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REPORT OF ECOLOGICAL RESEARCH AT
SAVANNAH RIVER ECOLOGY LABORATORY

ANNUAL REPORT

W. M. Lewis
M. H. Smith

R. J. Beyers

J. B. Gentry

J. W. Gibbons

F. G. Howell

M. J. O'Farrell

R. R. Sharitz

Savannah River Ecology Laboratory
Institute of Ecology
University of Georgia
Athens, Georgia 30601

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ABSTRACT

Research emphasis at the Savannah River Ecology Laboratory has focused on the effects of thermal effluents and the cycling of stable and radioactive elements in natural systems. These research efforts are strengthened by establishment of a foundation of basic ecological information from previous and on-going studies. On the basis of findings in the mineral cycling program the roles of plants and animals in elemental transport have been evaluated in a variety of ecosystems. Trophic transfer relationships have been determined in a variety of biological circumstances, particularly for radiocesium. The thermal program has stressed the determination of population and community responses to both high and low temperature inputs in natural environments. These findings are discussed and interpreted within the framework of basic environmental information obtained in concurrent SREL studies.

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INTRODUCTION

The Savannah River Ecology Laboratory has become a regional research facility in ecology operated by the University of Georgia for the Atomic Energy Commission. The research is organized around three areas: Cycling Processes, Thermal Ecology and Basic Ecology. Eight full-time senior staff carry out programs in these areas as well as participate in research training activities involving over 40 students per year. All of our activities are geared toward the publication of quality research in the open literature or oral communication with our peers and the general public.

Emphasis in the program has been placed upon field oriented research dealing with unique regional problems or those of local origin but with broad ecological significance. Thus much of the research has been done on the thermally altered Par Pond cooling reservoir system or the Savannah River Swamp which has received both thermal effluent and low levels of radioisotopes. These studies seek to document effects and the extent of local problems while also attempting to calculate predictable relationships that may have regional applicability. A limited number of our studies are more regional in nature, and data are collected over several southeastern states. Studies in post-thermal recovery areas are also an important part of the overall program.

Research in a vacuum would accomplish only part of the objectives of our program. We view communication as an essential part of our activities. Thus, the staff has given many talks at regional universities, colleges, high schools and local church and social groups. We have many visiting groups tour the laboratory and have an annual open house for university personnel and new students. Many of the students that participate in our program go back to their home institution and give talks about their experiences. During the last two years, we have sponsored two symposia (Thermal Ecology and Mineral Cycling) in which representatives from many different types of organizations have attended and participated. Over half of the staff have participated in a local TV program entitled "Ecology Today". All of these activities along with our publications lead to a high level of communication with a large variety of people.

The staff also has interactions at the international and national levels as well as within the southeastern region. Several serve on committees, as officers, or on the board of directors of national and international organizations. We participate in the worldwide IBP and Smithsonian programs. Many scientific papers and grant proposals are reviewed as part of the general laboratory routine. Our staff hold adjunct academic positions in universities in several states and serve on the committees of numerous University of Georgia graduate students. In addition, we have staff from a number of universities and colleges conducting research in collaboration with our staff. All of these activities put a large demand on the time of available staff and require a sophisticated support system both

in terms of facilities and personnel. The naming of Savannah River Ecology Laboratory as an on-site laboratory and the associated budgetary increases have made it possible to improve the research environment at the laboratory and to upgrade our safety program. Certainly the laboratory staff has reacted favorably to the many changes and a measure of the success of the program can be taken from the extent that the staff and students become totally engrossed and committed to the research program.

Savannah River Ecology Laboratory's progress during the last year should be judged in terms of the quality and quantity of the published research, the degree to which we have responded to the local environmental problems on the Savannah River Plant and the southeastern coastal plain, the impact we have had on the scientific community and the public in general, and lastly on the degree of professional advancement made by the staff and students associated with the laboratory. It will take longer than one year to evaluate the overall effect of this year's changes on the laboratory performance. However, the object of this report is to document our publication record since our last annual report and to point out some of the highlights of the research conducted during this last fiscal year. The three major areas of the report covered are Land Use, Cycling Processes and Thermal Ecology which corresponds to funding units in our last year's proposal. Also included in this report is the work done under AT(38-1)-718 in the Savannah River Swamp.

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LAND USE

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LAND USE STUDY TO REVEAL POTENTIAL RESEARCH SITES ON SAVANNAH RIVER PLANT

This study presently has three main objectives: 1) to survey and list categorically data which have been gathered on the ecology of the Savannah River Plant (SRP); 2) to describe the cover and present use of SRP land; and 3) to locate aquatic and terrestrial habitats that may need preservation or management for purposes of research or maintenance of ecological diversity.

As a part of the first objective, published papers and technical reports on the ecology of the SRP have been surveyed, and a 51 page index has been prepared that lists in some detail the available data on the physical and biological ecology of the SRP. The published papers and reports have originated from several sources, mainly the University of South Carolina, the Savannah River Ecology Laboratory, and the Savannah River Laboratory. The index should be useful to anyone searching for particular information or for gaps in the ecological data for the SRP as a part of research planning. In addition, each ecological publication is being categorized and assigned key words in preparation for computer listings. Finally, an effort is being made to gather, categorize, and file unpublished data on the ecology of the SRP so that the data will be readily available to researchers.

To accomplish the second and third objectives, maps are being drawn from SRP aerial photographs. The maps are scaled 8 inches to the mile, and show aquatic and terrestrial habitats or units down to an acre or less in size. An attempt is being made, during the time available to this study, to completely map in detail an east-west transect across the SRP, from 33° 20' to 33° 15' latitude, a north-south distance of approximately 6 miles. Each 2.5 minute block (approximately 6 square miles) within the transect is being mapped individually. To date, 12 blocks including approximately 83 square miles have been mapped, leaving about 12 square miles yet to be completed. Each terrestrial and aquatic unit within each block is being classified and described according to various criteria, and each is numbered in such a way that a researcher can easily locate any or all units of any type. These data are being analyzed statistically and being prepared for computer mapping. The maps should be of value in such areas as studying the ecology of certain habitat types on the SRP, planning ecological and radiological research over broad geographic areas within the SRP, and documenting and describing changes in land use. If the 1974 SRP areal photographs are available soon, they will be compared with the 1966 photos from which the present maps are being drawn, and changes in land use will be described. Mapping data on hardwood stands will be useful to U. S. Forest Service personnel, who want to maintain a certain proportion of hardwood and ecological diversity in all upland sites used predominantly for the culture of pines. The locality around the F and H separations area, which is of particular interest because of the future plutonium studies, has been completely mapped within the above transect from 81° 35' to 81° 45' longitude, an area of approximately 52 square miles. In addition, field checking was done to locate all streams in the F and H areas through which plutonium may have passed and left the immediate vicinity.

The location and identification of sites for research and possible preservation or management may be oriented toward small habitats such as Carolina Bays and small stands of hardwood, most of which have not been previously included in other maps such as the U. S. Geological Survey maps and the U. S. Forest Service timber compartment maps of the SRP. Small stands of hardwoods or belts of hardwoods, such as those of planted hedgerows, shelterbelts, and uncleared strips along intermittent streams or ditches, may be relics of forests present on the SRP before clearing for agriculture, and some of these should be preserved for research purposes and to maintain ecological diversity on the SRP.

* PRECIPITATION, RUN-OFF, AND TEMPERATURE CORRELATIONS WITHIN THE AIKEN - SAVANNAH RIVER PLANT AREA

In an attempt to more fully understand the local weather and its effects on the Savannah River Swamp, available weather data from the years 1952 through 1972 was gathered from the U. S. Weather Bureau, The U. S. Geological Survey, and Savannah River Plant sources. Nine different variables were considered. They were Savannah River Plant temperature (SRPT), Savannah River Plant precipitation (SRPP), Savannah River depth (SRD), Savannah River flow (SRF), Savannah River temperature (SRT), Aiken temperature (AT), Aiken precipitation (AP), Clark Hill Reservoir elevation (CHE), and Upper Three Runs Creek flow (UTRF). Simple regression analyses were run between the monthly means for all these variables. Of the forty-four possible combinations, thirty-seven were found to be correlated at the 0.05 level. However, the predictability of these correlations was low. Only seven had a predictability of greater than 80%. These were SRPT X SRT (.93), SRPT X AT (.99), SRPT X PP (.87), SRPP X AP (.81), SRD X SRF (.98), SRT X AT (.93), and AT X PP (.87). All seven of these correlations were significant at the 0.0001 level.

Although CHE and UTRF were significantly correlated with most of the other variables none of the regressions gave good predictability. Multiple regression analyses were attempted to improve the predictability for these and other variables, however no increase in predictability occurred. Thus it would appear that information of water in the swamp and its tributaries must be measured and cannot be calculated from other parameters.

All parameters were analyzed by months with the exception of UTRF. These figures represented 10 to 22 years of monthly data. It became apparent that some measures were much more variable than others. The elevation of Clark Hill reservoir, under the control of the U. S. Army Corps of Engineers, was the least variable. The three temperatures have monthly variabilities between 2 and 13%, while the run-off data are more variable by yet another order of magnitude (15 to 106%). Thus the local area may be stated to have fairly stable temperature regimes and less stable water run-off and precipitation conditions (Table 1).

Table 1. Monthly variabilities of various weather parameters of the Aiken - SRP Area.

DATA TYPE	RANGE IN COEFFICIENT OF VARIATION (%)	YEARS OF MONTHLY DATA
Clark Hill Reservoir Water Level	0.23 - 0.78	10
Aiken Temperature	1.8 - 9.3	18
Savannah River Plant Temperature	2.0 - 10.3	13
Savannah River Water Temperature	4.8 - 12.9	18
Savannah River Depth	15.1 - 35.9	10
Savannah River Flow Rate	18.2 - 67.7	10
Aiken Precipitation	40.8 - 93.7	18
Savannah River Plant Precipitation	38.8 - 105.8	18

CYCLING PROCESSES

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- ** Studies associated with dissertations or theses.

PRESCRIBED BURNING OF SOUTHERN PINE FORESTS VASTLY INCREASES THE MOBILITY OF CATIONS AND RESULTS IN LARGE VOLATILE LOSSES OF NITROGEN

Field and laboratory studies of nutrient movement following forest fires were designed to assess the importance of prescribed burning, a widespread management practice in the Southeast, on nutrient distribution. Emphasis was placed on possibilities for movement between compartments in the forest ecosystem and potential for movement of nutrients across ecosystem boundaries into aquatic systems. The field studies were set up on control and burned portions of the Par Pond watershed.

The prescribed fire in the treated portion of the Par Pond watershed reduced the dry weight of litter by 33%. Samples of the freshly-burned litter were returned to the laboratory and leached under standard conditions along with comparable unburned controls. The laboratory leaching demonstrated a dramatic increase in solubility of cations in the burned litter (Table 2). Divalent cations, which were 20 x more soluble after burning, changed more dramatically than monovalent cations, which were only 2 to 2.5 times as soluble as in unburned litter. Nitrate and phosphate yield of the litter was unchanged by the fire.

The ionic content of runoff, rainfall plus fallout, and groundwater in the burned and control areas was monitored for two months following the fire. Approximately 80% of the total leachable ions (as determined in the laboratory) were removed by natural leaching in the field within 30 days during which 80 mm of rain fell. Divalent cations were removed most rapidly from the litter but were efficiently adsorbed by the mineral soil. Significant amounts of cations were moved by wind transport of ash for more than a month following the fire. Runoff was rich in cations but they did not accumulate due to the high permeability of the soils. There was some evidence of increase in monovalent cations in superficial groundwater communicating with the lake in the burned area.

It is obvious that fire has the greatest relative effect on partitioning of divalent cations. Monovalent cations are not linked to structural components of leaf tissue and are consequently lost rapidly from unburned litter. Calcium and magnesium, on the other hand, are locked more securely into the dead tissues but are dramatically freed by fire. The high solubility of cations following fire is of potential concern wherever runoff is significant.

There was a small but steady gain in litter nitrogen following the fire, which is probably due to the microbial activity induced by greater structural vulnerability of litter. The gain in N is much smaller than the large volatile loss of N during the fire. There is obviously a net drain on the total N of the system due to fire, and preliminary estimates on rainfall and fixation rates would indicate that considerably more than one year of nitrogen input would be required to offset the loss. Increases of nutrients between compartments within the system may thus be achieved at the expense of the total nutrient inventory of the systems.

Table 2. Amounts of soluble material in litter from burned and control areas of the Par Pond watershed. Total soluble ionic content is represented as the specific conductance of soluble materials from 1 m² leached into 1 l of water. Cations, nitrate and phosphate are expressed as amount of leachable material per m² of watershed. Each figure is a mean of duplicate samples.

LOCATION		SOLUBLE MATERIAL						
	STATION	TOTAL IONS μmho/cm	Ca ⁺⁺	Mg ⁺⁺	Na ⁺ mg/m ²	K ⁺	NO ₃ ⁻ -N	PO ₄ ⁻ -P
Burned	1	864	71	4.3	3.4	49	.192	10.8
	2	4552	328	15.6	29.6	192	.263	6.2
	3	2501	184	12.1	24.0	148	.176	4.9
	4	2574	181	15.9	18.3	116	.122	3.0
	mean	2622*	191*	11.5*	18.8	126	.188	6.2
	SE	754	52	2.6	5.6	30	.029	1.7
Control	5	445	7	0.6	4.2	52	.215	5.3
	6	533	7	0.6	8.5	48	.186	6.2
	7	806	12	1.7	15.0	45	.136	4.8
	8	571	13	1.7	5.3	72	.209	7.2
	mean	588	9.7	1.15	8.3	54	.186	5.9
	SE	77	1.6	0.32	2.4	6	.018	0.5
Ratio: B/C		4.45	19.7	10.0	2.26	2.33	1.01	1.05

ADDITION OF LOW-GRADE HEAT TO WARM RESERVOIRS CAN BE EXPECTED TO
UPSET THE TIMING, DURATION, AND NATURE OF SEASONAL MIXING

The continuous addition of low-grade heat to relatively large lakes will be an increasingly widespread practice as power demands increase. Environmental effects of very broad scope are probable if such heat significantly affects the vertical exchange of nutrients and gases by changing the resistance to wind-generated turbulence in the water column. Par Pond has been observed as a case history in this respect. Field studies on heat and nutrient distribution over the past year and a half clearly indicate that the heat added to the lake causes substantial changes in overall seasonal cycle and lake metabolism even though the amount of heat added is not great.

The most serious methodological problem in the study of heated lakes is the great bulk of data that must be analyzed simply to provide the physico-chemical background for biological studies. Since the heat is distributed from a point source, artificial environmental gradients of varying stability are superimposed on the natural gradients in the water column. The data collection must therefore account for the three spatial dimensions of the water column as well as a temporal dimension. Means were developed in the course of Par Pond studies to reduce complex data matrices to simpler but biologically-meaningful variables (Fig. 1). The variables that prove to be most useful in assessing heat distribution include (1) a base temperature obtained in deep water, (2) a mean "excess" heat computed as the amount of heat above the base temperature in the upper water column, (3) a vertical temperature heterogeneity index designed to measure the evenness of heat distribution in the upper water column. These indices have been computed for a series of sampling stations on Par Pond over an annual cycle and appear to be suitable for general use in the investigation of heated effluents.

The Par Pond studies show that the addition of heated effluent is sufficient to generate an artificial thermal stratification during winter that would not normally occur. The likelihood that such artificial thermoclines will develop is a function of latitude, since lakes with higher base temperatures stratify more easily in response to a fixed addition of heat. Stratification is of course accompanied by deepwater oxygen depletion and other chemical changes that are unusual or impossible during normal winter conditions.

The winter stratification is punctuated by mixing during the coldest and windiest weather. Spring stabilization of the water column occurs earlier than normal and there is some oxygen debt at the onset of stratification due to the incompleteness of winter mixing. Deepwater anoxia thus occurs much more rapidly than would otherwise be expected. This is likely to be an important factor controlling the nature and distribution of benthos and the transfer of nutrients across the mud-water interface in heated lakes.

Although the warmest water has a strong tendency to remain near the top of the water column in a heated lake such as Par Pond, there is some transfer of heat to deep water during mixing and even during the stratification period. The base or hypolimnetic temperatures of

Figure 1. Distribution of temperature with depth in Par Pond at Station 3 on 23 February 1973. The curve illustrates the application of concepts described in the text. Parameters shown include base temperature (θ_h), excess temperature (θ_{ex}), epilimnetic depth (z_e), excess heat ($\bar{H}_{ex}$), and thermal heterogeneity ($\bar{\Phi}_{ex}$).

such lakes will therefore be higher despite the fact that artificial heat is primarily distributed over the surface. The hypolimnion of Par Pond is 4-5°C warmer than other comparable regional lakes. This implies higher decomposition rates and aggravation of anoxic tendencies in deep water.

Some rather surprising observations have been made on Par Pond in connection with studies of horizontal and vertical heat distribution in the upper water column in summer. The amount of excess heat per unit surface is not always located near the discharge. Heat may be transported by currents to points far from the discharge and then mixed more thoroughly with deeper epilimnetic water. Mixing reduces the heat dissipation rate and allows storage of greater amounts of excess heat. The vertical thermal heterogeneity is, unlike excess heat, almost always directly related to distance from the discharge. Thus from a biological point of view, the planktonic habitat routinely offers a greater variety of physico-chemical conditions near the discharge than distant from it, even when the total artificial heat load of the two locations is similar.

In summary, Par Pond provides a number of clear examples of changes in normal vertical density-temperature profiles over the seasons. These changes have manifold implications for lake metabolism.

* RADIOCESIUM LEVELS IN HERBACEOUS PLANTS NOT CORRELATED WITH TOTAL RADIOCESIUM CONCENTRATIONS IN THE SEDIMENTS SURROUNDING THEIR ROOTS

Sagittaria latifolia and Polygonum punctatum, two herbaceous plant species dominating the flora of the Steel Creek delta, were sampled at 60 m intervals along a 450 m x 450 m grid superimposed upon the creek floodplain. Soils samples were collected from around their roots. Radiocesium levels (pCi/g dry weight) were determined for the component organs of each plant and for the soil.

The distribution of soil radiocesium concentrations was bimodal with 46 samples having concentrations less than 100 pCi/g and the remaining samples ranging from 160 to 2620 pCi/g. For these reasons the samples were divided into two classes, low level soils (less than 100 pCi/g) and high level soils (greater than 160 pCi/g). Within each level the soil concentrations were approximately lognormally distributed ($P < 0.05$); therefore, means, variances and coefficients of variation were calculated from $\ln$ transformed data.

Radiocesium concentrations in the plant components were also approximated by lognormal distributions ($P < 0.05$), and a $\ln$ transformation was employed in the data analysis. The concentration of radiocesium in Sagittaria leaves was higher in plants collected from low level soils than in plants from high level soils (Analysis of Variance; $P < 0.05$); whereas, the concentrations in roots of plants from high and low level soils were not significantly different ($P > 0.05$). Also, Polygonum plants from high and low level soils did not demonstrate significant differences in radiocesium concentrations for any of the plant components sampled.

Furthermore, soil and plant radiocesium levels were not highly correlated. The only significant correlation ($P \leq 0.05$) was between soils and Polygonum stems ($r = 0.26$; $df = 67$). It is likely that this correlation is a spurious result; however even if it is real, the results indicate that plant concentrations are relatively independent of soil concentrations.

Significant correlations were observed between concentrations in component parts of the same plants (Table 3). Although the degree of intraplant correlation is apparently greater in Sagittaria, the trend in Polygonum is identical. Somewhat surprising were the high correlations between nearest-neighbor plants. In particular, the leaf concentrations of Sagittaria and Polygonum had higher correlations with the leaves of neighboring plants than with their own roots. Similar results were observed for Polygonum stems and dead leaves.

The high correlation between radiocesium levels in component parts of adjacent plants, and the lack of soil-plant correlations suggest that radiocesium uptake in Sagittaria and Polygonum varies across the Steel Creek delta independently of the radiocesium concentration in the soil, and that factors other than substrate concentration of the isotope affect its availability to the vegetation. The contrasts between the results of Steel Creek and White Oak Lake studies illustrate that a wide variability in radiocesium cycling processes exist.

RELATIONSHIP FOUND BETWEEN SPATIAL DISTRIBUTION AND MINERAL UTILIZATION OF HARVESTER ANT (Pogonomyrmex badius) COLONIES

The Florida harvester ant (Pogonomyrmex badius) causes phosphorus and potassium to accumulate at the surface of colony sites. Soil samples from the crater surface of five colonies contained 10.4 ± 1.0 ppm (SE) phosphorus and 16.5 ± 3.9 ppm potassium. Soil samples from control areas not associated with an ant colony contained 6.2 ± 0.5 ppm phosphorus and 6.6 ± 1.0 ppm potassium. The accumulation of nutrients is caused by the deposition of debris and waste products (seed covers, dead ants, feces and other metabolic products) around the crater rim.

The nutrient requirements of a harvester ant colony are met by foraging workers that gather seeds from the surrounding habitat. The foraging radius varies, likely with colony size, and may reach 50 m or more. The spatial arrangement of ant colonies within a given habitat is important to efficient utilization of available resources.

The dispersion pattern of P. badius colonies was observed for a three-year period in a 20-year abandoned field at SRP. The nearest neighbor technique was used to describe the spatial distribution. The method yields an index of dispersion (R) which has a limited range with values indicative of complete aggregation (0), random (1) and perfectly uniform (2.15) patterns of distribution. The dispersion pattern deviated significantly from random toward the uniform spacing

Table 3. Partial correlation coefficient matrix (r values) or radiocesium concentrations (pCi/g dry weight) in various components of Sagittaria latifolia collected from Steel Creek. (df = 95)

	<u>Plant 1</u>	<u>Plant 2</u>	
	Roots	Leaves	Roots
<hr/>			
<u>Plant 1</u>			
Leaves	0.51**	0.67**	0.24*
Roots		0.34**	0.39**
<u>Plant 2</u>			
Leaves			0.40**
Roots			
<hr/>			

* $P \leq 0.05$

** $P \leq 0.01$

end of the dispersion index spectrum (Table 4). In other words the mean observed distance to the nearest neighbor was 1.5 times greater than would be expected in a random distribution of the same density. The distribution remained constant over the three year period even though the colonies changed locations each summer. Individual colony relocation movements averaged almost three meters (range = 0.5-12m). Apparently movement directions are not random and are controlled through intercolony interactions. The final result is the maintenance of a spatial pattern that allows more efficient use of nutrient resources.

PREDICTABLE RELATIONSHIPS EXIST BETWEEN LEVELS OF RADIOCESIUM IN DOMINANT PLANTS AND ARTHROPODS IN A CONTAMINATED STREAMBED COMMUNITY

The question of the fate of radionuclides, and other pollutants, should be of paramount concern to industrialists, scientists and other interested citizens. Considerations of the mere physical aspects of waste disposal are not enough. It is also important to understand the role of the waste product within the biological system. For example, does a particular radionuclide cycle rapidly through a system or is it concentrated in certain components? Are species in higher trophic levels more useful in predicting radionuclide concentrations in other compartments of the system than species in lower trophic levels? Is there a general phenomenon of radionuclide concentration with increasing trophic levels? These and other important questions must be answered if we expect to make intelligent choices among alternative solutions to present and future waste disposal problems.

The study was carried out in a contaminated natural streambed on the Savannah River Plant. For several years the stream, Steel Creek, received reactor cooling water and disassembly basin effluents from two nuclear production reactors located near the stream's headwaters. When the stream no longer received reactor effluent in 1968, water flow was reduced and portions of the old streambed became exposed. Vegetation growing on contaminated soils then became available to animals as food. Thus, a unique opportunity was created to study the fate of radionuclides in a natural system. This preliminary study of the Steel Creek system was an investigation into the radiocesium levels and concentration ratios of plant - herbivore - predator food web.

Radiocesium concentrations in Steel Creek are generally larger than those found elsewhere. The most comparable situation is on the old-field sere in the White Oak Lake bed, where it has been reported that mean concentrations of 0.11 and 0.10 pCi/mg for arthropods and a mean of 0.38 pCi/mg for vegetation; we found means of 0.15 to 1.50 pCi/mg for arthropods and means of 0.37 to 2.30 pCi/mg for vegetation collected in this study (Table 5).

The degree of linear correlation between radiocesium concentrations in different types of plants and arthropods is summarized in Table 6. The coefficient of determination (r^2), which is the square

Table 4. Dispersion statistics for 200 P. badius colonies over a 3-year period in a 20-year abandoned field on the Savannah River Plant. Symbols: $\bar{r}_A$ = mean nearest neighbor distance; $\bar{r}_E$ = mean nearest neighbor distance expected in a large randomly distributed population of the same density; R = dispersion index; C = standard variate of the normal curve.

	1970	1971	1972
$\bar{r}_A$	11.80	11.74	11.80
$\bar{r}_E$	7.80	7.78	7.81
R	1.51	1.51	1.51
C	15.34*	15.36*	15.34*

* Significant at .01 level.

Table 5. Grand means ($\bar{X}$) of radiocesium (pCi/mg dry weight) concentrations for composite samples from floodplain areas taken throughout the study period.

	Number of samples	Floodplain $\bar{X}$	S.E.
Plant genera			
<u>Andropogon</u>	10	0.47	0.32
<u>Alnus</u>	10	0.37	0.06
<u>Myrica</u>	10	0.54	0.28
<u>Salix</u>	10	0.51	0.28
Arthropod orders			
Araneae	25	0.26	0.07
Coleoptera	25	0.44	0.29
Homoptera	25	0.15	0.07
Orthoptera	25	0.40	0.08

Table 6. Coefficients of determination (r^2) for the relationships between radiocesium concentrations in different components of the same ecosystem. Associated r values were significant at the 0.01 level with one exception.

	<u>Andropogon</u>	<u>Alnus</u>	<u>Myrica</u>	<u>Salix</u>	Araneae	Coleoptera	Homoptera
Plant Genera:							
<u>Andropogon</u>	1.00						
<u>Alnus</u>	0.72	1.00					
<u>Myrica</u>	0.49	0.55	1.00				
<u>Salix</u>	0.52	0.31*	0.49	1.00			
Anthropod Orders:							
Araneae	0.85	0.71	0.63	0.78	1.00		
Coleoptera	0.88	0.83	0.77	0.59	0.92	1.00	
Homoptera	0.74	0.42	0.63	0.89	0.86	0.78	1.00
Orthoptera	0.83	0.58	0.56	0.83	0.97	0.86	0.92

* Significant at 0.05 level

of the correlation coefficient, designates the proportion of the sums of squares attributable to the regression of Y on X. In general, correlations between the plant types were poorest; all six $r^2 \times 100$ values were less than 75%, and five were 55% or less. Eight of sixteen plant-arthropod correlations had r^2 larger than 75%, and three were greater than 85%. Arthropod concentrations were most highly correlated; all six r^2 values were larger than 75%, and five were greater than 85%.

The slopes of the relationships between radiocesium concentrations in the biological components of the ecosystem (Table 7) are relative indices of the functional positions of the organisms in the food web. Significant changes in these slopes from one location to the next or between different times would indicate a change in the adaptive functions of the organisms involved. For example, if the slope of the relationship between radiocesium concentrations in Araneae and Orthoptera ($Y = 0.60X$; Table 7) changed from 0.60 to 1.80, the proportion of Orthoptera in the diet of Araneae would have changed and the food web altered. The predictability of these relationships for radiocesium seems to be higher between biological components (Table 7) than between the soil and the biological components. From a theoretical point of view we would expect the linear relationships between radiocesium concentrations in plants and animals to extrapolate through the origin; intercepts were not significantly different from 0. If similar extrapolations continue to approximate the data points at higher concentrations, the results of this study will be useful in understanding the dynamics of more highly contaminated systems because the constancy of the functional indices (slopes) would indicate similar food webs and concentration factors independent of the level of contamination.

Coefficients of determination (r^2) were generally higher for predications involving arthropods than those with plants (Table 6). This may mean that species at higher trophic levels may effectively integrate over species specific differences at lower levels. If true, then interindividual variance should decrease with increasing trophic level. Animals may be important in the ecosystem partly because they reduce the total variance of the system. Future studies involving concentrations of stable and radioactive elements should be designed to test this hypothesis.

* , ** WATERFOWL FOUND TO BE IMPORTANT IN THE REDISTRIBUTION OF RADIOCESIUM IN STEEL CREEK DELTA

Most radioactive waste materials are released or disposed in areas with extensive buffer zones which insure little or no direct human exposure. However, the possibility exists that many game species utilized by man as food may serve as vectors of contamination to the food chain of man. Because of their mobility and food value, migratory waterfowl are particularly important in this respect.

The present study was designed to describe the accumulation, excretion, and redistribution of radiocesium by migratory waterfowl utilizing a reactor effluent system (Steel Creek). Attention was focused on radiocesium because of its biological significance and abundance in the system.

Table 7. Slopes (b) and one standard error for the linear relationships ($Y = a + bX$) between the radiocesium concentrations of plant and animal samples. All of the associated correlation coefficients were significant at the 0.05 level and intercept (a) values showed no trends in regards to deviations from 0.

Dependent Variables (Y)	Independent Variables (X)							
	<u>Andropogon</u>	<u>Alnus</u>	<u>Myrica</u>	<u>Salix</u>	Araneae	Coleoptera	Homoptera	Orthoptera
<u>Andropogon</u>	-----	2.10±0.49	0.90±0.35	0.92±0.33	2.10±0.33	2.20±0.30	2.60±0.59	1.30±0.21
<u>Alnus</u>	0.35±0.08	-----	0.39±0.13	0.29±0.16*	0.78±0.19	0.87±0.15	0.81±0.36*	0.43±0.14
<u>Myrica</u>	0.54±0.21	1.40±0.48	-----	0.69±0.27	1.40±0.40	1.60±0.33	1.90±0.55	0.80±0.27
<u>Salix</u>	0.57±0.21	1.10±0.60*	0.71±0.27	-----	1.60±0.31	1.40±0.44	2.30±0.30	0.99±0.17
Araneae	0.41±0.07	0.92±0.22	0.45±0.13	0.50±0.10	-----	0.99±0.11	1.30±0.19	0.60±0.04
Coleoptera	0.41±0.06	0.96±0.16	0.49±0.10	0.42±0.13	0.93±0.10	-----	1.20±0.23	0.55±0.08
Homoptera	0.28±0.06	0.52±0.23	0.33±0.10	0.39±0.05	0.68±0.11	0.67±0.13	-----	0.43±0.05
Orthoptera	0.66±0.11	1.30±0.43	0.69±0.23	0.84±0.14	1.60±0.11	1.60±0.24	2.10±0.24	-----

* Slopes not significantly different from 0.

To assess biological half-life of radiocesium, wood ducks (*Aix sponsa*) were captured from the Steel Creek study area by live trapping or removal from nest boxes during nest incubation. Following initial cesium determination birds were either held in pens or wing clipped, fitted with radio transmitters and released in an uncontaminated natural area. They were periodically analyzed to determine the rate of radiocesium elimination.

Wood ducks, with nondetectable radiocesium concentrations, were wing clipped, fitted with radio transmitters and released on the Steel Creek study area. The ducks were periodically recaptured and counted to determine the length of time for whole body radiocesium to reach equilibrium. Recapture, analysis, and release at capture site were completed on the same day.

Determination of radiocesium concentration was made on the day of capture using a Packard Model 446 Armac liquid scintillation detector equipped with a Packard tri-carb scintillation gamma spectrometer. Sensitivity was 0.30 pCi/g (picocuries per gram) for a 500 g sample.

During the fall, winter, and early spring wood ducks make flights to and from communal roost sites. The flights occur between sundown and dark and daylight and sunrise. Six sites along Steel Creek were selected for evening roost flight index counts. The site of greatest waterfowl utilization was counted bi-monthly. When man power was available all sites were utilized. Additional observations of waterfowl numbers were made while the investigator was engaged in other activities on Steel Creek.

Biological half lives were calculated from the long component elimination curves from the relationship $\frac{.693}{\text{slope}} = T_{1/2}$ (biological half-life). The short component elimination curve was not apparent. Biological half-life of the Cs^{137} long component in wood ducks was 6.65 (± 0.95 2SE, N = 12) days.

Accumulation of radiocesium by wing clipped wood ducks fitted with radio transmitters and released on Steel Creek was rapid reaching equilibrium in approximately 29 days (nondetectable to 62,000 picocuries whole body, N = 2). Concentration remained in a steady state from day 20 to time of removal from Steel Creek on day 41. The behavior of the experimental birds appeared to be normal throughout the experiment. They were observed in the company of wild ducks on several occasions.

Few wood ducks are seen on Steel Creek from April to October. In early October migratory wood ducks begin to arrive and reach an initial peak in early November (N = 186). The initial group arrive, stop over for 3-4 weeks, and a portion then moves on to more southern wintering grounds with the remainder overwintering on Steel Creek. Two additional peaks occur: one in December resulting in the peak wintering population (N = 224); and one in January as a result of northward bound migrants (N = 106).

During December and January 500 to over 1000 individuals of other waterfowl species (primarily mallards, Anas platyrhynchos) can be flushed from the Steel Creek delta on most days. Combining this information with the roost flight counts a minimum Steel Creek wintering waterfowl population of 1300 is evident (1000 mallards and 300 woods ducks). It is believed that approximately 3000 waterfowl utilize Steel Creek a sufficient length of time for radiocesium equilibrium to be reached if other waterfowl species reach equilibrium at a rate similar to wood ducks.

The average Cs^{137} concentration of mallards and wood ducks collected on Steel Creek during December and January was .0725 and .0509 microcuries (uc) whole body, respectively. Multiplying these values by the estimated minimum wintering population of the two species and adding the two values, results in a minimum of 88 uc of radiocesium transported off site by migratory waterfowl. If the upper population estimate is used 196 uc of radiocesium would be transported off site and redistributed along the migratory pathway each year.

Although this study is considered preliminary, it does indicate that waterfowl utilizing contaminated nuclear reactor effluent systems as feeding sites do remove significant amounts of radioactive material from the system.

**** DEPRESSION AND POSSIBLE ENHANCEMENT OF BENTHIC ALGAE AND PERIPHYTON BY LOW LEVELS OF MERCURY IN ARTIFICIAL STREAMS**

The main objective of this study was to determine responses of periphytic algae and benthic insects to constant low levels of mercuric ions in artificial streams. Treatment concentrations were within the range of contaminated waters in the United States, from 0.01 to 1.0 parts per billion.

The artificial stream facility consists of six concrete block channels approximately 90 m long, 0.6 m wide, and 0.4 m deep. The entire facility is lined with black PVC (0.5mm) plastic sheeting. Builder's sand with a mean depth of 5 cm was used as a substrate. Water was drawn from the Tuscaloosa aquifer. Mean flow for each stream was 0.85 min. The water was untreated except for passage through columns of limestone chips prior to entering the streams. The purpose of this treatment was to increase hardness and decrease free CO_2 content.

Mercuric chloride in 2% nitric acid was continually administered to the four experimental streams to maintain the proper concentration of the mercuric ion. Two streams were control streams; two were low level; and two were high level treatments. Sampling for periphyton and benthos was carried on at monthly intervals.

Mercuric ions generally cause a significant reduction in algae numbers, standing stock of biomass, and diversity in concentrations similar to those encountered in natural waters contaminated with mercury. However there is occasionally some evidence of enhancement

(Table 8). Reductions in diversity result from both a decrease in the evenness of distribution of numbers among species and a decline in the number of species. Although the algae community is affected by mercuric ions, the magnitude of the changes is small at the levels tested and the number of species affected are few. It can be suggested from this information that standing stocks of biomass and productivity would be useful parameters to measure areas suspected to be contaminated by mercurial salts. Productivity and biomass are simple to measure in comparison to community structure and the reduction in standing crops in response to mercury represented a change of much greater magnitude than the declines in diversity.

Contaminants can act directly on organisms by impairing their physiological abilities or indirectly by affecting their food source. The decline in algae standing crops is important since this effect may be transferred through the food chain possibly resulting in contaminant impact on organisms with physiological resistance to the contaminant. There was no evidence in this study of direct or indirect impact on the herbivorous or carnivorous midges. The impact on primary producers in this study was not sufficient to be transferred to consumer trophic levels.

*
RAPID LOSS AND THEN STABILIZATION OF ^{137}Cs CONTENT
AND BIOMASS OF LITTER IN THE SAVANNAH RIVER SWAMP ENVIRONMENT

It has long been known that respiratory rates are temperature dependent. Since decomposition rates are a function of the metabolic rates of decomposer organisms, it is logical to assume that decomposition will be a temperature dependent phenomenon. However, this may be true only up to a point. If the temperature optima of the decomposer organisms are exceeded, decomposition rates may be decreased. On 1 January, 1974 an experiment was initiated to determine if leaf litter decomposition rates in a stream receiving effluent from a nuclear reactor on the Savannah River Plant were equal to, higher, or lower than the decomposition rates of similar material in normal streams or in streams recovering from a thermal shock.

Litter bags filled with willow leaf litter were placed in Four Mile Creek, Steel Creek, and in Deep Swamp Creek, a previously unnamed tributary to Steel Creek located near the confluence of Steel Creek and the Savannah River. These three locations represent a thermally affected stream (mean high temperature 40°C), a recovery stream (mean high temperature 18°C), and a control stream (mean high temperature 15°C), respectively. Before being placed in the field, each bag was weighed empty and weighed filled with air-dried leaves. An empirically derived equation was used to convert air-dried weight to oven-dry weight. Ten bags were removed from each location at weekly intervals for four weeks and subsequently they were removed biweekly, to a total of seven weeks. The bags were oven-dried and then ground in a Wiley mill preparatory to the determination of radiocesium on a pulse height analyzer and 14 stable elements on the spark emission spectrophotometer. Biomass, radiocesium, and mineral losses were determined over time.

Table 8. mean relative abundance, standard error, and sample size across mercury level for algae responding to mercury treatment at various locations in the artificial streams.

Algae	Location	***Mean Relative Abundance			(Standard error)--% of total community					
		0.00 ppb			0.01 ppb			1.00 ppb		
		$\bar{x}$	$s_{\bar{x}}$	N	$\bar{x}$	$s_{\bar{x}}$	N	$\bar{x}$	$s_{\bar{x}}$	N
<u>Aphanochaete repens</u>	UV**	1.78	0.34	80	4.39	0.57	84	1.41	0.24	84
	UH**	1.70	0.25	74	4.34	0.53	68	2.10	0.35	68
<u>Charachinopsis anabaena</u>	UV**	3.60	0.47	80	1.55	0.22	84	3.29	0.44	84
	LV*	1.23	0.17	84	1.10	0.26	79	0.60	0.13	78
<u>Chromulina pseudoneouloosa</u>	UV**	32.79	1.81	80	33.29	2.39	84	45.11	2.72	84
	LV*	38.95	2.25	84	31.27	2.26	79	41.38	3.38	78
<u>Cosmarium asphaerosporum</u>	UV**	16.30	1.33	80	9.69	1.54	84	6.42	0.92	84
	LV**	9.48	0.65	84	5.81	0.96	79	3.86	0.46	78
	UH**	6.34	0.58	74	9.56	1.41	68	3.58	0.46	68
	LH**	5.44	0.61	74	12.43	1.65	72	2.10	0.28	74
<u>Mougeotia</u> (11 u wide)	UV**	0.11	0.08	80	1.61	0.59	84	0.13	0.06	84
	UH**	0.01	0.01	74	0.38	0.16	68	0.00	0.00	68
<u>Netrium oblongum</u>	UV**	4.81	1.81	80	2.08	2.39	84	2.95	2.72	84
	LV**	5.13	0.48	84	2.71	0.41	79	3.37	0.60	78

* significant P 0.05

** significant P 0.01

*** upstream vertical (UV) and horizontal (UH) plates downstream vertical (LV) and horizontal (LH) plates

Similar changes were observed in radiocesium content, biomass loss, and percent ash overtime (Fig. 2). The figure illustrates the high rate of loss in the first two weeks and then the subsequent stabilization of biomass content or perhaps continuation at a very slow loss rate. Percent ash, and 137 Cesium content showed this same pattern of rapid change and then a slower rate. These experiments are being continued to determine if the slower rate of loss continues.

**

RELATIONSHIPS BETWEEN AGGRESSIVE BEHAVIOR AND GENIC
HETEROZYGOSITY IN OLDFIELD MICE (PEROMYSCUS POLIONOTUS)

Concurrent shifts in behavior, genetics, and small mammal population density have caused ecologists to raise questions about the role of behavior-genetics in population processes. The genetic basis of aggressive behavior is important because selection for different behavioral phenotypes may affect the behavioral attributes of populations resulting in demographic changes. The effect of heterosis or heterozygosity on behavior and the consequences for population dynamics are largely unexplored.

Relationships between aggressive behavior and genic heterozygosity were investigated in oldfield mice (Peromyscus polionotus). Adult male mice were captured from five mainland and three beach locations in the southeastern USA. Beach mice differ from mainland populations in many ways and are discussed elsewhere. To test aggressive behavior, paired encounters between mice were staged in a circular arena. Social dominance, food control, and accumulated attack time were recorded. Genic heterozygosity was estimated for populations and individuals using starch-gel electrophoresis to examine allelic variation in 31 proteins.

In intralocality aggression tests, accumulated attack time increased with increasing average genic heterozygosity of mainland samples (Fig. 3). In interlocality matches, the average social dominance score increased with increasing average heterozygosity (Fig.). Socially dominant mice approached, attacked, and aggressively groomed their subordinate opponents which showed avoidance, defensive postures and submission. Aggressive and socially dominant mice had an advantage in competition for food as evidenced by a significant correlation between social dominance and food control ($r = 0.66$; $P < 0.01$).

Genic heterozygosity appears to be a major determinant of aggressiveness, social dominance, and success in competition for food among oldfield mice. Relationships between behavioral performance and genic heterozygosity support the contention that heterozygosity is an important determinant of fitness. Aggressiveness is generally recognized as important to individual fitness in small mammals.

If the behavior-genetic relationships found for oldfield mice on a geographic scale function at the local level, then temporal variation in genic heterozygosity resulting from density-dependent breeding

Figure 2. Percentage loss of biomass in radioactive willow leaf
litter bags placed in Deep Swamp Creek (Location C) for
a seven week period.

LOCATION C

% LOSS OF BIOMASS

40

30

20

10

0

0

1

2

3

4

5

6

7

8

WEEK

Figure 3. Mean accumulated attack time ($F_{1,3} = 106.8$) and mean social dominance ($F_{1,3} = 95.4$) regressed against mean genic heterozygosity of mainland oldfield mouse populations. The five sample locations and their estimated average percent genic heterozygosity were: (1) Columbia, S. C. (4.0), (2) Statesboro, Ga. (4.3), (3) Frostproof, Fla. (5.9), (4) Crestview, Fla. (6.5), and (5) Ocala, Fla. (7.8).

patterns, movement, and selection pressures, may contribute to demographic changes in mouse populations. Population subdivision and social restrictions on movement in expanding populations promote inbreeding. Decreased fitness of subordinate inbred phenotypes may precipitate a decline in population numbers, as observed in old-field mice and voles following peak densities. Since standing crop (i.e., density) is one of the most important variables in determining flow rates of stable elements and isotopes through natural systems and density is apparently a function of genic variability, then genic heterozygosity influences mineral cycling in natural systems and should be studied as a causative factor.

*
SEASONALITY INFLUENCES CESIUM TRANSFER ROUTES
BETWEEN TROPHIC COMPARTMENTS

One of the problems encountered in the estimation of Cs transfer coefficients between ecosystem components under natural conditions is delimiting the exact route (or routes) involved in the food web transfer of radiocesium. The situation becomes still more complicated if time is added as a variable. For these reasons, a population of web building spiders in a radiocesium contaminated habitat were examined through one growing season to determine the identity of their insect prey and the influence of time upon spider and prey radiocesium concentrations.

Web-building spiders offer special advantages in the study of cesium transfer between trophic levels of an arthropod community. Prey can be determined simply by removal from the web and, because spiders tend to remain at a given location for extended periods, they can be easily followed and collected through time. The web-building spider chosen for this study was Argiope aurantia (the garden spider) which is particularly abundant in the cesium contaminated habitat in the Savannah River Swamp and especially common throughout the southeastern United States. Information gained from this organism should be applicable to other areas in this geographical region.

Data on prey captured by A. aurantia spiders were collected by following a marked trail of approximately 100 spiders. Prey captured in the webs of the spiders were removed by forceps from webs and brought to the laboratory for identification. Webs were sampled every two-to-three weeks for three-to-four-day periods beginning at the first of June and extending through mid-October of 1973. Specimens subjected to cesium analysis were dried to a constant weight in vacuum drying ovens and counted for 30 minutes on pulse height analyzer.

Representatives of five insect orders were commonly found wrapped as prey in A. aurantia webs. Generally, Coleoptera, Hemiptera and Orthoptera contributed less than 10% each of the total prey captures per sampling periods. The importance of these groups remained fairly constant through time, declining to less than 3% by the final sampling period in mid-October. Odonata and Hymenoptera, however, were the major contributors or prey items during the study; the significance of each tending to vary according to season (Fig.4). Early samples, for

Figure 4. Percent frequency of dominant prey groups captured by
Argiope aurantia during a growing season.

example, showed an abundance of Odonata (damselflies and dragonflies), while later samples contained large numbers of bumble bees and honey bees.

A mosaic of factors appear responsible for the shifts in prey captured and fed upon by A. aurantia. These include spider development, web placement in respect to both vegetation and available insect flyways, seasonality of the insect populations utilizing the flyways, and habitat seasonality (blooming of flowers in late summer and fall).

Radiocesium body burdens of A. aurantia remained relatively low, throughout the study, i.e., 20 pCi/g (dry weight), whereas the dominant prey during the early season, dragonflies, typically carried burdens of 100 pCi/g (dry weight). Hymenoptera, the major prey near the season's end, were found consistently to be indistinguishable from background.

Based on this preliminary information, several characteristics of the system can be determined. As has been documented previously, radiocesium becomes diluted as it is transferred toward upper levels in the arthropod food chain. In this study, the dilution factor was in the range of 1 to 5. While the radiocesium content of A. aurantia's prey varied with time, radiocesium body burdens of the spiders remained relatively constant, making them good indicators of radiocesium content of the arthropod community. However, for opportunistic arthropod predators with rapid radiocesium turnover times, cesium transfer within a system may be highly influenced by prey availability, as demonstrated by the dramatic shift in A. aurantia's prey with time.

STANDING CROPS OF MACRO-MICRONUTRIENTS IN DEER ARE RELATIVELY SMALL COMPARED TO THOSE OF PRIMARY PRODUCERS IN SOUTHEASTERN FORESTS

Wet and dry weight concentrations of six macronutrients (Ca, K, Mg, N, Na and P), five micronutrients (Cu, Fe, Mn, Mo and Zn) were determined for whole body samples from 27 white-tailed deer (Odocoileus virginianus) (Table 9). Information on nutrient composition of deer were combined with biomass data to estimate standing crops of nutrients in deer herds on the Savannah River Plant and predict exportation of nutrients from the Savannah River Plant system during annual deer hunts. Nutrient standing crops in deer are small relative to those of the primary producer compartment of temperate forest ecosystems. Similarly, annual loss of nutrients by harvest of deer is small in comparison to annual nutrient budgets of southeastern forests.

* PREDICTABLE RELATIONSHIPS BETWEEN RADIOCESIUM CONCENTRATIONS IN WHOLE DEER AND VARIOUS ORGAN AND BODY COMPARTMENTS

Fresh biopsy samples, weighing approximately two g were taken from 17 deer for analysis. The body components sampled included:

Table 9. Average whole body, nutrient composition and standing crops for white-tailed deer and exportation of nutrients by harvest of deer on the Savannah River Plant (concentration data are means for 27 deer)

	Wet Weight Concentration ($\bar{X} \pm 2SE$)	CV ^a	Dry Weight Concentration ($\bar{X} \pm 2SE$)	CV ^a	Standing ^b Crop	Nutrient ^c Loss
Macronutrient	mg/g		mg/g		g/ha	g/ha/yr
Nitrogen	31.2 $\pm$ 0.8	6.6	104.0 $\pm$ 2.3	5.7	222.5	16.2
Calcium	9.28 $\pm$ 0.76	21.3	30.9 $\pm$ 2.6	21.5	66.2	4.8
Phosphorus	6.78 $\pm$ 0.47	18.1	22.6 $\pm$ 1.6	18.3	48.3	3.5
Potassium	2.86 $\pm$ 0.15	13.8	9.53 $\pm$ 0.50	13.6	20.4	1.5
Sodium	1.16 $\pm$ 0.05	11.5	3.88 $\pm$ 0.19	12.9	8.3	0.60
Magnesium	0.27 $\pm$ 0.03	29.4	0.91 $\pm$ 0.10	28.9	1.9	0.14
Micronutrient	µg/g		µg/g		mg/ha	mg/ha/yr
Iron	49.5 $\pm$ 3.3	19.9	164.5 $\pm$ 10.8	17.1	353	26
Zinc	20.6 $\pm$ 1.5	19.5	68.4 $\pm$ 4.7	17.8	147	11
Manganese	8.56 $\pm$ 1.23	37.3	28.5 $\pm$ 4.0	36.2	61	4.5
Copper	7.83 $\pm$ 0.53	17.5	26.1 $\pm$ 1.8	17.9	56	4.1
Molybdenum	0.91 $\pm$ 0.11	30.8	3.0 $\pm$ 0.3	29.9	6	0.5

^a Coefficient of variation (%)

^b Based upon an estimated density of 0.16 deer/ha with a mean live weight of 44.54 kg/deer

^c Based upon an estimated annual removal of 900 deer from the 780 square km Savannah River Plant

thigh skeletal muscle, heart, rumen contents, feces, liver, lung, spleen, kidney, adrenal gland, brain and bone (shank portion of femur). All biopsy samples plus the remaining total carcass were then frozen until further processing. While frozen solid, the remaining whole carcass was chopped and band-sawed into smaller (10-20 cm) cubes which were then passed several times through a Hobart model 4732 meat grinder with a grinder plate equipped with 15 mm openings to produce a uniform total body homogenate of the entire carcass. Six 250 g aliquots were then randomly taken from the whole-body homogenate of each deer and refrozen for subsequent analysis along with the organ biopsy samples. All samples of organs and aliquots of whole-body homogenates were subsequently freeze dried to a constant weight, and ground to a fine powder on a model no.3 Wiley mill equipped with a 2 mm grinder screen. A single aliquot weighing between one to two g was then taken of each dried and powdered sample and placed in a 1.5 x 11 cm glass counting tube for radiocesium determination. Determinations were made on a Nuclear Chicago pulse height analyser. All powdered samples were packed to a constant counting geometry in the bottom of the counting tube. Thirty min counts of the samples were compared to 30 min same-day counts of background and 30 min counts of dried biological material containing a known amount of radiocesium (phantoms). Counter sensitivity for the radiocesium determination procedures described was 10.96 pCi/g dry weight and samples whose radiocesium concentrations were less than twice this value were not considered to be significantly distinguishable from background. All values were finally expressed as pCi radiocesium/g dry tissue weight.

There were significant linear relationships between radiocesium concentrations of whole-body homogenates and each organ or body compartment (Table 10). Thus, subsamples can be taken from a deer and then used to predict the total amount of radiocesium in the whole body. The relationships involving the rumen contents and feces probably indicate the deer are approximately in equilibrium with their food environment. These calculations are necessary prerequisites to the construction of a model of elemental and radiocesium flow through deer herds on the SRP.

MONTE CARLO ESTIMATION OF PERCENTILES FOR THE MULTI-SAMPLE KOLMOGOROV-SMIRNOV TEST

The Kolmogorov-Smirnov (K-S) test has become a useful tool for the analysis of certain types of environmental data. The practical utility of the familiar two sided K-S test has been made possible by the availability of tables of exact probabilities for small sample sizes ($n_1 \leq 40$) and approximate probabilities for larger samples. Our purposes were to estimate the percentiles for the multisample K-S statistic for ranges of samples and sample sizes where the exact percentiles are unknown, and to use these percentiles to evaluate the large sample approximation procedures which have been suggested but not verified. This would increase the utility of the K-S test for data analysis within our group.

Table 10. Regression analyses of the variation in radiocesium concentrations of whole-body homogenates of white-tailed deer, from the AEC Savannah River Plant, as functions of the radiocesium concentrations of various body organs/compartments.^a

Organ or Compartment	F (df)	Y-intercept	Slope	r ²
Rumen Contents	5.18(1,13)* ^b	23.15**	0.41*	0.29
Feces	8.23(1,10)*	18.36	0.51*	0.45
Liver	26.02(1,10)**	10.35	1.42**	0.72
Spleen	31.49(1,12)**	9.82	0.78**	0.72
Kidney	20.80(1,12)**	11.42	0.29**	0.63
Lungs	11.43(1,12)**	9.80	1.29**	0.49
Adrenal	15.30(1,12)**	15.85*	0.22**	0.56
Brain	34.58(1,12)**	5.55	1.66**	0.74
Heart	46.91(1,11)**	7.77	0.75**	0.81
Skeletal Muscle	55.12(1,11)**	3.33	0.60**	0.83

^a All calculations are based on radiocesium concentrations expressed as pCi per gram dry weight of tissue.

^b Single and double asterisks represent either significant treatment effects (F values), significant deviations from a Y-intercept of zero or significant deviations from a slope of zero, at the 0.05 and 0.01 levels of probability, respectively.

A computer program was written in Fortran IV which (1) randomly generated from a uniform distribution k empirical distributions of size n_i ; (2) calculated the K-S value; (3) repeated steps (1) and (2) 5000 times to simulate the distribution of the K-S statistic; and (4) tabulated the desired percentiles. Accuracy of this method was checked by comparing Monte Carlo results with values already tabulated for $k = 3$ and n_i equal and less than 40. In 112 comparisons only two percentiles were overestimated by $1/n_i$.

The results are tabulated percentiles for the three, four, five and six sample K-S test with equal sample sizes and the three sample test with unequal sample sizes. Only one approximation procedure, suggested by Birnbaum and Hall, was found to be accurate for general use. New more accurate approximation formulae are calculated from the Monte Carlo results (Table 11).

Table 11. Large sample approximations for the multisample Kolmogorov-Smirnov test with equal sample sizes.

Number of Samples	P = .80	.90	.95	.98	.99
3	$1.77/\underline{n}^{-\frac{1}{2}}$	$1.98/\underline{n}^{-\frac{1}{2}}$	$2.12/\underline{n}^{-\frac{1}{2}}$	$2.33/\underline{n}^{-\frac{1}{2}}$	$2.47/\underline{n}^{-\frac{1}{2}}$
4	$1.91/\underline{n}^{-\frac{1}{2}}$	$2.12/\underline{n}^{-\frac{1}{2}}$	$2.26/\underline{n}^{-\frac{1}{2}}$	$2.47/\underline{n}^{-\frac{1}{2}}$	$2.55/\underline{n}^{-\frac{1}{2}}$
5	$2.05/\underline{n}^{-\frac{1}{2}}$	$2.19/\underline{n}^{-\frac{1}{2}}$	$2.47/\underline{n}^{-\frac{1}{2}}$	$2.55/\underline{n}^{-\frac{1}{2}}$	$2.68/\underline{n}^{-\frac{1}{2}}$
6	$2.12/\underline{n}^{-\frac{1}{2}}$	$2.26/\underline{n}^{-\frac{1}{2}}$	$2.47/\underline{n}^{-\frac{1}{2}}$	$2.62/\underline{n}^{-\frac{1}{2}}$	$2.76/\underline{n}^{-\frac{1}{2}}$

$\underline{n}$ = the size of the individual samples being compared

THERMAL ECOLOGY

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** GROWTH AND DEVELOPMENT OF LARVAL AMPHIBIANS ACCELERATED IN A THERMALLY ELEVATED RESERVOIR

Water temperature is generally regarded as the most critical environmental factor to which anurans are exposed during breeding and embryonic development. The development of anuran eggs and larvae has been shown to be directly related to water temperature. Thermal tolerances and developmental rates of anuran eggs, embryos, and larvae have been correlated with breeding habitat, season, and geographical distribution.

Toad (Bufo terrestris) larvae were discovered in cooler parts of a heated reservoir in South Carolina following a breeding migration in March 1972. Since the reservoir, Pond C, receives lethal levels of heated effluent from a nuclear production reactor at the Savannah River Plant, these larvae provided an excellent opportunity for a comparison of growth and developmental rates among larvae in different thermal regimes under natural conditions. The objective of the study was to document the rates of growth and development of larvae in areas receiving different levels of thermal loading and to determine whether total lengths at any given stage were independent of temperature.

Each sample of larval B. terrestris (30 specimens, if available) was removed with mesh dip net and preserved in the field with 150 ml of 10% Formalin. Formalin solutions were changed after one day and again after one week to ensure proper preservation of specimens. In the laboratory samples were identified, measured (total length), and staged according to the level of development. In the initial analysis 10 larvae were examined from each sample. These data indicated trends in growth and development; therefore 20 additional specimens were examined from areas where sample sizes permitted so that more precise (for Bufo larvae) staging could be applied. The temperature ranges reported represent the daily mean minimum and daily mean maximum temperatures at each study site during the four-week period of study.

Sufficient numbers of larvae were available for three consecutive samples at sampling areas B, A, and V. Area B (a cool pond peripheral to the reservoir) receives a constant flow of underground-stream seepage and is continuous with the reservoir only at times of high water levels. Temperatures there ranged from 8 to 24°C. Area A was located at the cooler end of the thermal gradient in the reservoir proper where temperatures ranged from 21 to 33°C. Area A received moderate thermal loading. Area V was the warmest area (27 to 34°C) from which successive samples were taken; it was 350 m closer to the thermal inflow than was the thermally intermediate area, area A.

Although successive samples were unavailable, larvae were removed from heated areas D (28 to 35°C) and K (29 to 36°C). Area D received little seepage, thus larvae did not have access to cool shallows as in area V. Area K was the hottest area from which larval amphibians were collected. It received cool seepage and was protected from lethal reservoir temperatures by a shallow sandbank between the pool and the reservoir.

Most of the Bufo terrestris larvae examined in this study are assumed to have developed from egg masses deposited in the study area on or before March 22. A consistent progression of advancing stages and increasing sizes was observed weekly in all areas except area K (Table 12). The larvae in heated water were more advanced and larger. Only data from the supplemental analyses ($n = 20$) were used for statistical tests. The few specimens collected from area K were insufficient to provide for supplemental analyses also. Specimens could not accurately be measured a second time. Thus, the data given for area K represent only the initial analyses ($n = 10$). After the first sampling period, total lengths and stages of development were positively related to the level of thermal loading in all areas, except, of course, K (Table 12). After the breeding migration, developing larvae and three separate egg masses were found at area K, but more than 95% of the eggs were dead. Fewer than 20 living embryos were found among the three egg masses present, all in the clutch closest to shoreline seepage. Several larvae, however, were removed from area K in the samples of March 29 and April 5.

Stages of development and lengths of larvae taken in weekly samples reveal a reversal of the initial relationship among the three areas. Statistical analysis of successive samples indicates that growth and development were significantly different among areas in the first and third weekly sample. At a given stage, however, larvae developing in cool water were larger than those reared in heated areas (Table 13).

The data from these natural field populations corroborate trends demonstrated among larval amphibians in the laboratory. Since conditions prevailing in field situations are much more variable than those maintained in laboratory experiments, thermal responses of organisms and populations in nature are not so easily documented. Although water temperatures were monitored at specific locations, toad larvae are known to thermoregulate behaviorally. They have been shown to aggregate selectively in warmer areas of a pond. Field studies are needed to determine the extent to which thermal parameters derived from the laboratory can be extrapolated to actual conditions in nature. Field data should be instructive in determining the thermal limits that can be imposed on biological systems without destroying their stability.

Table 12. Mean total length (mm) and mean development stage of Bufo terrestris larvae taken from different study areas.

	Study area				
	B (24.4°C), Mean $\pm$ SE	A (32.9°C), Mean $\pm$ SE	V (34.4°C), Mean $\pm$ SE	D (34.9°C), Mean $\pm$ SE	K (35.7°C), Mean $\pm$ SE
Mar. 29, 1972					
Total length	15.7 $\pm$ 0.42	14.8 $\pm$ 0.25	14.0 $\pm$ 0.31	Area not sampled	14.4 $\pm$ 0.64
Stage	31.7 $\pm$ 0.22	31.5 $\pm$ 0.17	30.8 $\pm$ 0.25		30.3 $\pm$ 0.52
Apr. 5, 1972					
Total length	16.6 $\pm$ 0.67	17.2 $\pm$ 0.64	18.2 $\pm$ 0.66	22.8 $\pm$ 0.51	11.6 $\pm$ 0.30
Stage	32.1 $\pm$ 0.52	33.5 $\pm$ 0.65	34.2 $\pm$ 0.63	39.8 $\pm$ 0.30	26.9 $\pm$ 0.18
Apr. 12, 1972					
Total length	16.8 $\pm$ 0.40	17.5 $\pm$ 0.52	20.1 $\pm$ 0.68	No larvae found	No larvae found
Stage	32.7 $\pm$ 0.54	34.2 $\pm$ 0.69	37.6 $\pm$ 0.70		
Apr. 19, 1972					
Total length	19.2 $\pm$ 0.38	Insufficient sample size	No larvae found	No larvae found	No larvae found
Stage	36.2 $\pm$ 0.70				

Table 13. Mean total lengths (mm) of larval toads at comparable stages of development, collected from cool and heated areas.

Stage	Study area			Kruskal-Wallis anova	
	B	A	V	H	P
	(24.4°C)	(32.9°C)	(34.4°C)		
31	14.7 (20)	14.2 (21)	14.2 (16)	4.11	<0.05
32	16.0 (16)	15.5 (14)	15.8 (12)	0.44	<0.50
33	18.0 (24)	16.9 (16)	16.7 (6)	5.04	<0.025

* THERMAL LOADING ALTERS THE FLORISTIC COMPOSITION OF THE SRP SWAMP
BUT DOES NOT CHANGE THE VEGETATIONAL DIVERSITY

Portions of the SRP swamp forest which have not received reactor effluents are floristically typical of second-growth, mixed hardwood swamps on the floodplains of major streams in the southeast. Low numbers of woody species are characteristic of these swamp forests and Acer rubrum, the canopy dominant of the SRP swamps, occurs extensively throughout such swamps. Because of the great reduction of light intensity beneath the canopy and the long hydroperiod, the number of herbaceous plants on the forest floor is typically low.

Although diversity of the canopy and subcanopy in the natural swamp forest is low (Table 14), values are within the range of values reported for swamp forest communities. Diversity increased in the understory, a trend which has also been reported for other forest types.

Release of thermal effluents into streams entering the SRP swamp forest destroyed the original canopy and altered the floristic composition. Large numbers of limbless, dead trees remain standing in both thermal and post-thermal areas. In the absence of a canopy, the floras of the thermally altered swamp areas are chiefly herbaceous; whereas, 54% of the species in the natural swamp are woody.

Water temperatures in the thermal areas sampled are too high for survival of vascular plants. The existing flora consists almost entirely of herbaceous species which occupy rotting stumps and fallen logs above the water surface. In spite of floristic differences, however, species diversity in the thermal swamp differs little from that of the ground flora of the natural swamp (Table 14). This unexpectedly high diversity results in part from the creation of the new habitat of stumps and logs allowing development of plant communities peripheral to the hot water. In addition, most of the plants on these islands are herbs similar in size and numbers of individuals. These characteristics insure a high species equitability (J') which increases diversity as based upon the Shannon-Weaver index.

Floristically, the post-thermal swamp five years following removal of the heated effluent, is most similar to the thermally affected swamp and, like the thermal area, most of the plant species are herbaceous. Ground flora diversity is also high in this early stage of post-thermal recovery before the formation of a canopy (Table 14). Woody plants typical of the river swamps are not yet becoming re-established upon the flood plain sediments.

Introduction of reactor effluent into the Savannah River Swamp not only added hot water to the system but also raised the water level and increased flotation. The floristic effects described may therefore be partially attributed to increase in flooding and silting as well as to high water temperatures.

Table 14. Plant species diversity and relative importance values of the dominant species in natural, thermal and post-thermal swamp communities.

	Natural Trees and Shrubs	Ground Flora	Thermal	Post-Thermal
Diversity ⁺				
H' (density)	2.48	3.58	3.65	3.78
H' (dominance)	3.19	3.10	4.01	3.20
J' (density)	0.62	0.67	0.72	0.64
J' (dominance)	0.80	0.58	0.79	0.54
Dominance Species	<u>Acer rubrum</u>	<u>Smilax</u> sp.	<u>Ludwigia leptocarpa</u>	<u>Polygonum punctatum</u>
(Importance values**	<u>Fraxinus</u> sp.	<u>Lobelia cardinalis</u>	<u>Boehmeria cylindrica</u>	<u>Sagittaria latifolia</u>
of 20-70)	<u>Planera aquatica</u>	<u>Panicum gymnocarpon</u>	<u>Cyperus strigosus</u>	<u>Leersia oryzoides</u>
	<u>Nyssa aquatica</u>	<u>Panicum</u> sp.	<u>Arundinaria gigantea</u>	
	<u>Taxodium distichum</u>		<u>Ammania coccinea</u>	
	<u>Liquidambar styraciflua</u>			

⁺ H' = Shannon-Weaver Diversity Index

$$H' = - \sum P_i \log_2 P_i$$

where P_i = decimal fraction of total individuals,

total dominance, or total of importance values, belonging to the i th species

$$J' = \text{Equitability Index} = \frac{\text{Shannon-Weaver Index}}{\log_2 \text{ number of species}}$$

** Importance Value = relative density + relative dominance + relative frequency

POORER BODY CONDITIONS FOUND TO BE CHARACTERISTIC OF LARGEMOUTH BASS INHABITING REGIONS OF HEATED EFFLUENT

Par Pond, the 2800 acre (1120 ha) cooling reservoir on the SRP, has received heated effluent from "P" production reactor since 1957. Among the many notable biological features of this reservoir system is the extremely dense population of largemouth bass (Micropterus salmoides). Numerous papers on the ecology of this species in Par Pond have resulted because of their abundance and obtainability. Therefore, it is worthwhile to examine as many biological facets of the Par Pond bass population as possible and to contrast and compare characteristics of this bass population with those from other areas. Because data have now been gathered on Par Pond bass for several years, comparisons of certain population parameters can also be made within the reservoir over time. One research objective has been to examine the body condition of individual fish as a function of year of capture, season, sex and location in the lake relative to the thermal effluent. Such information, based on a large sample of adult bass, is useful in providing a more complete understanding of the population dynamics of this economically important species which is a major component of aquatic ecosystems in the eastern United States.

Most of the larger individuals were collected by lure casting, a small proportion being obtained by electrofishing, seining or rotenoning. Specimens used in this study were collected for a variety of purposes -- tagging, dissection, behavioral studies -- but the following data were always obtained: date of capture, location within the reservoir, length (standard and/or total), body weight, and, when possible, sex. For purposes of the present analyses only those individuals were included which were 20.0 cm or greater in standard length. This included more than 5,000 adult largemouth bass. Body conditions were determined for individual fish using the relationship, $K = \frac{10^5 W}{L^3}$, where W = body weight in grams and L = standard length in millimeters.

Par Pond receives moderate thermal loading at one point creating winter surface temperatures often greater than 30°C compared to surface temperatures of 15°C in the thermally unaltered areas. For purposes of the present analyses, fish taken from the vicinity of the effluent entry point were classes as being from the heated area; those taken from other parts of the lake were grouped for analysis as being from the normal temperature habitats.

No consistent difference in condition factor was observed between the sexes (Table 15), consequently, samples were combined for subsequent comparisons. Although a significant difference in body length was observed between the sexes, females being larger, fish length within a sex remained constant between seasonal samples and areas. In seasonal comparisons, fish from normal temperature areas had higher mean condition factors than those from the heated area (Table 15). Condition factors were higher in winter than in any other season. The lowest values occurred in spring in the normal temperature areas, whereas summer was the period of poorest body condition in the effluent region. No apparent trend in body condition was noted from 1967 to 1973; however, 1971 was notable in having uncommonly low K-values in both winter and the following summer. The winter, and to some extent the summer, of 1972 yielded exceedingly

Table 15. Seasonal Change in Condition Factor ($\bar{X}$) in Male and Female Bass From Heated and Normal Temperature Locations in Par Pond. Numbers in Parentheses Indicate Sample Size.

	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Fall</u>
<u>Normal</u>				
Male	2.40 (277)	2.18 (251)	2.24 (519)	2.24 (257)
Female	2.36 (346)	2.19 (327)	2.29 (592)	2.21 (202)
All	2.36 (796)	2.19 (596)	2.27 (1276)	2.23 (479)
<u>Heated</u>				
Male	2.28 (90)	2.02 (107)	1.94 (194)	2.16 (82)
Female	2.30 (102)	2.14 (344)	1.94 (224)	2.07 (102)
All	2.27 (610)	2.11 (484)	1.94 (443)	2.01 (460)

high values. Both winters were exceptional in having higher mean condition factors in the heated waters than in the ambient temperature areas.

As body lengths within each sex were relatively constant between seasons and locations, the lower K-values in the heated effluent area can be attributed to lower individual weights in otherwise similarly-sized fish. Thus, unquestionable relationship exists between body condition of largemouth bass and the location of capture relative to heated effluent.

The most straight-forward explanation, based on previous studies, is that the bass are attracted to the heated end of the lake, creating a local population density too great to be sustained even by the higher productivity characteristic of the heated end of the reservoir. During the warmer months the lowered body condition becomes even more dramatic as metabolic costs become greater. Even though bass in an effluent area usually remain below the thermocline, a sufficient proportion of time is spent in the epilimnion to elevate body temperatures. The lack of a yearly trend in body condition suggests that the Par Pond fish population has stabilized in regard to size parameters. However, fluctuations in response to environmental changes peculiar to a particular year are to be expected.

The relationship between lowered body condition and thermal loading are obvious from the present study. Hence, attention to the negative effects of thermal effluents on size parameters in adult fish must be considered along with such positive effects as attraction, increased growth rate of juveniles, and nondisruption of the reproductive cycle.

ELEVATED WATER TEMPERATURES ALTER THE GROWTH AND REPRODUCTION OF CATTAILS

Two species of cattail, Typha latifolia and T. domingensis, dominate the emergent vegetation along the shoreline in Par Pond. Stands of these two species occur together throughout most of the lake at normal water temperatures. Typha latifolia occupies a depth range from the edge of the shoreline to about 90 cm, and T. domingensis, the larger and more southern species, occurs in water ranging in depth from 80 to greater than 200 cm. Although both are frequently colonizing species, T. domingensis is considered more characteristic of fluctuating water levels and unstable habitats than is T. latifolia.

Growth and reproductive characteristics of these two species have been measured in 50 stands occurring along the thermal gradient in Par Pond from normal water temperatures to those about 8°C above normal. Total leaf production per shoot in T. domingensis was enhanced as temperatures increased to 4°C above normal (Table 16). Beyond this temperature, with the exception of one small stand at +6°C, T. domingensis disappears entirely from the shoreline vegetation. Typha latifolia reaches maximum production at temperatures just beyond the thermal limits of T. domingensis (Table 16). As temperatures increase

Table 16. Growth ($\bar{X}$ leaves/shoot) and sexual reproduction ($\bar{X}$ inflorescences/10 m²) in Typha latifolia and T. domingensis along a gradient of increasing temperature. (N = 30 shoots in each of 50 stands; $\bar{X} \pm SE$).

Temperature Increase (°C)	Leaves/Shoot		Inflorescences/10 m ²	
	<u>T. latifolia</u>	<u>T. domingensis</u>	<u>T. latifolia</u>	<u>T. domingensis</u>
Normal	8.8 $\pm$ 0.7	9.2 $\pm$ 0.2	17.0 $\pm$ 8.7	17.3 $\pm$ 15.3
+1	9.5 $\pm$ 0.2	10.2 $\pm$ 0.3	17.0 $\pm$ 8.9	30.0 $\pm$ 16.5
+2	10.7 $\pm$ 0.3	10.5 $\pm$ 0.8	12.1 $\pm$ 4.2	7.0 $\pm$ 1.9
+3	10.1 $\pm$ 0.4	11.8 $\pm$ 0.3	0.3 $\pm$ 0.3	1.6 $\pm$ 1.6
+4	10.4 $\pm$ 0.1	12.8 $\pm$ 0.6	0.2 $\pm$ 0.1	2.6 $\pm$ 2.6
+5	10.9 $\pm$ 0.5	0	0	0
+6	9.5 $\pm$ 0.2	14.4*	2.1 $\pm$ 1.6	0
+7	7.2 $\pm$ 0.3	0	0	0

* Data from one stand

past this optimum, T. latifolia leaf production declines and stands growing at 7-8°C above normal exhibit a marked reduction in number of leaves. Growth characteristics including mean shoot height and standing crop, in T. domingensis, are unaffected by temperature increases up to the thermal limit of the species. Typha latifolia stands which continue to grow beyond this temperature exhibit a significant stunting and reduction in standing crop. These findings are similar to those of McNaughton (1966), who demonstrated an ecotypic variation in shoot height related to latitude (and therefore temperature) at which the stands were growing. Net productivity of T. latifolia has been examined in southeastern stands and determined that site fertility factors (with the exception of concentrations of phosphorus) do not appear to be related to variations in standing crop in this species.

Both species flower abundantly at normal water temperatures in Par Pond; however, as water temperatures increase, there is a marked reduction in the density of flowering stalks and neither species produces many inflorescences at the upper extent of its temperature range. This is especially true of T. latifolia. In the past two years reproduction in T. latifolia stands occurring at the highest temperatures has been solely by vegetative proliferation. It has also been demonstrated that Typha latifolia produces a greater number of rhizomes than T. domingensis; whereas, populations of T. domingensis produce a relatively larger percentage of flowering culms.

The thermally affected Typha population in Par Pond demonstrate many of the same responses as do the latitudinal ecotypes described in the literature. Although T. domingensis stands were much more productive than T. latifolia stands growing at the same temperature they were able to maintain this high productivity throughout only a limited temperature range. Typha latifolia, however, maintained a relatively uniform productivity over a greater temperature range. The distribution of this species appears to be a reflection of its greater physiological adaptability and increased capacity for vegetative reproduction.

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THE ABUNDANCE OF TURTLE PARASITES IS HIGHER IN HEATED LAKES

Although interest in the biological effects of thermal pollution has increased in recent years, one aspect has received little attention from either an applied or a theoretical viewpoint. The increased incidence of two bacterial diseases, Columnaris, in heated areas of the Columbia River, and Furunculosis is frequently mentioned in the thermal literature, but, other than these isolated cases, no studies in the United States have dealt with parasite populations in thermally manipulated ecosystems. The paucity of information in this field undoubtedly reflects a lack of interest in the economic potential of fisheries as an additional source of food in the United States. This situation may be changing, however, if the recent projects envisioning aquaculture of fish and mariculture of shellfish indicate a trend. Systems analysts and economists engaged in such projects should consider both the loss in organismal growth caused

by increased metabolic rates in heated waters and the potential losses in productivity caused by increased parasite loads.

This study examines population and community ecology of parasites in a definitive host, the yellow-bellied turtle (Pseudemys s. scripta), in natural, heated, and formerly heated areas presently undergoing a postthermal recovery succession. Incidence of parasitism, parasite levels, and parasite distribution are considered.

Approximately 400 turtles were captured from several locations on the Savannah River Plant (SRP) area with a variety of methods. For each turtle the following data were recorded: sex, plastron length, weight and, when possible, age. The entire intestinal tract was removed and examined for composition of food and parasitic helminths. The intestines were scraped and flushed with water, and the collections from this process were washed in a series of five soil screens (U. S. Nos. 30, 50, 60, 100, and 325). Thus small worms (1 mm) and small intermediate hosts (e.g., copepods and ostracods) were identified when present.

The host Pseudemys s. scripta is susceptible to infection by several species of parasitic nematodes, trematodes, and acanthocephalans. In our investigation we found nine different species of gastrointestinal parasitic worms: five Acanthocephala, two nematodes, and two trematodes. No host contained all species simultaneously.

The extent of parasitism in host populations varies among different types of habitat as does the number of parasites per infected host (Table 17). In the natural areas Spironoura sp. and Macravestibulum sp. differ significantly between ponds and river swamps in both abundance and parasite load. The nematode Spironoura sp. is more prevalent in the turtle populations from ponds; the trematode Macravestibulum sp. is more prevalent in river-swamp populations. On the other hand, the incidence and worm burden for nematodes (both Spironoura sp. and Camallanus sp.) are significantly lower in hot ponds than in any other habitat. The number of nematodes per infected host, however, is increased in the heated river swamps.

Trematodes appear to be adversely affected in areas receiving heated effluent regardless of habitat type. Although the incidence of trematodes in heated waters does not differ significantly from that in unaltered waters, the mean number of Macravestibulum sp. is significantly low in heated river swamps; the same trend of decreasing worm burden is evident for both trematode species in other thermal areas.

The number of Acanthocephala per host among the different areas demonstrates a highly significant effect of thermal loading (Table 17). The incidence of infection does not differ significantly among areas. The burden of Acanthocephala is the same in natural ponds and river swamps although turtles from thermally altered communities are definitely influenced with regard to the densities of Neoechinorhynchus spp. populations. Thus in heated ponds the mean level of worms is increased 15-fold over that found in natural ponds; in recovery ponds the number of worms is almost sevenfold greater. The trend suggests that recovery areas may be returning to normal. Because of the high variances, no

Table 17. Percent Incidence, Mean Number, and 95% Confidence Interval of Neoechinorhynchus spp. in Different Thermal Habitats

	Incidence, % *	Sample size	Mean	95% confidence interval	Adjusted mean
River swamp					
Hot	80	5	6.9	0 to 84	14.5
Recovery	71	41	30.8	14 to 67	28.3
Natural	86	21	12.0	6 to 26	13.0
Pond					
Hot	93	15	156.8	47 to 520	191.6
Recovery	97	86	75.8	51 to 111	69.0
Natural	80	59	11.0	7 to 17	12.0

* Calculated by $100 \times (\text{number of hosts infected with } Neoechinorhynchus \text{ spp.} / \text{total number of hosts in sample})$.

Mean number of *Neoechinorhynchus* per host calculated after transforming number of parasites to $\log$ of number of parasites +1.

95% Confidence interval of transformed mean number of *Neoechinorhynchus* per host.

Mean number of *Neoechinorhynchus* per host after adjusting for differences in host-population size among thermal areas.

significant difference can be demonstrated between population densities of Neoechinorhynchus in natural compared with thermally influenced river swamps. However, variances are higher in heated environments.

Clearly, additional research is necessary on the effects of thermal pollution on infectious disease of the indigenous fauna. As far as we are aware, our findings represent the first evidence that specific host-parasite relations are modified by the addition of heated effluent to aquatic ecosystems. The value of such data, in addition to contributing to our basic understanding of thermal systems, is central to the issue of whether or not the benefits of adding waste heat to a particular cooling system (e.g., lakes, streams, swamps, or cooling towers) outweigh potential economic costs of decreasing fishing (recreational use) or of jeopardizing the health of the indigenous fauna.

GROWTH RATES OF JUVENILE BASS ARE ENHANCED IN AREAS OF THERMALLY ELEVATED WATER TEMPERATURES

Temperature requirements for growth and reproduction of aquatic life may be the most important considerations in establishing thermal standards. Current data regarding temperature requirements of biota have been largely obtained from acute thermal-resistance studies. Consequently, data on growth and reproduction in waters receiving thermal discharges are not available for most species.

The largemouth bass (Micropterus salmoides) is an important species in lentic recreational fisheries. Much life-history information has been accumulated on this species under natural temperature regimes; however, few data are available about largemouth bass in waters warmed by waste-heat discharges. This study was initiated to compare growth and condition factors of juvenile largemouth bass from an area warmed by thermal effluent with those of fish in non-heated areas in the same reservoir.

Juvenile largemouth bass were collected by one to four seine hauls at representative stations in Par Pond at approximately one-week intervals from May through October 1969, and once a month from April through September 1970. Station 1 was located in a cove along the northeast shore, about 70 m from the thermal effluent. Stations 2 and 3 were located in nonheated areas. Station 2 was at the south shore of the outflow dam in Par Pond, and station 3 was in a 1.8-ha cove. Collections during 1970 were made only at stations 1 and 3. Temperatures at the sites of fish collections were measured with standard laboratory thermometers and maximum-minimum thermometers. Juvenile bass were transported to the laboratory in styrofoam coolers or plastic bags and processed within 24 hr. The fish were measured to the nearest 0.1 cm (total length) and weighed to the nearest milligram.

Mean surface-water temperatures at station 1 measured at the time and site of collection of juvenile largemouth bass exceeded temperatures in nonheated areas (stations 2 and 3) by 7°C for 1969 and 3°C for 1970. Water temperatures were generally similar between

stations 2 and 3, usually differing by $+2^{\circ}\text{C}$ for 1969 and 1970. Monthly water temperatures were generally higher in 1969 than 1970. The waters where juvenile bass were collected were usually stratified. Surface-water temperatures occasionally exceeded bottom temperatures by 16°C at the heated station and up to 14°C at nonheated areas.

Growth rates of juvenile largemouth bass were higher at the heated station than at the nonheated stations (Fig. 5). Growth rates of juvenile bass from stations 2 and 3 were similar ($t = 1.095$, 196 degrees of freedom (df)). These data were pooled for comparisons of growth between fish from heated and nonheated areas. Juvenile largemouth bass from the heated station grew significantly ($P < 0.05$) faster than bass of similar age from nonheated waters for 1969 ($t = 2.234$, 473 df) and 1970 ($t = 2.004$, 200 df). The following equations described the regressions of length (Y) and time (X):

Heated	1969	$Y = 0.251 + 0.0030X$
	1970	$Y = 0.371 + 0.0025X$
Nonheated	1969	$Y = 0.228 + 0.0026X$
	1970	$Y = 0.362 + 0.0019X$

The linear model used in this study provided an adequate comparison of growth rates of bass from heated and nonheated areas of Par Pond. During 1970 coefficients of determination (r^2) were high in the regressions of body length by time. Low coefficients of determination were calculated for the 1969 sample. The poorer fit to the linear model during 1969 may be attributed to rising water levels and the consequent mixing of individuals from a variety of environmental situations. The water level had stabilized by 1970 so that samples were more representative of a subpopulation.

The growth rates in juvenile largemouth bass from heated areas of Par Pond are probably related to thermal conditions. Our results indicate that early growth of juvenile largemouth bass may not be impaired by thermal effluents under the conditions existing in Par Pond.

TURTLES INHABITING POST-THERMAL ENVIRONMENTS DISPLAY FAST GROWTH AND LARGE BODY SIZE

Pseudemys s. scripta (Schoepff), the yellow-bellied turtle, is abundant in the southeastern United States and is found in many different aquatic habitats, both lentic and lotic. Habitat differences are often reflected in this group of turtles through changes in their growth and size parameters. For example, adult females captured from a heated reservoir were found to have reached significantly larger sizes than those from three natural areas.

Differences in body size and in juvenile growth rates have also been reported among populations of a closely related species (Chrysemys picta) living under differing environmental conditions in Michigan. Since both growth rate and size influence reproduction in the species, it is important to assess the effects of thermal loading in natural habitats on these parameters.

Figure 5. Growth rates of juvenile largemouth bass (Micropterus salmoides) from waters warmed by thermal effluent (----) and from nonheated waters (——) in Par Pond near Aiken, S. C. Growth rates were determined by simple linear regression; equations are given in the next text.

The objective of this study was to compare growth and size characteristics of *P. scripta* living under different thermal or chemical regimes in otherwise natural habitats. The habitat types were as follows: (1) natural, i.e., areas of normal water temperatures; (2) thermal, i.e., aquatic areas receiving heated effluents that elevate water temperatures and contiguous aquatic habitats; (3) postthermal recovery, i.e., areas that once received intense thermal loading but no longer do so; and (4) chemical, i.e., a farm pond receiving chemical wastes and sewage.

Collection techniques were similar to those used for *Chrysemys picta*. Records of capture location, plastron length (to the nearest millimeter), and sex (of individuals > 100 mm) were obtained for each specimen. Population size-structure comparisons were based on mature individuals of each sex (males, > 100 mm; females, > 160 mm). The annuli method described by Sexton (1959) was used to establish juvenile growth rates.

The adult females of *Pseudemys scripta* from the thermal and postthermal recovery areas had larger body sizes than those obtained from natural, undisturbed environments (Fig. 6). The mean plastron length of females from natural areas was 181 mm. Only 5% of the female turtles in the natural areas were as large as the mean length of the Par Pond turtles (219 mm), and fewer than 1% were as large as the mean length of female turtles from the combined recovery areas (221 mm) or from Pond C (225 mm).

The frequency distribution of the sizes of male turtles in thermally influenced areas also shifted toward larger sizes, although the contrast between natural and thermally affected areas was more dramatic for females than for males. The mean length of turtles living in natural areas was 133 mm. The mean length of the Par Pond turtles (157 mm) was similar to that of the recovery-area turtles (154 mm). None of the 17 turtles sampled from Pond C were as small as the mean size of those from the natural areas. Approximately 20% of the adult males from the natural areas were as large as the average size of those from the thermal habitats.

Growth rates of *P. scripta* from thermally affected habitats were significantly higher than those from a variety of natural areas. Although in natural areas growth rate decreased drastically after a mature size was reached, in many instances the mature turtles in the thermally influenced areas continued to grow as rapidly as immature ones. The turtles from Steed Pond, which receives biological and industrial wastes, also displayed a rapid growth rate. No adjustment was made for growth-rate differences between ages or sexes since preliminary analysis revealed that these factors would have minimal effect on comparisons between populations.

This study supports and extends earlier reports that *Pseudemys scripta* reach larger sizes in thermally affected habitats. The phenomenon apparently holds true in other thermal situations (Pond C) and for males as well as females. In addition, juvenile growth rates are substantially increased in the thermally altered areas. The larger size and faster growth observed in the post-thermal areas indicate that the phenomena are not merely responses

Figure 6. Percent of adult female Pseudemys scripta in different size classes from areas differently affected by thermal loading in the Savannah River Plant area.

POPULATION SIZE STRUCTURE

by the turtles living under conditions of elevated water temperatures.

If these community changes result in major changes in the population dynamics of other animal species, the interactions could have a further impact on environmental alteration. That such changes can result from either thermal or chemical causes, coupled with the evidence that post-thermal environments continue to show the changes, seems noteworthy in consideration of man's present and long-lasting effects on the environment.

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PARASITE POPULATION DENSITIES OF BASS AFFECTED BY HOT WATER

The discovery of seasonal periodicities in parasitic helminths (enteric) has been the object of much discussion in recent years. Seasonal periodicities have been documented for trematodes, cestodes, and acanthocephalans from many natural ecosystems. Several reasons have been proposed as being the primary stimulus for seasonal cycling in enteric parasite populations. Of the factors implicated, availability of infected intermediate hosts, hormonal changes and temperature have received the most attention. Since temperature is obviously such an important parameter in regulating host-parasite systems, it was felt that a more concentrated look at the interrelationship between temperature and parasitism was necessary.

The Savannah River Plant presents an ideal situation to study some of these temperature related phenomena. Par Pond provides an excellent opportunity for concentrated studies on the effects of temperature on the population dynamics of helminth parasites in largemouth bass (Micropterus salmoides) because of the substantial host population and the wide range of different thermal regimes within the reservoir. A two year program to study the affects of temperature on the population biology of the host-parasite relationship of largemouth bass and its helminths was undertaken.

The Par Pond study area was divided into six sampling stations representing both normal and thermally elevated water temperatures. Each station also had similar flora and fauna and the bass shared the top carnivore trophic level with the American alligator.

A minimum of 10 adult bass was taken with artificial lures each month from each of the stations. In accordance with standard parasitological techniques, the enteric helminths were removed, identified, sexed and preserved. Monthly water temperatures were also taken at a depth of 1 to 3 feet with a max-min thermometer at each of these sampling stations.

Water temperatures at the heated station generally averaged around 25°C for both the winter and spring (25.4 and 25.6 respectively) and 32°C for the summer and fall (32.8 and 32.9) respectively). A maximum of 35°C was recorded for the unheated areas in July and a minimum of 6°C was recorded in December. For the winter and spring, water temperatures averaged 11.9 and 15.9°C, respectively, and 26.8 and 22.3 for the summer and fall. The greatest differences (11° and 15°C) in the mean ambient water temperature between the heated and ambient areas occurred during the fall and winter. Water temperatures were

always more variable in the heated area as a result of periodic fluctuations in the activity of the reactor. There was never any overlap in the maximum water temperature of the heated and unheated areas, although there was considerable overlap in the minimum water temperature of the heated area and the maximum water temperature of the unheated areas.

Of the parasites collected, the acanthocephalan Neoechinorhynchus cylindratus was, by far the most abundant species encountered. This species was found in both heated and unheated areas but the total density of the Neoechinorhynchus cylindratus infrapopulation was much higher in waters receiving thermal input (Table 18). The cestodan parasite, Proteocephalus ambloplitis, on the other hand, was more abundant in water receiving no thermal input (Table 19).

Parasite populations respond in many different ways to the same stimulus. The acanthocephalan parasite responded to temperature with an increase in its total population densities, whereas the cestode responded with a lowering of the total population density. For the acanthocephalan, the increase in its population density resulted from the lengthening of the growing season or reproductive season of its primary intermediate host (ostracods). These invertebrates were found in heated waters during the winter but were very sparse in water receiving no thermal input. The fall of the year is the normal parasite recruitment season but it was extended into the winter in areas receiving thermal input.

The response of the cestode is probably a response to the combined stimulus of temperature and hormonal change. The tapeworm (adults) was found precisely at the time of gonadal recrudescence in adult bass. At the height of the spawning season (April & May) is when the majority of the adult tapeworms were found.

These different responses have different final outcomes also. The acanthocephalan may cause localized damage (lesions) to its host due to attachment and reattachment. The cestode, on the other hand, can cause permanent sterilization in the host since the larval stages are found in the gonads of the bass. Since large numbers of larvae were also found in waters receiving thermal input, the long range result could be a drastic decline in the bass population.

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STANDING CROP OF SPANISH MOSS (TILLANDSIA USNEOIDES) INCREASES ALONG THERMAL STREAMS IN THE SRP SWAMP

Tillandsia usneoides is an epiphytic vascular plant (family Bromeliaceae) growing on the branches of hardwood and cypress trees in the Savannah River Swamp. Previous studies of the ecology of this species indicate that it is restricted to well-lighted moist habitats and to suitable forest substrates undisturbed by fire and logging. The occurrence of horizontal branches is related to the abundance of this species. Although the plants produce viable seeds, reproduction of Spanish moss is generally accomplished vegetatively by means of fragmentation. Dissemination of the species by this means is slow, with the exception of hurricanes or violent storms.

Table 18. Seasonal variation in the mean ($\pm$ 1 SE) worm burden of N. cylindratus from heated and unheated areas of Par Pond. Numbers in parentheses indicate sample sizes.

	SEASON			
	<u>Fall</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>
Heated	66.7 $\pm$ 11.72 (31)	170.2 $\pm$ 35.38 (31)	161.92 $\pm$ 33.12 (25)	37.0 $\pm$ 5.52 (67)
Unheated	28.5 $\pm$ 2.58 (157)	108.5 $\pm$ 9.00 (149)	99.5 $\pm$ 8.10 (142)	35.1 $\pm$ 1.75 (315)

Table 19. Seasonal fluctuation in the mean number of Proteocephalus ambloplitis (larvae and adults) from heated and unheated areas of Par Pond.

	MONTH											
	J	F	M	A	M	J	J	A	S	O	N	D
Heated	2.00	4.12	1.20	2.40	.25	3.60	2.67	1.00	2.40	2.67	2.00	2.57
Unheated	3.24	4.33	2.36	3.57	8.33	12.83	4.54	1.40	1.88	2.17	3.57	6.32

Tillandsia usneoides was collected along the periphery of three drainage streams in the SRP swamp. These are Four Mile Creek which has received thermal effluents for 20 years; Steel Creek, a six-year post-thermal recovery stream; and Upper Three Runs Creek, a natural stream which has never received thermal effluents. Along each stream plants were sampled from 10 plots, each 4m x 4m, at heights of 0-2m, 2-4m, and 4-6m. Concomitant analysis of relative per cent substrate and tree composition of these plots were conducted.

Table 20 summarizes the horizontal and vertical distribution of dry weight biomass of T. usneoides for the three stream systems.

Total biomass values from the thermal and post-thermal stream locations were not significantly different; however the vertical distribution was reversed for these two sites. Preliminary indications link this reversal in abundance to the composition of the understory vegetation. The understory at Steel Creek consists chiefly of greenbriar and switch cane; whereas, the understory at Four Mile contains a greater number of small trees which provide more horizontal support. The vertical distribution of T. usneoides at Upper Three Runs follows the same pattern as that at Steel Creek; however, the reduction in total biomass along this natural stream may reflect the dense overhead canopy. It appears that the peripheral effects of the thermal effluents on the streamside vegetation is indirectly affecting the distribution and abundance of Spanish moss.

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THERMAL LOADING AFFECTS SEASONAL DISTRIBUTION OF THE AMERICAN ALLIGATOR ON PAR POND

Although the American alligator (Alligator mississippiensis) has increased in some portions of its range it remains on the list of rare and endangered species. A more complete understanding of the biology of the species is needed for proper management, particularly in the northern portion of its range. The alligator is of special interest to studies concerning thermal alteration of aquatic systems because it is a large motile ectotherm, which, unlike most other large reptiles is distributed in a temperate rather than a tropical climate. Behavioral thermal regulation allows the alligator to extend its period of activity. The addition of heated water would be expected to modify this behavior and allow the effects of water temperature to be isolated from that of air temperature and photoperiod. The purpose of this project was to determine the effects of heated effluent on the movement, distribution and thermal regulation of the alligator.

Night cruise counts were made at weekly intervals with a 12 volt spotlight. The entire reservoir was censused by boat and the location of each individual was noted. Air temperature was recorded before each cruise and the water temperature at five locations around the lake was also recorded. The population was estimated by mark-recapture and by the Hansen Plot Removal Method. Radio transmitter collars were used to track the movements of individual alligators on a daily basis.

Table 20. Horizontal and vertical distribution of T. usneoides biomass ($\bar{X}$ g dry weight $\pm$ 2 SE) for three stream systems on SRP.

	Level 1	Level 2	Level 3	Total
Four Mile Creek (thermal) N=10	1287 $\pm$ 199	672 $\pm$ 114	332 $\pm$ 59	2290 $\pm$ 255
Steel Creek (post-thermal) N=10	461 $\pm$ 84	821 $\pm$ 172	1265 $\pm$ 298	2547 $\pm$ 465
Upper Three Runs (natural) N=5	31 $\pm$ 13	54 $\pm$ 21	86 $\pm$ 41	170 $\pm$ 70

Daylight headcount data on Par Pond documents a seasonal fluxuation in alligator numbers in North Arm (ambient area) and the Hot Arm (area of thermal loading). These trends are primarily a function of water temperature. Night cruise counts indicate a seasonal trend in the number of alligators counted and a change in distribution with season for the entire lake. Distribution appears correlated to water temperature while visibility is influenced by air temperature as well as water temperature. All counts show very low numbers in North Arm during the colder months and high counts during the summer. The Hot Arm counts are high in the winter and low during the summer. Fall and spring night cruises show concentrations of animals at the mouth of the Hot Arm and two miles south of the northern extreme of North Arm.

Alligators equipped with radio transmitters showed movement between summer and winter ranges. In North Arm, transmitter equipped alligators restricted their winter range to at least one mile south of the northern extreme while the summer range consisted of the entire North Arm. In the Hot Arm, monitored animals wintered in the Hot Arm and moved to the Southwest Arm or the main lake during the summer. No movement between the North Arm and the Hot Arm was recorded. Repeated movements between winter and summer ranges occurred each fall and again each spring. This movement was generally about two miles one way and was made between 24 hour radio locations. Additional information was obtained during a mark recapture population estimation study. Animals were frequently recaptured in the same area during successive summers. The population estimate for adults (>6 foot) was 75 using the mark-recapture. Capture was accomplished by using baited trap snares. An estimate was also made of the entire population by the Hansen plot removal method using consecutive night cruises resulting in an estimated 126 alligators on Par Pond. The average size of adults was 9 feet and the sex ratio favored males. The proportional number of juveniles was low indicating a low reproductive rate. The average number of clutches surviving the first winter is less than two per year, and mortality in the first year is high. Water temperatures of less than 15°C results in a dormant state and no movement of alligators. Water temperatures greater than 15°C and less than 20°C result in a semi-dormant state. High air temperatures result in limited feeding activity and movements to the summer range but these activities are only temporary until the water temperature exceeds 20°C. The interval from 20 to 25°C results in the movement of alligators to the summer ranges and feeding activity. This interval also results in the activity of the smaller size classes including those which hatched the previous fall. Water temperatures greater than 25°C and less than 35°C and results in active feeding and dispersal of animals throughout the lake. Finally in the area of thermal loading summer water temperatures may exceed 35°C and utilization by alligators is restricted to short periods of feeding at night. Water temperature and air temperature have predictive value only as they affect body temperature. Behavioral thermal regulation and factors which influence its effectiveness may modify the effects of air and water temperature. Thus it would be advantageous at this point to monitor the body temperature and the factors which affect thermal regulation for a more exact quantification of microclimatic

requirements of the alligator.

ADDITION OF LOW-GRADE HEAT TO WARM RESERVOIRS CAN BE EXPECTED TO RESULT IN THE FORMATION OF PRESISTENTLY INDEPENDENT WATER MASSES WHOSE BOUNDARIES ARE FREQUENTLY MARKED BY COLLECTIONS OF ORGANIC MATTER, OR SLICKS

Par Pond is characterized by some highly unusual surface features, especially during summer. Except when the wind is very strong or the lake is flat calm, there are numerous elongate slicks over the lake surface, both near to and several km distant from the hot water source. The origin and nature of these slicks has been investigated over the last year.

Slicks on Par Pond range in length between 50 and 2000 m and are ordinarily 1 to 50 m wide. They appear as smooth portions of the water surface whenever the wind is between 0.5 and 5.0 m/sec. The material forming the slicks is an organic surface-active material, apparently of biological origin and not a petroleum product. Experiments with this material show that it is soluble in ethanol and is present in considerable quantities within the slick boundaries.

Slicks are almost always oriented parallel to the wind and accumulate macrophyte fragments and other debris as well as the organic surface-active material. Capillary waves are suppressed within slicks, which accounts for their distinctive appearance. The slicks are superficially similar to the somewhat enigmatic "taches d'huile" that have been observed by limnologists in many parts of the world, except the phenomenon is much more pronounced and frequent in Par Pond than in unaltered lakes.

The water column in the vicinity of slicks was mapped for temperature on numerous occasions and it was found that slicks were without exception located over or very near an abrupt horizontal discontinuity in temperature ranging from 0.05°C to 1.00°C , usually 0.10 to 0.20°C (Fig. 7). The discontinuity fades with depth but may be detected as deep as 5 m. Subsequent thermal mapping showed that while all slicks overlies temperature discontinuities, not all discontinuities are marked by slicks.

Currents were examined in the vicinity of slicks by means of some specially-designed floats that would be capable of measuring wind-generated currents at various depths in the water column. Currents flow at a variable angle to the wind but are rather precisely aligned with the long axis of slicks. The currents range in velocity between 4 and 31 cm/sec and are slightly convergent from the two sides of the slick.

The data on slicks have been combined to support a specific hypothesis explaining slick formation. It is postulated that separate water masses are formed due to the addition of heat and resist mixing with each other due to a density difference correlated with their temperature difference. Wind-generated currents within these masses meet at the boundary, where they either diverge or converge. If they converge, biological oils on the water surface are greatly concentrated

Figure 7. Temperature cross sections of two slicks constructed from thermister data. A. July 13, North Arm near mouth. B. August 7, North Arm at bend.

at the boundary as one water mass rolls against another.

If the proposed explanation of Par Pond slicks is correct, comparable slicks can be expected on other lakes receiving waste heat. Slicks on heated lakes should thus prove to be useful visual indicator of water mass boundaries and may also be of direct biological significance as a mechanism for concentration of organic matter.

*

DRAGONFLY NYMPHS ADAPT TO THERMAL EFFLUENTS

Dragonfly nymphs represent an important component of the benthic population in most aquatic systems. Within the same general habitat are species occupying narrowly separated niches. Niche selection by various dragonfly species is accomplished by several mechanisms, ranging from physiological responses to physico-chemical characteristics of the aquatic habitat to oviposition sites. Therefore, dragonflies adapted to different sets of conditions, are sensitive to changes in the aquatic environment.

On the Savannah River Plant, both numbers of individuals and species are reduced when thermal effluent from a nuclear reactor is received by a stream or pond. Surviving genera belong to the subfamily Libellulinae (Table 21). These are the "mud-sprawlers" which manage to survive on the bottom of small streamside pools, backwater areas and the extreme edges of ponds. Mortality is complete for the remaining families and subfamilies which contain the genera listed under the "burrowers, debris-sprawlers" and the "clingers and climbers".

The exact manner in which the addition of thermal effluent limits Odonate populations is difficult to assess. Some species are likely eliminated by the direct effects of increased water temperature. Others are reduced in numbers or eliminated indirectly due to habitat alterations. With the exception of blue-green algae, aquatic vegetation is eliminated either by elevated temperatures or increased siltation. Thus the heterogeneous habitat no longer exists for a diverse dragonfly nymph population, even if the increased water temperature could be tolerated. Further instability in the effluent stream results from periodic and unpredictable fluctuations in water level and temperature as the reactors are shut-down for routine maintenance. Nymphs do not follow the receding waterline but remain in the exposed mud. The reactor may be down for a few days to three weeks. During this period the water level may again be raised to the previous level as water at ambient temperature is flushed through the inactive reactor. During the winter, nymphs may be subjected to water temperatures as much as 15-20°C lower than when the reactor is operational. Thus, nymphs in the thermal effluent stream survive extended periods in relatively constant water temperatures interrupted by short periods of sudden temperature changes and water level fluctuations.

The continued survival of a given dragonfly species is dependent upon a degree of synchronous larval development. In some species of Odonata larval development in later instars may be controlled by temperature. Such species spend the late summer and winter months diapausing in the last instar, then emerge synchronously in the spring as water temperatures rise. Synchronized emergence patterns may decrease

Table 21. Dragonfly nymphs collected from thermal and non-thermal streams.

	THERMAL	NON-THERMAL
Gomphidae		
<u>Progomphus obscurus</u>		X
<u>Hagenius brevistylus</u>		X
<u>Dromogomphus spoliatus</u>		X
<u>Gomphus laurae</u>		X
Aeschnidae		
<u>Boyeria virosa</u>		X
<u>Anax junius</u>		X
<u>Epiaeschna heros</u>		X
Libellulidae		
Macrominae		
<u>Macromia illinoiensis</u>		X
Cordulirae		
<u>Neurocordulia alabamensis</u>		X
Libellulinae		
<u>Perithemis terera</u>	X	X
<u>Celithemis</u> sp.	X	X
<u>Libellula</u> sp.	X	X
<u>Plathemis lydia</u>	X	X
<u>Erythemis simplicicollis</u>	X	X
<u>Pachydiplax longipennis</u>	X	X

competition with adults of other species and increase the frequency of intraspecific encounters. The question of the effect of elevated water temperatures on the overall developmental cycle of dragonfly nymphs has not been fully investigated. We have found that populations of dragonfly nymphs in thermal streams have different size structures when compared to that of the same species from natural streams. Body size temperature may have been only indirectly related to water temperature. Other studies have shown that aquatic insect species diversity is significantly reduced in thermal streams. Such a change in community structure could allow more rapid growth in dragonfly nymphs of thermal streams due to a reduction in competition.

Nymphs of a Libellula species were collected from thermal effluent streams and their thermal preferences tested in a thermal gradient apparatus. Three groups of dragonflies were acclimated at 16°, 24°, and 32°C for 48 hours before being tested in the temperature gradient. Movement within the thermal gradient was restricted from either extreme, for all groups. Those dragonflies acclimated at 32° and 24°C avoided the heated section of the gradient. Dragonflies acclimated at 32°C preferred the area in the gradient between 31° and 40°C; those acclimated at 24°C showed a broader preferendum extending from 25° to 37°C. However, dragonflies acclimated at 16°C demonstrated a broad preference within the chamber extending from 14°C to 41°C. The 16°C group differed in their behavior during the tests from the other groups by frequently changing position. Those in the other groups tended to be akinetic during the tests. The shift in thermal preference according to acclimation temperature parallels a similar shift in CTM according to laboratory acclimation temperature. Dragonflies acclimated at lower temperatures express greater variation in thermal preference; higher acclimation temperatures tend to reduce the variation in thermal preference.

Dragonfly nymphs from thermally stressed streams have a higher thermal tolerance than nymphs from natural streams (Fig. 8). This higher thermal tolerance is reflected by a significantly higher critical thermal maximum (CTM) and a higher lethal temperature (LT) at different acclimation temperatures. Acclimation temperature, body length, and time of day are important factors determining the thermal tolerance of nymphs in natural and heated streams. Other important sources of variation in measuring thermal tolerance include observer, acclimation time, and rate of heating. Correlations between CTM, LT, and body length are significant. Mechanisms permitting the survival of dragonfly populations under thermally stressed conditions must include both physiological acclimatization to higher temperatures and directional selection for higher thermal tolerance. Current thermal tolerances as well as the potential of species to evolve in response to thermal stress are important in setting appropriate environmental standards.

Figure 8. Comparison of LT values for Libellula nymphs at five acclimation temperatures. Horizontal bars represent the mean, vertical bars $\pm 2SE$ and vertical lines the range. Sample sizes were: Four Mile Creek (thermal-effluent stream), 20 at all five acclimation temperatures; Steel Creek (control stream), 15 and 15°C, 20 at 20 to 30°C and 10 at 35°C.

* DIVERSITY CONCEPTS CAN BE USED TO EVALUATE THE IMPACT OF THERMAL STRESS UPON MACROBENTHIC ASSOCIATIONS

Changes in species associations within an ecosystem usually accompany environmental alterations, particularly in aquatic habitats. Following an environmental alteration, individuals of macrobenthic populations must either move to more favorable conditions, adapt to the new conditions or die. Under stress conditions, these associations are altered by populations of non-tolerant species being reduced in biomass and numbers of individuals, while populations of tolerant species, or those capable of surviving and reproducing under the new set of conditions, increase in biomass and numbers of individuals. This report investigates the application of information theory toward a numerical assessment of the influence of elevated temperatures upon macrobenthic associations.

Two different studies using different sampling techniques in various SRP streams reveal similar trends which may lend themselves toward construction of generalized concepts. If aquatic insect populations in thermal, post-thermal, and natural streams are sampled by drop-boxes and the contents compared according to species diversity and composition, it can be demonstrated that both species diversity and composition of these populations vary with the thermal history of the streams. Aquatic insect groups, such as plecopterans, odonates, ephemeropterans, and trichopterans are absent or highly reduced in streams currently receiving thermal effluents, but are well represented in natural streams. Variances associated with mean diversity values are homogeneous; means between thermal and natural streams differ statistically. Thermally affected streams are characterized by aquatic insect associations with low diversity values whereas associations in natural streams show relatively high diversity values.

Similar trends were seen in another study using leaf-litter baskets to attract macrobenthos from differentially affected portions of confluent natural and reactor discharge streams. In these studies, macrobenthic associations in natural zones showed high diversity values, while associations in thermally affected zones showed statistically lower values.

Another trend consistent between both studies was seen in the variances associated with evenness (J') components of diversity estimations. Evenness (J') values quantify the comparison of the observed diversity to the maximum diversity possible with the same number of species and can be used as another evaluation term for biotic associations. As illustrated in Fig. 9, associations in natural streams show high evenness values associated with low variances whereas associations in thermally affected streams show lower evenness values associated with wider variances. The variances plotted in Fig. 9 are heterogeneous and demonstrate a trend of decreasing variance with decreasing thermal stress.

As an evaluation term, J' reflects the predictability associated with numbers and kinds of individuals represented in single collections

Figure 9. Means, 2 standard errors, standard deviation, and ranges for J' values calculated for macrobenthic collections made from each of three streams on the Savannah River Plant. $N = 18$ per stream; T = thermal stream; PT = post-thermal stream; C = climax or natural stream. $J' = H'/\log S$ where S = number of species.

from the streams. With increasing thermal stress, the predictability is lowered. Low J' values with low predictability in the thermally affected streams probably is a result of habitat differences along the transects from which the samples were collected. Collections made from natural streams contained similar numbers and kinds of individuals as reflected in high J' values. In collections made from thermally affected streams, this relationship breaks down because thermally stressed habitats can not support similar kinds and numbers of individuals due to variations in environmental rigor.

* MOSQUITOFISH (Gambusia affinis) HAVE NATURALLY HIGH THERMAL TOLERANCES

Adaptations of fish to different thermal environments have been studied from many different points of view. Geographical variation in thermal tolerances are known for several species but most studies have been conducted at more northern latitudes. Adaptations to relatively high temperatures have been documented for desert pupfish and for bluegill inhabiting thermal effluent areas. Other southern species and especially those living in streams and lakes with nuclear reactors and other power plants should be studied to determine their thermal tolerances.

Our primary purpose was to determine thermal tolerances in mosquitofish (Gambusia affinis) living in natural lentic and lotic environments or those stressed by heated effluents discharged from nuclear production reactors. The mosquitofish is a top minnow living in the very shallow parts of the littoral zone. As such it may be routinely exposed to higher temperatures than deep dwelling forms, such as centrarchid species. Gambusia is found in a wide variety of habitats at up to 43°C on the SRP and obviously must have a high thermal tolerance. Documentation of thermal tolerances is needed for establishing water temperature criteria to protect aquatic life.

Mean Critical Thermal Maxima (CTMs) and Death Points (DP) are given for each location-sex-acclimation temperature subgroup in Table 22. Acclimation temperature (T_a) has the strongest effect on thermal tolerance of any variable considered ($F = 247$ to 295 for DPs and CTMs of the sexes considered separately). Death points and CTMs (Table 22) were linearly related to acclimation temperature (Table 23). However, there was a slight tendency for DPs and CTMs to level off at both high and low acclimation temperatures suggesting a sigmoid function as demonstrated for the pupfish and previously for the mosquitofish.

There were significant positive linear correlations between CTM and DP for both males and females (Table 22). The relatively high degree of predictability associated with these relationships suggest that CTM and DP may be measuring different aspects of the same process.

There were no significant correlations between body length and T_a , CTM or DP in males ($r = 0.01$ to -0.07) but this was not true for females ($r = 0.16$ to 0.25 with $P < 0.01$ in each case). The significant correlation between female body length and T_a slightly confounds the interpretation of the simple effects of other variables. However, the slope

Table 22. Mean critical thermal maxima (CTM) and mean death points (DP) for male and female mosquitofish from four localities acclimated to six temperatures. Pond C and Four Mile Creek currently receive thermal effluent while Ellenton Bay and Steel Creek are at ambient temperature. Sample sizes followed by mean body size in millimeters are given in parentheses.

Acclimation Temperature	Criterion of Thermal Tolerance	Lentic				Lotic				All Localities Both Sexes
		Pond C		Ellenton Bay		Steel Creek		Four Mile Creek		
		♂ (58:22.9)	♀ (90:33.9)	♂ (49:26.6)	♀ (59:31.6)	♂ (42:21.6)	♀ (66:23.8)	♂ (69:22.2)	♀ (74:26.3)	
16°	DP	39.68	41.23	39.42	38.76	37.01	38.32	38.97	39.19	39.07
	CTM	36.36	37.94	37.30	37.93	35.50	37.58	36.26	37.80	37.08
20°	DP	40.50	40.49	38.59	40.21	38.46	38.74	37.94	38.73	39.21
	CTM	38.11	38.60	36.76	37.75	36.99	37.87	36.97	37.98	37.63
24°	DP	41.31	41.12	40.78	41.16	40.73	41.23	40.42	40.48	40.90
	CTM	39.55	39.57	39.34	39.36	38.80	40.49	39.16	39.63	39.49
28°	DP	42.51	42.47	41.77	42.56	42.28	42.29	41.78	41.24	42.11
	CTM	40.90	41.20	40.62	40.80	41.25	41.69	41.40	40.52	41.05
32°	DP	43.66	43.76	42.20	43.54	42.94	43.22	42.80	42.90	43.14
	CTM	42.71	42.40	41.35	42.44	42.54	42.66	42.35	42.44	42.36
36°	DP	43.86	44.56	43.43	43.99	43.60	43.57	43.45	43.57	43.75
	CTM	42.68	43.65	42.73	43.18	43.22	43.21	41.45	42.49	42.82

Table 23. Correlations and regressions between acclimation temperature (T_a), critical thermal maxima (CTM) and death points (DP) for male and female mosquitofish. Slopes and intercepts are given below the diagonal and correlation coefficients above it.

	T_a		CTM		DP	
	σ	ϕ	σ	ϕ	σ	ϕ
T_a						
Intercept			0.90*	0.89*	0.88*	0.88*
Slope						
CTM						
Intercept	31.11*	32.77*			0.93*	0.92*
Slope	0.33*	0.29ns				
DP						
Intercept	34.20*	34.70*	-6.42*	-1.21ns		
Slope	0.27*	0.26*	1.12*	1.00*		

* Significant at 0.001 level.

ns Not significant at 0.05 level.

($b = 0.22$) is relatively close to 0, although significantly different from it, and the predictability was also quite low ($r^2 = 0.05$). At any rate body length was not quite distributed at random across temperature acclimation groups in females as it was in males.

Thermal tolerance data for males and females were analyzed separately because of significant statistical interactions between sex and T_a and location. Females obviously have higher CTMs and DPs than do males. Females are considerably larger than males in all treatment subgroups (29.2 and 23.3 mm, respectively). The effects of sex and body length are confounded, and it is not possible to separate their effects with this data set. A separate experiment with a wider range of sizes of males and females would be needed to distinguish between the effects of these two variables.

The absolute difference between the male and female CTMs and DPs show a curvilinear decrease with increasing T_a . This may partially explain the significant interactions of sex with the other variables. Males generally have lower thermal tolerances (CTMs and DPs) than do females, and this difference is accentuated at low T_a s. In addition the difference between mean DP and CTM for both sexes combined decreases as a function of T_a . Thus less of a change in environmental temperature is needed to take the fish from behavioral disequilibrium to its upper lethal limit at a higher T_a than at a lower one.

Location also has significant effects on DP ($F \sigma = 26.8$ and $F \varnothing = 39.3$) and CTM ($F \sigma = 2.59$, $F \varnothing = 3.73$ and $P < 0.05$ in every case). Males and females had higher CTMs and DPs in Pond C but lower in Four Mile Creek than in Steel Creek and Ellenton Bay. Pond C and Four Mile Creek are the two localities currently receiving heated effluent. The apparent lack of high thermal tolerances in fish from Four Mile Creek may be partially due to its being a lotic environment. There was a tendency for fish from standing water environments to have higher CTMs and DPs although this trend is significant for the Ellenton Bay population for only the DPs of the females.

The mosquitofish apparently has a high thermal tolerance that adapts it to shallow southern waters. The species has a higher tolerance in the thermal lake (Pond C) possibly indicating an evolutionary response to the thermal loading. It also appears that fish from running water environments may have lower thermal tolerances, but more work is needed on this point. Mosquito fish represent an ideal species to stock in thermally affected areas.