits mature at the bottom. At the start of an experiment, an inflorescence is marked by excising a flower at a stage of development where the ovary equals in size the perianth parts (Figure 1, A1). One week after the experiment, the ten fruits immediately above the pedicel of the excised flower are scored for the number of abortive fruits (Figure 1, B2).

Table 1 presents data from control and fumigation experiments for 5 populations. Dose was 0.8 ppm SO_2 for 9 hours. The first

3 populations originate from inside of the Copper Basin, the last 2 from outside. All populations have a similar number of abortive fruits in control experiments - an average of 6.7%. Chi Square contingency analysis showed no difference ($p>0.95$) among controls. This is identical to the percentage of aborted fruits in fumigated inflorescences below the excised flower, which is 73 of 1094, or 6.67%.

In all populations, at the dosage used, there is an adverse effect of SO_2, with fumigated inflorescences having at least 2X more abortive fruits than controls. The results for all comparisons below were found to be highly significant ($p<0.005$) in Chi Square contingency tests. Furthermore, the two populations from outside of the Copper Basin had the greatest deviation between control and fumigated with 4 to 8 times more aborted fruit in the latter. Experiments are in progress at lower doses, which will allow a more precise estimate of the lowest level of SO_2 stress to cause an adverse effect on sexual reproduction.

Lepidium inflorescences differ in the number of flowers at the same stage of anthesis while another on the same plant may have only one or two flowers in anthesis. Thus, a prolific inflorescence may have a greater number of aborted fruits as a result of a fumigation than one less prolific. This problem can be circumvented by comparing inflorescences as to whether or not an effect greater than background occurs. The number of aborted fruits in control inflorescences is 0.067. Thus, a conservative assumption would be to consider one aborted fruit out of the 10 scored fruits to represent "no effect" and to compare populations in terms of the percent inflorescences with two or more aborted fruits, which represents an effect. These data are presented in Table 2 and illustrated in Figure 2. The two populations from outside of the Copper Basin have control values similar to the rest, but fumigation values are very divergent from their controls. Deviation from control is the important value, since populations may vary in their background levels of aborted fruits.

Geranium carolinianum

Experiments with this species, which appears to be excluded from the Copper Basin, show that an adverse effect on sexual reproduction when plants are fumigated for 9 hours at 0.8 ppm but not at 0.6 ppm SO_2. Also, at this dose, SO_2 has an adverse effect on processes of sexual reproduction which occur on the day of anthesis and on the first and second days following anthesis.

A number of experiments were done using different plants for control and fumigation experiments before it was discovered that individual plants may differ considerably in fertility. A design was therefore worked out whereby the same plants were used for both control and fumigation experiments. Individual flowers were labeled in the morning and plants placed in the chamber for a 9-hour control. The next morning, another set of flowers on the same plants were labeled and plants placed in the chamber for fumigation. Five days later fruits of labeled flowers were scored for the number of successful fertilizations. Plants which did not produce fruit under control conditions were eliminated from the data.

Results of experiments at 0.4, 0.6, and 0.8 ppm SO_2 for 9 hours are presented in Table 3 and illustrated in Figure 3. There was no significant difference in fertility between control and fumigated flowers at concentrations of 0.4 and 0.6 ppm SO_2, but at 0.8 ppm, the fumigated flowers were significantly less fertile than control flowers. The latter result is probably due to direct effects of SO_2 on processes of sexual reproduction, which occur on the day of anthesis (pollination and pollen germination). However, there is a significant difference in fertility between control plants used in the 0.4 and 0.6 ppm experiments and those used in the 0.8 ppm experiments. This is probably due to effects of SO_2 on pollen tube growth and fertilization, processes of sexual reproduction which occur on the day following anthesis.

Results of a set of experiments involving two consecutive controls followed by a fumigation support the idea that SO_2 has an adverse effect on sexual reproduction processes, which occur one and two days after anthesis (Table 3). Plants fumigated at 0.8 ppm SO_2 for 9 hours on the day of anthesis had twice as many fertilized ovaries as plants fumigated one or two days after anthesis.

These results are quite significant in terms of the current national ambient air standards for SO_2 which allow exposures up to 0.8 ppm. For example, the 24 hour average maximum concentration is 0.14 ppm SO_2 and this average allows 5 hours exposure at concentrations up to 0.7 ppm or 4 hours exposure at 0.8 ppm. Based on the results reported here - that fertility was reduced following a 9 hour SO_2 fumigation at 0.8 ppm, but not at 0.6 ppm - it is essential to determine:

1) the actual concentration above 0.6 ppm at which an adverse plant response occurs:
2) the shortest interval of time at the critical concentration; and
3) the phase of sexual reproduction most vulnerable to SO_2 pollution.

TABLE 1. Percent aborted fruit in inflorescences of *Lepidium virginicum* populations fumigated for 9 hours with 0.8 ppm SO_2 and controls.

POPULATION	CONTROL			FUMIGATED		
	Total fruit	Aborted fruit N	%	Total fruit	Aborted fruit N	%
Inside Copper Basin						
6/29/5	140	8	6%	70	15	21%
8/3/5	80	4	5%	310	41	13%
6/29/6	80	6	7.5%	70	9	13%
	300	18		450	65	
Outside Copper Basin						
7/12/9	310	22	7%	90	51	57%
7/1/8	50	4	8%	70	23	33%
	360	26		160	74	

Chi Square Contingency Tests

Inside population vs. outside population for control fumigation $x^2 = 0.393$ $(p>0.95)$

Inside population vs. outside population for SO_2 fumigations $x^2 = 67.86$ $(p<0.005)$

Control vs. SO_2 fumigation for inside population $x^2 = 13.04$ $(p<0.005)$

Control vs. SO_2 fumigation outside population $x^2 = 108.6$ $(p<0.005)$

TABLE 2. Percent inflorescences in *Lepidium virginicum* populations with 2 or more aborted fruits.

POPULATION	CONTROL		FUMIGATED	
	N	%	N	%
Inside Copper Basin				
8/3/5	8	0	31	26
6/29/5	14	21	7	29
6/29/6	8	12	7	43
Outside Copper Basin				
7/1/8	5	0	7	86
7/12/9	31	23	9	100

TABLE 3. Percent flowers of *Geranium carolinianum* with successful fertilizations in control and fumigation experiments of different dosages.

DOSE	CONTROL		FUMIGATED	
	N	% Fertilized	N	% Fertilized
0.4 ppm SO_2, 9 hrs.	27	56	36	61
0.6 ppm SO_2, 9 hrs.	8	62	22	59
0.8 ppm SO_2, 9 hrs.	46	24	38	13

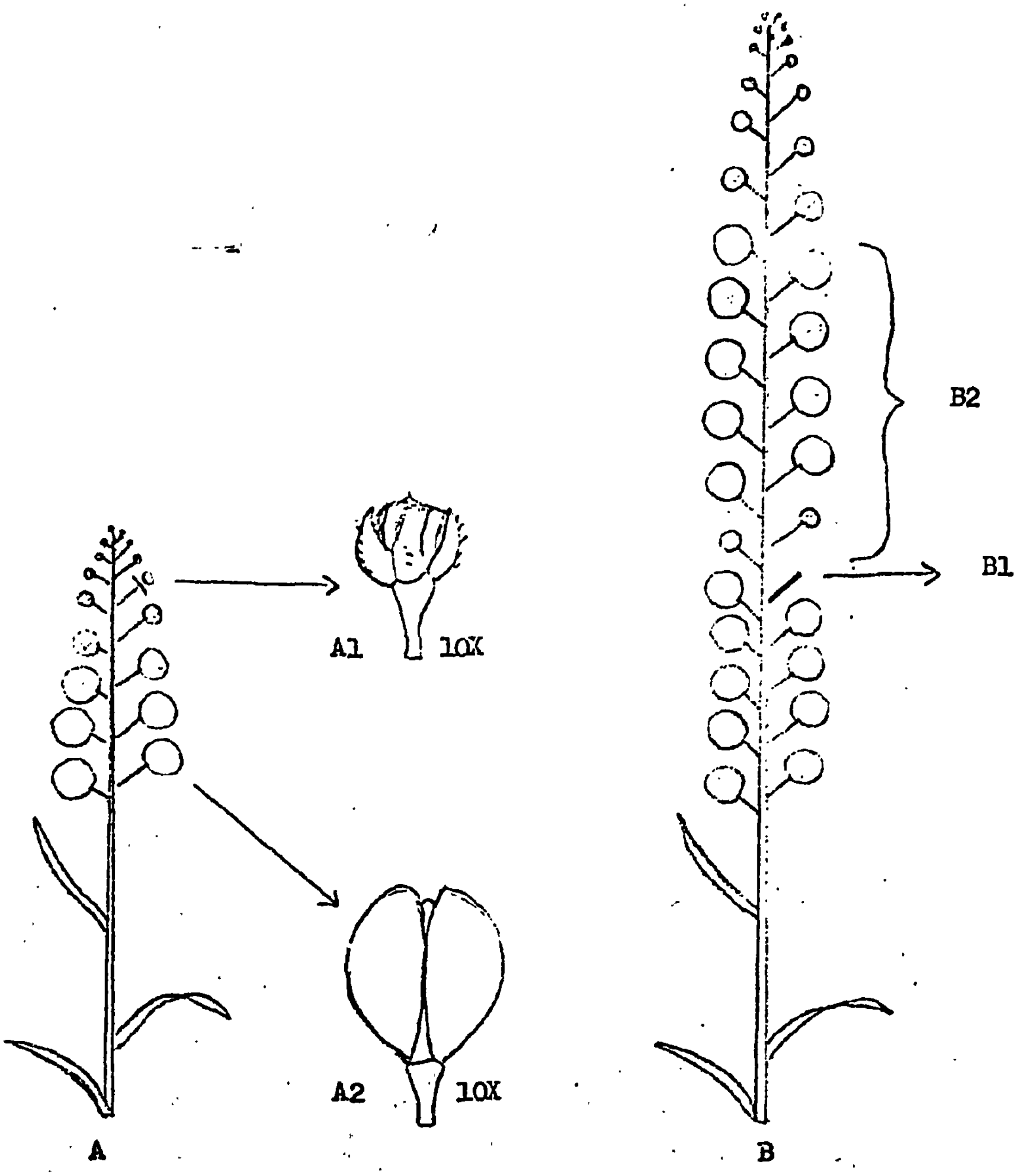


Figure 1. An inflorescence of Lepidium virginicum: A, at the start of an experiment; and B, one week later. A1, excised flower; A2, maturing, normal fruit; B1, pedicel of excised flower; B2, location of fruits scored at the completion of the experiment.

Figure 2. Percent inflorescences of *Lepidium virginicum* populations with 2 or more aborted fruits. The symbols and denote control and fumigation experiments respectively. The first three populations are from inside, and the last two from outside, of the Copper Basin.

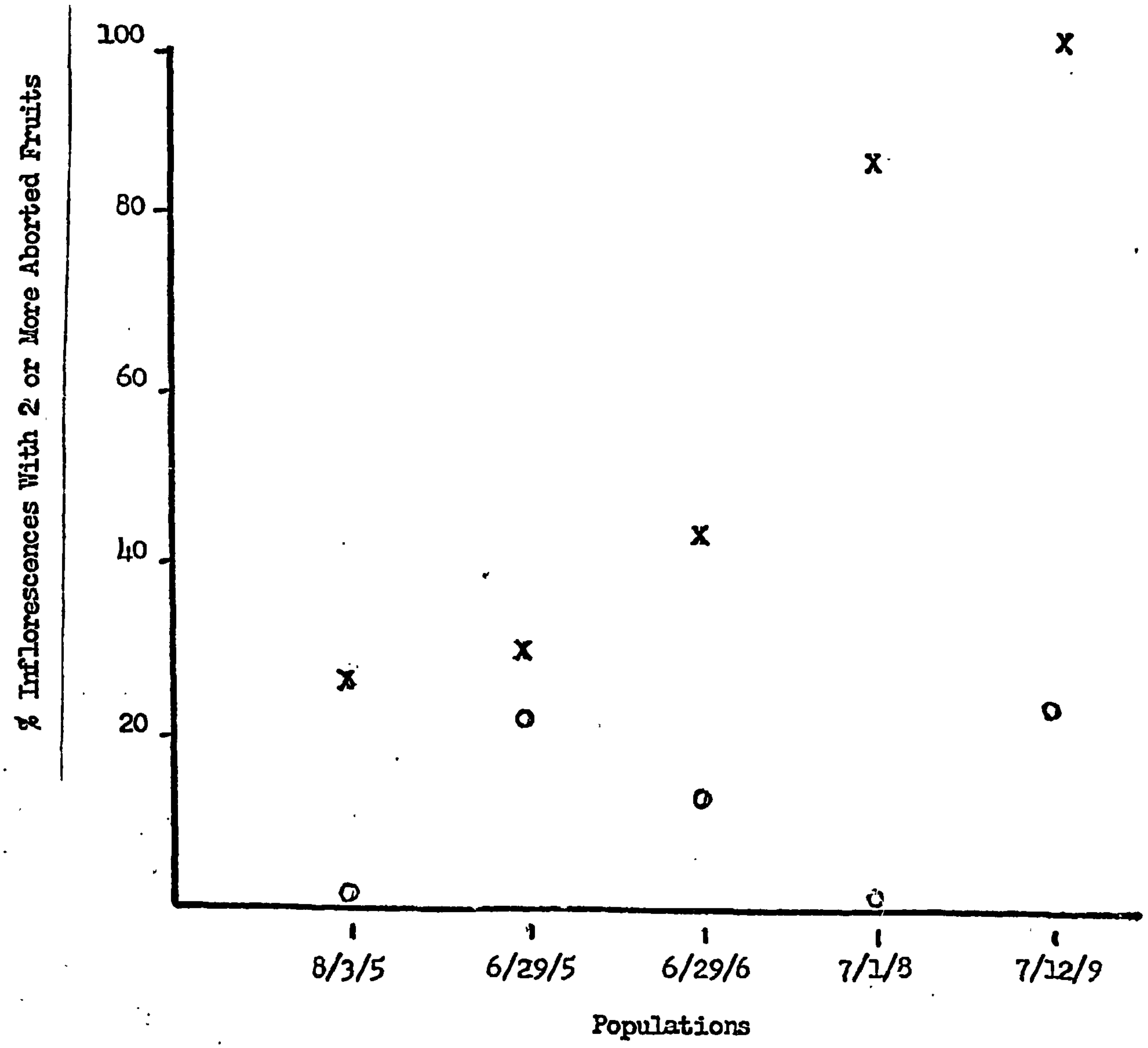
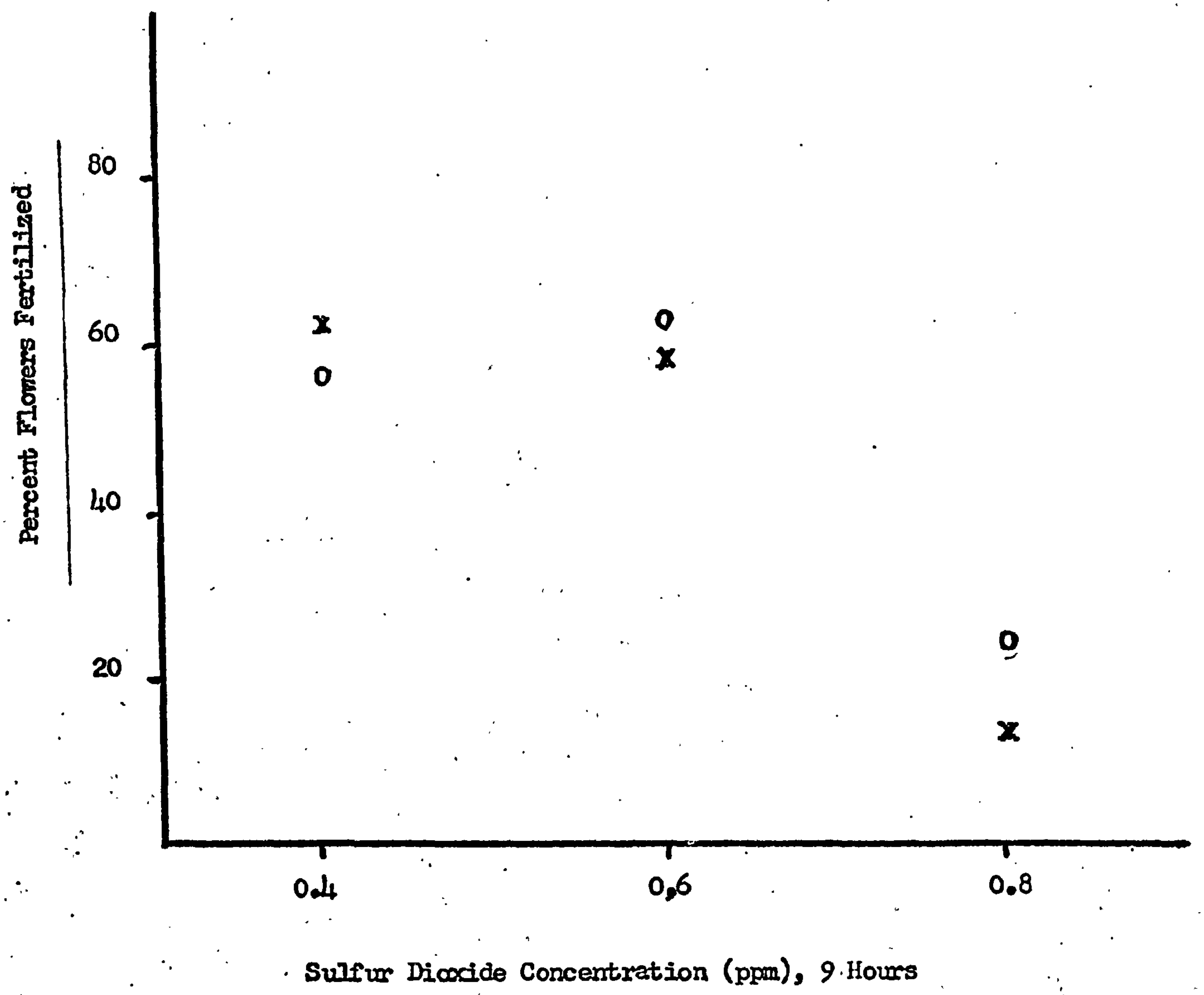


Figure 3. Percent flowers of Geranium carolinianum which become fertilized in control (O) and fumigation (X) experiments at different dosages.



APPENDIX 1: Floral Morphology and Anthesis in *Geranium carolinianum* L.

The floral morphology of this species is typical of the genus *Geranium*: five sepals, five petals, ten fertile stamens and five distinct stigma lobes. The androecium consists of two whorls of five stamens each, the inner whorl alternating with the stigma lobes.

The first indication of anthesis is the unfolding of the calyx. The corolla is funnel-shaped with an opening at the apex. The stigma lobes are immediately visible and are divergent from one another. The androecium remains appressed to the style and is not mature. As the corolla unfolds slowly, both whorls of anthers become visible. The stigma is receptive to pollen deposition at this time, and successful fertilizations are achieved.

As anthesis continues, the inner whorl of anthers begins to dehisce in sequence around the flower. The outer whorl follows. As a result of the divergence of the stigma lobes and the elongation of the androecial filaments, the inner ring of anthers is projected slowly between the stigma lobes and eventually above the gynoecium. During the elevation of the anthers, the anther sacs may touch the lateral sides of the stigma lobes. Once above the gynoecium, the elevated anthers coalesce and eventually absciss, falling on the stigma lobes.

This sequence of maturation is partial or overlapping dichogamy in which the gynoecium is receptive prior to the maturation of the andoecium. *G. carolinianum* is therefore protogynous.

The sequence of events during anthesis may be categorized as follows:

1. unopened bud
2. initial bud opening
3. appearance of corolla apical margins
4. appearance of divergent stigma lobes
5. appearance of inner whorl of androecium
6. appearance of outer whorl of androecium
7. anther dehiscence
8. elevation of inner whorl of androecium
9. coalescence of inner whorl of androecium above stigma lobes
10. anther abscission

Under optimum field conditions (bright, sunny day) in early May, anthesis begins in the early morning (0800-0900 hours) and is complete by mid-day. The flower remains open throughout the day, however, by 1600 hours the petals wilt and fall. The above description applies to the majority of flowers in bloom on any given day. There is some variation in initiation of anthesis; a few flowers have been observed to begin anthesis in the afternoon but this does not appear to be genetically controlled since it is not specific to any given individual.

Under chamber conditions with or without sulfur dioxide, the events of anthesis are unchanged, however the speed with which the flower matures is slower than that recorded in the field. Initiation of flowering is common before the chamber is closed, usually between

0700 and 0900 hours. Of those flowers that initiate anthesis at the time of the exposure in the chamber, the following time sequence of anthesis is expected:

Time	
0 hours	Flower initiation - Stage 1-2
3 hours	Anther dehiscence - Stage 7
5 hours	Inner whorl of anthers at level of stigmas - Stage 8
7 hours	Inner whorl of anthers elevated and coalesced - Stage 9-10

As for the receptivity of the stigmatic surface, successful pollinations and fertilizations have been achieved experimentally on plants in the greehouse and under chamber conditions from stages 1-9 (flowers were emasculated so that the stage of anthesis was approximated). Successful fertilizations could be achieved 24 hours after stage 9, but the frequency was very low. These conclusions are based upon the following data:

Flower Description	No.	No. Showing Fruit Devel.	Maximum Carpel No.	Observed Carpel No.
Emasculated	8	0	40	0
Emasculated and Cross Pollinated*	8	2	40	2

*Cross pollinations 24 hours after Stage 9 or approximately 32 hours after initiation of anthesis.

These data were recorded for plants emasculated just prior to being subjected to chamber fumigation conditions without sulfur dioxide. Following 8 hours of exposure, the plants were removed from the chamber and placed on the lab bench below the gro-lux lights. The following conclusions are drawn:

1. No pollen vectors exist under the stated chamber and laboratory conditions.
2. The potential for pollination and fertilization 1 day after Stage 9 or 32 hours after initiation of anthesis exists but is very low (2/40).

Successful fertilizations can be determined 5 days after anthesis.

APPENDIX 2: Floral Morphology and Anthesis in *Lepidium virginicum* L.

The floral morphology of *Lepidium virginicum* is slightly different from most cruciferae: four sepals, four petals, four stamens of which only two are fertile and a compound pistil with two fused carpels and a mushroom-shaped stigma which appears capitate over its surface. The two fertile stamens are situated on opposite sides of the laterally compressed gynoecium. A droplet of liquid, presumably indicative of a nectary, exists at the base of the two fertile staminal filaments.

The unopened bud is enclosed by the perianth. The first indication of anthesis is the unfolding of the perianth and exposure of the stigmatic surface. The anthers are still enclosed by the perianth and are not mature. Further unfolding of the perianth reveals maturing anthers with a grainy surface. Each anther is proximal to and level with the stigma but not touching, separated by no more than one millimeter. From a lateral view, the filaments are bowed out, a geometry which places the face of the anthers flush with the stigma. Anthesis continues with no apparent change in morphology except for a continued perianth divergence. The anthers do not appress themselves to the stigma.

The chronology of anthesis in this species cannot be sequenced since convenient changes in flower morphology are not readily visible. New flower anthesis occurs throughout the day. Under laboratory conditions (not chamber environment) those flowers initiating anthesis in the morning show definite ovary elongation by the following morning if pollination has occurred. The ovary and placement of the anthers remains unchanged if pollination is absent. Fruit maturation takes approximately 2 weeks under laboratory conditions.

It is probable that self-pollination is common in the field resulting from mechanical stimuli (wind, disturbance, etc.) which causes the anthers to touch the stigma. Casual observations have recorded moths visiting infloresences of L. virginicum in the field and in the greenhouse. Consequently, the existence of a pollen vector promoting cross-pollination exists.

Both self and cross-pollination produce fully matured fruit and seed as shown in the following data.

		FULL DEVELOPMENT			
Flower Manipulation	No.Flowers	No.Fruits	Number Mature Seed No.Expected	Small Devel.	Number (Aborted) Devel.
Emasculation	5	0	0/0	4	1
Emasculation + Cross Pollination	4	4	6/8	0	0
Emasculation + Self Pollination	3	3	6/6	0	0

Any inflorescence in fruit usually possesses 2 different types of fruit: large + normal and small and aborted. The majority are fully formed, mature siliques, while interspersed throughout the infloresence are a few small or aborted fruits. The fully formed fruits which result from natural processes produce 2 mature seed per fruit. In emasculated + cross-pollinated fruits which are fully formed, two of the four siliques had only one mature seed and one aborted seed. The aborted fruits never develop past the flower stage. Small fruits exhibit some degree of maturation, however no seed exist in either carpel. It is probable that an absence of pollination and fertilization, either cross or self, is the cause of abnormal fruit development.