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**Patterns of Fish Assemblage Structure and Dynamics in
Waters of the Savannah River Plant**

Comprehensive Cooling Water Study Final Report

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98

Executive Summary

Research conducted as part of the Comprehensive Cooling Water Study (CCWS) has elucidated many factors that are important to fish population and community dynamics in a variety of habitats on the Savannah River Plant (SRP). Information gained from these studies is useful in predicting fish responses to SRP operations. As a result of this research, the Savannah River Ecology Laboratory can provide informed technical recommendations to the Department of Energy - Savannah River Operations Office on optimal strategies for minimizing impacts to SRP fish populations.

The overall objective of the CCWS was (1) to determine the environmental effects of SRP cooling water withdrawals and discharges and (2) to determine the significance of the cooling water impacts on the environment. The purpose of this study was to:

1. Examine the effects of thermal plumes on anadromous and resident fishes, including overwintering effects, in the SRP swamp and associated tributary streams (see Chapters 1 through V of this report).
2. Assess fish spawning and locate nursery grounds on the SRP (see Chapters I through III of this report).
3. Examine the level of use of the SRP by spawning fish from the Savannah River (see Chapters I, II and V of this report). This objective was shared with the Savannah River Laboratory, E.I. du Pont de Nemours and Company.
4. Determine impacts of cooling-water discharges on fish population and community attributes (see Chapters I through V of this report).

Five studies were designed to address the above topics. The specific objectives and a summary of the findings of each study are presented below.

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Chapter 1. Ichthyoplankton dynamics were studied from February through August 1984 in three regions of the Steel Creek delta in the Savannah River Swamp System (SRSS): (1) Lower Steel Creek, (2) post-thermal recovery areas, and (3) undisturbed areas of cypress/tupelo forest. From the post-thermal recovery and cypress/tupelo forest regions, two habitat types were sampled: shallow, structured and deep, channel habitats. The objectives of the study were: (1) to describe spatial and temporal patterns of larval fish distribution and abundance and (2) to correlate effects of habitat modification on larval fish recruitment patterns.

Larval fish of 17 taxa were most abundant from March through May at all habitat sites. Larval fish densities fluctuated and peaked with a series of recruitment pulses. The occurrence of peak larval abundance differed significantly by two to four weeks between habitats. Peak larval densities occurred first in the post-thermal recovery regions and later in Lower Steel Creek and sites within the natural cypress/tupelo forest. Water temperature and cumulative degree days (above 0°C) were significantly positively correlated with timing of peak larval fish recruitment. Correlations of larval fish density and seasonal fluctuations in water level were detected only in channelized habitats of the cypress/tupelo forest and Lower Steel Creek.

• Total ichthyoplankton abundance varied among habitats. Disturbed sites had the greatest mean larval abundance, Lower Steel Creek was intermediate, and sites within the undisturbed cypress/tupelo forest had the lowest larval fish abundance. Regardless of region, shallow, structured habitats had greater numbers of larval fish than channelized habitats. The increased abundance of herbaceous plants in the post-thermal recovery areas is likely a major reason for the higher densities.

Recruitment of the numerically dominant species exhibited a seasonal succession. Chronology of recruitment was similar in all sites with darters initially dominating the larval fish assemblage followed by a mix of lake chubsuckers and pirate perch, and later by sunfish and cyprinids. Spawning of pirate perch, sunfish, minnows, and suckers generally commenced earlier in previously disturbed sites than natural, forested sites.

Shallow, structured habitats in both disturbed and natural regions of the SRSS had the most taxa of larval fish compared to other habitats. Common taxa groups were brook silversides, pirate perch, minnows, sunfishes, percids, and suckers. Anadromous clupeids also used the SRSS for spawning with most activity in the Lower Steel Creek channel or adjacent swamp habitats.

Chapter 2. Ichthyoplankton were sampled across a gradient in water temperatures from nine sites, that represented three major geographic regions in the SRSS from January through July 1985. Temperatures ranged from 2-19°C above ambient to temperatures characteristic of the region. The objective of this study was to characterize the effect of thermal alteration on reproductive cycles and the early life histories of fishes in the SRSS. Two questions were addressed: (1) Does density, species composition, and timing of reproduction vary between areas of different thermal characteristics? and (2) Do patterns of species seasonal succession vary across environmental temperature gradients?

A total of 6,975 fish larvae and eggs representing 21 taxa was collected in the SRSS. All major ichthyoplankton taxa were present at each of the three regions regardless of thermal characteristics. Most of the larval fish (>95%) were collected from shallow, vegetated habitats rather than deep, channelized habitats.

Recruitment of larval stages occurred earliest in the heated sites. Timing of peak larval fish densities differed by about eight weeks between the warmest site and a site in the natural cypress/tupelo forest in Steel Creek. Temperature differentials as little as 2°C above ambient regional temperatures were sufficient to advance reproduction. Overall, the mean ichthyoplankton density was lower at all thermal sites compared to the cooler sites, except one. Among the five thermal sites, there was no relationship between larval fish abundance and a sites's rank order of temperature.

Total ichthyoplankton density varied seasonally. Eggs and larval fish densities increased in a series of pulses during January through May and declined during June and July. Phenological patterns were disrupted in the heated areas. Taxa of larval fishes that normally occurred at different times of the year, overlapped temporally at heated sites. Larval stages of most taxa from the thermal areas were found earlier and at warmer temperatures than the same taxa found in nonthermal areas.

Chapter 3. Juvenile and adult fish were studied from 12 sites representative of habitat types in the SRSS. The objective of the study was to identify patterns in fish distribution, abundance, and composition in the SRSS adjacent to the SRP to determine: (1) if discrete fish assemblage types were present in the SRSS, (2) if there was a relationship between fish assemblage structure, habitat structure, and physical disturbances from natural events and reactor operations, and (3) if assemblage structure was temporally persistent and stable in the face of seasonally changing environmental conditions.

From captures of almost 12,000 individuals, 17 families represented by 51 species of fish were recorded across the SRSS. Of these, 17 species representing 11 families comprised greater than 90% of the ichthyofauna. Seventeen species were classified as rare based on the collection of less than 10 individuals during the

period of March 1983 through July 1985. Eight species were only found at single locations. Most individuals were recognized as year-round freshwater residents, but anadromous and catadromous species also utilized the SRSS.

From the 12 sample sites in the SRSS, no location had a unique fish fauna due to the widespread distribution patterns of most of the species. Composition of the fish assemblage, however, did vary between sites as a consequence of habitat characteristics. Areas receiving thermal effluents greater than 5°C above regional ambient temperatures were depauperate in numbers of species and numbers of fish. Sites with an overstory canopy and moving water had higher species richness and abundance, and the assemblage was dominated by both large and small-bodied species. Sites with emergent and submergent aquatic vegetation had even greater numbers of species and fish abundance; these assemblages were dominated by small-bodied species such as cyprinids and brook silversides. The differences in assemblage composition are shaped by gradients of habitat heterogeneity, productivity (as determined by the extent of aquatic macrophyte cover), and water temperature regimes.

The SRSS is a highly complex, fluctuating environment in which the relative abundance of fish species varies naturally, both seasonally and annually. Over a period of 27 months (10 seasons), fish assemblage structure within Steel Creek was highly persistent with many of the same species repeatedly found over census periods. Stability of the fish assemblage was also high with many species contributing the same rank order of abundance. Thus, while physical factors are important in determining fish distribution and abundance, the high persistence and stability of the assemblages are suggestive that biotic interactions are probably also important in structuring the fish assemblage.

The SRSS is a major and valuable source pool of fish for tributary streams, the Savannah River, and contiguous swamp habitats. However, modification from extrinsic industrial operations could directly affect fish assemblages through habitat alteration. Indirect effects in contiguous areas could also be important by producing changes in faunal composition (prey, predators, and fish species) in affected habitats, although the potential for recolonization from peripheral areas would persist.

Chapter 4. Fish communities were sampled in three SRP stream systems, Pen Branch, Steel Creek, and Meyer's Branch. The objectives were: (1) to determine patterns in species richness, species diversity, relative abundance, and trophic composition between the different stream systems and among locations within each stream, (2) to determine whether compositional variability changes in a predictable manner along an upstream/downstream gradient, and (3) to examine the potential importance of upstream migration to assemblage persistence and stability in these small blackwater streams. While the long-term goal is identifying patterns and processes underlying stream fish structure and function, these findings should be invaluable in assessing the impact of perturbation regimes (e.g. increased discharge and temperature) and lead to formulation of appropriate management policies.

From collections made from March 1983 through December 1985, more than 16,000 individuals representing a cumulative total of 49 species of fish were collected. Nine species of fish were common to all sampling sites and an additional 11 species were collected at seven or eight of the locations. These 20 species accounted for greater than 90% of the numerical abundance.

Species diversity was similar in each stream, although Steel Creek had slightly higher values. Within each stream, diversity progressively increased with increasing

distance downstream. Similar patterns were observed for species richness. Steel Creek had slightly more species than either Pen Branch or Meyer's Branch because of its greater stream width. Regardless of stream system, numbers of species were highest in downstream reaches. Assemblage abundance was temporally and spatially variable with no consistent pattern within or between seasons. Only in Meyer's Branch were consistent changes in abundance detected along the upstream/downstream gradient with greater abundance in upstream habitats. Despite the variability in assemblage composition, only at the upper site on Pen Branch did trophic composition differ. At most sites, surface water invertivores were the dominant feeding group of fish followed by similar proportional abundance of generalist and benthic invertivores. The invertivore-piscivore group was typically the least abundant at all sites except the upper site on Pen Branch where they were dominant.

There was no indication that persistence or stability of the fish assemblage changed in a predictable manner from upstream to downstream. Rather, each site had comparable levels of assemblage consistency. Likewise, persistence and stability of the fish assemblages did not differ between streams isolated for most of the year from downstream reaches (Pen Branch), undergoing post-thermal recovery (Steel Creek), and those that have been open for upstream migration for approximately 20 years (Meyer's Branch). The lack of pattern suggests that recolonization and extirpation events were not major factors structuring fish assemblages in these southeastern coastal plain streams.

Chapter 5. Patterns of fish recolonization were examined in stream channels that periodically receive thermal effluents from nuclear production reactors. The objectives of the study were: (1) to determine the extent of utilization of thermal

stream channels by fishes during reactor shutdown and (2) to assess variability in abundance and species composition during recolonization as a function of season, duration of reactor shutdown, temperature regime of the stream, and distance from source pools within the SRSS.

In general, fishes do not invade or inhabit thermal streams upstream of the SRSS during periods of reactor operation. However, fishes reinvade effluent streams within 24 hours of reactor shutdown and continue to enter and move upstream as long as normal temperature waters are present. The extent of reinvansion of the stream channels varied seasonally and among years, but usually was greatest in the spring and lowest during summer and early fall. Thirty-four species of fish were captured in Four Mile Creek and Pen Branch over 19 reactor cycles. However, based on patterns of species utilization, composition varied seasonally with a common seven fish species occurring in greater than 70% of the cycles, a group of 11 species occurring 30-70% of the time, and a large group of uncommon species captured in less than 30% of the reactor cycles investigated.

The reinitiation of thermal effluents following short-term reactor shutdown does not result in major fish kills as most individuals of most species return to cooler temperature waters before lethal temperatures are reached in the stream. Recolonization and habitation of an entire stream system by a major portion of the fish species living in the SRSS would be expected following the permanent termination of thermal effluents.

Table of Contents

	Page
General Introduction	1
Chapter	
I. Seasonal Changes of Larval Fish Populations in Natural and Altered Habitats of the Savannah River Swamp System	4
A. Introduction	5
B. Study Area	6
C. Methods	10
D. Results	14
1. Changes in water quality and water temperature	14
2. Spatial and temporal patterns of ichthyoplankton occurrence	14
3. Species composition	21
E. Discussion	32
F. Conclusions	38
G. Literature Cited	41
II. Response of Larval Fish Assemblage Structure in the Savannah River Swamp System to Temperature Gradients from Nuclear Production Reactor Effluents	47
A. Introduction	48
B. Study Areas	49
C. Methods	52
D. Results	56
1. Changes in water temperature and water quality	56
2. Ichthyoplankton distribution and composition	59
E. Discussion	82
F. Conclusions	88
G. Literature Cited	90
III. Spatial and Temporal Patterns in Fish Assemblages Within the Savannah River Swamp System	94
A. Introduction	95
1. Factors influencing fish assemblage structure in swamp habitats	95
B. Study Area	97
C. Methods	100
1. Fish and environmental sampling	100
2. Data analysis	106
D. Results	108
1. Spatial distribution of fishes within the SRSS	113
2. Temporal persistence in assemblage composition	123

Table of Contents, continued

	Page
E. Discussion	128
F. Conclusions	138
G. Literature Cited	140
IV. Structure of Fish Communities in the Savannah River Plant Streams	146
A. Introduction	147
B. Study Areas	149
C. Methods	151
D. Results	156
1. Habitat structure	156
2. Fish assemblage structure	159
E. Discussion	179
F. Conclusions	186
G. Literature Cited	188
V. Recolonization Patterns in Fish of Streams Receiving Thermal Effluents From Nuclear Production Reactors	192
A. Introduction	193
B. Study Areas	195
C. Methods	195
D. Results	199
1. Temporal patterns of stream use	199
2. Within stream movement patterns	207
3. Species composition	210
4. Fish kills	219
E. Discussion	220
F. Conclusions	227
G. Literature Cited	229
VI. Acknowledgements	233

List of Figures

	Page
<p>Figure 1.1. Sampling sites in the riverine swamp located on the Savannah River Plant (SRP) near Aiken, SC. Samples were taken in five habitats: sites 1-4 were in Lower Steel Creek; sites 5-6 were in a disturbed channel; sites 7-8 were in a natural channel; sites 9-10 were in disturbed structure; and sites 11-12 were in a natural structure</p>	8
<p>Figure 1.2. A) Seasonal changes in total densities of larval fish in the five major habitat types. DS - disturbed structure, DC - disturbed channel, LSC - lower Steel Creek, NS - natural structure, and NC - natural channel. B) Water temperatures in the five habitats. C) Water level variation for the natural channel and the Savannah River at Jackson, SC (relative to the 85 foot mark at Jackson)</p>	16
<p>Figure 1.3. Two dimensional plot of sites on Principal Components Axes I and II</p>	24
<p>Figure 1.4. Seasonal changes in the densities of the five most abundant taxa by habitat. Densities are presented for <u>Catostomidae</u> (primarily <u>Ermiyzon sucetta</u>), <u>Percidae</u> (<u>Etheostoma sp.</u> and <u>Percina sp.</u>), <u>Lepomis spp.</u>, <u>Aphredoderus sayanus</u>, and <u>Cyprinidae</u> (<u>Notropis spp.</u>)</p>	31
<p>Figure 2.1. Map of the SRP showing sampling sites along thermal plumes. Stations 1 to 5 were thermal areas numbered from warmest to coolest. Stations 1 to 3 were in Four Mile Creek thermal plume; stations 4 and 5 were in the Pen Branch thermal plume. Within Steel Creek, stations 8 and 12 were in natural forested areas while stations 6 and 10 were located in previously disturbed areas with no overstory canopy</p>	50
<p>Figure 2.2. Temporal changes in physical conditions in the Savannah River Swamp System. A) Seasonal trends of water temperature at the five thermal and four nonthermal sampling stations. B) Swamp water levels in 1984 and 1985. C) Periods of hot (high flow) and cold (low flow) reactor discharges down the Pen Branch and Four Mile Creek tributaries in 1985</p>	57
<p>Figure 2.3. Seasonal changes in total ichthyoplankton density at each station during 1985</p>	63
<p>Figure 2.4. Variation in the composition of ichthyoplankton assemblages between sampling stations in 1985, as summarized by the first three principal components</p>	81

List of Figures, continued

	Page
Figure 2.5. Variation in community composition between 1984 and 1985 summarized by principal components analysis	83
Figure 3.1. Map of the Savannah River Swamp System (SRSS) showing the location of the twelve sampling sites from the Four Mile Creek (FMC), Stave Island (SI), Steel Creek (SC), and Deep Swamp (DP) regions	99
Figure 3.2. Cumulative catch curves comparing total number of fish species captured at a site in the Savannah River Swamp System where samples were collected using either four or six 50 m transects	103
Figure 3.3. Results of the average linkage cluster analysis of the fish assemblage structure from the 12 sites and 3 seasons collections in the Savannah River Swamp System	114
Figure 3.4. Size structure of the fish assemblage in the eight site groups identified through cluster analysis	120
Figure 3.5. Canonical discriminant analysis of the 12 study sites with the SRSS based on environmental data. Axis 1 is related to macrophyte cover and current velocity; axis 2 is related to water temperature and degree of canopy cover	122
Figure 3.6. Fluctuations in water level within the Steel Creek region of the Savannah River Swamp System from November 1983 through September 1985	124
Figure 3.7. Seasonal changes in the mean number of species (species richness) per sample and mean total fish abundance per transect for sites within the Steel Creek delta region of the SRSS	125
Figure 4.1. Location of study sites in three streams on the Savannah River Plant, South Carolina	150
Figure 4.2. Temporal variation in mean monthly discharge during the 2 year sample at the USGS gauging stations on Steel Creek (SC1 and SC3) and Pen Branch (PB3)	158
Figure 4.3. Classification analysis of the nine stream sites on the Savannah River Plant using average linkage clustering	165
Figure 4.4. Between-site variation in the trophic guild composition of the fish assemblage in three streams on the Savannah River Plant	166

List of Figures, continued

	Page
Figure 4.5. Length frequency distributions for collections of <i>Notropis lutipinnis</i> from three sample stations and three seasons in Steel Creek	168
Figure 5.1. Map of the Savannah River Plant with highlights of the Savannah River Swamp System and the location of the fyke nets and backwater habitats sampled by electrofishing within Four Mile Creek and Pen Branch	196
Figure 5.2. Temporal and positional changes in the mean number of species (richness) and mean total number of individuals (abundance) captured per day in the fyke nets during each reactor cycle on Pen Branch and Four Mile Creek	201
Figure 5.3. Variability in daily number of species and individuals entering Pen Branch and Four Mile Creek on different reactor cycles in 1983 through 1985	208
Figure 5.4. Overall numerical percentage composition of the fish assemblage caught in the fyke nets in Pen Branch (n = 2636) and Four Mile Creek (n = 1114)	211
Figure 5.5. Frequency distribution of the occurrence of fish species moving into Pen Branch and Four Mile Creek during periods of reactor shutdown	218

List of Tables

	Page
Table 1.1. Types of habitats sampled in the Steel Creek delta portion of the Savannah River Swamp System, February to August 1984	9
Table 1.2. Mean water temperature (± 1 SD) for the five major habitat areas sampled for ichthyoplankton during 16 consecutive semi-weekly samples (February to June 1984) from the Savannah River Swamp System	15
Table 1.3. Mean number of ichthyoplankton (per 1000 m ³ \pm 95% confidence intervals) overall percent composition, and mean number of ichthyoplankton of selected taxa (per 1000 m ³) collected at each site during 16 weeks of continuous sampling in the SRSS in 1984	17
Table 1.4. Analysis of variance results testing for temporal and spatial differences in ichthyoplankton (eggs and larvae) abundance in Steel Creek delta	19
Table 1.5. Principal components analysis of major community/habitat associations in 1984. The eigenvectors of the first three principal components are given	22
Table 1.6. Spearman rank correlation coefficients for the test of the null hypothesis that ranks of site position along ordination axes are not associated with ranks of four environmental variables	25
Table 1.7. Mean total number of ichthyoplankton (per 1000 m ³) and mean number of individuals of selected taxa (per 1000 m ³) collected at each habitat area during 16 consecutive semi-weekly samples (February to June 1984) from the Savannah River Swamp System	26
Table 2.1. Physical conditions and collection summaries for thermally-altered, post-thermal recovery, and natural, cypress-tupelo forest sites sampled in the Savannah River Swamp System	53
Table 2.2. Seasonal changes in water temperature ($^{\circ}$ C) (± 1 SE) recorded at the nine sampling stations within the Savannah River Swamp System from January through July 1985.	58
Table 2.3. Mean number of ichthyoplankton (per 1000 m ³ \pm 95% C1), mean total ichthyoplankton density, and percent composition within each sampling area during January to July 1985. Fish were identified to the lowest possible taxonomic level	61

List of Tables, continued	Page
Table 2.4. Microhabitat differences in mean ichthyoplankton density (per 1000 m ³ ± 1 SE) at nine sampling stations in the Savannah River Swamp System	62
Table 2.5. Mean total number of ichthyoplankton (per 1000 m ³ ± 1 SE) collected at nine sites from the Savannah River Swamp System during weekly collections from January to July 1985	64
Table 2.6. Results of analysis of variance for spatial and temporal differences in ichthyoplankton density for sites in the Savannah River Swamp System	65
Table 2.7. Weekly changes in the mean ichthyoplankton density (per 1000 m ³) for each taxon at nine sampling stations within the Savannah River Swamp System	69
Table 2.8. Mean time of occurrence and mean water temperature for when larval stages of 12 common fish taxa were collected between thermal stations (1-5), natural areas (8, 12), and post-thermal recovery areas (6,10)	78
Table 2.9. Loadings of major fish taxa on three components produced by a principal components analysis of overall ichthyoplankton densities per sampling station. A) 1984 collections. B) 1984 and 1985 collections	80
Table 2.10. Comparison of mean ichthyoplankton densities for major taxa groupings across the Savannah River Swamp System for collections made in 1984 and 1985	84
Table 3.1. Limnological and habitat characteristics for the 12 study sites in the Savannah River Swamp System	101
Table 3.2. Summary of relationships of species richness and fish abundance per 50 m transect using Pearson product moment correlation and Spearman rank correlation for all sites combined and by specific site within the Savannah River Swamp System	104
Table 3.3. Distribution of the fish assemblage among sites and collections within the Savannah River Swamp System. Included are the number of fish collected, percent composition, number of sites that a species was found, and the total number of times a species was found in the seasonal collections at all sites	109
Table 3.4. Seasonal changes in species composition and relative abundance (mean number of individuals per 50 m transect) at the 12 sampling sites in the Savannah River Swamp System	110

List of Tables, continued

	Page
Table 3.5. Summary of univariate analysis of variance testing for differences in mean site group species richness any mean site group abundance (per 50 m transect) between the eight site groups identified through normal classification methods (species as attributes of sampling locations)	115
Table 3.6. Patterns of species richness and assemblage abundance (per 50 m transect) for site groups A-H in the Savannah River Swamp System	117
Table 3.7. Two way coincidence table comparing site groups and fish species associations within the Savannah River Swamp System	118
Table 3.8. Analysis of variance of temporal variation in number of fish species (A) and number of individuals (B) per 50 m transect present on three sites in the Steel Creek delta (data log x + 1 transformed prior to analysis)	126
Table 3.9. Seasonal changes and results of multiple comparison tests (Student-Newman-Keuls) for mean number of species and mean assemblage abundance \pm 95% CI (per 50 m transect) for three sites in the Steel Creek delta region of the Savannah River Swamp System	127
Table 3.10. Analysis of fish assemblage persistence and assemblage stability using an index of persistence (PR) and Kendall's Coefficient of Concordance (W) for three sites within the Steel Creek delta region of the SRSS	129
Table 3.11. Seasonal changes in the percent relative abundance of fishes from SC 1 within the Steel Creek delta region of the Savannah River Swamp System	130
Table 3.12. Seasonal changes in the percent relative abundance of fishes from SC2 within the Steel Creek region of the Savannah River Swamp System	131
Table 3.13. Seasonal changes in the percent relative abundance of fishes from SC3 within the Steel Creek region of the Savannah River Swamp System	132
Table 4.1. Selected habitat characteristics of sites on three SRP streams. Values were calculated over all seasonal collections	155

List of Tables, continued

	Page
Table 4.2. Names and trophic classification of fish species collected from Pen Branch, Steel Creek, and Meyer's Branch. Trophic groups: surface-water invertivore (SWI), generalized invertivore (GI), benthic invertivore (BI), and invertivore-piscivore (IP)	157
Table 4.3. Species diversity (H'), species richness, and mean relative abundance (individuals per 100 m ²) of fish assemblages from nine stream sites on the Savannah River Plant from March 1984 through December 1985	160
Table 4.4. Distribution and percent composition of the fish assemblages collected from streams on the Savannah River Plant	163
Table 4.5. Seasonal changes in the percent relative abundance of fishes from sites in Pen Branch, Steel Creek, and Meyer's Branch	169
Table 4.6. Analysis of fish assemblage persistence and assemblage stability using an index of persistence (PR) and Kendall's Coefficient of Concordance (W) for nine stream sites on the Savannah River Plant	178
Table 5.1. Changes in mean number of species per day (richness) and mean total number of individuals per day (abundance) ($\pm 95\%$ CI) over time and position of the fyke nets for fishes caught during each reactor cycle on Pen Branch and Four Mile Creek ..	202
Table 5.2. Results of analysis of variance examining for differences in the number of species and relative abundance of fish caught in the fyke nets in Pen Branch between reactor cycles and position of the nets in the stream channel	203
Table 5.3. Results of analysis of variance examining for differences in the number of species and relative abundance of fish caught in the fyke nets in Four Mile Creek between reactor cycles and position of the nets in the stream channel	205
Table 5.4. Results of analysis of variance examining for daily differences in the number of species and relative abundance of fish caught in the fyke nets in Pen Branch and Four Mile Creek	206
Table 5.5. Direction of continued movement of fish within Pen Branch based on mark-recapture studies.	209

List of Tables, continued

	Page
Table 5.6. Summary of the frequency of occurrence (%) and mean abundance (\bar{x}) of fishes captured in each reactor cycle in Pen Branch and Four Mile Creek and species group designations (1 = rare, 2 = intermediate, 3 = common)	212
Table 5.7. Summary of the mean total length (± 1 SE) and range of sizes for fishes caught in Pen Branch and Four Mile Creek	215
Table 5.8. Species composition and percentage relative abundance of fishes in backwater regions on Pen Branch and Four Mile Creek	221

General Introduction

A central goal of population and community ecology is to understand mechanisms and processes responsible for differences and similarities among systems. One approach is to compare populations or communities occurring along environmental gradients such as physiological stress or resource availability. This approach provides valuable basic data and encourages the development of testable hypotheses. It also increases our ability to predict effects of, and to manage perturbations on an aquatic system.

The mosaic of lentic, lotic, and river-swamp aquatic habitats on the Savannah River Plant (SRP) supports a diverse fish community in excess of 60 species. Most fish species found in these environments are categorized as permanent freshwater residents, but at least six species are anadromous or catadromous in life history. Patterns of fish distribution and abundance in SRP waters have both ecological and economic importance. From a structural and functional viewpoint, the responses that different life history stages exhibit to environmental variations make them good indicators of wetland integrity. Economically, SRP stream and river-swamp habitats may provide valuable feeding, spawning, and nursery areas for local fish populations in the Savannah River and stock recruitment for several recreationally important migratory species.

Few studies, however, have focused on identifying factors influencing the distribution and abundance of fishes in these diverse wetland systems on the SRP. Limitation of the database on fish population and community dynamics has two important consequences. First, it restricts information available for mitigation of habitat modification and loss associated with the operation of several nuclear production reactors on the SRP. Secondly, most existing models of structure and function of lentic and lotic fish communities are largely based on patterns observed in forested, north temperate systems. Coastal plain stream and swamp systems have

received less attention although such habitats extend from New England to Texas and northward into the Mississippi Embayment, and many fish species, or species complexes, have a broad geographic distribution patterns. Thus, the geographic perspective on which to develop general concepts pertaining to fish population and community dynamics needs reconsideration using tests in other environments.

The initiation of the Comprehensive Cooling Water Study, in accordance with 316(a) and (b) legislation for mitigative purposes accompanying the planned restart of a nuclear production reactor, L-Reactor, on the SRP, promoted the development of comparative field studies to examine patterns in fish population and community dynamics. A main objective of this program was to evaluate potential effects of reactor operation, particularly the consequences of thermal effluents, on fishes from selected habitats. However, it also afforded the opportunity to develop studies that should be applicable to other coastal plain habitats, to be of comparative utility for research in other physiographic or faunal regions, and to serve as an essential preliminary step in the use of experimental manipulations and other hypothesis-testing research.

Our goal was to detect patterns and processes influencing fish distribution and abundance. This was accomplished by focussing attention in four major areas. Investigations included: (1) study of the importance of habitat modifications and elevated water temperature regimes on reproductive cycles and larval fish recruitment dynamics on several spatial scales, (2) examination of patterns of fish macrohabitat utilization in the river-swamp and associated streams, (3) identification of seasonal changes in fish utilization of thermal areas in relation to reactor operation schedules from a perspective of ecosystem recovery, and (4) the documentation of fish kills. Knowledge of behavioral and ecological processes over space and time are of fundamental importance in understanding structure and function in natural and disturbed systems. Information from these studies should

enable predictions to be made regarding the effects of environmental variation (natural or artificial) on persistence and stability of fish population and community dynamics. The identification of these patterns at many levels of organization will enable future research to focus more upon process-oriented questions thereby increasing our knowledge of species responses to environmental perturbation, and ways to minimize or effectively mitigate for the disturbance.

**I. Seasonal Changes of Larval Fish Populations in Natural
and Altered Habitats of the Savannah River Swamp System**

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Introduction

Many of the major rivers of the southeastern United States are bordered by broad floodplain forests. These swamp ecosystems are highly variable in hydrologic source, frequency of flooding, and plant community structure (Day, 1982; Wharton et al., 1982). The variable hydrologic regime associated with adjacent alluvial rivers and blackwater streams create highly dynamic environments that influence the distribution and abundance of plant and animal components of these ecosystems. Despite the importance of floodplain swamps as natural filters, or sinks, of stream water (Ewel and Odum, 1978; Mulholland, 1981), relatively little information is available regarding the functioning of these ecosystems and the structure of component assemblages. Prior investigations on river-swamps have focused primarily on aspects of nutrient cycling and the structure and function of plant assemblages in nonriverine swamp habitats (e.g., Connor and Day, 1976; Schlesinger, 1978; Brown, 1981; Day, 1982) and riverine forests (Brinson et al., 1980, 1981; Mulholland, 1981). Studies of fish assemblages within these ecosystems are rare (Kushlan, 1976; Carlson and Duever, 1976; Ross and Baker, 1983; Freeman and Freeman, 1985; Finger and Stewart, 1987), and relatively little is known about habitat requirements of their early life history stages in these environments.

As a continuum of flowing to backwater areas, three general habitat types occur in river-swamp systems: submerged wood or snags, rooted or floating macrophytes, and open water areas with mud-sand substrate. Investigations in other freshwater wetlands have stressed the functional importance of submerged aquatic vegetation as foraging areas and as refuges from predation for fishes (Hall and Werner, 1977; Mittelbach, 1981; Crowder and Cooper, 1982; Savino and Stein, 1982; Gilinsky, 1984; Werner et al., 1983). The nursery role of these habitats may, however, be limited because emergent and submergent vegetation are usually only a small overall habitat component within many river-swamp systems. In addition,

water level fluctuations, as it affects habitat structure and availability, have also been shown to be influential in determining recruitment success and assemblage composition (Starrett, 1951; Hassler, 1970; Kushlan, 1976). Because of the probable importance of larval fishes in swamp production and energy transfer, more information is needed on the ecology of the early history stages within river-swamp ecosystems. This need is heightened because swamp/floodplain wetlands are being altered at an increasing rate for commercial and recreational purposes.

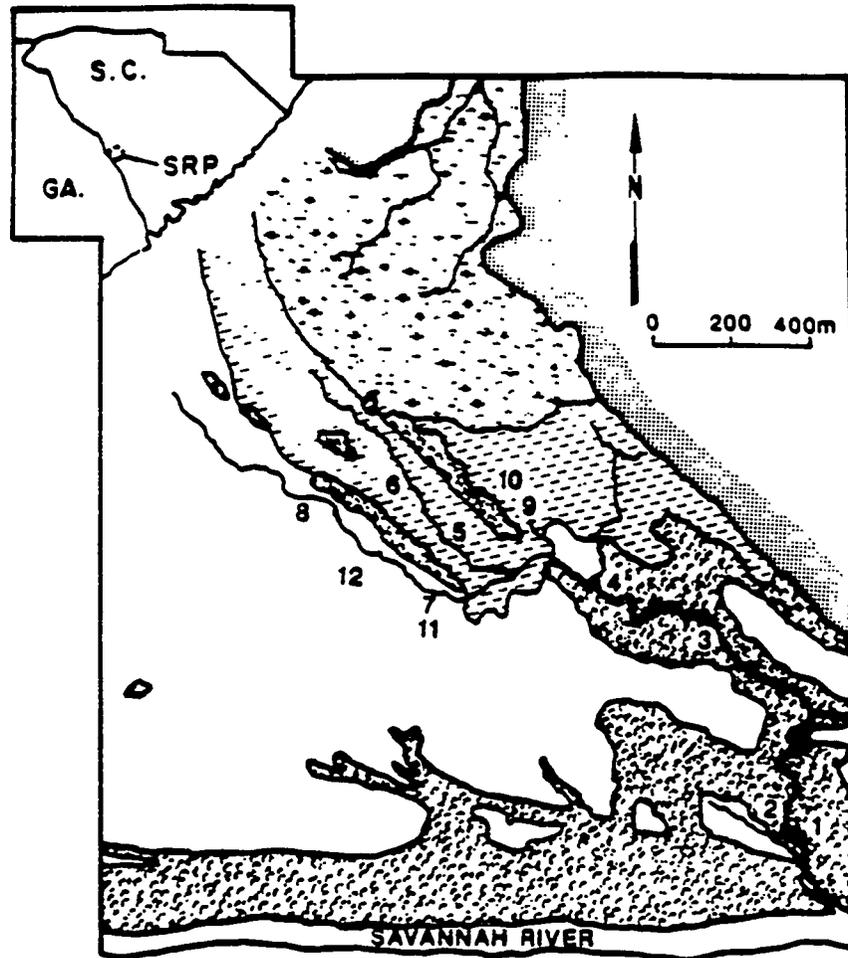
This investigation was conducted to answer basic questions regarding the location of nursery grounds and ichthyoplankton dynamics in one such river-swamp ecosystem, the Savannah River Swamp System, in South Carolina. Specific objectives were: (1) to describe spatial and temporal patterns of larval fish distribution and abundance and (2) to correlate effects of habitat modification on ichthyoplankton recruitment patterns. Our long-term goal is to determine the relative importance of physical constraints, biotic interactions, and resource limitations in determining larval fish population and community dynamics.

Study Area

Along the Savannah River near Aiken, SC, a 3200 ha river-swamp system, the Savannah River Swamp System (SRSS), forms the southwest border of the U.S. Department of Energy's Savannah River Plant (SRP). A second-growth forest of bald cypress (Taxodium distichum), water tupelo (Nyssa aquatica), and bottomland hardwoods form a closed canopy over all but 200-300 ha of the swamp (Sharitz et al., 1974). Three major creeks located on the SRP drain into the SRSS (Steel Creek, Four Mile Creek, and Pen Branch) and since the early 1950s, each has periodically carried heated effluents from nuclear production reactors into the swamp. Where water from the creeks first enters the SRSS, extensive tree mortality has occurred through an interaction of direct thermal effects (ca. 40°C), elevated water levels

because of the increased discharge rates (11.3 m³/s), and increased sedimentation (Sharitz et al., 1974; Sharitz and Lee, 1985; Scott et al., 1986). Although heated effluents are still discharged into two streams, Steel Creek and its associated delta have been undergoing post-thermal recovery since 1968. Currently, water temperatures (<30°C) and discharge rates (ca. 1.4 m³/s) approximate pre-disturbance levels.

Sampling for larval fishes was restricted to three major regions within the Steel Creek delta portion of the SRSS, but were representative of current, nonthermal habitats in this river-swamp ecosystem (Figure 1.1; Table 1.1). These were regions of natural forest, post-thermal recovery from prior reactor discharges, and a large channel that carries water from this portion of the swamp to the Savannah River through a break in the river levee. Natural forested sites were characterized as having a well developed overstory canopy of cypress or tupelo and had not previously experienced any form of thermal perturbation. Macrophyte growth in the understory was sparse (<20% areal cover) with most being submergent species (e.g., Myaca spp., Ceratophyllum spp.). Macrophyte growth became dense only in gaps in the canopy or along the edge of small channels. Despite 16 years of succession, overstory canopy development remains scarce within the previously disturbed habitats. Instead, vegetation is dominated by both a scrub-shrub community exploiting dead and decaying logs and stumps as a substrate for establishment and an extensive (>60% areal coverage) herbaceous marsh of emergent (e.g., Hypericum spp., Polygonum spp.) and submergent (e.g., Myriophyllum spp.) macrophytes (Sharitz et al., 1974; Martin, et al., 1977). Within both the disturbed and natural forested regions, two macrohabitat types were recognized: deeper, channelized areas and shallow, structured areas. Channel areas were characterized as having depths ranging from 0.75 to 2.5 m during periods of no flooding, current velocities ranging from 15-50 cm/s, and generally



CANOPY REMOVED

-  DISTURBED HABITATS (PERENNIALY WET)
-  DELTAIC FAN (SHALLOWLY FLOODED)

CANOPY NOT REMOVED

-  CYPRESS-TUPELO (PERENNIALY WET)
-  BOTTOMLAND HARDWOODS (SEASONALLY FLOODED)
-  UPLAND (INTERMITTENTLY FLOODED)

Figure 1.1. Sampling sites in the riverine swamp system located on the Savannah River Plant (SRP) near Aiken, SC. Samples were taken in five habitats: sites 1-4 were in Lower Steel Creek; sites 5-6 were in a disturbed channel; sites 7-8 were in a natural channel; sites 9-10 were in disturbed structure; and sites 11-12 were in natural structure.

Table 1.1. Types of habitats sampled in the Steel Creek delta portion of the Savannah River Swamp System, February-August 1984. Site designations follow Figure 1.1.

	Post-Thermal Recovery				Natural Forest				Lower Steel Creek			
	5	6	9	10	7	8	11	12	1	2	3	4
<u>Open-canopied habitats</u>												
Indistinct channels; shallow, generally < 1.0 m deep; abundant emergent and submergent vegetation, > 60% areal coverage			X	X								
Current velocity 0-15 cm/s			X									
Current velocity 0-30 cm/s				X								
Distinct channels; shallow, generally < 1.5 m deep; abundant emergent and submergent vegetation, > 50% areal coverage; current velocity usually < 30 cm/s	X	X										
Channel narrow, ca. 3 m					X							
Channel wide, ca. 6 m	X											
<u>Closed-canopied habitats</u>												
Indistinct channels; shallow, generally < 0.5 m deep; current velocity 0-15 cm/s							X	X				
Submergent vegetation fairly abundant									X			
Submergent vegetation present							X					
Direct channels; submergent vegetation present, usually along channel margins					X	X						
Depth usually < 1.5 m, slow current velocity, 0-25 cm/s							X					
Depth usually < 2.5 m, current velocity, 0-35 cm/s					X							
Submergent vegetation rare or absent; current velocity frequently > 50 cm/s									X	X	X	X
Depth ca. 1.5 m deep; channel < 5 m wide										X		X
Depth usually > 1.5 m deep; channel > 15 m wide									X		X	

little habitat structural complexity from snags or vegetation. Structured areas were shallow (usually < 1.5 m), had low current velocities (< 30 cm/s), and high habitat complexity due to the presence of macrophytes, snags, or extant trees. The third major region, Lower Steel Creek, was a steep-sided channel having depths frequently exceeding 2 m, current velocities that periodically were > 1 m/s, few macrophytes, and a compacted sand/clay substrate.

Methods

Spatial and temporal patterns of larval fish distribution and abundance were determined twice weekly for 16 consecutive weeks beginning the last week of February and continuing through the third week of June 1984. Additional collections were made at biweekly intervals through the end of August. A single sample was also taken during the first week of February, but no larval stages were found. To assess ichthyoplankton distribution in relation to macrohabitat characteristics, two sampling sites were chosen within four of the habitat types (natural channel, natural structure, disturbed structure, and disturbed channel) while four sites were selected along the watercourse of Lower Steel Creek (Figure 1.1; Table 1.1).

Sampling technique for all collections and dates was identical. Rather than standard plankton nets, a high volume centrifugal pump was used to filter 12.8 m³ of water through a 0.505 mm mesh conical (0.5 wide mouth, 2.5 m length) plankton net trailed into the water to minimize abrasion to eggs and larvae. Two replicate samples were taken at each of the twelve sites from the same depth strata (≤ 0.5 m) from a stationary boat; a distance of ca. $1-2$ m separated collections made within a site. Characteristics of the pump used in this study (7.6 cm intake hose diameter, 0.85 m³/min discharge rate, capability of handling a 3.8 cm diameter spherical solid) approximated those used in other studies (Aron, 1958; Cada and Loar, 1982; Gale

and Mohr, 1978; Leithiser et al., 1979; Portner and Rohde, 1977; Taggart and Leggett, 1984). Pumping rates were calibrated by filling containers of known volume. Water temperatures were taken on each visit using a digital thermometer except for sampling periods 2 and 3 due to equipment failure. All samples were collected between 0900 and 1430 hrs.

Pump sampling was selected because it had several advantages to conventional net samplers including: (1) ability to collect in shallow, vegetated habitats, (2) no bias due to variable filtering efficiencies induced by clogging, and most importantly, (3) the ability to sample at biologically relevant time and spatial scales. While this methodology has been criticized because of its potential to damage or destroy the organisms they sample, evidence from other studies (Aron, 1958; Cada and Loar, 1982; Leithiser et al., 1979; Portner and Rohde, 1977; Taggart and Leggett, 1984) and observations made in the present investigation, suggest pump-related damage may not represent a major shortcoming. Only Gale and Mohr (1978) found evidence for pump-related damage to ichthyoplankton. They observed that the proportion of larvae in 'good-excellent' condition was higher when mesh size of the filtering mesh was decreased (0.50 to 0.22 mm) and adjusting the net so that it 'ballooned' during sampling. Regardless of net type, however, Gale and Mohr (1978) were still able to identify all larvae in the collections. Some larvae were found damaged in the present study, but represented only a small proportion (2.7%) of all the larvae collected (Table 1.3). Some damage to the egg chorion was also noted in several instances. While this might be suggestive of a possible underestimate of egg abundance, the bias should be similar in all sites because of the consistency in sampling methodology. Thus, there is apparently only minor loss in taxonomic classification using pump sampling. These comparative studies have also generally found that the density of organisms sampled with pumps was equal to that sampled by towed net samplers although some variation in

efficiency was noted between different length classes of larvae and vertical distribution of eggs.

All samples were immediately preserved in 5% formalin containing Phloxine B stain and transported to the laboratory. All larvae and eggs were counted and where possible, identified following keys and descriptions provided in Auer (1982), Hogue et al. (1976), or Wang and Kernehan (1979). Further recognition of described and undescribed taxa was based on specimens raised in our laboratory for ancillary projects. Most eggs, however, were recorded as unidentified eggs. Only damaged larvae were recorded as unidentified larvae; all others were identified to some taxonomic level.

Water level fluctuations within the SRSS were recorded by gauges located in the natural channel habitat and at the mouth of Lower Steel Creek (J.B. Gladden, Savannah River Laboratory, E.I. du Pont de Nemours and Company, Aiken, SC, unpublished data). Fluctuations in river water level and water levels in these two sites were standardized against discharge rates recorded by the U.S. Geological Survey gauging station at Jackson, SC, during a period of constant flood conditions from August 7-11, 1984. Water quality determinations were performed on 34 parameters at two-week intervals during the study from sites within Lower Steel Creek, the natural channel (Site 8), and the disturbed channel (Site 6) (Newman, 1986).

A split-plot analysis of variance (ANOVA) was used to test for differences in the spatial and temporal patterns of ichthyoplankton occurrence and abundance among the 768 samples. The 12 sites were treated as subplots within the five habitats (Snedecor and Cochran, 1980). Densities of eggs and larvae (number of individuals/1000 m³) were transformed by $\ln(x + 1)$ before analysis since the required assumption of homogeneity of variance was not originally met (Downing, 1979). Correlation analyses were also used to examine variation in ichthyoplankton

abundance as influenced by either water temperature or water level in the SRSS on the day of sampling and for a one-week lag period. Correlation analyses were also done comparing the weekly change in ichthyoplankton densities to the weekly differential in water level.

Differences of water temperatures between habitats were examined using a nonparametric sign test. We tested whether water temperatures recorded on sampling dates were warmer or cooler in one habitat more often than would be expected if those outcomes were equally probable. All statistical analyses were done using the Statistical Analysis System (SAS, 1985) and procedures outlined in Sokal and Rohlf (1981). Significance levels for parametric and correlation analyses were $p \leq 0.05$. To minimize Type 1 error associated with multiple comparison testing, significance levels for the sign tests were $p < 0.01$.

Principal component analysis (PCA) was used to examine covariation in abundance among groups of larvae across the five major habitats. The analysis was done from a correlation matrix of the 12 most common taxa pooled over the sampling period to produce groups of species that presumably were responding to the environmental variables in the same general way. Spearman rank correlation was used to determine if site PCA position correlated with water depth, current velocity, areal macrophyte cover, or areal canopy cover. Water depth and current velocity for each site was based on average measurements recorded over the study. Percent areal macrophyte cover and percent areal canopy cover were visually estimated at five randomly selected locations at each site on 12 May 1984. Light intensity within the open and closed canopy habitats was determined in March 1985 using a Lambda Instruments LI-185A light meter. For all statistical tests, null hypotheses were rejected at $p \leq 0.05$.

Results

Changes in water quality and water temperature

For most parameters measured, water quality did not vary appreciably between locations and exhibited parallel seasonal changes at the three major habitat regions within Steel Creek delta. Average annual values of selected physical characteristics from the natural channel site were: pH 6.68, dissolved oxygen 6.65 mg/l, turbidity 5.4 NTU, total suspended solids 3.14 mg/l, specific conductance 73.1 umho/cm, and total alkalinity 13.14 mg/l as CaCO₃.

Water temperature varied seasonally and changed concurrently at all sites (Table 1.2; Figure 1.2), but temperature differentials were only slight for sites within a habitat and between macrohabitat types. On average, only 2.4°C separated the warmest and coolest macrohabitats with most between habitat comparisons differing by less than 1.5°C. Over 16 weeks of study, however, most between habitat comparisons of water were significant. Only for the two natural, undisturbed swamp sites were no obvious differences in water temperature demonstrated (Sign test, $p > 0.05$). The disturbed structure site was consistently the warmest followed by the disturbed channel, natural structure and channel, and Lower Steel Creek having progressively cooler water temperatures.

Spatial and temporal patterns of ichthyoplankton occurrence

A total of 54 eggs (3 brook silverside Labidesthes sicculus, 7 American shad Alosa sapidissima, and 44 unidentified) and 2,422 larval fishes were collected during this study (Table 1.3). The overall mean total ichthyoplankton density was 252 individuals per 1000 m³. Within the Steel Creek delta, ichthyoplankton were first collected in all habitats during early March (Figure 1.2). At the time of first capture, water temperatures ranged from 10° to 13°C. Larval stages were present in each

Table 1.2 Mean water temperature (\pm S.D.) for the five major habitat areas sampled for ichthyoplankton during 16 consecutive semi-weekly samples (t) (February to June, 1984) from the Savannah River Swamp System. All sites are located within the vicinity of Steel Creek delta; DS = disturbed structure, DC = disturbed channel, LSC = lower Steel Creek, NS = natural structure, and NC = natural channel. Number of replicates within each collection period were $n = 2$ at all areas except Lower Steel Creek (LSC) which were $n = 4$. Water temperatures were measured between 0900 and 1400 hrs.

Sample period (t)	DS	DC	LSC	NS	NC
1	12.0 \pm 1.0	10.5 \pm 0.5	8.5 \pm 0.3	9.5 \pm 0.5	9.0 \pm 0.0
2	-*	-	-	-	-
3	-	-	-	-	-
4	11.5 \pm 0.5	10.5 \pm 0.5	8.8 \pm 0.3	8.5 \pm 0.5	9.0 \pm 0.0
5	11.0 \pm 0.0	10.5 \pm 0.5	10.3 \pm 0.3	10.0 \pm 0.0	10.0 \pm 0.0
6	17.0 \pm 0.0	13.5 \pm 0.5	12.8 \pm 0.3	13.0 \pm 0.0	13.0 \pm 0.0
7	20.5 \pm 0.5	18.0 \pm 2.0	15.3 \pm 0.5	16.5 \pm 0.5	15.5 \pm 0.5
8	18.0 \pm 0.0	15.5 \pm 0.5	14.8 \pm 0.3	16.5 \pm 0.5	15.5 \pm 0.5
9	17.5 \pm 0.5	16.0 \pm 1.0	15.5 \pm 0.3	15.5 \pm 0.5	17.0 \pm 1.0
10	16.0 \pm 0.0	15.5 \pm 0.5	15.3 \pm 0.8	15.5 \pm 0.5	16.5 \pm 0.5
11	16.5 \pm 0.5	15.0 \pm 1.0	14.5 \pm 0.9	15.5 \pm 0.5	15.0 \pm 1.0
12	15.5 \pm 0.5	14.0 \pm 1.0	14.8 \pm 0.5	15.0 \pm 1.0	15.5 \pm 0.5
13	16.0 \pm 2.0	15.5 \pm 1.5	15.3 \pm 0.9	16.0 \pm 2.0	15.5 \pm 1.5
14	16.5 \pm 0.5	16.0 \pm 0.0	14.8 \pm 0.3	16.0 \pm 0.0	16.0 \pm 0.0
15	17.5 \pm 0.5	16.5 \pm 0.5	16.8 \pm 0.5	17.5 \pm 0.5	16.5 \pm 0.5
16	17.0 \pm 0.0	15.5 \pm 0.5	15.3 \pm 0.5	16.0 \pm 0.0	16.0 \pm 0.0
17	19.5 \pm 0.5	20.5 \pm 0.5	19.3 \pm 0.9	20.5 \pm 0.5	20.0 \pm 0.0
18	18.0 \pm 0.0	19.0 \pm 1.0	17.0 \pm 0.4	16.5 \pm 0.5	16.0 \pm 1.0
19	21.5 \pm 4.5	19.0 \pm 2.0	16.0 \pm 0.8	17.0 \pm 1.0	17.0 \pm 1.0
20	22.5 \pm 0.5	20.5 \pm 0.5	18.3 \pm 1.2	17.5 \pm 0.5	18.0 \pm 0.0
21	21.0 \pm 1.0	18.0 \pm 1.0	18.0 \pm 0.8	18.0 \pm 1.0	18.0 \pm 1.0
22	17.5 \pm 0.5	16.0 \pm 0.0	16.5 \pm 0.3	17.0 \pm 0.0	17.0 \pm 0.0
23	19.5 \pm 0.5	18.5 \pm 0.5	17.8 \pm 0.3	18.5 \pm 0.5	18.5 \pm 0.5
24	20.5 \pm 1.5	21.0 \pm 2.0	17.0 \pm 0.4	20.0 \pm 2.0	18.5 \pm 1.5
25	23.0 \pm 1.0	23.0 \pm 0.0	19.3 \pm 0.5	21.5 \pm 0.5	20.0 \pm 0.0
26	22.5 \pm 0.5	23.0 \pm 1.0	20.5 \pm 0.3	22.0 \pm 0.0	21.5 \pm 0.5
27	21.0 \pm 0.0	21.0 \pm 1.0	20.0 \pm 0.6	19.0 \pm 0.0	20.0 \pm 0.0
28	19.0 \pm 0.0	19.0 \pm 1.0	16.8 \pm 0.3	18.0 \pm 1.0	17.5 \pm 0.5
29	24.5 \pm 0.5	24.0 \pm 1.0	20.5 \pm 0.5	22.0 \pm 0.0	20.5 \pm 0.5
30	26.5 \pm 0.5	25.0 \pm 0.0	23.8 \pm 0.3	24.0 \pm 0.0	21.0 \pm 0.0
31	25.5 \pm 0.5	24.5 \pm 0.5	23.0 \pm 0.6	23.0 \pm 1.0	23.0 \pm 0.5
32	26.0 \pm 1.0	25.5 \pm 0.5	22.5 \pm 0.9	24.5 \pm 0.5	22.5 \pm 0.5

* No data available.

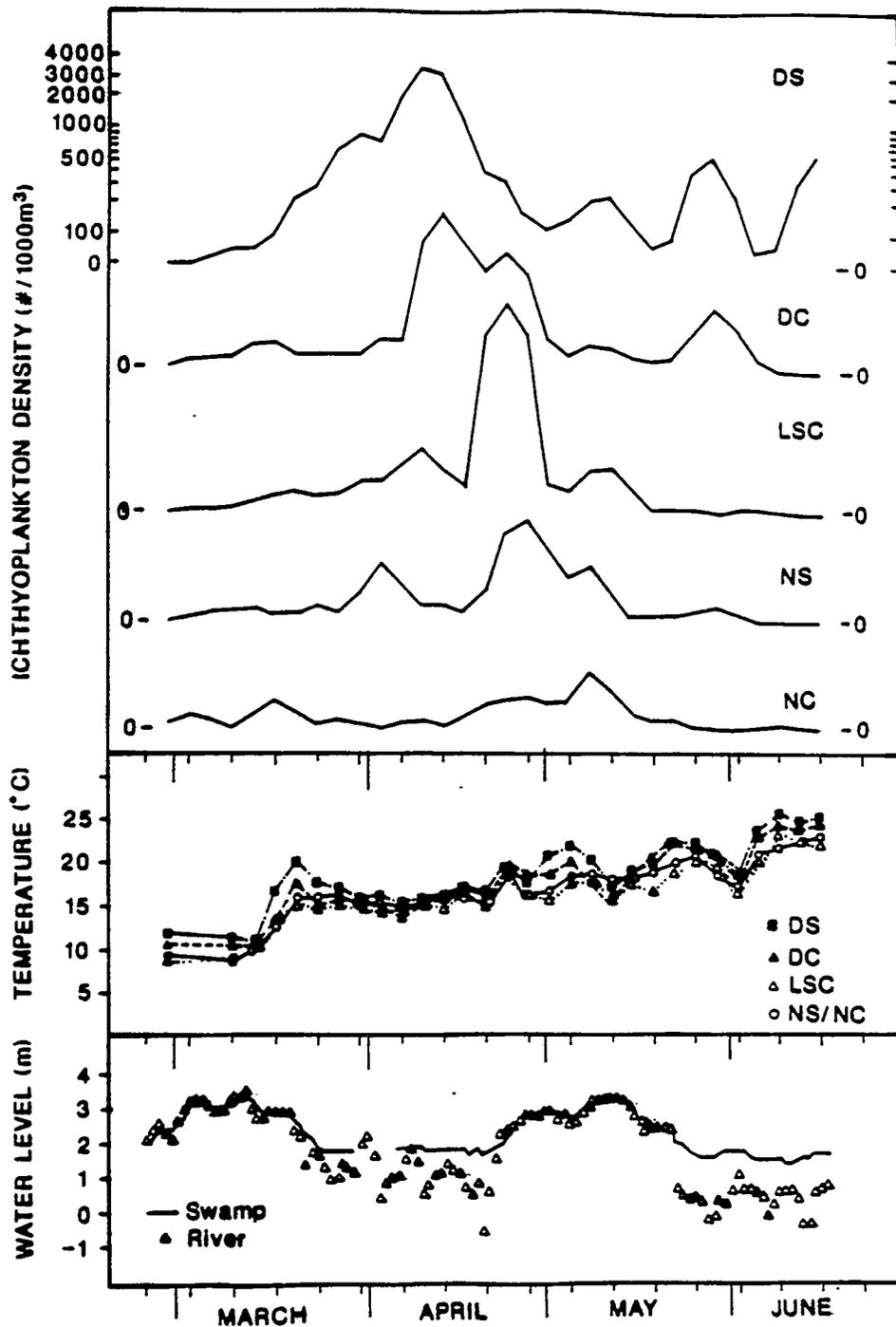


Figure 1.2. (A) Seasonal changes in total densities of larval fish and fish eggs in the five macrohabitats. A three-point running mean computed from samples taken twice each week is plotted on a logarithmic scale ($Y_t' = 0.25 Y_{t-1} + 0.5 Y_t + 0.25 Y_{t+1}$). DS--Disturbed structure, DC--Disturbed channel, LSC--Lower Steel Creek, NS--Natural structure, NC--Natural channel. (B) Water temperatures in the five habitats. (C) Water level variation for the natural channel habitat and the Savannah River at Jackson, S.C. (relative to the 85 foot mark at Jackson).

habitat throughout the spring, but only three additional individuals were collected after the third week of June when water temperatures generally exceeded 23-25°C at all sites. Although ichthyoplankton abundance fluctuated temporally, with a series of recruitment pulses (ANOVA, time treatment $p < 0.001$; Table 1.4, Figure 1.2), the temporal pattern of recruitment differed between habitats (ANOVA, habitat*time interaction, $p < 0.001$; Table 1.4). Timing of peak ichthyoplankton densities differed by two to four weeks and occurred earliest in the disturbed habitats, then Lower Steel Creek, and later in the natural structure and channel habitats. While generally paralleling the slight, but consistent temperature differences between habitats, the temporal separation of the peaks in ichthyoplankton abundance did not correspond to comparable temperatures between habitats. Rather, timing of peak ichthyoplankton density was positively correlated with a site's water temperature over that week ($r = 0.71$, $df = 10$, $p < 0.01$) and also its cumulative degree days (above 0°C) ($r = 0.95$, $df = 10$, $p < 0.001$) since sampling first began.

Ichthyoplankton densities differed among regions with previously disturbed areas of Steel Creek delta having the greatest mean abundance, Lower Steel Creek being intermediate, and the natural, forested swamp region having the lowest ichthyoplankton abundance (Table 1.3). Structured environments also had greater ichthyoplankton densities than channelized environments except for those of Lower Steel Creek. Despite these apparent differences, there was no significant overall effect of major habitat type on ichthyoplankton abundance (ANOVA, habitat treatment, $p > 0.25$; Table 1.4). There were, however, consistent differences among sites within habitats (ANOVA, sites within habitat treatment, $p < 0.001$; Table 1.4) with ichthyoplankton densities being higher in upstream (even numbered sites except site 2) compared to downstream sites (Table 1.3). Variability of larval abundance patterns among sites within habitats reflected the importance of local

Table 1.4. Analysis of variance table for tests of temporal and spatial differences in total ichthyoplankton (eggs and larvae) abundance within the Steel Creek delta. Columns summarize the source of variation, degrees of freedom, F-value, and significance level of the F-test.

Source	df	SS	MS	F	p
Habitat	4	32.76	8.19	1.57	>0.25
Time	31	96.10	3.10	13.43	0.001
Habitat*Time	124	106.64	0.86	3.74	0.001
Sites (Habitat)	7	37.31	5.33	10.08	0.001
Samples (Habitat*Time)	160	36.80	0.23	0.44	>0.25
<u>Error</u>	<u>441</u>	<u>233.73</u>	0.53		
Total	767	543.34			

environmental heterogeneity on the distribution and abundance of early life history stages (Table 1.1). Within structured habitats, the uppermost sites were typically in poorly defined channels with variable amounts of submergent and emergent aquatic macrophytes. Lowermost stations were still in poorly defined channels, but macrophyte coverage was reduced. For channelized habitats, including Lower Steel Creek, there was a trend for channel width, depth, and velocity to increase in the downstream sites. Vegetation coverage was higher in upstream channel sites except in Lower Steel Creek where aquatic macrophytes were rare in occurrence. There were no significant differences in ichthyoplankton density for replicate samples (ANOVA, samples within habitat and time treatment, $p > 0.25$; Table 1.4).

Two flood events, indicated by approximately a 1 m change in water level in March and April-May, occurred during the major spawning interval within the SRSS (Figure 1.2). Because of differences in timing of peak recruitment, there were no significant correlations between mean ichthyoplankton density for pooled collections and water level ($r = 0.01$), water level the previous week ($r = -0.19$), or in the weekly differential of larval abundance and weekly variation in water level ($r = 0.18$). For each habitat, the relationship between ichthyoplankton density and water level, water level the previous week, or in the weekly differences in fish density and water level fluctuation exhibited no consistent pattern. Only within the natural channel was a significant relationship detected between larval fish density and water level ($r = 0.45$, $df = 31$, $p < 0.01$). Significant correlations also existed in larval density and water levels the previous week in the natural channel ($r = 0.29$, $df = 31$, $p < 0.05$) and in weekly variation in larval density and water level for Lower Steel Creek ($r = 0.35$, $df = 30$, $p < 0.05$).

Species composition

Seventeen taxa representing 10 families of fish were collected over the course of this investigation (Table 1.3). Six taxa were collected in all major habitat types. These were brook silversides, pirate perch, minnows, sunfishes, percids, and suckers. An additional four taxa (longnose gar, Alosa sp., carp, and swampfish) were collected on single occasions and generally were recorded from structured habitats. While most of the larval fish assemblage was comprised of resident fishes, anadromous clupeids (e.g., blueback herring, American shad) also used the SRSS for spawning. Most of the clupeid larval stages were eggs collected throughout Lower Steel Creek, but some eggs and larvae were also found in the disturbed and natural structure habitats.

Despite being dominated (ca. 91% of the individuals) by just five taxa (suckers, 49.5%; percids, principally Etheostoma and Percina spp., 21.7%; sunfishes (Enneacanthus, Elassoma, Lepomis spp.), 9.3%; minnows, principally Notropis spp., 6.4%; and pirate perch, 4.2%), composition of the larval fish assemblage differed among habitats (Table 1.3). Total species richness (the cumulative number of species over all collections) differed more between, than within, habitats. Structured environments, disturbed and natural, had the most species ($\bar{x} = 9.5$) compared to the other habitat types ($\bar{x} = 7.0$, $\bar{x} = 7.2$, $\bar{x} = 6.0$ for disturbed channel, Lower Steel Creek, natural channel, respectively). Thus, structured habitats exhibited a greater faunal richness than the other sites even when the five taxa constituting the core of the larval fish assemblage were not considered.

Principal components analysis provided an additional method of summarizing covariation in species-abundance patterns between sites in the Steel Creek delta. The first three axes of the analysis accounted for 79.3% of the total variance in the species abundance matrix (Table 1.5). The first axis largely represented an abundance gradient separating one of the disturbed, structure sites (10) from the

Table 1.5. Principal components analysis of major community/habitat associations in 1984. The eigenvectors of the first three principal components are given.

Taxa	PCI	PCII	PCIII
Eigenvalue:	6.05	1.89	1.69
% variance:	50.4	15.8	13.1
<u>Alosa aestivalis</u>	-.01	-.49	-.39
<u>Alosa sapidissima</u>	-.10	-.02	.59
<u>Dorosoma cepedianum</u>	.34	-.05	-.27
Esocidae	.22	-.49	.04
Cyprinidae	.40	.07	.03
Catostomidae	.16	-.04	.60
<u>Aphredoderous sayanus</u>	.39	.06	.09
<u>Labidesthes sicculus</u>	-.01	.56	-.20
<u>Lepomis/Enneacanthus/ Elassoma spp.</u>	.40	.01	-.05
<u>Micropterus salmoides</u>	.39	.12	.01
<u>Pomoxis spp.</u>	-.08	.37	-.13
Percidae	.40	.15	.01

rest of the locations (Figure 1.3) because of its high loading scores of minnows, pirate perch, centrarchids, and darters (Table 1.5). The second axis loaded heavily on brook silverside, crappie (Pomoxis spp.), blueback herring, and Esox spp. Sites located in the upper half of the plot tended to currently be undergoing post-thermal recovery and sites previously unaffected by thermal discharges were in the lower half. Lower Steel Creek had also been previously thermally affected, and was located near the origin of the scatterplot. Compositional variability along PCA axis II, therefore, reflected differences in environmental complexity and perturbation regime. Both macrophyte coverage (progressing from sites of low to high availability) and current velocity (faster to slower) were significantly associated with this axis (Table 1.6). While not plotted, the third component distinguished sites according to the abundance of clupeids (e.g., gizzard shad and blueback herring) and suckers (Table 1.5). Thus, there was a gradual spatial change in species composition and abundance between natural, forested habitats and disturbed, marsh habitats and channelized to structured environments.

Recruitment of the numerically dominant species exhibited a seasonal succession (Table 1.7; Figure 1.4). Chronology of recruitment was similar in all sites with darters initially dominating the larval fish assemblage followed by a mix of catostomids and pirate perch, and later by sunfish and cyprinids. Where specific identifications could be made, lake chubsuckers (Erimyzon sucetta) were the predominant component (>95% of the individuals) of the Catostomidae in the Steel Creek delta. Similar to patterns of reproductive activity observed for overall abundance, timing of first appearance and peak abundance differed between habitats; spawning of pirate perch and lake chubsucker commenced earlier in disturbed areas than natural areas (Figure 1.4). Temporal separation of the peaks in ichthyoplankton abundance did not correspond to comparable water temperatures between habitats, but were correlated to the cumulative degree days ($r = 0.98$,

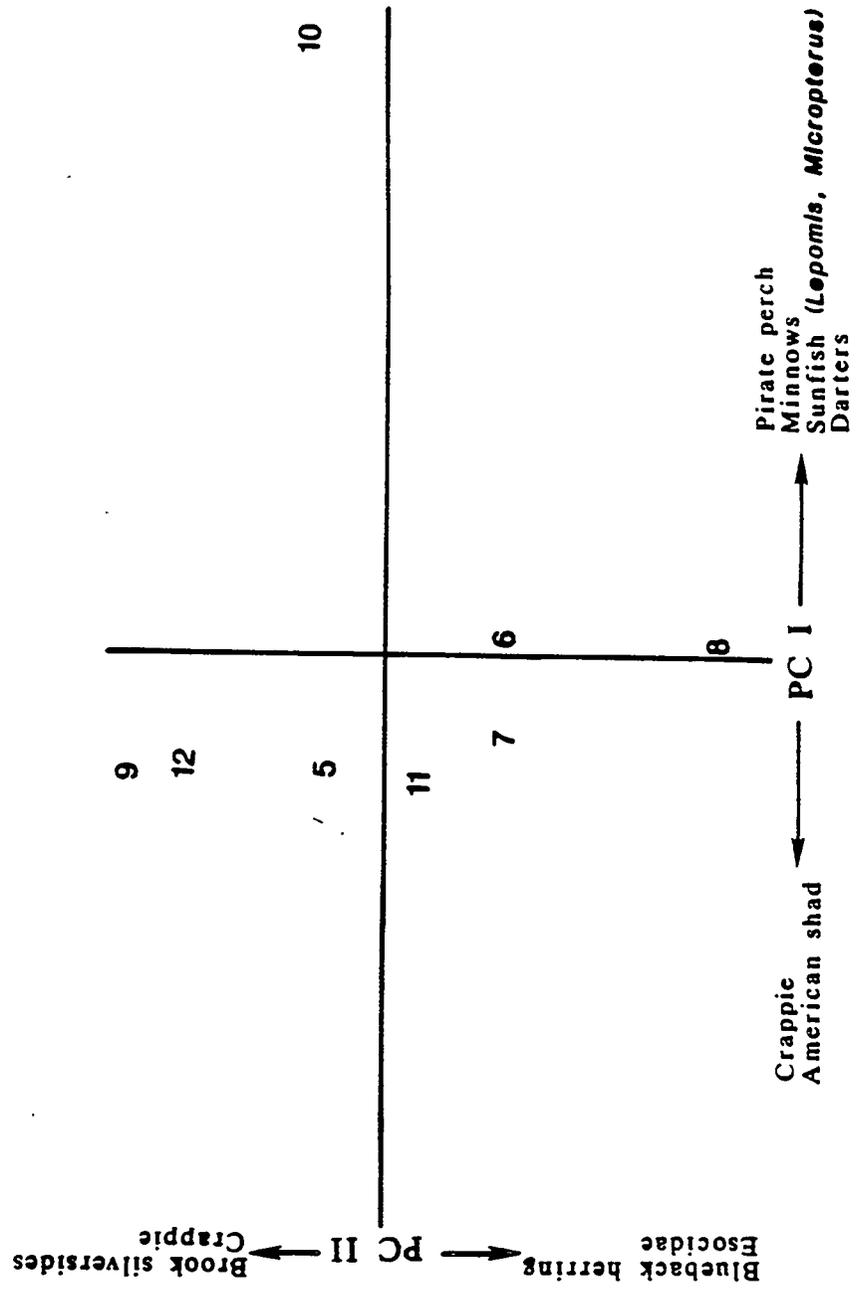


Figure 1.3. Two dimensional plot of sites on Principal Components I and II. Site numbers correspond to Figure 1.1; Lower Steel Creek sites are represented as site number 1.

Table 1.6. Spearman rank correlation coefficients for the test of the null hypothesis that ranks of site position along ordination axes are not associated with ranks of four environmental variables.* = null hypothesis rejected (ranks significantly associated) at significance level $p \leq 0.05$.

Environmental variable	Axis I	Axis II
Canopy cover	0.39	-0.50
Macrophyte cover	0.21	0.68*
Depth	-0.53	-0.58
Current velocity	0.07	-0.64*

Table 1.7. Continued

E. NATURAL CHANNEL

Sample Period (t)	Mean Total Ichthyoplankton Abundance (± 1 SE)	Mean Total Abundance*	Mean Ichthyoplankton Abundance by Taxa												
			Percidae	Aphredoderidae	Catostomidae	Cyprinidae	<u>Lepomis/</u> <u>Elassoma/</u> <u>Enneacanthus</u> <u>spp.</u>	<u>Labidesthes</u> <u>sicculus</u>	<u>Dorosoma</u> <u>cepedianum</u>	Unidentified eggs	Unidentified larvae				
1	0	14.7	0	0	0	0	0	0	0	0	0	0	0	0	0
2	58.6 ± 37.4	34.2	58.6	0	0	0	0	0	0	0	0	0	0	0	0
3	19.5 ± 19.5	24.4	19.5	0	0	0	0	0	0	0	0	0	0	0	0
4	0	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	39.1	0	0	0	0	0	0	0	0	0	0	0	0	0
6	156.3 ± 55.3	78.2	156.3	0	0	0	0	0	0	0	0	0	0	0	0
7	0	39.1	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	9.8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	39.1 ± 39.1	19.6	0	0	19.5	0	0	0	0	0	0	0	19.5	0	0
10	0	9.8	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0
12	19.5 ± 19.5	14.6	0	0	0	0	0	0	0	0	0	0	0	0	0
13	19.5 ± 19.5	19.5	0	0	0	0	0	0	0	0	0	0	0	0	0
14	19.5 ± 19.5	14.6	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	29.3	0	0	0	0	0	0	0	0	0	0	0	0	0
16	97.7 ± 97.7	68.4	19.5	0	78.1	0	0	0	0	0	0	0	0	0	0
17	78.1 ± 78.1	92.8	19.5	0	0	0	0	19.5	0	0	0	0	0	0	0
18	117.2 ± 117.2	97.7	19.5	0	0	0	0	19.5	0	0	0	0	0	0	0
19	78.1 ± 31.2	73.2	0	0	0	0	0	19.5	78.1	0	0	0	0	0	0
20	19.5 ± 19.5	92.8	0	0	0	0	0	0	58.6	0	0	0	0	0	0
21	253.9 ± 102.7	156.3	0	0	0	0	0	0	0	0	0	0	0	0	0
22	97.7 ± 49.2	122.1	0	0	0	0	0	0	0	0	0	0	0	0	0
23	39.1 ± 22.5	43.9	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	24.4	0	0	0	0	0	0	0	0	0	0	0	0	0
25	58.6 ± 58.6	29.3	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	14.7	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0
30	19.5 ± 19.5	9.8	0	0	0	0	0	0	0	0	0	0	0	19.5	0
31	0	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* Values based on 3-point running mean, $0.25 Y_{t-1} + 0.5 Y_t + 0.25 Y_{t+1}$.

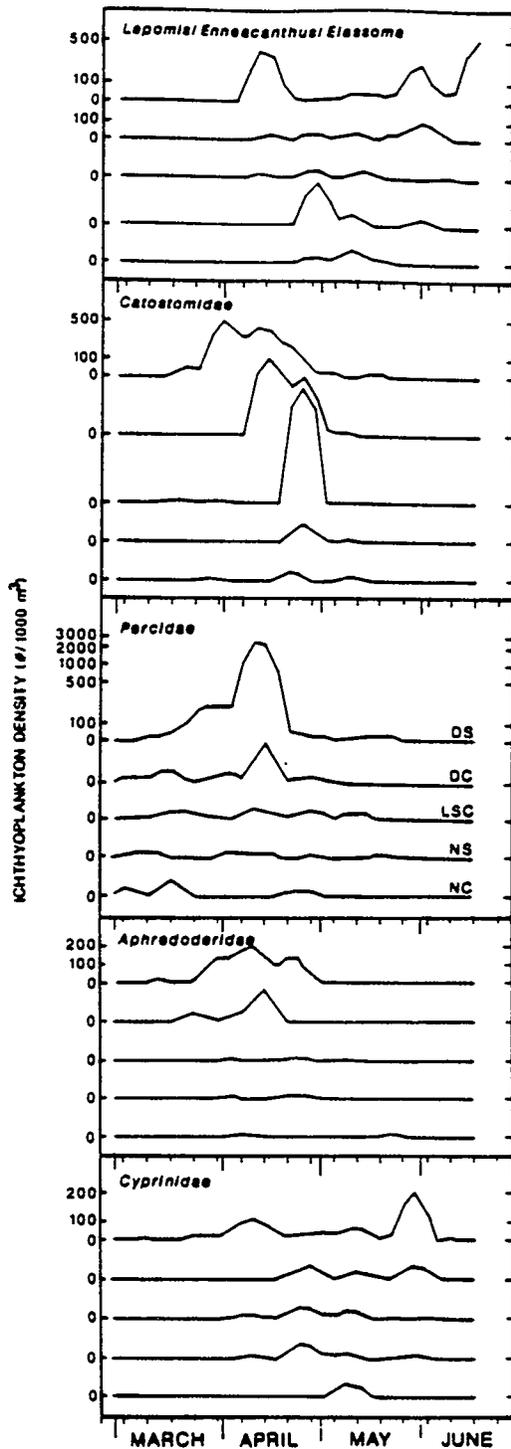


Figure 1.4. Seasonal changes in the densities of the five most abundant taxa plotted by habitat. The relative position of habitats within each panel and habitat abbreviations are as presented in Figure 1.2A. Densities are plotted for Catostomidae (primarily Erimyzon sucetta), Percidae (Etheostoma and Percina spp.), Lepomis/Enneacanthus/Elassoma spp., Aphredoderus sayanus, and Cyprinidae.

$n = 5$, $p < 0.01$) in each habitat. Since cyprinids, sunfishes, or darters could not be positively identified to species, seasonal reproductive cycles of individual species could not be discerned. However, even amongst these taxa groupings there was still temporal separation of pulses in recruitment between habitats which paralleled an earlier appearance in the post-thermal recovery areas and later in unaffected portions of this portion of the SRSS (Figure 1.4). Thus, variability in the onset of, and time of occurrence for, peak recruitment was apparently not the result of differences in faunal composition between habitats, but reflected slight temporal shifts in reproductive cycles between habitats.

Discussion

Ichthyoplankton distribution and abundance differed among regions within the Steel Creek delta region of the SRSS. Previously disturbed areas characterized by extensive herbaceous marshes (>60% areal coverage) were more heavily used by larval fish than sites within the natural cypress-tupelo forest (<20% areal coverage by macrophytes). Only Lower Steel Creek, which serves as the main outlet channel for water from this portion of the SRSS, had densities comparable to the disturbed regions, but ichthyoplankton densities were high only at the site nearest the swamp. Where information is available, other studies of larval fish distribution patterns have also reported high concentrations of individuals in vegetated habitats (Gregory and Powles, 1985; Floyd et al., 1984; Holland and Sylvester, 1983; Holland and Huston, 1985). Similar observations for the importance of vegetated habitats for juvenile and adult fishes (Hall and Werner, 1977; Werner et al., 1977; Mittlebach, 1981; Werner et al., 1983; Rozas and Odum, 1987) have also reported high concentrations of fishes in vegetated habitats. As many of the fish species (e.g., suckers, sunfish, percids, brook silverside) within the SRSS are phytophils or lithophytophils (Balon, 1975), the macrophytes provide an important spawning

substrate and nursery area. For many riverine-swamp habitats, however, the occurrence of herbaceous vegetation is patchy in distribution and in many cases are restricted to only gap openings in the forest canopy.

The ichthyoplankton assemblage in Steel Creek delta was dominated by taxa regarded as permanent freshwater residents. Several species of anadromous clupeids were also present indicating some utilization of the SRSS as a spawning area. Most of their spawning activity, however, appeared to be restricted to the Lower Steel Creek channel. This observation would parallel reports that anadromous clupeids spawn primarily along the surface in open areas, in deep channels adjacent to shoals (such as present where water from the swamp first enters Lower Steel Creek), or over extensive flats of shallow sand or pebbles near creek mouths (Ulrich et al., 1979). Lower Steel Creek has also been recognized as an important spawning tributary for anadromous fishes, particularly blueback herring, within the Savannah River drainage (Paller et al., 1984).

Composition and abundance of the ichthyoplankton assemblage varied both within and between habitats. Patterns of species richness reflect broad scale changes in habitat heterogeneity with the greatest number of species found in shallow, structured environments and fewer in less complex, channelized environments. At the coarse macrohabitat scale, areal coverage of macrophytes and current velocity between sites describe the gradient in environmental conditions associated with prior disturbance events in this portion of the SRSS. As determinants of habitat structural complexity, both are significant factors accounting for inter-site differences in ichthyoplankton composition. Compositional variability relative to either vegetation or current velocity probably result from differential habitat availability affecting spawning success as most species of adult fishes present in the SRSS are found in all regions of the Steel Creek delta (Aho and Anderson, unpublished data; see Chapter III). Patterns of larval

distribution and abundance may also be influenced by the structural characteristics of the vegetation. Macrophyte composition within the herbaceous marsh are dominated by several species of emergent plants, particularly Polygonum spp and Hypericum spp. The dominant species in the forested habitat (e.g., Myaca, Ceratophyllum) are architecturally complex, and even at low areal coverage may impart enough physical structure to the habitat configuration to enable a substantial amount of recruitment to occur. These observations concur with findings from estuarine and other freshwater systems (Heck and Orth, 1980; Coen et al., 1981; Rozas and Odum, 1987) indicating structural complexity as a major factor influencing habitat utilization. The importance of local habitat complexity influencing the distribution and abundance of larval fish probably also contributed to the lack of demonstrable differences between major habitat types.

The use of vegetated areas probably also functions as a refuge and important substrate for food resources. Recent laboratory and field studies of estuarine (Coen et al., 1981; Heck and Thonan, 1981) and freshwater (Hall and Werner, 1977; Crowder and Cooper, 1982; Savino and Stein, 1982; Werner et al., 1983) habitats have shown that aquatic vegetation provides protection to small fishes by reducing foraging efficiency of large predators. Occupation of these habitats may also increase the availability of food resources by providing greater standing crops of invertebrates per unit area (Menzie, 1980; Gilinsky, 1984). Small invertebrates (e.g., insects and zooplankton) may be an important food to many species of larval fish (e.g., Turner, 1977; Mills et al., 1985). Menzie (1980) found that the fish food potential was increased substantially by the presence of macrophytes in the lower Hudson River. Although <2% of the total area of a habitat was vegetated, Menzie (1980) estimated that submerged aquatic vegetation produced 14 to 25% of the total chironomid standing crop. In the present study, numerous amphipods, chironomids and other insect larvae, and cladocerans were observed on the stems

and leaves of vegetation during sample processing (personal observations). Thus, growth rates and survivorship in this critical life history period would probably be higher in vegetated areas.

Duration and timing of the period of reproduction are two critical components of an organism's life history strategy. The variability in reproductive periodicity and timing of peak recruitment between habitats, however, presents some interesting problems for the comparative study of life history strategies.

Based on data for many species of temperate zone fishes, water temperature and photoperiod influence the timing of reproduction (Lam, 1983). The seasonal pattern of recruitment within Steel Creek delta also supports temperature and/or photoperiod, as proximate mechanisms controlling reproduction. However, the slight differences in either factor, or water quality, between habitats cannot completely account for the observed pattern of earlier recruitment in the disturbed habitats compared to other regions of the swamp. Rather, the shifts in reproductive periodicity in the different habitats is believed to result from fish responding to small-scale differences in food availability and suitability of spawning sites. Within Steel Creek delta, changes in the areal coverage and biomass of aquatic macrophytes varied seasonally and between habitats (Smith et al., 1981; Dunn and Sharitz, 1987; Aho et al., personal observations). Although present year round, vegetation growth occurred earlier and was more expansive in the disturbed habitats. Data on seasonal changes in macroinvertebrate abundance or biomass are not available, but based on annual estimates, macroinvertebrate abundance was substantially greater in the open-canopied habitats compared to sites within the natural swamp forest (Kondratieff and Kondratieff, 1985). Taken together, the temporal shifts in reproductive activity appear to coincide with periods when resource availability (food or spawning substrate) may be high. Variation in light intensity (ca. 10% differential in March) between habitats probably contributed to

reproduction, but indirectly through its influence on plant growth. Similar patterns of maximum abundance of juveniles and adult fishes in vegetated areas coinciding with periods of peak plant biomass have been reported in other freshwater (Kemp et al., 1984; Rozas and Odum, 1987) and marine (Munro et al., 1973; Kock, 1982) systems.

Since our study was limited to a five-month period within a single year, little information is available on long-term temporal variations in recruitment patterns. We are certain, however, that these occur. For example, changes in year class strength and growth rates for several species of fish have been linked to variability in the timing, intensity, and duration of floods in both tropical and temperate river systems (Welcomme, 1979; Ross and Baker, 1983). Observations made in other river-swamp systems indicate an increased upstream migration and lateral movement of fish into backwater and floodplain habitats with increasing water levels associated with flood cycles during periods of spawning activity (Netsch and Witt, 1962; Johnson, 1963; Hassler, 1970; Fraser, 1972; Ross and Baker, 1983). Periods of high water appear to promote growth and establishment of high population sizes whereas periods of low water level usually coincide with reduced fish abundance patterns. Utilization of floodplain habitats could provide greater nutrient and habitat availability for reproduction and larval growth at a time when energy demands from gonadal development and rising water temperatures would be increasing. It is also apparent that each species responds differently to these factors and assemblage composition can change over short periods of time (e.g., Starrett, 1951; Carlson and Duever, 1976; Kushlan, 1976; Moyle and Li, 1979; Welcomme, 1979; Grossman et al., 1982; Ross and Baker, 1983). The role of river-swamp habitats as spawning and nursery areas has been suggested by Christiansen and Smith (1965) and Guillory (1979).

Changes in water level may also result in the loss of larvae from a floodplain/backwater system. Collections made within Steel Creek delta indicated a correlation between water level, or weekly changes in water level, and ichthyoplankton density only in Lower Steel Creek and natural channel habitats. For the natural channel habitat, the correlation between water level and fish density suggests ichthyoplankton were being transported downstream away from structured habitats during periods of rising water level. The correlation of water level variability and ichthyoplankton density in Lower Steel Creek also supports the hypothesis of increased downstream transport of larvae. Based on channel morphology (e.g., fast current velocity, rare aquatic vegetation) and species reproductive habits, however, only the clupeids are thought to spawn in Lower Steel Creek with the majority of ichthyoplankton collected being individuals transported out of the main body of the swamp. Similar observations of increased transport of larvae accompanying changes in water level have been made in other river-swamp wetlands (Gallagher and Connor, 1980) and along stream margins (Olmsted, 1981; Floyd et al., 1984). While the downstream transport of ichthyoplankton could potentially represent a major loss of larval stages from the SRSS, fringing river-swamp systems may function as important spawning grounds for fish populations in larger rivers such as the Savannah River.

Accompanying the restart of L-Reactor, water levels and flow rates in structured areas should increase. One proposed outcome of these changes may be that assemblage structure in shallow, structured areas will become more similar to communities of nearby channels. Higher flows will shift the assemblages in structured habitats from darters, pirate perch and sunfish to dominance by lake chubsuckers and brook silversides. Increased flow may, however, increase downstream displacement of larval fish unable to find shelter, which could contribute to a loss of system productivity (Olmsted, 1981). It is unclear how species

composition might change if flow erodes substrates or alters macrophyte growth, but ichthyoplankton densities should be substantially reduced in these areas.

Warmer temperatures following reactor operations should also accelerate spawning of many species. It is highly probable that increased water temperatures will have other direct and indirect effects on reproductive activity as evidenced through changes in larval fish dynamics (Lam, 1983). Elevated temperatures may alter the timing and sequence in which species reproduce. Consequently, larvae and eggs may be present during periods of low resource availability; this would be an example of the match-mismatch hypothesis affecting recruitment success (Frank and Leggett, 1982). Direct thermal effects may also simply increase mortality rates by exceeding physiological threshold limits. These thermal effects may alter community structure more than the increase in water flow. Since larval densities change quickly in the natural habitats, densities must be measured frequently over the spawning season to correctly evaluate the effects of environmental disturbances.

Conclusions

Larval fish were studied from February through August 1984 in three regions in the SRSS: (1) Lower Steel Creek, (2) post-thermal recovery areas, and (3) undisturbed areas of cypress/tupelo forest. From the post-thermal and cypress/tupelo regions, two habitat types were sampled: shallow, structured and deep, channelized habitats. The objectives of the study were (1) to describe spatial and temporal patterns of larval fish distribution and abundance and (2) to correlate effects of prior habitat modification on larval fish recruitment patterns. Conclusions of the study are summarized below.

- Larval stages of 17 taxa were most abundant from March through May in all habitat sites.

- Larval fish densities at all sites fluctuated temporally with a series of recruitment pulses.
- Occurrence of peak larval abundance differed significantly by two to four weeks between habitats. Peak larval densities occurred earliest in sites from the post-thermal recovery region, and later in Lower Steel Creek and sites within the undisturbed cypress/tupelo forest.
- Slight, but consistent differences in water temperature were found between most habitats in Steel Creek delta. Temporal separation of the peaks in ichthyoplankton abundance, overall and for several of the dominant taxa, did not, however, correspond to the occurrence of comparable temperatures between habitats. Instead, the shifts in the timing of reproductive activity followed progressively increasing water temperatures between habitats; early peaks in abundance occurred at cooler temperatures compared to peaks recorded later in the spring. Water level was significantly correlated with larval fish density in channel sites within the cypress/tupelo forest and Lower Steel Creek.
- Densities of larval fish varied among regions with disturbed sites having the greatest mean larval abundance, Lower Steel Creek intermediate, and sites within the undisturbed cypress/tupelo forest having the lowest larval fish abundance. The increased abundance of herbaceous plants in the disturbed areas is likely a major reason for the higher densities. Within each region, shallow, structured habitats also consistently had greater numbers of ichthyoplankton than channelized habitats. However, the differences in larval abundance between sites within habitat and shifts in the timing of reproduction probably prevented detection of significant differences in ichthyoplankton abundance between the five major habitat types within Steel Creek delta.

- Shallow, structured habitats in both disturbed and natural regions of the SRSS had the most species of larval fish compared to other habitats. Common taxa groups were brook silverside, pirate perch, minnows, sunfishes, percids, and suckers. Anadromous clupeids also used the SRSS for spawning with most activity in the Lower Steel Creek channel or adjacent swamp habitats.
- Recruitment of the numerically dominant species exhibited a seasonal succession. Chronology of recruitment was similar in all sites with darters initially dominating the larval fish assemblage followed by a mix of lake chubsuckers and pirate perch, and later by sunfish and cyprinids. Spawning of pirate perch, sunfish, minnows, and suckers generally commenced earlier in disturbed sites than natural sites.

Literature Cited

- Aron, W. 1958. The use of a large capacity portable pump for plankton sampling, with notes on plankton patchiness. *Journal of Marine Research* 16:158-173.
- Auer, N. A. (editor). 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission. Special Publication 82-3: Ann Arbor, MI.
- Balon, E. 1975. Reproductive guilds of fishes: A proposal and definition. *Journal of the Fisheries Research Board of Canada* 32:821-864.
- Brinson, M.M., H.D. Bradshaw, R.N. Holmes, and J.B. Elkins, Jr. 1980. Litterfall, stemflow, and throughfall nutrient fluxes in an alluvial swamp forest. *Ecology* 61:827-835.
- Brinson, M.M., A.E. Lugo, and S. Brown. 1981. Primary productivity, decomposition, and consumer activity in freshwater wetlands. *Annual Reviews of Ecology and Systematics* 12:123-161.
- Brown, S. 1981. A comparison of the structure, primary production, and transpiration of cypress ecosystems in Florida. *Ecological Monographs* 51:403-427.
- Cada, G. F. and J. M. Loar. 1982. Relative effectiveness of two ichthyoplankton sampling techniques. *Canadian Journal of Fisheries and Aquatic Sciences* 39:811-814.
- Carlson, J. E., and M. J. Duever. 1976. Seasonal fish population fluctuations in a south Florida swamp. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 31:603-611.
- Christiansen, L.M. and L.L. Smith. 1965. Characteristics of fish populations in upper Mississippi River backwater areas. *United States Fish and Wildlife Service Circular* 212. 53 pp.
- Coen, L.D., K.L. Heck, Jr., and L.G. Abele. 1981. Experiments on competition and predation among shrimps of seagrass meadows. *Ecology* 62:1484-1493.
- Connor, W.H. and J.W. Day, Jr. 1976. Productivity and composition of a bald cypress-water tupelo site and a bottomland site in a Louisiana swamp. *American Journal of Botany* 63:1354-1364.
- Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. *Ecology* 63:1802-1813.
- Day, F.P. 1982. Litter decomposition rates in the seasonally flooded Great Dismal Swamp. *Ecology* 63:670-678.
- Downing, J. A. 1979. Aggregation, transformation, and the design of benthos sampling programs. *Journal of the Fisheries Research Board of Canada* 36:1454-1463.

- Dunn, C. P. and R. R. Sharitz. 1987. Revegetation of a *Taxodium-Nyssa* forested wetland following complete vegetation destruction. *Vegetatio* 72:151-157.
- Ewel, K. C. and H. T. Odum. 1978. Cypress domes: nature's tertiary treatment filter. In: *Cypress wetlands for water management, recycling, and conservation* (eds. H.T. Odum and K. C. Ewel), pp. 35-60. Fourth Annual Report to NSF-RANN and the Rockefeller Foundation. Gainesville, FL.
- Finger, T. R. and E. M. Stewart. In press, 1987. Responses of fish to flooding regime in lowland hardwood wetlands. In: *Evolutionary and community ecology of North American stream fishes* (eds. W.J. Matthews and D.C. Heins). University of Oklahoma Press: Norman, OK.
- Floyd, K. B., R. D. Hoyt, and S. Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. *Transactions of the American Fisheries Society* 113:217-223.
- Frank, K. T. and W. C. Leggett. 1982. Environmental regulation of growth rate, efficiency, and swimming performance in larval capelin (*Mallotus vilbosus*) and its application to the match/mismatch hypothesis. *Canadian Journal of Fisheries and Aquatic Sciences* 39:691-699.
- Fraser, J. C. 1972. Regulated discharge and the stream environment. In: *River ecology and man* (eds. R.T. Oglesby and J.A. McCann), pp. 263-286. Academic Press: New York, USA.
- Freeman, B. J. and M. C. Freeman. 1985. Production of fishes in a subtropical blackwater ecosystem: The Okefenokee Swamp. *Limnology and Oceanography* 30:686-692.
- Gale, W. F. and H. W. Mohr, Jr. 1978. Larval fish drift in a large river with a comparison of methods. *Transactions of the American Fisheries Society* 107:46-55.
- Gallagher, R. P., and J. V. Conner. 1980. Spatio-temporal distribution of ichthyoplankton in the lower Mississippi River, Louisiana. In: *Proceedings of the Fourth Annual Larval Fish Conference* (ed. L.A. Fuiman), pp. 101-115. United States Fish and Wildlife Service, Biological Services Program, FWS/OBS-80/43, Ann Arbor, Michigan, USA.
- Gilinsky, E. 1984. The role of fish predation and spatial heterogeneity in determining benthic community structure. *Ecology* 65:455-468.
- Gregory, R. S. and P. M. Powles. 1985. Chronology, distribution, and sizes of larval fish sampled by light traps in macrophytic Chemung Lake. *Canadian Journal of Zoology* 63:2569-2577.
- Grossman, G. D., P. B. Moyle, and J. O. Whitaker, Jr. 1982. Stochasticity in structural and functional characteristics of an Indiana stream fish assemblage: A test of community theory. *American Naturalist* 120:423-454.
- Guillory, V. 1979. Utilization of an inundated floodplain by Mississippi River fishes. *Florida Scientist* 42:222-228.

- Hall, D. J. and E. E. Werner. 1977. Seasonal distribution and abundance of fishes in the littoral zone of a Michigan lake. *Transactions of the American Fisheries Society* 106:545-555.
- Hassler, T. J. 1970. Environmental influences on early development and year-class strength of northern pike in lakes Oahe and Sharpe, South Dakota. *Transactions of the American Fisheries Society* 99:369-375.
- Heck, K. L., Jr. and R. J. Orth. 1980. Seagrass habitats: the role of habitat complexity, competition, and predation in structuring associated fish and macroinvertebrate assemblages. In: *Estuarine Perspectives* (ed. V.S. Kennedy), pp. 449-464. Academic Press: New York.
- Heck, K. L., Jr. and T. A. Thonan. 1981. The nursery role of seagrass meadows in the upper and lower reaches of the Chesapeake Bay. *Estuaries* 7:70-92.
- Hogue, J. J., Jr., R. Wallus, and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tennessee Valley Authority, Technical Note B19, Norris, Tennessee, USA.
- Holland, L. E., and M. L. Huston. 1985. Distribution and food habits of young-of-the-year fishes in a backwater lake of the upper Mississippi River. *Journal of Freshwater Ecology* 3:81-91.
- Holland, L. E. and J. R. Sylvester. 1983. Distribution of larval fishes related to potential navigation impacts on the upper Mississippi River, Pool 7. *Transactions of the American Fisheries Society* 112:293-301.
- Johnson, R. P. 1963. Studies on the life history and ecology of the bigmouth buffalo, *Ictiobus cyprinellus* (Valenciennes). *Journal of the Fisheries Research Board of Canada* 20:1397-1429.
- Kemp, W. M., W. R. Boynton, and R. R. Twilley. 1984. Influences of submerged vascular plants on ecological processes in upper Chesapeake Bay. In: *The estuary as a filter* (ed. V. Kennedy), pp. 367-394. Academic Press: New York.
- Kock, R. L. 1982. The patterns of abundance variation in reef fishes near an artificial reef at Guam. *Environmental Biology of Fishes* 7:121-136.
- Kondratieff, P. and B. C. Kondratieff. 1985. A lower food chain community study: thermal effects and post-thermal recovery in the streams and swamps of the Savannah River Plant. Report ECS-SR-19, DPST-85-376. Environmental and Chemical Sciences, Inc., Aiken, SC.
- Kushlan, J. A. 1976. Environmental stability and fish community diversity. *Ecology* 57:821-825.
- Lam, T. J. 1983. Environmental influences on gonadal activity in fish. In: *Fish Physiology, Volume 9B* (eds. W.S. Hoar, D.J. Randall, and E.M. Donaldson), pp. 65-116. Academic Press: New York.
- Leithiser, R. M., K. F. Erhlich, and A. B. Thum. 1979. Comparison of a high volume pump and conventional plankton nets for collecting fish larvae entrained in

- power plant cooling systems. *Journal of the Fisheries Research Board of Canada* 36:81-84.
- Martin, C. E., E. J. Christy, and K. W. McLeod. 1977. Changes in the vegetation of a South Carolina swamp following cessation of thermal pollution. *Journal of the Elisha Mitchell Society* 93:173-176.
- Menzie, C. A. 1980. The chironomid (Insecta: Diptera) and other fauna of a Myriophyllum spicatum L. plant bed in the lower Hudson River. *Estuaries* 3:38-54.
- Mills, C. A., W. R. C. Beaumont, and R. T. Clarke. 1985. Sources of variation in the feeding of larval dace Leuciscus leuciscus in an English river. *Transactions of the American Fisheries Society* 114:519-524.
- Mittelbach, G. C. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. *Ecology* 62:1370-1386.
- Moyle, P. B. and H. Li. 1979. Community ecology and predator-prey relations in warmwater streams. In: *Predator-prey systems in fisheries management* (ed. H. Clepper), pp. 171-180. Sport Fishing Institute: Washington, D.C.
- Mulholland, P. J. 1981. Organic carbon flow in a swamp-stream ecosystem. *Ecological Monographs* 51:307-322.
- Munro, J. L., V. C. Gaut, R. Thompson, and P. H. Reeson. 1973. The spawning seasons of Caribbean reef fishes. *Journal of Fish Biology* 5:69-84.
- Netsch, Lt. N. F., and A. Witt, Jr. 1962. Contributions to the life history of the longnose gar, (Lepisosteus osseus) in Missouri. *Transactions of the American Fisheries Society* 91:251-262.
- Newman, M. C. 1986. Water Quality. Comprehensive Cooling Water Report, Volume 2: Water Quality. Savannah River Ecology Laboratory, Division of Wetlands Ecology, Aiken, SC. 600 pp.
- Olmsted, L. L. 1981. Effects of moderate flooding on aquatic organisms and chemical characteristics of a piedmont stream. In: *The Warmwater Streams Symposium* (ed. L.A. Krumholz), pp. 54-69. Southern Division American Fisheries Society, Lawrence, Kansas, USA.
- Paller, M., J. O'Hara, V. Osteen, W. Specht, and M. Kania. 1984. Annual report of the Savannah River Aquatic Ecology Program, September 1982 - August 1983. Volume I. Environmental and Chemical Sciences, Inc., Aiken, SC. ECS-SR-8, DPST-84-252.
- Porter, E. M. and C. A. Rohde. 1977. Tests of a high volume pump for ichthyoplankton in the Chesapeake and Delaware canal. Applied Physics Laboratory, Johns Hopkins University, Laurel, MD. JHU-PPSE-T-3. 50 pp.
- Ross, S. T. and J. A. Baker. 1983. The response of fishes to periodic spring floods in a southeastern stream. *American Midland Naturalist* 109:1-14.

- Rozas, L. P. and W. E. Odum. In press, 1987. Fish and macrocrustacean use of submerged plant beds in tidal freshwater marsh creeks. *Marine Ecology-Progress Series*.
- SAS. 1985. SAS User's Guide: Statistics. Version 5. Statistical Analysis Institute. Cary, NC.
- Savino, J. F. and R. A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. *Transactions of the American Fisheries Society* 111:255-266.
- Schlesinger, W. H. 1978. Community structure, dynamics, and nutrient cycling in the Okefenokee cypress swamp-forest. *Ecological Monographs* 48:43-65.
- Scott, M. L., R. R. Sharitz, and L. C. Lee. 1986. Disturbance in a cypress-tupelo wetland: An interaction between thermal loading and hydrology. *Wetlands* 5:53-68.
- Sharitz, R. R., J. E. Irwin, and E. J. Christy. 1974. Vegetation of swamps receiving reactor effluents. *Oikos* 25:7-13.
- Sharitz, R.R. and L.C. Lee. 1985. Recovery processes in southeastern riverine wetlands. In: *Riparian ecosystems and their management: Reconciling conflicting uses*. First North American Conference, General Technical Report RM-120, Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, U.S.D.A., Ft Collins, CO. pp. 449-501.
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. 1981. An evaluation of the Steel Creek ecosystem in relation to the proposed restart of L-Reactor. Savannah River Ecology Laboratory Report, SREL-9. Savannah River Ecology Laboratory, Aiken, SC.
- Snedecor, G. W., and W. G. Cochran. 1980. *Statistical Methods*. Seventh edition. The Iowa State University Press: Ames, Iowa, USA.
- Sokal, R. R., and F. J. Rohlf. 1981. *Biometry*. Second Edition. W. H. Freeman and Company: San Francisco, USA.
- Starrett, W. C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. *Ecology* 32:13-27.
- Taggart, C. T. and W. C. Leggett. 1984. Efficiency of large volume plankton pumps, and evaluation of a design suitable for deployment from small boats. *Canadian Journal of Fisheries and Aquatic Sciences* 41:1428-1435.
- Turner, E. A. 1977. Food habits of larval *Lepomis* spp. in Old Hickory Reservoir Tennessee. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 31:432-436.
- Ulrich, G., N. Chipley, J. W. McCord, D. Cupka, J. L. Music, Jr., and R. K. Mahood. 1979. Development of fishery management plans for selected anadromous fishes in South Carolina and Georgia. Special Publication 14, Marine Resources Center, SC Wildlife and Marine Resources Department, Columbia, SC. 135 pp.

- Wang, J. C. S. and R. J. Kernehan. 1979. Fishes of the Delaware estuaries: a guide to early life histories. Ecological Analysts Communications, Towson, Maryland, USA.
- Welcomme, R. L. 1979. Fisheries ecology of floodplain rivers. Longman: New York. 317 pp.
- Werner, E. E., D. J. Hall, D. R. Laughlin, D. J. Wagner, L. A. Wilsmann, and F. C. Funk. 1977. Habitat partitioning in a freshwater fish community. Journal of the Fisheries Research Board of Canada 34:360-370.
- Werner, E. E., J. F. Gilliam, D. J. Hall, and G. G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64:1540-1548.
- Wharton, C. H., W. M. Kitchens, E. C. Pendelton, and T. W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a communtiy profile. U.S. Fish and Wildlife Service, Biological Sciences Program, Washington, D.C. FWS/OBS-81/37. 133 pp.

**II. Response of Larval Fish Assemblage Structure in the
Savannah River Swamp System to Temperature Gradients from Nuclear
Production Reactor Effluents**

Charles S. Anderson, John M. Aho, and Keith B. Floyd

Introduction

Wetland habitats have unique biological, ecological, and hydrologic characteristics. The integrity of these habitats is, however, becoming increasingly disrupted for purposes ranging from wastewater treatment to aquaculture. Included among these uses is the mitigation of thermal effluents from power plants and other industrial facilities. Many of the biological effects of thermal alteration on aquatic ecosystems have been summarized by Gibbons and Sharitz (1974), Coutant and Talmage (1976), Esch and McFarlane (1976), Thorp and Gibbons (1978), and McCort (1987). From a fish population and community perspective, studies have examined the effects of thermal loading on movement patterns (e.g., Neill and Magnuson, 1974; Stauffer et al., 1976; Spigarelli et al., 1982; Block et al., 1984; Roosenburg et al., 1988), survivorship and growth (Hutchinson, 1976; Coutant and DeAngelis, 1983; Kellogg and Gift, 1983; Wrenn, 1984), metabolic processes (Rice et al., 1983), and species diversity patterns (McErlean et al., 1973; Parker et al., 1973; McFarlane, 1976). Other studies have examined the importance of thermal influences on interactions among different fish species for food or space and the importance of temperature as a resource (Magnuson et al., 1979; Brandt et al., 1980; Block et al., 1984; Janssen and Giesy, 1984). In contrast, comparatively little is known regarding effects of elevated water temperatures on reproductive cycles and the early life history stages of most fishes.

In a cypress-tupelo floodplain forest in South Carolina, the Savannah River Swamp System (SRSS), extensive environmental temperature gradients are established from heated effluents discharged from two nuclear production reactors. Fish are not found in areas of extreme water temperatures ($>45^{\circ}\text{C}$), but are distributed along thermal gradients as water meanders through the swamp and cools to regionally ambient values. The heterogeneous environment created by the reactor effluents simulate gradients commonly used in laboratory experiments to

examine fish responsiveness to temperature (e.g., thermal preference: McCauley and Huggins, 1979; Reynolds, 1977), yet retains many of the diverse biological and physical characteristics of a fish's environment. These environmental temperature gradients, therefore, allow for field comparisons over short geographic distances to examine factors influencing reproductive activity in fishes.

The objective of this study was to characterize the effect of thermal alteration on fish reproductive cycles and the distribution and abundance of their early life history stages in a South Carolina river-swamp ecosystem, the Savannah River Swamp System (SRSS). Pertinent to this objective, two questions are addressed: (1) Do density, species composition, and timing of reproduction vary between areas of different thermal characteristics? and (2) Do patterns of species seasonal succession vary across environmental temperature gradients? The study also summarizes annual variability in recruitment for 1984 and 1985, and contrasts larval fish assemblage structure between years of different water level to test the hypothesis that water level does not influence species composition or abundance. The observed patterns will be useful in predicting how water level and temperature fluctuations of ca. 0.5 m and 3-5°C associated with the restart of a nuclear reactor production facility, L-Reactor, will have on larval fish dynamics. Together, these findings should provide additional information assessing fish spawning, location of nursery areas, and thermal impacts on reproductive processes across the SRSS.

Study Areas

The Savannah River Swamp System (SRSS) is a 3200 ha floodplain forest located along the Savannah River on the U.S. Department of Energy's Savannah River Plant (SRP), in South Carolina (Figure 2.1). Vegetation in this wetland is composed of second-growth stands of bald cypress (Taxodium distichum) and water tupelo (Nyssa aquatica) that were logged near the turn of the century and mesic hardwood stands

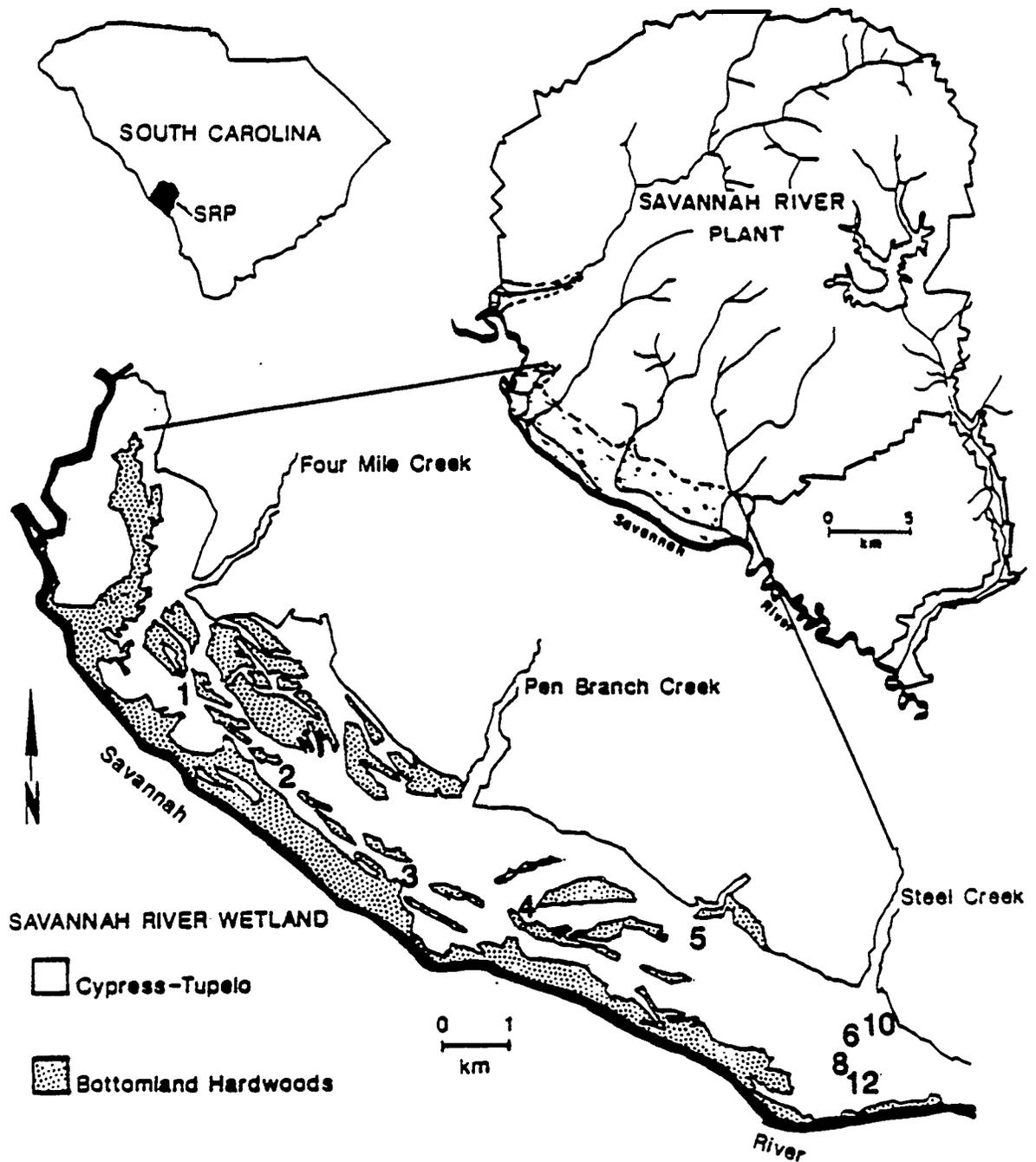


Figure 2.1. Map of the SRP showing sampling sites along thermal plumes. Stations 1 to 5 were thermal areas numbered from hottest to coolest. Stations 1 to 3 were in the Four Mile Creek thermal plume; stations 4 and 5 were in the Pen Branch thermal plume. Within Steel Creek, stations 8 and 12 were in natural forested areas while stations 6 and 10 were located in previously disturbed areas with reduced overstory canopy.

on old river levees. Since 1954, water pumped from the Savannah River has been periodically used as a source of cooling water for three reactors with heated effluents discharged into three major tributary streams flowing into the SRSS before draining into the Savannah River. Prior to 1954, each stream had a discharge rate $<2.0 \text{ m}^3/\text{s}$; current thermal discharges average $11.3 \text{ m}^3/\text{s}$ and water temperatures typically exceed 40°C where the streams enter the swamp. Elevated temperatures, water levels, and increased sedimentation associated with reactor operations have resulted in degradation of both canopy and understory vegetation in the vicinity of each stream mouth (Sharitz et al., 1974). Limited mortality, principally of mesic hardwoods, has also occurred over about 50% of the swamp (Sharitz et al., 1974).

Two of the streams, Four Mile Creek and Pen Branch, continued to periodically carry heated discharges into the SRSS in 1985 (Figure 2.1). Approximately 60% of the discharge released into Four Mile Creek goes directly to the Savannah River through a break in the river levee. However, some flow, as well as all flow from Pen Branch, moves laterally through the swamp in shallow (typically $\leq 2\text{m}$ deep) channels before entering the Savannah River through a second break (Lower Steel Creek) in the natural river levee. The third stream, Steel Creek, received thermal effluents from 1954 to 1968, and since that time has had regionally ambient water temperatures and flows. Although undergoing post-thermal recovery for almost 20 years, the disturbed area near the mouth of Steel Creek still lacks development of an overstory canopy. In areas where trees had been killed in the vicinity of the Steel Creek delta, herbaceous marshes and open water channels are the dominant habitat type; natural cypress-tupelo forests still exist in regions where there was no thermal impact.

Reactor operations have also altered the hydrology of this swamp system such that natural draw-downs in water level have virtually been eliminated except

during periods of drought. Water levels currently fluctuate between 10 cm and 1.5 m above the substrate surface depending on reactor operation schedules (Repaske, 1981). Variability in SRSS water levels are also influenced by flood control dams located upstream of the SRP on the Savannah River. Controlled releases of water from these dams now directly influence the magnitude and timing of floods in the SRSS (Sharitz et al., 1986).

Methods

Within the SRSS, nine sampling stations were established to determine the influence of temperature on composition and phenology of larval fish assemblages (Figure 2.1, Table 2.1). Criteria used for site selection was based on current temperature regime and prior history of environmental perturbation from SRP operations. Five stations were located along thermal plumes originating from Four Mile Creek and Pen Branch and represented habitats with water temperatures ranging from ca. 2-19°C above ambient. These sites have been numbered 1-5, from hottest to coolest along the gradient. Four more stations were selected near the mouth of Steel Creek and represent previously disturbed and natural forested swamp habitats. Previous studies on larval fish population and assemblage dynamics had been conducted in this region (Aho et al., 1986; see Chapter I), so original site designations have been retained for reference. These included: (a) Station 6, located adjacent to a channel flowing through the thermally disturbed area where overstory canopy had been destroyed; (b) Station 8, located on a channel flowing through a previously unimpacted portion of the swamp; (c) Station 10, a shallow backwater area from the previously disturbed area; and (d) Station 12, a shallow backwater in the natural cypress-tupelo forest. Within Steel Creek, therefore, habitat conditions contrast disturbed/undisturbed and fast/slow current velocities (Table 2.1).

Table 2.1. Physical conditions and collection summaries for thermally altered, post-thermal recovery, and natural cypress/tupelo forest sites sampled in the Savannah River Swamp System.

Site	Number of Weekly Collections	Temperature Condition	Temperature (°C) Mean \pm 95% CI (range)	Velocity* (cm/s) Mean \pm 95% CI	Depth* (cm) Mean \pm 95% CI	Percent** Vegetation Cover	Total Number of Fish Collected
1	23	Heated	28.3 \pm 5.0 (5.7-37.0)	12.6 \pm 2.9	88.5 \pm 20.6	Low	181
2	23	Heated	24.9 \pm 6.9 (6.1-33.5)	12.3 \pm 2.5	93.5 \pm 23.2	Low	242
3	23	Slightly heated	20.8 \pm 5.3 (5.9-30.8)	7.5 \pm 1.8	85.6 \pm 18.5	Low	155
4	26	Slightly heated	23.5 \pm 6.6 (7.6-29.2)	9.6 \pm 2.7	102.8 \pm 26.9	Low	142
5	26	Slightly heated	18.7 \pm 5.5 (3.1-29.6)	9.8 \pm 2.0	86.4 \pm 222.3	Low	275
6	27	Ambient/Post-thermal	17.9 \pm 6.9 (0.5-28.7)	12.1 \pm 3.6	66.1 \pm 8.2	High	3030
8	27	Ambient	17.5 \pm 4.7 (0.6-26.9)	17.3 \pm 3.9	78.8 \pm 10.9	Moderate	752
10	27	Ambient/Post-thermal	18.9 \pm 8.1 (0.5-32.0)	3.6 \pm 0.9	58.0 \pm 23.4	High	2151
12	27	Ambient	17.1 \pm 4.8 (0.6-26.2)	10.5 \pm 5.1	43.3 \pm 15.6	Moderate	59

* Mean velocity and depth at each site includes values from deep, channel and shallow, vegetated microhabitats.

** Visual estimates of percentage areal coverage by aquatic macrophytes: low <20%, moderate 20 to 40%, high >50%.

Spatial and temporal changes in ichthyoplankton abundance and water temperature associated with the appearance (e.g., first date of appearance, mean julian day for the interval a taxa was present at a site) of various larval fish taxa were determined by weekly sampling at each station. Samples were taken from the second week of January through the fourth week of July in 1985. Exceptions occurred when natural low water levels, or change in water levels associated with cessation in reactor operations, prohibited access to certain sites. Specifically, sampling was not possible at Stations 1 to 3 during the 24th week and after week 25, for weeks 26, 27, and 29 at Stations 4 and 5, and during weeks 26 and 29 at Stations 6, 8, 10, and 12.

At most stations, three replicate samples were taken from each of two microhabitats (shallow, vegetated areas and deeper, open-water habitats). Samples were collected using a high-volume centrifugal pump to filter 15.3 m³ of water through a 0.505 mm mesh conical (0.5 m wide mouth, 2.5 m long) plankton net trailed into the water and positioning it so it 'ballooned' to minimize abrasion to eggs and larvae. Pump discharge rates (1.5 m³/minute) were calibrated against known volumes of water before collections began. All collections were consistently taken at a depth of 10-30 cm, and replicate samples within a microhabitat (shallow or channel) were ca. 3-5 m apart; greatest distance separating all samples within a site was generally less than 50 m. Channel samples were not taken at Stations 10 and 12 because this habitat type was not present in these backwater areas. Pump characteristics and cautionary notes are similar to those outlined in Chapter I. Pumping rate was slightly higher, compared to 1984 collections, to enable greater number of replicate samples to be taken per site and microhabitat and be of similar total volumes. All samples were taken in the daytime between 0900 and 1430 hours.

Upon collection, all samples were immediately preserved in 5% formalin containing Phloxine B stain. Larvae and eggs were enumerated and identified to the lowest possible taxonomic level following keys by Auer et al. (1982), Hogue et al. (1976), and Wang and Kernehan (1979). Further recognition of the early life history stages of described and undescribed species was based on specimens (e.g., redbreast sunfish Lepomis auritus, spotted sunfish L. punctatus) raised in the laboratory for ancillary projects.

Temporal and spatial variability in the total densities of eggs and larvae were analyzed separately by microhabitat to permit a balanced analysis of variance (ANOVA). Weeks with incomplete sampling were excluded from the analysis. Total ichthyoplankton densities (eggs and larvae) were transformed by $\ln(x + 1)$ before analysis because the assumption of homogeneity of variance was not originally met. Criteria for choice of transformation is given in Downing (1979). Use of nonparametric analyses included rank correlation to determine relationships between temperature and mean density and sign tests to examine for trends in timing and accompanying temperature of appearance for larval fish recruitment patterns in the SRSS. All statistical analyses were done using either SAS (1985) or followed procedures outlined in Sokal and Rohlf (1981) or Snedecor and Cochran (1980); significance levels were $p \leq 0.05$.

Covariation in taxa abundance across habitats sampled in 1985 were examined using a principal components analysis (PCA) as a method of describing spatial variability in assemblage structure. The analysis was done from a correlation matrix of pairwise comparisons at the nine stations (Pielou, 1984). Outlying samples containing large numbers of larvae (>200 fish from a sample) were winsorized (replaced by their neighboring values; Sokal and Rohlf, 1981) before yearly totals were recomputed for PCA. A second PCA incorporating ichthyoplankton data from stations 6, 8, 10, 12, and sites in Lower Steel Creek in 1984 was also done to

summarize temporal variation in the distribution and abundance of larval fish assemblages between years. Because several taxa collected in 1984 were not identified beyond the family level, samples from 1985 were pooled into the same taxonomic groups.

Water temperatures were measured using continuous recording thermographs (Ryan Model J, Ryan Instruments) at each station. Seasonal changes in water temperature among sampling stations were summarized using quadratic regressions (Sokal and Rohlf, 1981) of water temperature over time in order to account for changes in weather conditions or reactor operations. Use of this predicted trend, rather than actual values, should better reflect long-term environmental conditions experienced by both spawning adults and early life history stages.

Fluctuations in water levels in the SRSS were recorded by gauges located in the disturbed channel and disturbed shallow areas near the mouth of Steel Creek (M. C. Coulter and K. W. Dyer, Savannah River Ecology Laboratory, unpublished data). For this study, gauges were standardized based on water levels recorded during floods in 1984. Water quality records were also taken near Stations 6 and 8 and in the thermal plume at the mouth of Pen Branch, and in the Four Mile Creek swamp near its confluence with the Savannah River as part of an extensive monitoring program (Newman, 1986).

Results

Changes in water temperature and water quality

Although water temperatures were consistently higher for sites along the thermal plumes in the SRSS, seasonal changes were still pronounced and nearly coincident between thermal and nonthermal areas (Figure 2.2A; Table 2.2). Daily fluctuations occurred at all sites because of changes in air temperature and cloud

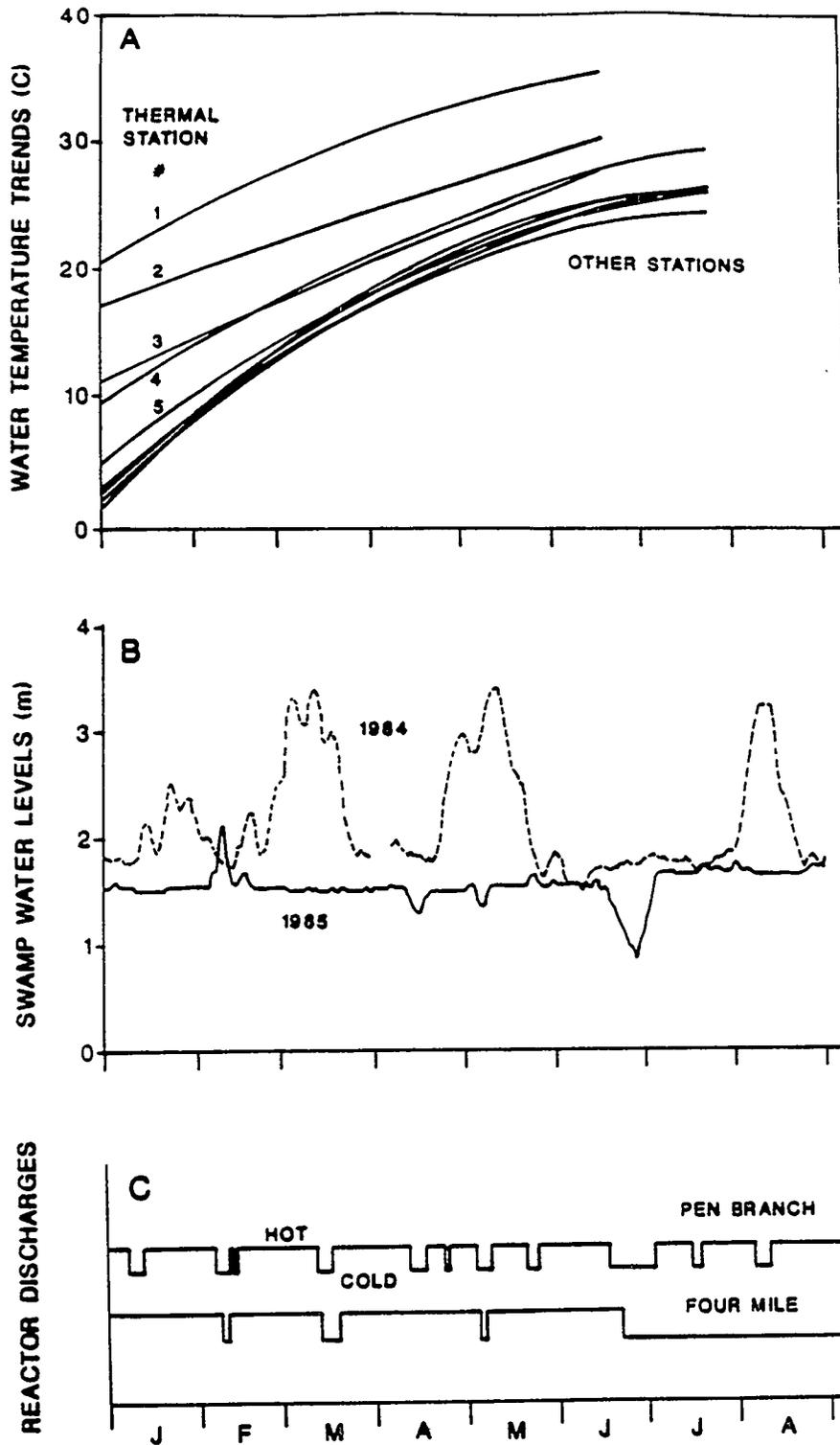


Figure 2.2. Temporal changes in physical conditions in the Savannah River Swamp System. A) Seasonal trends of water temperatures at the five thermal and four nonthermal sampling stations. B) Changes in swamp waters in 1984 and 1985 based on measurements taken in Steel Creek delta. C) Periods of hot (high flow) and cold (low flow) reactor discharges down the Pen Branch and Four Mile Creek tributaries in 1985.

Table 2.2. Seasonal changes in water temperature (°C) (± 1 SE) recorded at the nine sampling stations within the Savannah River Swamp System from January through July 1985.

Sample Period (week)	Sample Station									
	1	2	3	4	5	6	8/12*	10		
1	27.9 \pm 3.7	21.5 \pm 1.0	19.8 \pm 3.8	21.4 \pm 2.2	16.2 \pm 1.9	14.1 \pm 4.1	14.5 \pm 3.7	14.3 \pm 4.4		
2	24.4 \pm 0.9	19.1 \pm 0.9	14.2 \pm 0.7	16.5 \pm 1.8	11.4 \pm 2.1	8.1 \pm 1.4	7.3 \pm 0.8	7.9 \pm 2.9		
3	23.7 \pm 1.1	18.1 \pm 0.9	13.4 \pm 0.9	15.3 \pm 2.1	9.5 \pm 1.8	7.2 \pm 1.6	5.8 \pm 1.5	6.9 \pm 2.6		
4	21.5 \pm 2.2	15.7 \pm 2.3	10.9 \pm 2.2	14.4 \pm 1.9	8.1 \pm 1.7	4.5 \pm 2.3	5.0 \pm 1.3	4.2 \pm 2.5		
5	26.1 \pm 2.9	20.7 \pm 3.5	15.9 \pm 3.9	19.8 \pm 3.6	11.6 \pm 4.8	9.9 \pm 4.6	9.3 \pm 4.7	10.2 \pm 5.9		
6	26.5 \pm 3.8	18.8 \pm 7.7	14.7 \pm 5.6	17.4 \pm 4.8	9.6 \pm 2.8	8.4 \pm 2.1	9.2 \pm 2.9	8.3 \pm 2.2		
7	24.4 \pm 2.5	19.7 \pm 4.0	13.5 \pm 2.8	12.3 \pm 3.3	7.4 \pm 2.6	7.1 \pm 1.2	6.2 \pm 1.3	6.7 \pm 1.3		
8	30.3 \pm 2.9	24.9 \pm 2.7	19.9 \pm 2.8	20.4 \pm 2.5	14.2 \pm 1.8	11.3 \pm 2.4	11.7 \pm 2.3	11.6 \pm 2.9		
9	30.4 \pm 1.5	26.0 \pm 1.9	22.8 \pm 2.0	24.1 \pm 1.3	18.1 \pm 1.8	16.4 \pm 1.8	17.3 \pm 1.7	17.8 \pm 3.1		
10	29.7 \pm 1.8	25.1 \pm 1.9	20.8 \pm 1.8	23.3 \pm 1.7	16.9 \pm 2.2	16.5 \pm 2.7	15.9 \pm 1.7	17.4 \pm 3.6		
11	29.1 \pm 2.1	24.2 \pm 1.9	20.1 \pm 2.3	20.5 \pm 3.5	16.4 \pm 1.9	16.6 \pm 2.8	16.3 \pm 1.7	17.2 \pm 4.3		
12	27.5 \pm 1.7	20.3 \pm 1.8	15.4 \pm 2.6	23.8 \pm 2.7	18.2 \pm 1.7	13.6 \pm 2.7	12.4 \pm 1.3	14.5 \pm 4.3		
13	31.3 \pm 2.1	26.5 \pm 1.7	21.6 \pm 2.3	24.1 \pm 2.5	16.9 \pm 3.6	18.5 \pm 3.8	16.4 \pm 3.0	19.3 \pm 4.6		
14	31.1 \pm 1.8	26.5 \pm 1.6	21.8 \pm 1.9	23.1 \pm 2.3	18.3 \pm 2.3	18.3 \pm 2.9	17.8 \pm 2.2	19.6 \pm 3.9		
15	30.4 \pm 1.9	24.1 \pm 1.8	20.5 \pm 1.8	21.9 \pm 1.6	16.5 \pm 2.1	16.9 \pm 2.7	15.8 \pm 1.9	18.5 \pm 3.9		
16	32.8 \pm 1.6	26.6 \pm 1.0	23.3 \pm 1.1	21.9 \pm 3.5	18.7 \pm 1.6	20.7 \pm 2.6	18.5 \pm 1.2	21.9 \pm 4.6		
17	34.0 \pm 1.3	27.9 \pm 0.6	24.7 \pm 0.9	26.4 \pm 1.8	21.5 \pm 1.1	22.6 \pm 1.9	21.7 \pm 0.8	24.2 \pm 3.5		
18	32.8 \pm 1.5	27.2 \pm 1.2	24.3 \pm 1.3	26.0 \pm 2.0	21.3 \pm 1.5	21.2 \pm 1.8	20.6 \pm 1.3	22.6 \pm 2.9		
19	30.6 \pm 4.3	25.0 \pm 2.2	22.4 \pm 1.0	23.0 \pm 3.2	19.2 \pm 1.9	21.9 \pm 2.4	19.7 \pm 1.4	23.1 \pm 3.6		
20	34.0 \pm 1.9	29.0 \pm 1.6	25.9 \pm 1.4	28.4 \pm 1.6	23.6 \pm 1.9	23.3 \pm 1.6	22.6 \pm 1.2	24.1 \pm 2.9		
21	33.7 \pm 1.4	27.6 \pm 1.0	24.8 \pm 1.2	24.8 \pm 2.2	21.4 \pm 1.4	22.1 \pm 1.9	21.8 \pm 0.9	23.2 \pm 3.4		
22	34.2 \pm 1.5	28.3 \pm 1.3	25.5 \pm 1.4	28.3 \pm 1.5	22.7 \pm 1.8	22.2 \pm 1.8	21.6 \pm 1.6	24.7 \pm 3.4		
23	34.9 \pm 1.9	31.4 \pm 1.3	28.9 \pm 1.2	30.9 \pm 1.2	26.0 \pm 1.2	26.8 \pm 1.4	26.1 \pm 0.9	27.8 \pm 3.2		
24	30.8 \pm 2.1	29.8 \pm 1.7	26.9 \pm 1.8	29.5 \pm 1.6	24.2 \pm 2.1	23.7 \pm 2.1	23.8 \pm 1.9	25.4 \pm 2.9		
25	28.4 \pm 1.9	29.1 \pm 1.5	26.5 \pm 1.7	27.8 \pm 1.7	23.5 \pm 2.0	23.3 \pm 1.2	23.3 \pm 1.4	26.4 \pm 5.7		
26	26.3 \pm 0.9	26.5 \pm 0.9	25.8 \pm 0.9	28.1 \pm 1.5	23.9 \pm 1.0	24.9 \pm 2.5	24.1 \pm 1.3	25.3 \pm 5.6		
27	..**	-	-	28.9 \pm 1.3	24.1 \pm 1.1	23.7 \pm 0.5	23.3 \pm 0.5	25.3 \pm 5.6		
28	-	-	-	30.1 \pm 0.8	23.9 \pm 0.9	24.7 \pm 1.3	24.6 \pm 0.8	25.4 \pm 4.2		
29	-	-	-	28.7 \pm 1.8	24.9 \pm 0.8	25.5 \pm 1.2	24.9 \pm 0.6	25.9 \pm 3.1		
30	-	-	-	24.8 \pm 0.7	25.2 \pm 0.7	25.7 \pm 1.1	24.5 \pm 0.3	26.0 \pm 4.1		

* Temperature differences between stations 8 and 12 were only slight, so they are combined here for presentation.

** No further temperature records collected once reactor operations ceased.

cover, but along the thermal plumes, water temperatures also varied in response to changes in reactor operations. At Stations 1-3, water temperatures were observed to change at a rate approximating 1°C per hour. Temperature change associated with initiation and cessation of reactor operations were more gradual at Stations 4 and 5 because of their distance from where water first enters the SRSS and the mixing of cooler water originating from Four Mile Creek. Periodicity of reactor discharges released into Pen Branch and the SRSS were, however, more variable creating a highly fluctuating hydroperiod and thermal environment compared to Four Mile Creek (Figure 2.2 B, C; Table 2.2). Among the nonthermal sites, temperatures typically varied 3-5°C daily in Steel Creek delta with differentials of 7-8°C frequently recorded over a 24-h period. The most extreme fluctuations in water temperature occurred at Station 10, the shallow disturbed area with minimal canopy insolation. A maximum difference of 20°C was recorded over a two-week period in late January associated with a period of prolonged cold temperatures.

No substantial differences in water quality parameters, other than temperature, could be detected at sites in the mouth of Pen Branch, Four Mile Creek, the natural, forested and disturbed, open-canopied stations, as well as Lower Steel Creek which carries water from Steel Creek delta to the Savannah River (Newman, 1986). Dissolved oxygen levels differed between locations, but were usually >70% saturation. Ranges of selected parameter values recorded biweekly from January through August 1985 were: pH 5.7-9.2, DO 5-12 mg/l, turbidity 1.3-57.4 NTU, total suspended solids 0.25-36.7 mg/l, specific conductance 38.4-98.3 µmho/cm, and total alkalinity 7.7-26.4 mg/l as CaCO₃.

Ichthyoplankton distribution and composition

A total of 168 eggs (2 Catostomidae, 24 brook silverside Labidesthes sicculus, 142 unidentified) and 6,819 larval fishes were collected during this study; overall

mean total ichthyoplankton density across the SRSS was 417.4 ± 135.6 per 1000 m³ (Table 2.3). Grouping different stations into general regions (e.g., 1-3 belong to Four Mile Creek, 4-5 were Pen Branch, and the remainder, Steel Creek), all major taxa of ichthyoplankton were found throughout the SRSS. At stations 1-8 where equal sampling efforts were made in both channels and adjacent shallow, vegetated habitats, there was no qualitative difference in the composition of the ichthyoplankton assemblage. Of the 19 identifiable ichthyoplankton taxa collected over the 29 week sampling interval, only pirate perch (Aphredoderus sayanus), lined topminnow (Fundulus lineolatus) and the four rarest taxa (Ictaluridae, swampfish Chologaster cornuta, tessellated darter Etheostoma olmstedi, and gizzard shad Dorosoma cepedianum) were not recorded from the channel microhabitat. Microhabitat was, however, an important determinant of ichthyoplankton abundance (Table 2.4). Greater than 95% of the total density of ichthyoplankton were collected from shallow, vegetated habitats. Only at station 5 was the proportional abundance of larval stages in the deep, channel microhabitat higher; nonetheless, the density was still greatest in the shallow, weedy areas.

Total ichthyoplankton density varied seasonally at each station (ANOVA, time treatment, $F_{22,412} = 9.98$, $p < 0.001$) (Figure 2.3; Tables 2.5 and 2.6). Densities were low at the onset of sampling with larval stages only being recorded from stations 3 and 10 in the first week of collections. Occurrence and abundance of ichthyoplankton then generally increased in a series of recruitment pulses during spring before becoming less numerous over late June and July irrespective of location. While influenced mainly by recruitment patterns in the shallow, vegetated microhabitat because of the differential ichthyoplankton density, a similar pattern of seasonality was also observed in the channelized microhabitat. The interval of sampling, therefore, included the major period of fish reproduction in the SRSS.

Table 2.3. Mean number of ichthyoplankton (per 1000 m³ ± 95% confidence interval), mean total ichthyoplankton density, and percent composition (*) within each sampling area during January-July 1985. Fish were identified to the lowest possible taxonomic level.

Common Name	Family or Species	Sampling Stations												Mean Total (%)
		Disturbed						Post-thermal Recovery						
		1	2	3	4	5	6	10	8	12				
Gizzard shad	<u>Dorosoma cepedianum</u>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.1 (<0.1)*			
Pickrel	Esocidae	0.0	0.0	0.0	0.0	0.0	2.8	0.8	0.8	0.8	0.6 (0.1)			
Minnow	Cyprinidae	42.6	56.4	6.6	13.4	2.5	4.8	0.8	23.8	0.8	16.9 (4.0)			
Golden shiner	<u>Notemigonus crysoleucas</u>	0.5	0.5	0.5	0.4	0.0	1.2	612.4	0.8	0.8	68.6 (16.4)			
Ironcolor shiner	<u>Notropis chalybaeus</u>	2.8	3.8	2.8	1.7	0.4	9.3	0.0	158.6	0.0	19.9 (4.8)			
Lake chubsucker	<u>Erimyzon succetta</u>	8.5	0.9	2.8	0.0	0.0	9.3	0.8	4.0	0.8	3.0 (0.7)			
Catfish	Ictaluridae	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	<0.1 (<0.1)			
Swampfish	<u>Chologaster cornuta</u>	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0	<0.1 (<0.1)			
Pirate perch	<u>Aphredoderus sayanus</u>	0.0	0.0	1.9	0.4	1.7	1.6	6.5	4.4	0.0	1.8 (0.4)			
Lined topminnow	<u>Fundulus lineolatus</u>	0.9	1.4	0.0	0.0	0.0	1.2	1.6	0.4	0.0	0.6 (0.1)			
Brook silverside	<u>Labidesthes sicculus</u>	5.2	7.1	6.2	5.9	4.6	7.7	2.4	4.4	0.0	4.8 (1.2)			
Banded pygmy sunfish	<u>Elassoma zonatum</u>	0.5	0.5	9.9	2.1	1.7	33.5	63.7	12.9	4.8	14.4 (3.4)			
Bluespotted sunfish	<u>Enneacanthus gloriosus</u>	0.0	0.5	0.9	0.0	0.0	55.7	28.2	53.7	0.8	15.5 (3.7)			
Sunfish	<u>Lepomis</u> spp.	10.9	14.2	15.6	5.4	8.0	36.7	353.4	23.0	0.0	51.9 (12.4)			
Redbreast sunfish	<u>L. auritus</u>	0.0	0.0	0.5	1.3	0.8	2.4	1.6	0.4	0.0	0.8 (0.2)			
Spotted sunfish	<u>L. punctatus</u>	1.9	2.8	3.3	5.4	2.1	5.7	0.8	0.8	0.8	2.6 (0.6)			
Largemouth bass	<u>Micropetrus salmoides</u>	2.4	10.9	7.1	4.2	0.8	897.3	516.4	1.2	0.0	160.0 (38.3)			
Darter	Percidae**	5.2	1.9	9.9	13.8	85.9	142.4	130.7	8.1	0.0	44.2 (10.6)			
Tessellated darter	<u>Etheostoma olmstedti</u>	0.0	0.0	0.0	0.0	0.4	0.0	0.0	1.2	0.0	0.2 (<0.1)			
Unidentified eggs		0.9	9.9	2.8	4.6	5.0	8.1	13.7	3.2	36.3	9.4 (2.2)			
Unidentified larvae***		3.3	2.8	1.9	0.8	0.8	2.8	1.6	1.2	0.8	1.8 (0.4)			
Mean overall abundance		85.7 ± 61.3	113.7 ± 75.3	73.4 ± 28.3	59.5 ± 28.3	115.2 ± 42.2	1222.5 ± 1496.9	303.4 ± 196.1	1735.7 ± 1218.1	47.6 ± 30.9	417.4 ± 135.6			

* Mean number of individuals by taxon (percent composition of total ichthyoplankton assemblage).

** Only darters found

*** Includes specimens damaged so no specific identification could be made.

Table 2.4. Microhabitat differences in mean ichthyoplankton density (per 1000 m³ ± 1 SE) at nine sampling stations in the Savannah River Swamp System.

Microhabitat Type	Sample Station								
	1	2	3	4	5	6	8	10	12
Deep, channel	8.5 ± 4.0	6.6 ± 2.7	5.7 ± 2.6	4.2 ± 1.8	83.8 ± 26.2	45.9 ± 28.5	26.6 ± 15.1	--*	--*
Shallow, vegetated	162.9 ± 72.8	220.7 ± 89.2	141.1 ± 32.0	114.8 ± 32.9	146.6 ± 43.4	2398.9 ± 1867.6	580.2 ± 241.5	1735.7 ± 716.5	47.6 ± 18.2

* No samples taken; channelized microhabitat not present.

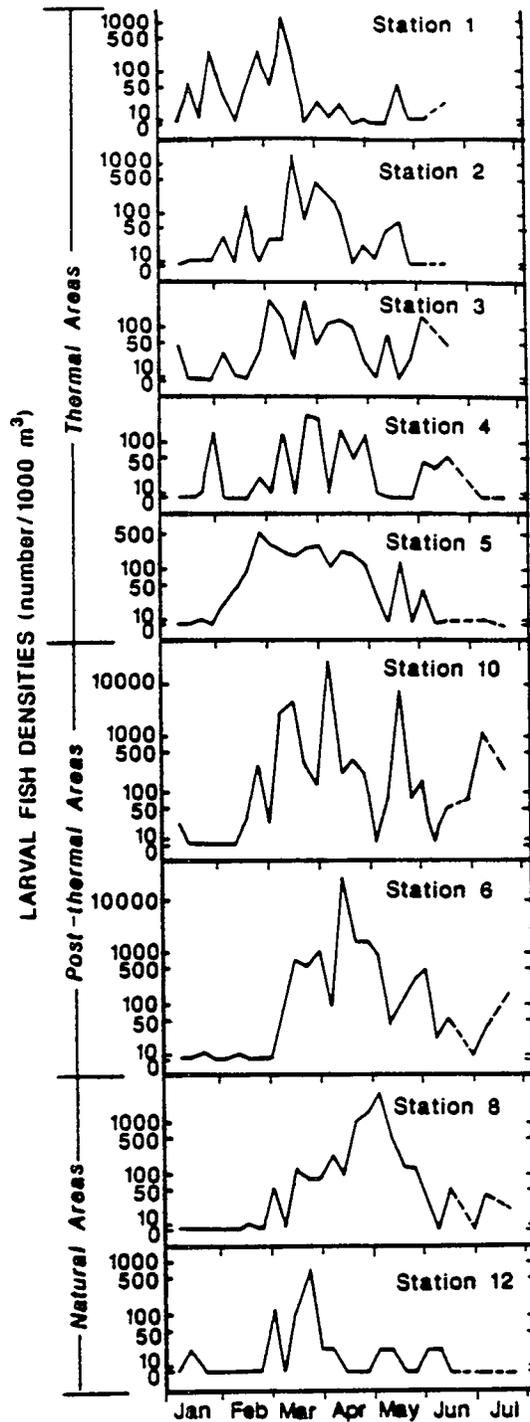


Figure 2.3. Seasonal changes in mean total ichthyoplankton density at each station during January to July 1985. Mean densities were computed from the total number of fish per sample and plotted on a log scale. Broken lines show intervals when weekly samples were not taken. Stations 1-5 were thermal areas, 6 and 10 were post-thermal recovery areas, and 8 and 12 were natural forested cypress/tupelo forest swamp areas.

Table 2.5. Mean total number of ichthyoplankton (per 1000 m³ ± 1 SE) collected at nine sites from the Savannah River Swamp System during weekly collections from January to July 1985. Sample period corresponds to the calendar week that samples were collected.

Sample Period (week)	Station											
	1	2	3	4	5	6	8	10	12			
2	0	0	43.6(43.6)*	0	0	0	0	21.8(21.8)	0	21.8(21.8)	0	0
3	54.5(35.5)	10.9(10.9)	0	0	0	0	0	0	0	0	0	0
4	10.9(10.9)	10.9(10.9)	0	10.9(10.9)	10.9(10.9)	10.9(10.9)	0	0	0	0	0	0
5	272.3(176.5)	10.9(10.9)	0	163.4(150.7)	0	0	0	0	0	0	0	0
6	32.7(22.3)	32.7(14.6)	32.7(32.7)	0	21.8(13.8)	0	0	0	0	0	0	0
7	0	0	10.9(10.9)	0	43.6(27.6)	10.9(10.9)	0	0	0	0	0	0
8	43.6(32.3)	130.7(105.4)	0	0	98.0(62.6)	0	10.9(10.9)	21.8(21.8)	0	21.8(21.8)	0	0
9	228.8(126.0)	10.9(10.9)	32.7(22.3)	21.8(21.8)	599.1(482.8)	0	0	130.7(130.7)	0	130.7(130.7)	0	0
10	43.6(32.3)	32.7(22.3)	348.6(236.1)	10.9(10.9)	315.9(123.3)	10.9(10.9)	54.5(34.5)	21.8(21.8)	152.5(78.6)	21.8(21.8)	0	0
11	1013.1(769.1)	32.7(32.7)	163.4(119.0)	152.5(96.5)	217.9(154.4)	98.0(85.6)	0	3006.6(1881.9)	0	3006.6(1881.9)	0	0
12	108.9(108.9)	1372.6(912.4)	21.8(13.8)	10.9(10.9)	185.2(117.4)	664.5(415.6)	130.7(105.4)	4400.9(2570.8)	174.3(43.6)	4400.9(2570.8)	174.3(43.6)	0
13	0	76.3(39.3)	337.7(197.8)	359.5(320.9)	261.4(150.9)	522.9(434.5)	87.1(62.4)	305.0(178.3)	806.1(152.5)	305.0(178.3)	806.1(152.5)	0
14	21.8(13.8)	424.8(234.3)	43.6(43.6)	283.2(151.6)	305.0(165.1)	980.4(436.2)	87.1(64.6)	108.9(57.6)	21.8(21.8)	108.9(57.6)	21.8(21.8)	0
15	10.9(10.9)	228.8(128.2)	119.8(76.3)	10.9(10.9)	119.8(107.3)	87.1(27.6)	239.7(173.5)	28496.9(10948.2)	21.8(21.8)	28496.9(10948.2)	21.8(21.8)	0
16	21.8(21.8)	98.0(55.3)	130.7(60.9)	185.2(119.8)	239.7(175.9)	1514.2(1488.1)	1056.7(432.0)	196.1(196.1)	0	196.1(196.1)	0	0
17	0	0	98.0(85.6)	54.5(35.5)	196.1(124.0)	1568.6(1315.9)	1632.1(1016.3)	392.2(199.7)	0	392.2(199.7)	0	0
18	10.9(10.9)	21.8(21.8)	21.8(21.8)	141.6(94.6)	130.7(92.4)	1568.6(1315.9)	1632.1(1016.3)	196.1(65.4)	0	196.1(65.4)	0	0
19	0	10.9(10.9)	0	10.9(10.9)	32.7(14.6)	740.7(531.9)	3779.9(2909.0)	65.4(37.7)	21.8(21.8)	65.4(37.7)	21.8(21.8)	0
20	0	43.6(21.7)	65.4(44.7)	0	0	43.6(43.6)	522.9(321.9)	7603.5(3792.4)	0	7603.5(3792.4)	0	0
21	54.5(34.5)	65.4(53.4)	0	0	152.5(90.4)	108.9(76.7)	152.5(87.1)	65.4(37.7)	0	65.4(37.7)	0	0
22	10.9(10.9)	0	21.8(21.8)	0	0	272.3(222.2)	141.6(86.7)	152.5(121.3)	21.8(21.8)	152.5(121.3)	21.8(21.8)	0
23	10.9(10.9)	0	152.5(88.9)	43.6(43.6)	43.6(13.8)	468.4(354.2)	98.0(36.8)	21.8(21.8)	0	21.8(21.8)	0	0
24	**	-	-	32.7(22.3)	0	21.8(21.8)	0	43.6(21.8)	0	43.6(21.8)	0	0
25	21.8(13.8)	0	43.6(21.8)	54.5(35.5)	10.9(10.9)	54.5(26.2)	54.5(42.7)	65.4(37.7)	0	65.4(37.7)	0	0
26	-	-	-	-	-	10.9(10.9)	0	1328.9(545.9)	0	1328.9(545.9)	0	0
27	-	-	-	0	10.9(10.9)	32.7(14.6)	43.6(32.3)	239.7(78.3)	0	239.7(78.3)	0	0
28	-	-	-	0	0	152.5(108.9)	21.8(21.8)	0	0	0	0	0
29	-	-	-	-	0	0	0	0	0	0	0	0
30	-	-	-	0	0	0	0	0	0	0	0	0

* Mean (1 SE)

** No samples collected.

Table 2.6. Results of analysis of variance for spatial and temporal differences in ichthyoplankton density for sites in the Savannah River Swamp System. To permit balanced ANOVA data on microhabitat were analyzed separately with emphasis on the shallow, vegetated habitat because of its greater abundance of ichthyoplankton.

	df	SS	MS	F	p
Shallow, vegetated microhabitat					
Site	8	50.67	6.34	9.60	<0.0001
Week	22	14.91	6.59	9.98	<0.0001
Site * Week	175	394.96	2.26	3.42	<0.0001
Error	<u>412</u>	<u>271.89</u>	0.66		
Total	617	862.45			
Deeper, channelized microhabitat					
Site	6	8.23	1.37	9.13	<0.0001
Week	22	9.96	0.45	3.00	<0.0001
Site * Week	132	31.51	0.24	1.60	0.0007
Error	<u>322</u>	<u>48.95</u>	0.15		
Total	482	98.65			

Seasonal changes in ichthyoplankton density, however, differed between the nine sampling stations (ANOVA, time*station interaction, $F_{175,412} = 3.42$, $p < 0.001$) (Figure 2.3; Tables 2.5 and 2.6). Occurrence and recruitment of substantial numbers of larval stages began earlier in the hottest stations (1-2), with an advancement in spawning time observed even at temperature differences of ca. 2°C above regional ambient values. Temporal shifts in the timing of peak ichthyoplankton density were also evident with about an eight-week difference separating the warmest site (Station 1) and a natural, forested site within Steel Creek delta (Station 8) (Figure 2.3; Table 2.5). Densities at the remaining thermal (2-5) and post-thermal recovery sites (6 and 10) peaked within this time interval; however, most recruitment occurred earlier in the warmer stations. Similar to patterns observed for the onset of recruitment in the nine sites, spawning activity declined and appeared to end earliest in the warmest areas. Ichthyoplankton were present over a longer period of time at the remaining sites, but at low levels, until sampling ceased.

Temporal variation in reproductive activity was also evident on a smaller spatial scale within areas of the Steel Creek delta (Stations 6, 8, 10, and 12). Timing of peak ichthyoplankton recruitment occurred two to four weeks earlier in the previously disturbed areas, where canopy trees had been killed, than in the natural, forested areas of the swamp (Table 2.5, Figure 2.3). Variability in timing of recruitment was not due to either faunal differences in the ichthyoplankton assemblage between sites within Steel Creek (Table 2.3) or to differences in seasonal phenology of the major taxa (Table 2.7). Regardless of site, chronology of recruitment was similar with darters initially dominating the larval fish assemblage followed by lake chubsucker (*Erimyzon sucetta*), pirate perch, and banded pygmy sunfish (*Elassoma zonatum*) at approximately the same time, and later by brook silversides, other centrarchids and cyprinids overlapping during spring to early

summer (April through July) (Table 2.7). Where larvae were collected early in the sampling interval (e.g., Station 10, 12), only specimens of pickerel, Esox spp., were recorded. As all individuals were either late metalarvae or recently transformed juvenile developmental stages in January, the spawning period for pickerel was thought to be early winter.

Comparing patterns in the mean date of appearance and mean water temperature of occurrence with reproductive phenology of the different taxa present in the thermal areas to patterns observed in Steel Creek delta, however, some important differences were apparent. Although each site except Station 1 experienced similar ranges of water temperature during periods of reproductive activity, the observed shifts in recruitment did not correspond to the occurrence of comparable water temperatures between sites. Instead, the temperature at which a taxon occurred differed between thermal, post-thermal recovery, and natural forested regions with larvae of each of the 12 common taxa (within all three regions and at least present in two weekly samples from a region) being found at significantly warmer temperatures in the thermal areas (Stations 1-5) than in either natural, forest swamp areas (Stations 8, 12) or previously disturbed habitats (Stations 6, 10) in Steel Creek (sign test, $p < 0.05$ both comparisons) (Table 2.8). For sites within Steel Creek delta, there was no demonstrable difference in mean water temperature between disturbed, open-canopied habitats and natural, cypress/tupelo forest habitats for when the different taxa were present (sign test, $p > 0.15$). The mean date of taxa occurrence was also not different between regions within Steel Creek possibly because of the longer reproductive period (sign test, $p > 0.10$), but there was a trend for each taxa to appear earlier in the disturbed habitats (Table 2.7, 2.8). This observation would also be consistent with observations of shifts in the timing of peak recruitment between stations in Steel Creek delta. Thus, in addition to larvae from the thermal areas being found

consistently earlier in the reproductive period (sign test, $p < 0.05$; Table 2.8), they were also found at warmer temperatures than the same taxa from nonthermal sites.

There were also important differences in reproductive phenology between thermal and ambient temperature areas. Most pronounced was an alteration in the seasonal succession of taxa recruitment into the larval fish assemblage (Table 2.7). The following species were collected concurrently at Stations 1 and 2 by the first week of February when total ichthyoplankton densities were beginning to rise: larval cyprinids of several unidentified taxa (but mostly Notropis spp.), golden shiner (Notemigonus crysoleucas), brook silversides, and sunfish. Other species, such as pirate perch and banded pygmy sunfish, were found later. The low density of larvae in the first week of sampling and progressive increase in total density over the next several weeks suggested that many of the typically spring- or summer-spawning species (e.g, cyprinids, centrarchids) began to reproduce in thermal areas by early January. While some fish species may possibly have been capable of spawning during fall and early winter in thermal areas, the taxa affected most by elevated temperature regimes represented a major component of the ichthyoplankton assemblage in the SRSS (Table 2.3). Thus, taxa of larval fishes that usually did not co-occur now overlapped temporally. Phenology of species succession was also altered at the remaining thermal sites, but the degree of species overlap and asynchrony was not as pronounced.

Total ichthyoplankton densities differed between sampling stations (ANOVA, location treatment: Total density, $F_{8,412} = 9.60$, $p < 0.001$, Tables 2.3 and 2.6). Because densities were higher in thermal areas early in the year, but greater in nonthermal areas later, it is hard to summarize overall density differences between stations. Some insight into density differences between areas is possible, however, by examining the mean density of ichthyoplankton collected in each area, although there is no statistical replication at that level (Table 2.3). Overall, mean

Table 2.7. Weekly changes in mean ichthyoplankton density (per 1000 m3) for each taxon at nine sampling sites within the Savannah River Swamp System. Collections were made from the second through thirtieth week of 1985 (January through July). When samples were not taken, they are indicated (-*) in the table.

Station 1: Heated		Mean Ichthyoplankton Abundance by Taxa												
Sample Period (week)	Percidae	Erimyzon succetta	Cyprinidae	Notropis chalybaeus	Notemigonus crysoleucas	Lepomis spp.	Lepomis punctatus	Elassoma zonatum	Micropterus salmoides	Labidesthes sicculus	Fundulus lineolatus	Unidentified eggs	Unidentified larvae	
2	0	0	0	0	0	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	54.5	0	0	0	0	0	0	0	
4	10.9	0	0	0	0	0	0	0	0	43.6	0	0	0	
5	54.5	130.7	21.8	0	0	21.8	0	0	10.9	10.9	0	0	0	
6	0	10.9	0	0	0	0	0	0	0	0	0	0	0	
7	0	0	0	0	0	0	0	0	0	0	0	0	0	
8	21.8	10.9	0	10.9	0	0	0	0	0	0	0	0	43.6	
9	10.9	32.7	21.8	54.5	0	43.6	0	0	10.9	10.9	0	0	10.9	
10	0	0	0	0	0	32.7	0	0	0	43.6	0	21.8	0	
11	21.8	10.9	849.7	0	0	65.4	0	0	21.8	0	0	0	0	
12	0	0	87.2	0	0	0	0	0	0	0	0	0	0	
13	0	0	0	0	10.9	0	0	10.9	0	0	0	0	0	
14	0	0	0	0	0	0	0	0	0	0	0	0	0	
15	0	0	0	0	0	0	0	0	10.9	0	0	0	0	
16	0	0	0	0	0	0	0	0	10.9	10.9	0	0	10.9	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	10.9	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	32.7	0	0	0	21.8	0	0	
22	0	0	0	0	0	0	10.9	0	0	0	0	0	10.9	
23	0	0	0	0	0	0	0	0	0	0	0	0	0	
24	0*	0	0	0	0	0	0	0	0	0	0	0	0	
25	0	0	0	0	0	21.8	0	0	0	0	0	0	0	

Table 2.7. Continued.

		Mean Ichthyoplankton Abundance by Taxa												
Sample Period (week)	Percidae	Cyprinidae	Notropis chalybaeus	Lepomis spp.	Lepomis auritus	Lepomis punctatus	Elassoma zonatum	Micropterus salmoides	Labidesthes sicculus	Aphredoderus sayanus	Choloqaster cornuta	Etheostoma olmstedi	Unidentified eggs	Unidentified larvae
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	10.9	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	21.8	0	0	0	0	0	0	0	0	0	0	0	21.8	0
7	21.8	0	0	0	0	0	0	0	0	0	0	0	10.9	0
8	87.2	0	0	0	0	0	0	0	0	0	0	0	0	0
9	577.1	0	10.9	0	0	0	0	0	0	0	0	0	10.9	0
10	305.0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	196.1	0	0	0	0	0	0	0	0	21.8	0	0	0	0
12	65.4	43.6	0	10.9	0	0	21.8	0	21.8	0	0	0	10.9	0
13	228.8	0	0	0	0	0	10.9	0	0	0	10.9	0	21.8	0
14	272.3	0	0	10.9	0	0	0	0	0	0	0	0	0	0
15	76.3	21.8	0	0	0	0	0	0	0	21.8	0	10.9	0	0
16	196.1	0	0	10.9	0	0	0	0	0	0	0	0	0	0
17	152.5	0	0	21.8	0	0	0	0	0	0	0	0	10.9	0
18	21.8	0	0	87.2	0	0	0	0	10.9	0	0	0	21.8	0
19	0	0	0	10.9	0	0	0	0	0	0	0	0	0	0
20	0	0	0	10.9	0	0	0	0	65.4	0	0	0	10.9	10.9
21	0	0	0	0	0	54.5	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	43.6	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	10.9	0	0	0	0	0	0	0	0	0
26	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	0	0	0	0	10.9	0	0	0	0	0	0	0	0	0
29	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2.7. Continued.

		Mean Ichthyoplankton Abundance by Taxa															
Sample Period (week)	Percidae	Erimyzon succella	Cyprinidae	Notropis shalybeyer	Notemigonus crysoleucas	Lepomis spp.	Lepomis auritus	Lepomis punctatus	Enneacanthus gloriozus	Elassoma zonatum	Micropterus salmoides	Labidesthes sicculus	Aphredoderus sayanus	Fundulus lineolatus	Esocidae	Unidentified eggs	Unidentified larvae
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.9	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.9	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.9
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	10.9	0	0	0	0	0	0	0	0	10.9	0	0	0	0	32.7	0	0
12	424.8	10.9	0	0	0	0	0	0	0	206.9	0	0	0	0	21.8	0	0
13	359.2	76.3	21.8	0	0	0	0	0	0	54.5	0	0	0	0	0	10.9	0
14	392.2	32.7	10.9	0	0	0	0	0	0	392.2	0	0	0	0	0	152.5	0
15	10.9	0	0	0	21.4	0	0	0	0	21.8	32.7	0	0	0	0	0	21.8
16	1361.7	32.7	0	0	0	0	0	0	0	65.4	24008.9	10.9	0	0	0	0	0
17	1241.8	0	0	0	0	130.7	0	0	0	43.6	0	10.9	0	0	0	0	0
18	10.9	54.5	0	87.2	0	10.9	0	0	0	76.3	0	130.7	0	0	0	21.8	0
19	32.7	43.6	0	54.5	0	76.3	0	0	0	32.7	10.9	10.9	0	0	0	0	0
20	0	0	0	21.8	10.9	0	0	0	0	0	0	0	0	21.8	0	0	0
21	0	0	0	10.9	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.9	0
23	0	0	0	0	0	0	0	0	0	0	174.3	21.8	0	0	0	0	32.7
24	0	0	0	76.3	0	0	0	0	0	0	0	0	0	0	0	0	10.9
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	10.9	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	21.8	0	0	0	0	0	0	0	0	0	10.9	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	10.9	0	0	21.8	65.4	10.9	21.8	0	0	0	0	10.9	0	10.9	0

Table 2.7. Continued

Station 10: Post-thermal, ambient		Mean Ichthyoplankton Taxa Abundance														
Sample Period (week)	Percidae	Erimyzon succetta	Cyprinidae	Notemigonus crysoleucas	Lepomis spp.	Lepomis auritus	Lepomis punctulatus	Enneacanthus gloriopis	Elaosoma zonatum	Micropterus salmoides	Labidesthes sicculus	Aphredoderus sayanus	Fundulus lineolatus	Esocidae	Unidentified eggs	Unidentified larvae
2	0	0	0	0	0	0	0	0	0	0	0	0	0	21.8	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	21.8	0	0	0	0	0	0	0	0	0	0	0	0	0	130.7	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	21.8	0	0	0	0	0	0	0	21.8	0	0	0	0	0	0	0
11	392.2	21.8	0	2592.6	0	0	0	1111.1	0	21.8	0	0	0	0	0	0
12	2766.9	0	0	479.3	0	0	0	130.7	0	0	0	21.8	0	0	108.9	0
13	43.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	108.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	174.3	0	0	13464.2	21.8	0	0	544.7	305.0	13834.5	0	152.5	0	0	0	0
16	0	0	0	0	0	0	0	0	130.7	0	65.4	0	0	0	0	0
17	0	0	0	0	305.0	0	0	0	21.8	65.4	0	0	0	0	0	0
18	0	0	0	0	108.9	21.8	43.6	0	0	21.8	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	43.6	0	0	0	0	0	0	0	21.8	0	0	0
21	0	0	21.8	0	7451.0	0	0	0	0	0	0	0	0	0	108.9	21.8
22	0	0	0	0	43.6	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	21.8	0	108.9	0	0	0	0	0	0	0	21.8	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	43.6	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	65.4	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	1328.9	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	108.9	21.8	65.4	0	0	0	0	0	21.8	0	0	0

Table 2.8. Mean time of occurrence and mean water temperature for when larval stages of 12 common fish taxa were collected between thermal stations (1-5), natural areas (8, 12), and post-thermal recovery areas (6, 10). Comparisons are made to detect differences between areas in the timing and temperature for the appearance of ichthyoplankton. Julian date and predicted seasonal warming curves were used to compute time and temperature relationships for the different taxa in the nine areas of the Savannah River Swamp System.

	<u>Mean Julian Day / Mean Temperature (°C)</u>		
	<u>Thermal areas (1-5)</u>	<u>Natural areas (8,12)</u>	<u>Canopy removed (6,10)</u>
Cyprinidae	88/23.0	136/21.6	131/21.4
Golden shiner	80/23.3	89/16.9	96/18.5
Ironcolor shiner	91/23.3	135/21.6	135/22.1
Lake chubsucker	61/24.3	111/19.4	99/18.4
Pirate perch	78/18.3	102/18.3	85/17.4
Brook silverside	96/23.7	135/21.7	127/21.5
Banded pygmy sunfish	72/19.3	93/17.3	97/18.6
Bluespotted sunfish	147/27.8	150/22.8	147/23.0
<u>Lepomis spp.</u>	101/23.9	152/22.7	151/23.5
Spotted sunfish	155/28.6	152/23.1	172/24.5
Largemouth bass	88/23.8	119/20.1	113/20.5
Percidae	68/18.8	90/16.7	90/17.6

ichthyoplankton density was consistently low at all five thermal sites compared to sites within Steel Creek, except Station 12. Within the thermal regions, there was no relationship between abundance and a site's rank order of mean water temperature (Spearman Rank Correlation, $r = -0.20$, $n = 5$, $p > 0.50$). For Steel Creek sites, abundance of larval stages varied spatially with previously disturbed regions having the greatest density of ichthyoplankton. Larval densities were comparable between both previously disturbed sites. The discrepancy between Station 12 and the other sites was apparently not related to its suitability as a spawning site as eggs were present and ichthyoplankton densities had begun to increase during March. Instead, the reduction in ichthyoplankton densities after this initial increase were most likely associated with the reduction in water levels during April (Figure 2.2B) that exposed areas of silt/mud substrate and submergent vegetation. Low water levels also reduced habitat availability in the disturbed shallow areas (Station 10), but spawning continued, and larvae were probably concentrated, due to the presence of isolated pools.

Except for lake chubsucker and blue-spotted sunfish (*Enneacanthus gloriosus*), larvae of the common taxa were present across all three geographic sampling regions (Four Mile Creek, Pen Branch, Steel Creek), but their contribution to assemblage composition differed (Table 2.3). Between-site variation in composition was recognizable using principal components analysis (Table 2.9A, Figure 2.4). The first three axes of this analysis explained 83% of the overall variance contained in the distribution of taxa among sites. The first axis, responsible for the greatest amount of variance, emphasized the similarity among thermal sites and differences between the Steel Creek sites. The separation of sites represented a disturbance gradient based on the abundance of sunfish, pirate perch, pygmy sunfish, brook silversides, and cyprinids. The second and third axes described differences between natural and disturbed portions of the Steel Creek portion of the SRSS. Axis 2

Table 2.9. Loadings of major fish taxa on three components produced by a principal components analysis of overall ichthyoplankton densities per sampling station.

A) 1984 collections.

	PCI	PCII	PCIII
Cyprinidae	-0.27	-0.11	0.29
Golden shiner	0.39	-0.16	-0.31
Ironcolor shiner	0.16	0.00	0.63
Catostomidae	0.01	0.36	0.22
Pirate perch	0.42	-0.02	0.30
Brook silverside	-0.31	-0.38	0.11
Banded pygmy sunfish	0.40	0.27	-0.13
Bluespotted sunfish	0.26	0.33	0.37
<u>Lepomis</u> spp.	0.45	0.08	-0.17
Spotted sunfish	-0.22	0.38	-0.19
Largemouth bass	0.06	0.43	-0.16
Percidae	0.08	0.41	-0.15
Eigenvalue	4.13	3.77	2.12
% Variance Explained	34	31	18

B) 1984 and 1985 collections.

	PCI	PCII	PCIII
Clupeidae	0.22	-0.30	-0.10
Cyprinidae	-0.09	0.16	0.75
Catostomidae	0.46	0.04	0.01
Pirate perch	0.52	0.16	0.10
Brook silverside	-0.20	0.44	-0.40
<u>Lepomis</u> spp.	-0.02	0.48	0.41
Largemouth bass	-0.22	0.49	-0.21
<u>Pomoxis</u> spp.	0.51	0.10	-0.05
Percidae	0.32	0.43	-0.19
Eigenvalue	3.22	2.55	1.45
% Variance Explained	36	28	16

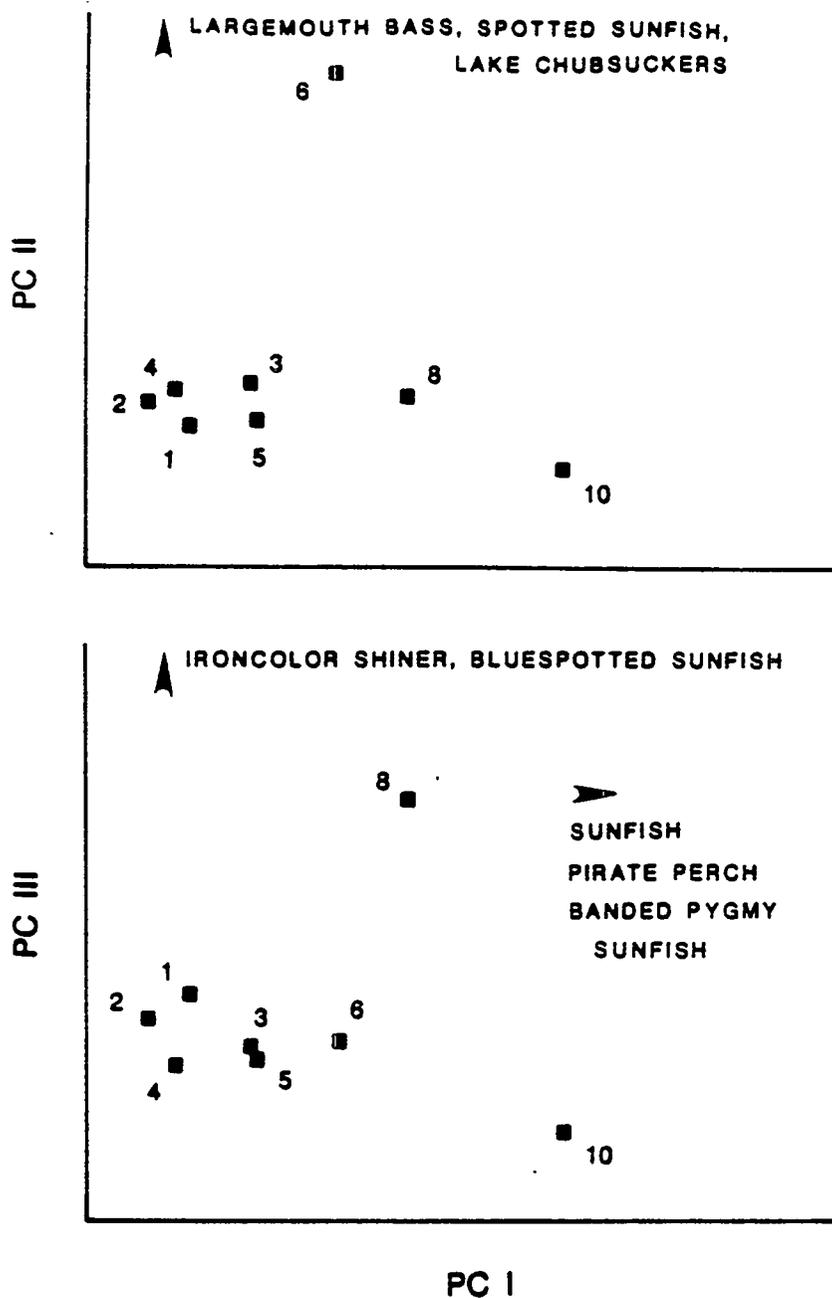


Figure 2.4. Variation in the composition of ichthyoplankton assemblages between sampling stations in 1985, as summarized by the first three principal components. Direction of the arrows are in the direction of high positive scores on the different axes. The nonthermal areas have higher scores on the first axis which result from relatively high numbers of *Lepomis*, pirate perch and banded pygmy sunfish. Station 6, along a channel in the disturbed area, has a high score on the second axis reflecting relatively high numbers of largemouth bass, spotted sunfish, and lake chubsuckers. The high score of the natural channel (Station 8) on the third component reflects greater numbers of ironcolor shiners and bluespotted sunfish.

reflected the relatively high numbers of largemouth bass (Micropterus salmoides), spotted sunfish (Lepomis punctatus), and lake chubsuckers in the disturbed portion of the swamp. The high score for the natural, forested region of the swamp (Station 8) on the third component resulted from greater numbers of ironcolor shiner (Notropis chalybaeus) and bluespotted sunfish.

Where comparable data were available in Steel Creek, ichthyoplankton densities differed between 1984 and 1985 (Table 2.10). Except for Station 12, mean ichthyoplankton densities were greatest in 1985 when water levels were low throughout the SRSS (Figure 2.2C). A similar PCA incorporating collections made in 1984 and 1985 provided a descriptive method of examining compositional variability between years (Tables 2.9B and 2.10; Figure 2.5). The first axis, accounting for 36% of the variance, distinguished between thermally altered, post-thermal recovery, and unimpacted sites within the swamp. The separation of collections made in 1984 and 1985 also emphasized the possible importance of water level on recruitment dynamics. The first axis loaded high for pirate perch, black crappie, and lake chubsucker reflecting their greater abundance during 1984 when water levels were high and several flooding cycles occurred (Table 2.10; Figure 2.2B). The second axis also differentiated between years with high positive loadings for largemouth bass and several taxa of sunfish that paralleled increased densities, and negative loadings for clupeids which were only rarely present, in 1985 (Table 2.10). Although little separation was exhibited for collections during 1984, the third axis also showed between-site differences based on cyprinid and brook silverside abundance patterns.

Discussion

The influences of thermal discharges on fish growth, distribution, movements, and genetics have been documented to varying degrees (e.g., Janssen and Giesy

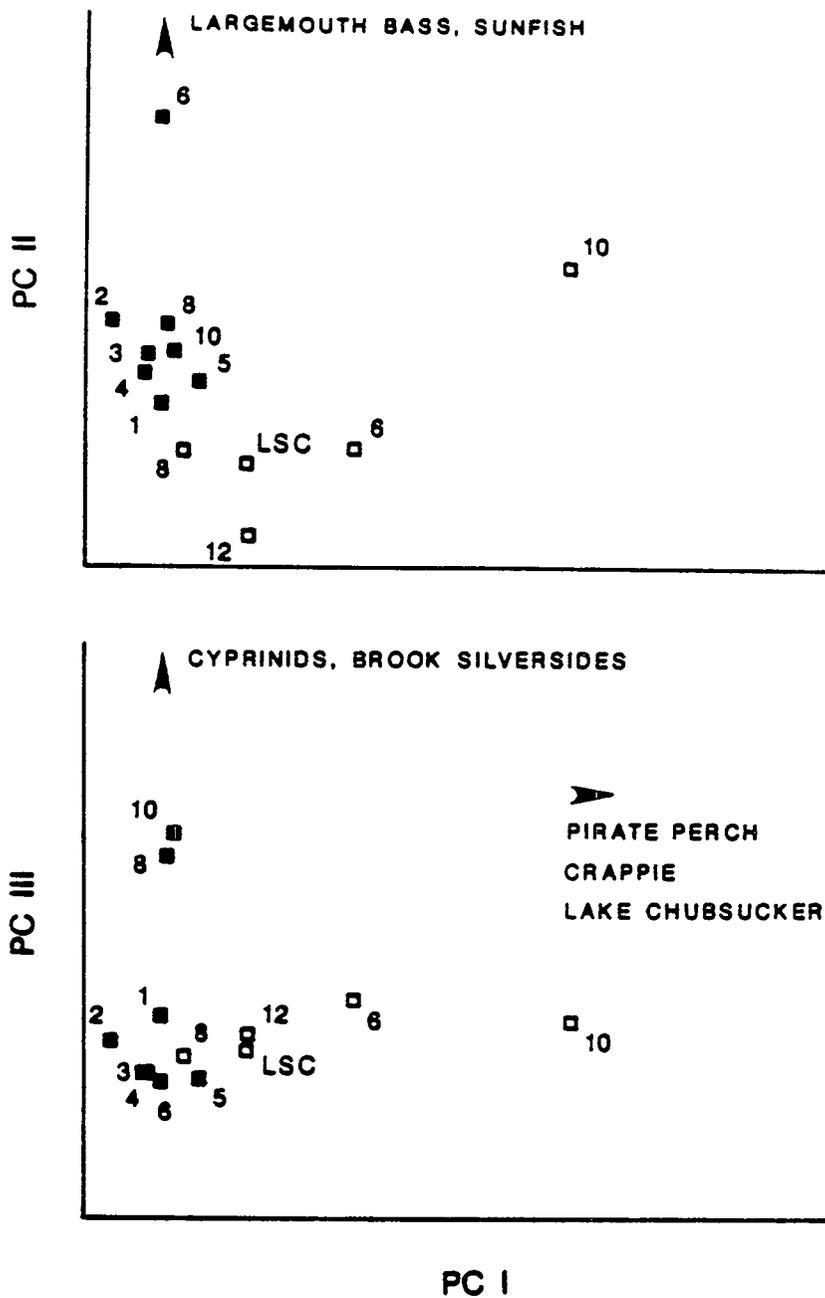


Figure 2.5. Variation in ichthyoplankton assemblage composition between years summarized by Principal Components Analysis. Direction of the arrows are indicative of positive loadings on the different axes. Assemblages in the wet year (1984) have high scores on the first axis reflecting greater numbers of pirate perch, crappie, and lake chubsuckers. The assemblages taken in 1985, especially at Station 6 (along a disturbed channel), tend to have high scores on the second axis reflecting greater abundance of largemouth bass and Lepomis. The dry year assemblages at Stations 10 (disturbed shallows) and 8 (natural channel) separate on the third axis because they had more cyprinids and fewer brook silversides than other areas. Open squares are 1984 samples; darkened squares are 1985 samples.

Table 2.10. Comparison of mean total ichthyoplankton densities for major taxa grouping across the Savannah River Swamp System for collections made in 1984 and 1985. Station designations are as presented in text. LSC represents sites within the Lower Steel Creek channel that carries water from the swamp to the Savannah River.

Taxa Group	Station												LSC				
	1	2	3	4	5	6	8	10	12	1984	1985	1984		1985	1984	1985	
Clupeidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	6.1	6.1	0.0	0.0	18.4	0.0	2.4
Cyprinidae	45.9	60.7	9.9	15.5	2.9	14.7	15.3	2.4	183.2	89.1	89.1	613.2	13.4	1.6	10.1	0.0	0.0
Catostomidae	8.5	0.9	2.8	0.0	0.0	196.6	9.3	7.3	4.0	157.5	4.0	157.5	0.8	0.8	10.9	0.8	275.9
Pirate perch	0.0	0.0	1.9	0.4	1.7	30.5	1.6	2.4	4.4	80.6	4.4	80.6	6.5	2.4	2.4	0.0	1.8
Brook silverside	5.2	7.1	6.2	5.9	4.6	0.0	7.7	10.9	4.4	4.9	4.9	4.9	2.4	2.4	1.2	0.0	4.9
<u>Lepomis/Elassoma/</u> <u>Enneacanthus spp.</u>	13.3	18.0	30.2	14.2	12.6	21.9	134.0	3.7	90.8	157.5	157.5	447.7	37.8	6.4	6.1	0.0	6.1
Largemouth bass	2.4	10.9	7.1	4.2	0.8	0.0	897.3	0.0	1.2	3.7	3.7	516.4	0.0	0.0	0.0	0.0	0.0
Crappie	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Percidae	5.2	1.9	9.1	13.8	86.3	43.9	142.4	12.2	9.3	473.7	473.7	130.7	9.8	0.0	12.5	0.0	12.5
Mean site abundance	85.7	113.7	73.4	59.5	115.2	330.8	1222.5	46.4	303.4	983.9	983.9	1735.7	103.8	47.6	337.2	0.0	337.2

1984). However, comparatively little is known about the influences of altered temperature regimes on reproductive cycles or the success of early developmental stages. Because industrial discharges are commonly limited to low level increases in water temperature, the influence that a wide range of temperature variation has on fish population and community dynamics has not been examined in great detail. The 2 to 19°C change in water temperature occurring along thermal plumes in the SRSS provides a unique situation to examine the influences of environmental perturbations on reproductive activity and the composition of larval fish assemblages.

Evolutionary theory suggests the proximate mechanisms governing reproductive cycles and mating behavior evolved so that reproduction is precisely synchronized with particular environmental conditions (Crews and Moore, 1986). Reproductive cycles of fish in southeastern swamp systems have evolved where seasonal changes in temperature and water levels are predictable, but short-term fluctuations in either temperature or individual floods are not. As environmental cues and physiological constraints that govern reproduction vary among fish species, reproductive responses to thermal loading must be examined empirically (Lam, 1983). The results of this study demonstrate several responses that occurred in many of the common taxa along the thermal plumes.

Patterns in chronology of appearance indicated that the common taxa from the thermal areas were found earlier in the year, and were present at consistently warmer temperatures, than the same taxa from nonthermal habitats. If reproduction were regulated by a simple thermal threshold phenomenon, appearance of a specific taxon would have been expected earlier in the thermal areas, and later in the season for nonthermal areas as they attain the same thermal threshold. Similarly, if reproduction were regulated by a photoperiod threshold, larvae of a specific taxa should be found at the same time, though at elevated

temperatures in thermal areas. However, neither pattern was observed in more than one species. Thus, it is probable that temperature and some other factor(s) (e.g., photoperiod, food supply, or availability of suitable spawning substrates) jointly influence reproduction of most fish species in this swamp system.

Hubbs (1985) summarized information on reproductive seasonality of several species of darters and concluded that photoperiod and temperature acted as interactive factors. Photoperiod often governed initiation of spawning while warm temperatures during the year appeared to limit duration of the spawning season. The regulation of mating behavior by both photoperiod and temperature could be adaptive for fishes that spawn during spring by reducing sensitivity to rapidly fluctuating environmental conditions. A governing response to increasing photoperiods could prevent spawning during brief warm periods when temperatures fluctuate early in the year. A response to seasonal temperature trends would advance the spawning season in consistently warm years and delay, or suppress it in cold years. The control of reproductive cycles by multiple cues is common in fish (Lam, 1983) and other vertebrates (Crews and Moore, 1986).

While important, the reproductive patterns observed across the SRSS suggest proximate mechanisms controlling reproduction may be more complex. This is evident from areas within Steel Creek where the overstory canopy has been removed. Within these habitats, early life history stages of most taxa have been found several weeks earlier than adjacent regions possessing a complete overstory canopy; water temperatures are similar in both habitats. This pattern has been observed over two years of collections (Aho et al., 1986; see Chapter I) and occurs among sites with different habitat characteristics less than 300-500 m apart. Thus, evidence indicates many of the species of fish are responding to very small scale differences in environmental factors. Differences occur between disturbed and natural swamp habitats in macroinvertebrate abundance (Kondratieff and

Kondratieff, 1984) and macrophyte composition and cover (Smith et al., 1981; Dunn and Sharitz, 1987). Alteration of food resources or spawning substrate availability could, therefore, act as important proximate factors influencing recruitment periodicity. Both factors may also be important determinants of higher ichthyoplankton densities in the previously disturbed regions compared to natural swamp habitats in Steel Creek delta. Differences in light regime between habitat types may indirectly influence recruitment dynamics by affecting plant growth dynamics. Regardless, changes in the physical structure of the environment have the potential to alter reproductive cycles of resident fishes.

Modification of species phenology patterns, particularly at Stations 1 and 2 where changes were most pronounced, also suggests reproductive control processes fail under extreme environmental conditions. Species may fail to reproduce without the proper combination of environmental cues. Alternately, fish may reproduce when there is a mismatch between reproductive cues and other environmental variables, thereby exposing early developmental stages to potentially stressful conditions. Although most taxa were widespread in distribution, the similar species composition of larval assemblages from the thermal areas, but low densities, suggests problems either in reproductive success, growth, or survivorship. Match/mismatch hypotheses have been shown to be of major importance in determining environmental performance in fish population and community dynamics (e.g., Frank and Leggett, 1982).

The influence of fluctuating environmental conditions on assemblage characteristics can be illustrated by variation between wet and dry years and between shallow and channel habitats. The 1984 assemblages were dominated by lake chubsuckers but also contained clupeids and crappie; there were proportionately few sunfish present. The channel areas had relatively more lake chubsuckers and fewer sunfish than structured (shallower) areas. Comparisons

between wet and dry years and between channel and shallow habitats, therefore, indicate a shift in species composition toward increased representation by suckers, and fewer centrarchids, during extended periods of high waters. Sudden fluctuations produced by reactor operations had additional influences on larval populations. Densities fell at sites at the hot end of the thermal plume when thermal discharges suddenly ceased. In addition, larval densities were low at Station 4 where warm and cool water masses mixed and temperatures fluctuated irregularly.

In late 1985, associated with the restart of production operations on a nuclear production reactor, L-Reactor, thermal effluents will again be discharged into Steel Creek delta. Fluctuations in thermal and hydrological regime accompanying the moderate thermal discharges ($<32^{\circ}\text{C}$) into this portion of the SRSS may be expected to perturb larval fish assemblages in similar ways to other sites along the thermal plumes. Lake chubsuckers, unlike sunfish, prefer the greater depth which accompanies increased discharge as found in channels and during wet years. In addition, it is probable that elevated water temperatures will advance the spawning season and expose eggs and larvae to warmer than regional ambient temperatures.

Conclusions

Larval fish were sampled across a thermal gradient in the SRSS. Temperatures ranged from 2 - 19°C above ambient temperatures characteristic of the region. The objective of this study was to characterize the effect of thermal alteration on reproductive cycles and the early life histories of fishes in the Savannah River Swamp System. Two questions were addressed: (1) Does density, species composition, and timing of reproduction vary between areas of different thermal characteristics?,

and (2) Do patterns of species seasonal succession vary across environmental temperature gradients? Conclusions of the study are summarized below.

- A total of 6,987 fish larvae and eggs representing 21 taxa was collected in the SRSS. With two exceptions, all major taxa were present at each of three major sampling regions in the SRSS regardless of thermal characteristics. Most of the larval fish (>95%) were collected from shallow, vegetated rather than channelized habitats.
- Total larval fish density varied seasonally. Eggs and larval fish densities increased in a series of pulses during January through May and declined during June and July.
- Recruitment of larval stages was earliest in the heated sites. Even differences approximating 2°C above ambient regional temperatures advanced spawning. Timing of peak larval fish densities differed by about eight weeks between the warmest site and a site in the natural cypress/tupelo forest in Steel Creek.
- Overall, mean density of larval fish was lower at all thermal sites compared to the cooler sites, except one. Among the five thermal sites, there was no relationship between larval fish abundance and a sites's rank order of temperature.
- Taxa of larval fishes that normally occurred separately, overlapped temporally at heated sites suggesting reproductive control processes fail under extreme environmental conditions.
- Larval stages of most taxa from the thermal areas were found earlier and at warmer temperatures than the same taxa found in nonthermal areas. This potentially may affect recruitment success by having early developmental stages present when environmental conditions (e.g., food availability) are not best suited to the performance, growth or survivorship of the species.

Literature Cited

- Anderson, C. S., J. M. Aho, K. B. Floyd, and M. R. Meador. 1986. Seasonal changes of larval fish populations in natural and altered habitats of a riverine swamp system. In: Comprehensive Cooling Water Study Final Report, Patterns of Fish Assemblage Structure and Dynamics in Waters of the Savannah River Plant. Savannah River Ecology Laboratory, Division of Stress and Wildlife Ecology.
- Auer, N. A. (editor). 1982. Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage. Great Lakes Fishery Commission. Ann Arbor: Michigan Special Publication 82-3.
- Block, C. J., J. R. Spotila, E. A. Standora, and J. W. Gibbons. 1984. Behavioral thermoregulation of largemouth bass, Micropterus salmoides, and bluegill, Lepomis macrochirus, in a nuclear reactor cooling reservoir. *Environmental Biology of Fishes* 11:41-52.
- Brandt, S. B., J. J. Magnuson, and L. B. Crowder. 1980. Thermal habitat partitioning by fishes in Lake Michigan. *Canadian Journal of Fisheries and Aquatic Sciences* 37:1559-1564.
- Coutant, C. C. and D. L. DeAngelis. 1983. Comparative temperature dependent growth rates of largemouth and smallmouth bass fry. *Transactions of the American Fisheries Society* 112:416-423.
- Coutant, C. C. and S. S. Talmage. 1976. Thermal effects. *Journal of the Water Pollution Control Federation* 48:1486-1544.
- Crews, D., and M. C. Moore. 1986. Evolution of mechanisms controlling mating behavior. *Science* 231:121-125.
- Downing, J. A. 1979. Aggregation, transformation, and the design of benthos sampling programs. *Journal of the Fisheries Research Board of Canada* 36:1454-1463.
- Dunn, C. P. and R. R. Sharitz. 1987. Revegetation of a Taxodium-Nyssa forested wetland following complete vegetation destruction. *Vegetatio* 72:151-157.
- Hogue, J. J., Jr., R. Wallus, and L. K. Kay. 1976. Preliminary guide to the identification of larval fishes in the Tennessee River. Tennessee Valley Authority, Technical Note B19, Norris, Tennessee, USA.
- Esch, G. W. and R. W. McFarlane (editors). 1976. Thermal Ecology II. ERDA Symposium Series (CONF-750425). National Technical Information Center: Springfield, VA.
- Frank, K. T. and W. C. Leggett. 1982. Environmental regulation of growth rate, efficiency, and swimming performance in larval capelin (Mallotus villosus) and its application to the match/mismatch hypothesis. *Canadian Journal of Fisheries and Aquatic Sciences* 39:691-699.

- Gibbons, J. W. and R. R. Sharitz (editors). 1974. Thermal Ecology. AEC Symposium Series (CONF-730505). National Technical Information Center: Springfield, VA. 670 pp.
- Hubbs, C. 1985. Darter reproductive seasons. *Copeia* 1985:56-68.
- Hutchinson, V. 1976. Factors influencing thermal tolerances of individuals organisms. In: *Thermal Ecology II* (G.W. Esch and R.W. McFarlane, editors), pp. 10-26. ERDA Symposium Series (CONF-750425). National Technical Information Service: Springfield, VA.
- Janssen, J., and J. P. Giesy. 1984. A thermal effluent as a sporadic cornucopia: effects on fish and zooplankton. *Environmental Biology of Fishes* 11:191-203.
- Kellogg, R. L. and J. J. Gift. 1983. Relationship between optimum temperatures for growth and preferred temperatures for the young of four selected fish species. *Transactions of the American Fisheries Society* 112:424-430.
- Kondratieff, P. and B. C. Kondratieff. 1985. A lower food chain community study: thermal effects and post-thermal recovery in streams and swamps of the Savannah River Plant. Report ECS-SR-19, DPST-85-376. Environmental and Chemical Sciences, Inc., Aiken, SC.
- Lam, T. J. 1983. Environmental influences on gonadal activity in fish. In: *Fish Physiology* (W. S. Hoar, D. J. Randall, and E. M. Donaldson, editors), pp. 65-116. Volume 9B. Academic Press, New York, USA.
- McCauley, R. W. and N. W. Huggins. 1979. Ontogenetic and nonthermal seasonal effects on thermal preferenda of fish. *American Zoologist* 19:267-271.
- McCort, W. D. 1987. Effects of thermal effluents from nuclear reactors. In: *Environmental consequences of energy production: Problems and prospects* (S. K. Majumdar, F. J. Brenner, and E. W. Miller, editors), pp. 386-401. Pennsylvania Academy of Science.
- McErlean, A. J., G. O'Connor, J. A. Mihursky, and C. I. Gibson. 1973. Abundance, diversity, and seasonal patterns of estuarine fish populations. *Estuarine and Coastal Marine Science* 1:19-36.
- McFarlane, R. W. 1976. Fish diversity in adjacent ambient, thermal, and post-thermal freshwater streams. In: *Thermal Ecology II* (G. W. Esch and R. W. McFarlane, editors), pp. 268-271. ERDA Symposium Series (CONF-750425). National Technical Information Service: Springfield, VA.
- McNeeley, D. L. and W. D. Pearson. 1974. Distribution and condition of fishes in a small reservoir receiving heated waters. *Transactions of the American Fisheries Society* 103:518-530.
- Magnuson, J. J., L. B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. *American Zoologist* 19:331-343.
- Neill, W. H. and J. J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant

- at Lake Monona, Wisconsin. *Transactions of the American Fisheries Society* 103:663-710.
- Newman, M. C. 1986. *Water Quality. Comprehensive Cooling Water Report, Volume 2: Water Quality.* Savannah River Ecology Laboratory: Aiken, SC. 600 pp.
- Parker, E. D., M. F. Hirshfield, and J. W. Gibbons. 1973. Ecological comparisons of thermally affected aquatic communities. *Journal of the Water Pollution and Control Federation* 45:726-733.
- Pielou, E. C. 1984. *The interpretation of ecological data.* Wiley and Sons, New York, New York, USA.
- Repaske, W. A. 1981. *Effects of heated water effluents on the swamp forest at the Savannah River Plant, South Carolina.* M.S. thesis. University of Georgia: Athens, GA. 81 pp.
- Reynolds, W. W. 1977. Temperature as a proximate factor in orientation behavior. *Journal of the Fisheries Research Board of Canada* 34:734-739.
- Rice, J. A., J. E. Breck, S. M. Bartell, and J. F. Kitchell. 1983. Evaluating the constraints of temperature, activity, and consumption on growth of largemouth bass. *Environmental Biology of Fishes* 9:263-275.
- Roosenburg, W. M., J. R. Spotila, J. M. Aho, T. A. Tuel, E. A. Standora, and H. W. Avery. 1988. Population response to stress: population structure and movement of largemouth bass in a nuclear reactor cooling reservoir. In: *Freshwater Wetlands and Wildlife: Perspectives in natural, man-made, and degraded ecosystems* (R. R. Sharitz and J. W. Gibbons, editors). In press.
- SAS. 1985. *SAS Users Guide, Statistics. Version 5.* Statistical Analysis Institute: Cary, NC.
- Sharitz, R. R., J. E. Irwin, and E. J. Christy. 1974. Vegetation of swamps receiving reactor effluents. *Oikos* 25:7-13.
- Sharitz, R. R., K. W. Dyer, N. C. Martin, C. E. Mitchell, and R. L. Schneider. 1986. Effects of SRP cooling water discharges on regeneration of floodplain forests. In: *Comprehensive Cooling Water Report. Wetlands Volume 1*, pp. 1-94. Savannah River Ecology Laboratory, Aiken, SC. 369 pp.
- Smith, M. H., R. R. Sharitz, and J. B. Gladden. 1981. An evaluation of the Steel Creek ecosystem in relation to the proposed restart of L-Reactor. *Savannah River Ecology Laboratory Report, SREL-9.* Savannah River Ecology Laboratory, Aiken, SC.
- Snedecor, G. W., and W. G. Cochran. 1980. *Statistical Methods.* Seventh edition. Iowa State University Press, Ames, Iowa, USA.
- Sokal, R. R. and F. J. Rohlf. 1981. *Biometry.* Second Edition. W. H. Freeman and Company, San Francisco, USA.

- Spigarelli, S. A., R. M. Goldstein, W. Prepejchal, and M. M. Thommes. 1982. Fish abundance and distribution near three heated effluents to Lake Michigan. *Canadian Journal of Fisheries and Aquatic Sciences* 39:305-315.
- Stauffer, J. R. Jr., K. L. Dickson, J. Cairns, Jr., and D. S. Cherry. 1976. The potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. *Wildlife Monographs* 50:1-50.
- Thorp, J. H. and J. W. Gibbons (editors). 1978. Energy and Environmental Stress in Aquatic Systems. DOE Symposium Series (CONF-771114). National Technical Information Center: Springfield, VA. 854 pp.
- Wang, J. C. S., and R. J. Kernehan. 1979. Fishes of the Delaware estuaries: a guide to early life histories. *Ecological Analysts Communications*, Towson, Maryland, USA.
- Wrenn, W. B. 1984. Smallmouth bass reproduction in elevated temperature regimes at the species' native southern limit. *Transactions of the American Fisheries Society* 113:295-303.

**III. Spatial and Temporal Patterns in Fish Assemblages Within the
Savannah River Swamp System**

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Introduction

Throughout the southeastern United States, river-swamp or floodplain forests are conspicuous components of many aquatic systems. They are recognized as unique systems characterized by their acidic, tanin-stained water and highly variable hydrologic regime and plant community structure (e.g., Day, 1982; Wharton et al., 1982). Despite the importance of swamps as natural filters of stream water (Ewel and Odum, 1978) and as refugia for many relict species (Wharton et al., 1982), little information is available on the natural functioning of these ecosystems and the structure of the component assemblages. Prior investigations have principally focused on organic matter processing dynamics and the structure and function of plant assemblages in nonriverine (e.g., Connor and Day, 1976; Schlesinger, 1978; Brown, 1981; Day, 1982) and riverine swamp wetlands (Brinson et al., 1980; 1981; 1983; Mulholland, 1981). Studies on the utilization of these wetland habitats by fish have emphasized their importance as nursery, foraging, and overwintering sites for many species of resident and migratory fishes (Forbes, 1925; Starrett, 1951; Bennett, 1958; Guillory, 1979; Ross and Baker, 1983; Finger and Stewart, In press). Few studies, however, have examined patterns in the distribution and abundance of these fishes and identified potential factors structuring these assemblages.

Factors influencing fish assemblage structure in swamp habitats

The distinctive characteristics of these wetlands suggest many factors could influence assemblage dynamics. These include the environmental variability, availability of suitable habitat, physiological stresses, and biotic interactions. In many river-swamp habitats, attributes of the fish assemblage are frequently related to temporal instability of the water regime of the area. Recent studies within the Everglades have demonstrated shifts in species composition with water level

constancy (Kushlan, 1976; Carlson and Duever, 1976). Several species of small omnivorous fish dominate the fish assemblage when seasonal drawdowns in water level occur; avian predation is important during this time. During extended periods of high water levels, however, fish predation becomes more important resulting in a shift in species and size composition of the assemblage toward large predatory fishes. Temporal variability in water regime also influences secondary production of three species of fish in the Okefenokee Swamp (Freeman and Freeman, 1985) and population abundance of fishes utilizing southeastern floodplain habitats (Ross and Baker, 1983; Finger and Stewart, 1987) by changing nutrient and habitat availability. Thus, water level fluctuation may be a form of environmental perturbation producing a cascade of responses among trophic levels, influencing species responses and assemblage structure.

Other attributes of the physical environment may affect patterns of distribution and abundance in swamp fishes. Since river-swamps represent a mosaic of habitat types, local changes in environmental conditions could produce spatial differences in fish assemblage structure. Variable habitat characteristics and levels of structural complexity could modify food availability (Benke et al., 1984; Thorp et al., 1985) and limit the abundance of refugia used by the different life history stages (Emery, 1978). The accumulation of detrital and refractory materials over much of the bottom effectively reduces the availability of sand or gravel substrates common in coastal plain stream systems. The predominance of detritus/mud substrates may alter the composition of the macroinvertebrates at a site, and further modify food resources utilized by fishes. The lack of a sand or gravel bottom may also limit fish species requiring a firm substrate for successful reproduction (Balon, 1975). Wetland degradation could also influence fish faunal properties, but its impact will likely be related to the severity, timing, and frequency of the disturbance events as well as the size of the area affected (Sousa, 1984). Although generalizations on the

influence of chemical factors (e.g., low pH values and dissolved oxygen concentrations) on patterns of fish distribution and abundance are difficult to predict, they have been shown to be important physiological stressors in a number of aquatic systems (e.g., Frey, 1951; Gee et al., 1978; Weiner and Geisy, 1979; Laerm et al., 1980; Rahel and Magnuson, 1983; Schindler et al., 1985). The influence of biotic interactions, however, remains largely unknown.

As a basic step in understanding population and community dynamics, we used a comparative approach to characterize and identify environmental factors (physical and biotic) important to fish assemblage structure in the Savannah River Swamp System. Such an approach has been invaluable in other studies and can be used to generate and test hypotheses, to assess mechanisms, and to produce explanations for community level problems under a variety of conditions (e.g., Diamond, 1978; Werner et al., 1978). We addressed the following questions: (1) Are there discrete types of fish assemblages within the Savannah River Swamp System?, (2) If so, what are the relations between fish assemblage structure, habitat structure, and physical disturbance?, and (3) Is assemblage structure temporally persistent and stable in the face of seasonally changing environmental conditions? Our long-term goal is to identify patterns in fish assemblage structure as a first step in investigating the organizational processes of floodplain swamps and their biotic communities. This information is also needed to effectively predict effects of, or manage for, artificial perturbations such as increased flow rates or water temperature associated with the operation of several nuclear production reactors have on fish community organization in these systems.

Study Area

Located along the Savannah River near Aiken, S.C., is a 3200 ha river-swamp, the Savannah River Swamp System (SRSS), which forms the southwestern border of

the U.S. Department of Energy's Savannah River Plant (SRP) (Figure 3.1). A second growth forest of bald cypress (Taxodium distichum) and water tupelo (Nyssa aquatica) cover approximately 50% of the floodplain forest. Fragmentary mesic bottomland forests, dominated by oaks (Quercus spp.), red maple (Acer rubrum), sweetgum (Liquidambar styraciflua), and hackberry (Celtis laevigata), occupy 40% of the river-swamp and are confined to old river levees and isolated islands of well-drained soil. The remaining 10% consists of scrub-shrub, herbaceous marshes, and open water (Sharitz et al., 1974).

Beginning in the 1950s, water from the Savannah River has provided a source of coolant for several nuclear production reactors on the SRP. Heated effluents from three reactors have periodically been discharged into three streams draining into the SRSS (Pen Branch, Four Mile Creek, and Steel Creek). Because of reactor production activities, discharge rates have increased from $<2 \text{ m}^3/\text{s}$ to ca. $11.3 \text{ m}^3/\text{s}$ and has altered the hydrology of this wetland by virtually eliminating natural seasonal drawdown. Water levels currently can fluctuate between 10 cm and 1.5 m above the sediment surface in a period of hours depending on reactor operations (Repaske, 1981). The seasonal timing, magnitude, and frequency of flood events has also been disrupted by the presence of a series of flood control dams located upstream of the SRP on the Savannah River (Sharitz et al., 1986). Depending on timing, duration, frequency of occurrence, and extent of habitat affected, natural and artificial variability in water level potentially represent an important disturbance regime to the plant and animal components of the SRSS. The fact that the swamp remains wet throughout the year, however, provides a valuable contrast to many other swamp systems.

Water temperatures where the streams enter the SRSS frequently exceed 40°C and establish longitudinal thermal gradients. The combination of increased water level, temperature, and substrate instability has resulted in the loss of both canopy

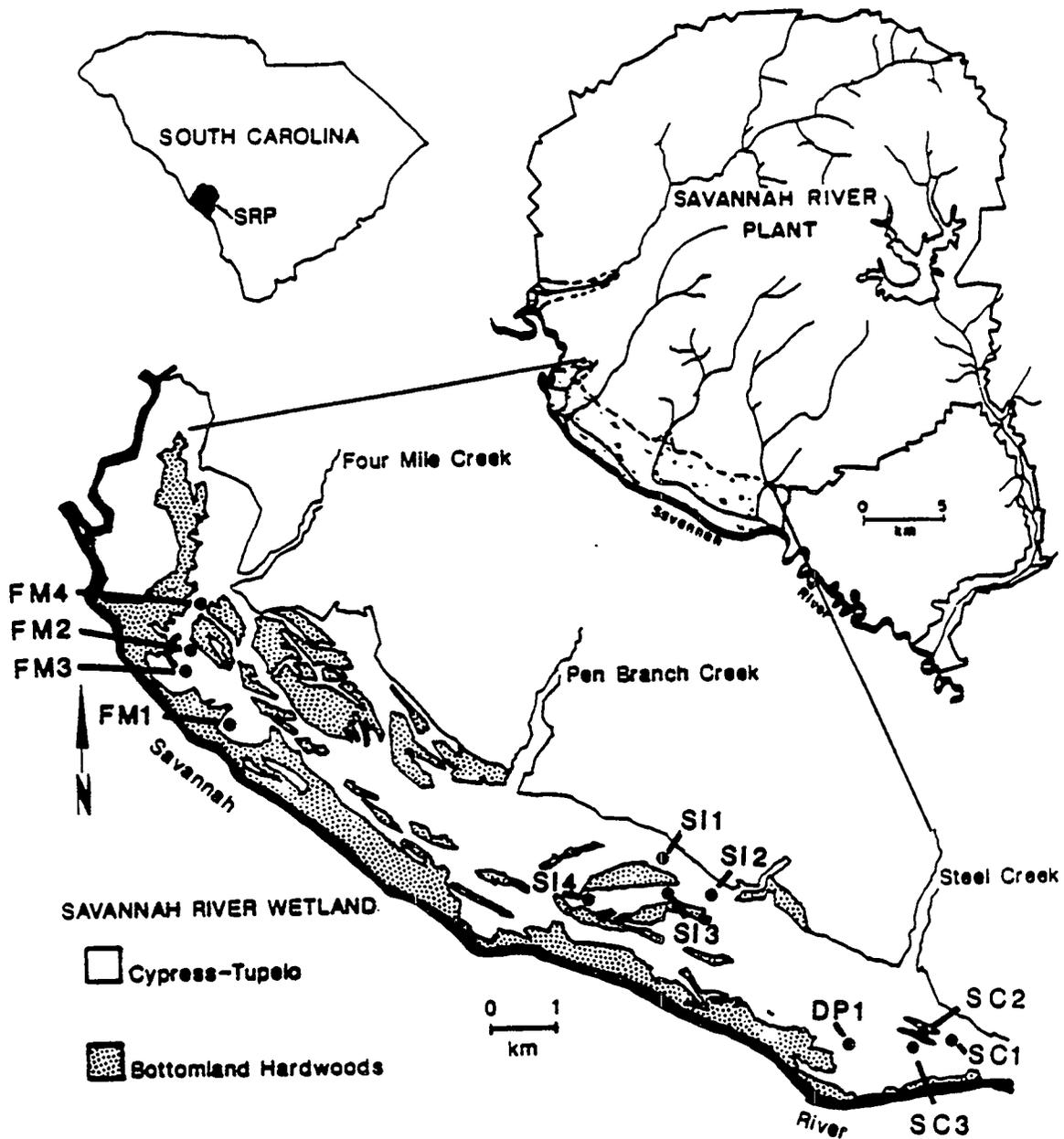


Figure 3.1. Map of the Savannah River Swamp System (SRSS) showing the location of the twelve sampling sites from the Four Mile Creek (FMC), Stave Island (SI), Steel Creek (SC), and Deep Swamp (DP) regions.

and understory vegetation in the vicinity of each stream mouth (Sharitz et al., 1974). Unlike Pen Branch and Four Mile Creek, which carried heated effluents to the SRSS for the duration of this study, the immediate vicinity of Steel Creek has been undergoing post-thermal recovery since 1968. In contrast to other disturbed regions within the SRSS, vegetation in the post-thermal recovery areas of Steel Creek is now dominated by extensive herbaceous macrophyte growth with only limited regeneration of woody vegetation or tree regrowth (Smith et al., 1981; Dunn and Sharitz, 1987). This region, however, will again be disturbed by high flows and water temperatures after October 1985 following the restart of L-Reactor that originally released discharges into Steel Creek.

Methods

Fish and environmental sampling

Twelve sites, representing four major areas of the river-swamp, were selected for study (Figure 3.1). Four sites were from the Four Mile Creek (FM) region, four in the vicinity of Stave Island near Pen Branch (SI), and three within the Steel Creek (SC) region. A single site was selected from an undisturbed region of cypress-tupelo forest (Deep Swamp-DP) located approximately 2 km from the Steel Creek region. Sites chosen were representative of habitat types present in the SRSS as determined from aerial imagery (Christiansen et al., 1984) and summarize variation in habitat structure, potential sources of energy, and environmental perturbation (Table 3.1). Seven sites had some extent of thermal addition, three sites were at regionally ambient water temperatures, and two sites were undergoing post-thermal recovery.

Fish populations were sampled using electrofishing techniques (DC pulsed) to quantify the relative abundance of all species at the twelve sites. Sampling intensity was greatest in the Steel Creek region with collections beginning in March and June

Table 3.1 Limnological and habitat characteristics for the twelve study sites in the Savannah River Swamp System. Water quality parameters are from Newman (1986). Remaining data were collected during the present study.

Site	Temperature Condition	Mean Maximum Temperature (°C)	Maximum Depth (m)	Mean Current Velocity (cm/s)	pH	Dissolved Oxygen (mg/l)	Conductivity (µs/cm at 20°C)	Predominant Substrate Type	Percent Canopy Cover	Percent Vegetative Cover	Dominant Riparian Vegetation
SC1	Ambien/ Post Thermal	24.1	1.5	37	6.5	6.7	71.5	M**	5	20	Macrophyte
SC2	Ambien/ Post Thermal	26.3	1.2	24	6.5	6.7	68.5	M	0	80	Macrophyte
SC3	Ambient	24.2	2.2	22	6.5	6.7	73.1	M/S	75	5	Cypress/ Tupelo Forest
DP1	Ambient	24.0	1.6	11	6.6	7.1	73.4	M	10	70	Macrophyte
SI1	Ambient	23.8	1.0	5	6.4	6.8	71.9	M	50	20	Cypress/ Tupelo Forest
SI2	Slightly Heated	26.9	1.5	18	6.4	6.7	69.5	M	60	10	Cypress/ Tupelo Forest
SI3	Slightly Heated	28.5	1.1	16	6.3	6.7	70.8	M	80	5	Cypress/ Tupelo Forest
SI4	Slightly Heated	31.5	1.5	18	6.5	6.7	71.5	M	30	30	Cypress/ Tupelo Forest
FM1	Heated	42.3	2.1	55	6.8	7.0	79.5	M	70	0	Tupelo Forest
FM2	Heated	44.9	1.4	36	6.7	6.8	78.4	M	0	0	Disturbed *
FM3	Heated	43.6	1.6	23	6.7	6.9	75.4	M	0	0	Disturbed *
FM4	Heated	45.4	0.5	47	6.6	6.4	76.3	M	0	0	Disturbed *

* No instream macrophytes or overhanging vegetation.

** M = Mud, S = Sand.

1983 and then monthly from August 1983 through July 1985. Collections from the other three regions began in March (Four Mile Creek) or April (Stave Island and Deep Swamp) 1984 and continued through November 1984; adherence to a monthly sampling interval was not always possible because low water levels (natural or associated with cessation in reactor operations) periodically prevented access to certain sites. The level of sampling effort differed slightly between regions. At the Four Mile Creek, Stave Island, and Deep Swamp sites, four 50-m transects per site were repeatedly sampled on each collection date. At Steel Creek, six 50 m sections were selected from a thermally undisturbed area of cypress-tupelo forest (SC3) and a post-thermal recovery site (SC2). Only three 50 m sections were sampled from the second post-thermal recovery site in Steel Creek (SC1). While the number of transects reflected our ability to sample, and the amount of available habitat at specific sites, the differential effort was not thought to introduce a substantial bias in the comparison of fish assemblage structure. Examination of cumulative species richness (the number of new species added on each successive 50 m transect) for sites sampled by four and six transects indicated essentially no difference in catch rates (Figure 3.2), and that >75% and 85% of the species at a site were collected in three and four transects, respectively. Based on patterns of species richness at the different sites (see Table 3.3 for details on species composition) and the observed catch curves for sites with six transects, it is expected that only an additional 1-3 species would have been added to the overall faunal composition at the remaining sites. Because of the high positive correlation between species richness and abundance of fish on a transect both overall and for most locations (Table 3.2), comparisons of fish abundance between sites were also not affected substantially by differences in the number of transects per site. Most of the 'core' group of species were present in the first two transects, so any new

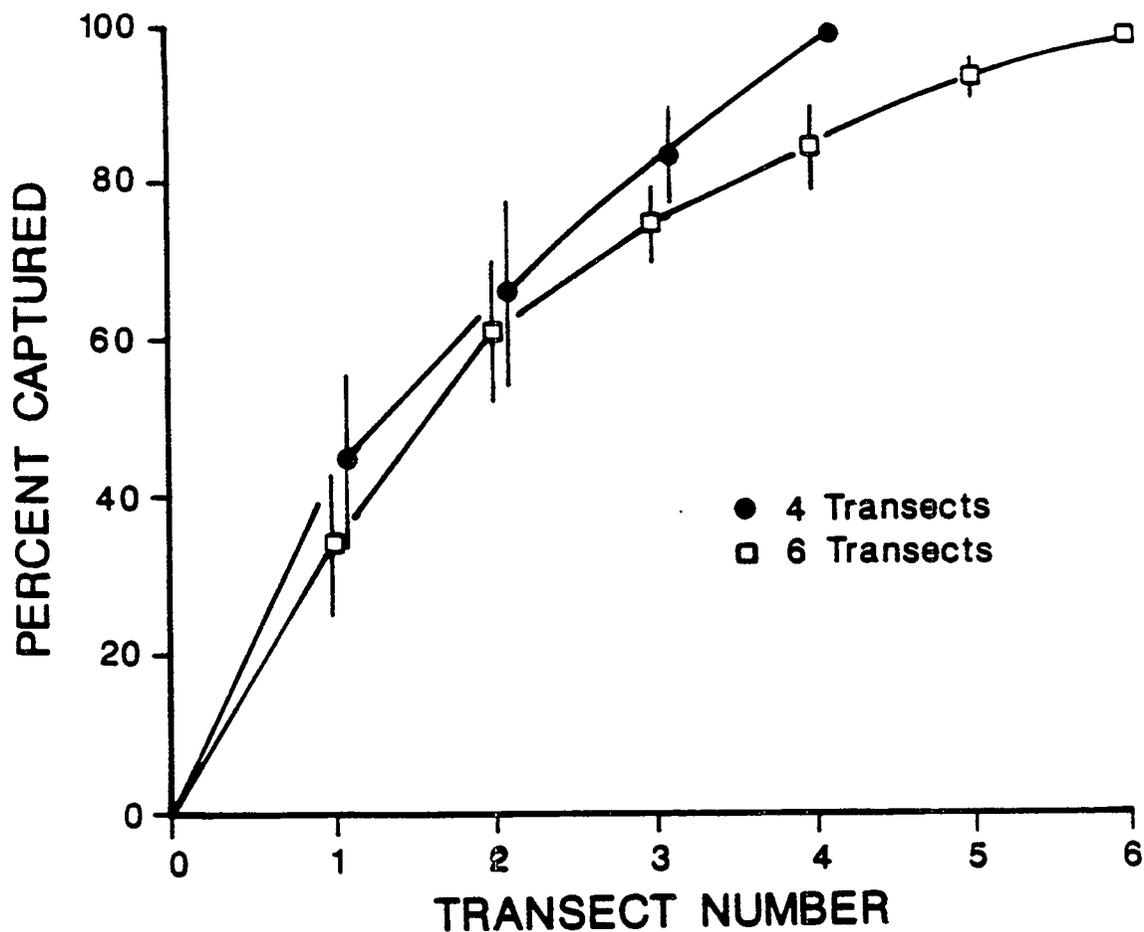


Figure 3.2. Cumulative catch curves comparing total numbers of fish species captured at a site in the Savannah River Swamp System where samples were collected using either four or six 50 m transects. Curves depict the accrual of new species on each additional 50 m transect. Data used in construction of the curve were from spring to fall 1984 collections. Symbols indicate mean percentage of the total number of species collected on each transect for each sampling period; vertical bars represent the 95% CI.

Table 3.2. Summary of relationships of species richness to fish abundance per 50 m transect using Pearson product-moment correlation and Spearman rank correlation for all sites combined and by specific site within the Savannah River Swamp System. Data used in the calculations was from spring, summer, and fall 1984.

	<u>Pearson Correlation</u>	<u>Spearman Rank</u>
All locations together, n = 374	0.70***	0.95 ***
By sampling site		
SC1	0.84 ***	0.88 ***
SC2	0.72 ***	0.83 ***
SC3	0.74 ***	0.87 ***
DP	0.43, ns	0.43, ns
SI1	0.38, ns	0.53 *
SI2	0.57 *	0.72 **
SI3	0.51 *	0.85 ***
SI4	0.52 *	0.87 ***
FM1	0.92 ***	0.97 ***
FM2	0.84 ***	0.98 ***
FM3	0.91 ***	0.99 ***
FM4	0.85 ***	0.98 ***

ns No significant relationship
 * P < 0.05
 ** p < 0.01
 *** p < 0.001

additions would represent rare or infrequently captured species that were also represented by only a few individuals.

Fishes were identified to species, counted, total length measured, and then released at the point of capture; only specimens of questionable identification were returned to the laboratory for verifications. Identification followed keys of Menhinick (1975), Pflieger (1975), and Bennett and McFarlane (1983).

During fish collections, a series of environmental parameters were measured that might be related to the number of individuals and types present at a site. Habitat characteristics included water temperature, current velocity, depth and substrate composition. These were measured from a minimum of three transects per site located perpendicular to the electrofishing transect; 5-10 individual measurements were made off each transect. Variability in the number of measurements was dependent on habitat conditions (e.g., size of the region, degree of habitat complexity). Substrate composition was visually inspected for proportion of hard material (e.g., sand, gravel, large rocks). In most instances, however, soft organic muck was the predominant substrate type and this variable was not considered further in the analysis. Percent areal canopy closure and abundance of aquatic vegetation were also recorded at each site. Vegetation abundance was determined by line intercept methods; canopy closure was visually assessed at each site. Field and laboratory determination of water chemistry parameters for the sites, or adjacent regions, were done as part of a large-scale project on the influence of reactor operations on water quality (Newman, 1986). Conductivity, dissolved oxygen, and pH were measured biweekly using a Hydrolab 6-D water quality analyzer (Hydrolab Corporation). Fluctuations in water levels within the Steel Creek delta region were recorded by gauges located at SC2 and an additional site in the post-thermal recovery area (M. Coulter and K. Dyer, Savannah

River Ecology Laboratory, unpublished data). Continuous data records were available from November 1983 through September 1985.

Data analysis

Multivariate techniques of classification and discriminant analysis were used to detect spatial patterns in the fish assemblages within the SRSS and to relate these patterns to environmental factors. Classification methods (average linkage clustering) were used to group sites according to their similarity in species abundances (normal classification). As continuous monthly collections were not possible at all sites across the SRSS, collections made during 1984 at each site were pooled by season (spring = March-May, summer = June-August, and fall = September-November). Relative abundances (mean number of individuals per 50 m transect) of species were then converted to standardized data ($\bar{x} = 0$; $s = 1.0$) to minimize domination by abundant species. If geographically distinct assemblages remained stable over several seasons, collections would form groupings by sampling site or region. If assemblages responded to common environmental features, distinct groups would form but might include samples from several different sites. If the composition of the fish fauna were independent of site or regional features, then there would be no tendency for interpretable groups to form. Hypotheses generated by the normal classification analyses were examined using discriminant analysis. Inverse classification methods (Clifford and Stephenson, 1975) were also performed using average linkage clustering to group species according to their site of occurrence (i.e., the sites become attributes of the species). Dendrograms for site and species similarity were constructed and cross-tabulated in a two-way coincidence table. Cluster and discriminant analysis were done using programs in the Statistical Analysis System (SAS, 1985).

Temporal variability in assemblage structure for the three Steel Creek sites was examined using data collected from ten seasons (March 1983 through July 1985). Species richness and abundance per collection provided a general indication of assemblage stability, but may remain constant even though a change in assemblage identity may occur. As an alternative method to examine the continued presence or absence of a species at a site, a measure of persistence based on an index of species turnover was generated (Diamond and May, 1977; Jarvinen, 1979), $T = (C + E)/(S_1 + S_2)$ where C and E are the number of taxa that appeared or disappeared between sampling periods, and S1 and S2 are the number of species in each sample. Persistence (PR) was then calculated from $1 - \bar{T}$ where \bar{T} equals the mean turnover rate for all adjacent samples within the sampling interval. Persistence values range from 0 (no persistence) to 1.0 (complete persistence).

Stability of species relative abundance rankings in Steel Creek was tested by their concordance over the entire study period using Kendall's coefficient of concordance (W) corrected for ties (Seigel, 1956). This procedure tests the null hypothesis that abundance rankings change randomly through time; rejection of this hypothesis indicates rankings have some degree of consistency over time. Rather than use the entire fish assemblage at a site, only those species accounting for at least 1% of the collection within any season at a site were included in the analysis. This omits rare or infrequently captured species whose capture might not accurately reflect their abundance, or presence or absence, at a locality. Jumars (1980) has indicated that statistical tests for rank correlation were, in general, suspect since they are based on the null hypothesis that all rankings are equally likely to occur. Because these stability analyses were done on a truncated species list, virtually all of the species included were thought to be capable of achieving moderate to high abundance ranks. Thus, it is felt that rank correlation methods were appropriate statistical tests to detect stability or stochastic variation in the

assemblage structure. Significance of W was tested using χ^2 values following Seigel (1956).

Numerical (species richness and abundance per 50 m transect) and environmental measurements (except pH) were $\log_{10}(x + 1)$ transformed to stabilize variance prior to use in multivariate and parametric analyses. Univariate and bivariate analysis of variance (ANOVA) and Student-Neuman-Keuls (SNK) multiple sample comparison tests were used to detect differences in species richness and abundance between groups identified by cluster analysis. Similar analyses were used to detect spatial and temporal differences in numbers of species and individuals per transect over a longer time interval from the Steel Creek collections. Correlation analysis was done on untransformed variables to examine relationships of number of species and individuals with environmental parameters (e.g., water depth, water depth in the previous time interval). Unless otherwise stated, statistical significance was taken at $p < 0.05$.

Results

A total of 11,996 individuals comprising 51 species were collected over the course of the study; to enable spatial comparison across the SRSS, only collections where all sites were sampled concurrently are discussed further (Tables 3.3 and 3.4). While most of the fish assemblage was categorized as year round freshwater residents, three species (hickory shad, *Alosa mediocris*; striped mullet, *Mugil cephalus*; and American eel, *Anquilla rostrata*) were migratory. Other species of anadromous fishes, particularly the clupeids, have been reported to utilize portions of the SRSS and associated tributary streams (Bennett and McFarlane, 1983; Aho and Anderson, unpublished data), but none were found in these study areas. Of the resident species, abundance differed greatly with four common species accounting for > 65% of the total number of individuals. Seventeen species accounted for

Table 3.3 Summary of the distribution and overall abundance of the fish assemblage among sites and collections within the Savannah River Swamp System. Only data for spring, summer and fall 1984 are presented here to allow spatial comparison. Included are the number of fish collected, percent composition, number of sites that a species was found, and the total number of times a species was found in the seasonal collections for all sites. For the percentage of occurrence, a species could be recorded a maximum of 36 times.

Species	Common Name	Number Collected	Percent Composition	Sites	Percentage Occurrence
<i>Notropis petersoni</i>	Coastal shiner	1185	24.3	11	75
<i>Labidesthes sicculus</i>	Brook silverside	867	17.8	10	72
<i>Notropis chalybaeus</i>	Ironcolor shiner	894	18.4	8	53
<i>Micropterus salmoides</i>	Largemouth bass	274	5.6	11	78
<i>Lepomis punctatus</i>	Spotted sunfish	213	4.4	10	69
<i>Lepisosteus osseus</i>	Longnose gar	160	3.3	11	58
<i>Erimyzon sucetta</i>	Lake chubsucker	153	3.1	8	44
<i>Amia calva</i>	Bowfin	136	2.8	12	67
<i>Aphredoderus sayanus</i>	Pirate perch	144	2.9	8	53
<i>Notemigonus crysoleucas</i>	Golden shiner	115	2.4	5	33
<i>Minytrema melanops</i>	Spotted sucker	86	1.8	10	47
<i>Lepomis microlophus</i>	Redear sunfish	63	1.3	10	50
<i>Gambusia affinis</i>	Mosquitofish	56	1.2	6	33
<i>Anguilla rostrata</i>	American eel	53	1.1	8	56
<i>Esox niger</i>	Chain pickerel	64	1.3	9	50
<i>Notropis cummingsae</i>	Dusky shiner	51	1.1	8	33
<i>Dorosoma cepedianum</i>	Gizzard shad	66	1.4	8	33
<i>Perca flavescens</i>	Yellow perch	41	0.8	5	25
<i>Lepomis auritus</i>	Redbreast sunfish	30	0.6	8	39
<i>Lepomis gulosus</i>	Warmouth	12	0.3	5	19
<i>Chologaster cornuta</i>	Swampfish	22	0.5	3	14
<i>Mugil cephalus</i>	Striped mullet	26	0.5	3	17
<i>Notropis emiliae</i>	Pugnose minnow	14	0.3	5	14
<i>Percina nigrofasciata</i>	Blackbanded darter	25	0.5	7	36
<i>Elassoma zonatum</i>	Banded pygmy sunfish	16	0.3	3	11
<i>Fundulus lineolatus</i>	Lined topminnow	10	0.2	2	17
<i>Leopmis macrochirus</i>	Bluegill	9	0.2	3	14
<i>Pomoxis nigromaculatus</i>	Black crappie	10	0.2	5	19
<i>Lepisosteus platyrhincus</i>	Florida gar	8	0.2	5	17
<i>Esox americanus</i>	Redfin pickerel	11	0.2	1	8
<i>Notropis maculatus</i>	Taillight shiner	12	0.3	3	11
<i>Ictalurus natalis</i>	Yellow bullhead	4	0.1	1	8
<i>Ictalurus punctatus</i>	Channel catfish	3	0.1	2	8
<i>Noturus gyrinus</i>	Tadpole madtom	3	0.1	2	8
<i>Ictalurus platycephalus</i>	Flat bullhead	4	0.1	3	11
<i>Ictalurus nebulosus</i>	Brown bullhead	5	0.1	3	11
<i>Lepomis marginatus</i>	Dollar sunfish	7	0.1	2	6
<i>Enneacanthus gloriosus</i>	Bluespotted sunfish	9	0.2	3	14
<i>Etheostoma fusiforme</i>	Swamp darter	3	0.1	2	6
<i>Etheostoma olmstedii</i>	Tesselated darter	3	0.1	3	11
<i>Notropis lutipinnis</i>	Yellowfin shiner	1	<0.1	1	3
<i>Cyprinus carpio</i>	Carp	1	<0.1	1	3
<i>Notropis hudsonius</i>	Spottail shiner	1	<0.1	1	3
<i>Etheostoma serriferum</i>	Sawcheek darter	1	<0.1	1	3
<i>Alosa mediocris</i>	Hickory shad	1	<0.1	1	3
<i>Umbra pygmaea</i>	Eastern mudminnow	1	<0.1	1	3

Table 3.4 Seasonal changes in species composition and relative abundance (mean number of individuals per 50 m transect) at the 12 sampling sites in the Savannah River Swamp System. Dates of collection were March through November 1984; spring = March-May, summer = June-August, fall = September-November. Numbers in parentheses are ± 1 SE.

Species	SC1			SC2			SC3			DP1		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
<i>Notropis petersoni</i>	1.25 (0.81)	9.33 (2.88)	4.00 (1.38)	0.88 (0.34)	4.50 (1.16)	2.83 (0.83)	0.54 (0.35)	3.50 (1.35)	3.67 (1.48)	0.50 (0.50)	1.25 (0.95)	2.13 (0.89)
<i>Notropis thalybaeus</i>	0.0	3.78 (2.83)	3.22 (1.72)	2.75 (1.23)	4.78 (1.31)	12.39 (3.13)	0.88 (0.83)	1.11 (0.32)	0.94 (0.44)	4.25 (2.09)	22.00 (7.43)	28.25 (8.71)
<i>Notropis cummingsae</i>	0.0	0.0	0.44 (0.44)	0.0	0.0	0.0	0.0	0.06 (0.06)	0.0	0.50 (0.50)	1.00 (1.00)	0.0
<i>Notropis maculatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Notropis hudsonius</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Notropis lutipinnis</i>	0.0	0.11 (0.11)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Notemigonus crysoleucas</i>	0.0	0.22 (0.15)	0.11 (0.11)	0.79 (0.58)	0.94 (0.31)	0.50 (0.39)	0.17 (0.13)	0.50 (0.23)	1.50 (0.58)	0.50 (0.29)	1.50 (0.87)	2.63 (1.66)
<i>Notropis emiliae</i>	0.0	0.0	0.11 (0.11)	0.0	0.0	0.0	0.0	0.0	0.11 (0.08)	0.0	0.0	0.0
<i>Cyprinus carpio</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Erimyzon succetta</i>	0.0	0.33 (0.33)	0.33 (0.24)	0.71 (0.19)	2.11 (0.57)	3.33 (0.79)	0.0	0.0	0.0	0.0	0.0	0.0
<i>Minytrema melanops</i>	0.42 (0.19)	0.22 (0.15)	0.22 (0.15)	0.29 (0.14)	0.44 (0.18)	0.06 (0.06)	0.33 (0.13)	0.11 (0.08)	0.17 (0.09)	0.50 (0.50)	0.25 (0.25)	1.38 (0.42)
<i>Micropterus salmoides</i>	0.17 (0.11)	2.00 (0.58)	0.78 (0.22)	0.83 (0.33)	2.72 (0.56)	1.67 (0.32)	0.58 (0.19)	0.67 (0.27)	1.33 (0.36)	0.0	0.0	0.25 (0.19)
<i>Lepomis punctatus</i>	0.08 (0.08)	2.00 (1.05)	1.11 (0.77)	0.67 (0.18)	2.56 (0.72)	2.61 (0.42)	0.08 (0.06)	0.28 (0.11)	0.33 (0.14)	0.0	0.25 (0.25)	0.38 (0.18)
<i>Lepomis auritus</i>	0.08 (0.08)	0.0	0.0	0.0	0.0	0.06 (0.06)	0.08 (0.06)	0.11 (0.08)	0.33 (0.19)	0.5 (0.29)	0.75 (0.48)	0.88 (0.39)
<i>Lepomis marginatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.11 (0.08)	0.0	0.0	0.0
<i>Lepomis microlophus</i>	0.25 (0.13)	0.22 (0.15)	0.11 (0.11)	0.17 (0.08)	0.17 (0.12)	0.11 (0.08)	0.04 (0.04)	0.0	0.17 (0.12)	0.0	0.0	0.0
<i>Lepomis macrochirus</i>	0.0	0.0	0.0	0.04 (0.04)	0.17 (0.12)	0.06 (0.06)	0.0	0.11 (0.11)	0.0	0.25 (0.25)	0.50 (0.50)	0.0
<i>Enneacanthus gloriosus</i>	0.08 (0.08)	0.0	0.0	0.08 (0.05)	0.17 (0.09)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Pomoxis gulosus</i>	0.0	0.0	0.0	0.0	0.17 (0.09)	0.06 (0.06)	0.0	0.0	0.0	0.0	0.50 (0.50)	0.25 (0.25)
<i>Pomoxis nigromaculatus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.04 (0.04)	0.06 (0.06)	0.11 (0.08)	0.0	0.0	0.0
<i>Elaeostoma zonatum</i>	0.0	0.0	0.0	0.0	0.50 (0.34)	0.33 (0.19)	0.0	0.0	0.0	0.0	0.0	0.0
<i>Percina nigrofasciata</i>	0.08 (0.08)	0.22 (0.15)	0.22 (0.22)	0.04 (0.04)	0.06 (0.06)	0.11 (0.08)	0.08 (0.08)	0.0	0.17 (0.09)	0.0	0.0	0.0
<i>Etheostoma olivstedti</i>	0.0	0.0	0.0	0.0	0.06 (0.06)	0.0	0.04 (0.04)	0.06 (0.06)	0.0	0.0	0.0	0.0
<i>Etheostoma ferriferum</i>	0.0	0.0	0.0	0.0	0.0	0.06 (0.06)	0.0	0.0	0.0	0.0	0.0	0.0
<i>Etheostoma fusiforme</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Percia flavescens</i>	0.0	0.0	0.11 (0.11)	0.0	0.11 (0.11)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ictalurus natalis</i>	0.17 (0.11)	0.0	0.11 (0.11)	0.0	0.11 (0.08)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ictalurus nebulosus</i>	0.0	0.0	0.11 (0.11)	0.0	0.11 (0.08)	0.0	0.46 (0.13)	0.50 (0.17)	0.61 (0.26)	0.0	0.0	0.0
<i>Ictalurus punctatus</i>	0.0	0.0	0.0	0.0	0.11 (0.08)	0.06 (0.06)	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ictalurus platycephalus</i>	0.0	0.11 (0.11)	0.0	0.0	0.06 (0.06)	0.11 (0.08)	0.0	0.0	0.06 (0.06)	0.0	0.0	0.0
<i>Noturus gyrinus</i>	0.0	0.11 (0.11)	0.0	0.0	0.06 (0.06)	0.06 (0.06)	0.04 (0.04)	0.0	0.06 (0.06)	0.0	0.0	0.0
<i>Labidesthes sicculus</i>	0.0	0.0	0.0	0.04 (0.04)	0.06 (0.06)	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Brook silverside</i>	0.08 (0.08)	0.44 (0.24)	1.56 (0.73)	0.67 (0.28)	3.56 (1.12)	7.61 (1.89)	1.38 (0.66)	1.33 (0.24)	1.44 (0.61)	0.75 (0.25)	6.50 (5.55)	6.63 (2.93)
<i>Mosquitofish</i>	0.08 (0.08)	0.22 (0.15)	0.22 (0.15)	0.04 (0.04)	0.28 (0.14)	0.72 (0.27)	0.0	0.0	0.23 (0.10)	0.25 (0.25)	3.75 (1.25)	1.13 (0.64)
<i>Lined topminnow</i>	0.0	0.0	0.0	0.04 (0.04)	0.06 (0.06)	1.17 (0.31)	0.0	0.0	0.0	0.25 (0.25)	0.50 (0.29)	0.63 (0.18)
<i>Pirate perch</i>	0.08 (0.08)	0.78 (0.36)	0.89 (0.59)	0.08 (0.06)	0.33 (0.11)	0.44 (0.15)	0.04 (0.04)	0.06 (0.06)	0.39 (0.20)	0.25 (0.25)	0.50 (0.29)	0.38 (0.18)
<i>Amia calva</i>	0.25 (0.17)	0.55 (0.29)	0.67 (0.44)	0.21 (0.11)	2.72 (1.09)	0.0	0.0	0.0	1.78 (0.83)	0.0	0.0	3.00 (1.41)
<i>Bowfin</i>	0.42 (0.23)	0.11 (0.11)	0.22 (0.15)	0.0	0.0	0.11 (0.08)	0.0	0.0	0.22 (0.13)	0.0	0.0	0.0
<i>American eel</i>	0.0	0.0	0.0	0.21 (0.10)	0.06 (0.06)	0.0	0.08 (0.31)	0.06 (0.06)	0.06 (0.06)	0.0	0.0	0.0
<i>Longnose gar</i>	0.33 (0.18)	0.11 (0.11)	0.22 (0.22)	0.42 (0.13)	0.28 (0.11)	0.06 (0.06)	0.0	0.0	0.06 (0.06)	0.25 (0.25)	1.00 (0.41)	0.50 (0.33)
<i>Chain pickerel</i>	0.0	0.0	0.0	0.13 (0.07)	0.33 (0.23)	0.11 (0.08)	0.0	0.0	0.0	0.0	0.0	0.0
<i>Gizzard shad</i>	0.08 (0.08)	0.0	0.0	0.0	0.0	0.0	0.50 (0.34)	0.22 (0.17)	0.0	0.0	0.0	0.0
<i>Hickory shad</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Striped mullet</i>	0.25 (0.25)	0.11 (0.11)	0.0	0.04 (0.04)	0.11 (0.08)	0.0	0.04 (0.04)	0.89 (0.25)	0.17 (0.12)	0.0	0.0	0.0
<i>Eastern mudminnow</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Swampfish</i>	0.0	0.0	0.0	0.04 (0.04)	1.00 (0.78)	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 3.4 Continued

Species	SI1			SI2			SI3			SI4		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
<i>Notropis petersoni</i>	1.75 (1.75)	16.25 (7.39)	23.92 (9.08)	7.75 (7.75)	0.25 (0.25)	3.67 (1.06)	5.25 (2.02)	5.50 (1.76)	8.33 (2.69)	2.50 (2.18)	1.50 (0.29)	5.67 (4.01)
<i>Notropis chalybaeus</i>	0.50 (0.50)	0.00	0.08 (0.08)	4.00 (4.00)	0.00	2.58 (1.54)	2.25 (1.31)	1.50 (0.29)	0.08 (0.08)	0.00	0.00	0.08 (0.08)
<i>Notropis cummingsae</i>	1.50 (1.50)	0.00	0.33 (0.19)	4.00 (4.00)	0.00	0.42 (0.42)	0.25 (0.25)	0.00	0.00	0.00	0.00	0.08 (0.08)
<i>Notropis maculatus</i>	0.00	0.13 (0.13)	0.00	1.50 (0.67)	0.00	0.17 (0.17)	0.00	0.00	0.42 (0.19)	0.00	0.00	0.00
<i>Notropis hudsonius</i>	0.25 (0.25)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Notropis lutipinnis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Notropis holbrooki</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Notemigonus crysoleucas</i>	0.00	0.00	0.17 (0.11)	0.00	0.00	0.42 (0.26)	0.00	0.00	0.00	0.00	0.00	0.17 (0.17)
<i>Notropis emiliae</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08 (0.08)
<i>Cyprinus carpio</i>	0.00	0.00	0.17 (0.11)	0.00	0.25 (0.25)	0.17 (0.11)	0.00	0.00	0.25 (0.18)	0.00	0.00	0.17 (0.11)
<i>Erimyzon sucetta</i>	0.00	0.38 (0.26)	0.17 (0.11)	0.00	0.00	0.25 (0.18)	0.00	0.00	0.00	0.00	0.00	0.17 (0.11)
<i>Minytrema melanops</i>	0.25 (0.25)	0.00	0.17 (0.17)	0.00	0.00	0.25 (0.18)	0.00	0.00	0.00	0.00	0.00	0.17 (0.11)
<i>Micropterus salmoides</i>	1.00 (0.71)	1.88 (0.52)	0.50 (0.26)	0.75 (0.48)	0.25 (0.25)	1.50 (0.45)	1.75 (0.63)	2.25 (0.85)	0.92 (0.31)	0.50 (0.50)	0.75 (0.25)	1.25 (0.37)
<i>Lepomis punctatus</i>	0.50 (0.29)	1.38 (0.67)	1.00 (0.35)	0.75 (0.48)	0.00	0.25 (0.13)	0.75 (0.48)	0.50 (0.25)	0.33 (0.14)	0.25 (0.25)	0.75 (0.48)	0.17 (0.11)
<i>Lepomis auritus</i>	0.00	0.25 (0.16)	0.08 (0.08)	0.00	0.25 (0.25)	0.00	0.00	0.25 (0.25)	0.67 (0.22)	0.25 (0.25)	1.25 (0.63)	0.17 (0.11)
<i>Lepomis marginatus</i>	0.00	0.00	0.00	1.50 (1.50)	0.00	0.00	0.00	0.00	0.08 (0.08)	0.00	0.00	0.00
<i>Lepomis microlophus</i>	0.25 (0.25)	0.25 (0.16)	1.08 (0.57)	0.00	0.50 (0.29)	0.67 (0.31)	0.25 (0.25)	0.00	0.00	0.00	0.00	0.75 (0.58)
<i>Lepomis macrochirus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Enneacanthus gloriosus</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Lepomis gulosus</i>	0.00	0.25 (0.16)	0.00	0.25 (0.25)	0.00	0.00	0.00	0.00	0.00	0.25 (0.25)	0.00	0.00
<i>Pomoxis nigromaculatus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Elassoma zonatum</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Percina nigrofasciata</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.17 (0.17)	0.00	0.50 (0.50)	0.00	0.00	0.00	0.08 (0.08)
<i>Etheostoma olivstedii</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.00	0.00	0.00	0.00	0.50 (0.50)	0.00	0.00
<i>Etheostoma ferriferum</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.25 (0.13)	0.00	0.25 (0.25)	0.33 (0.19)	0.25 (0.25)	0.00	0.00
<i>Etheostoma fusiforme</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Percia flavescens</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ictalurus natalis</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ictalurus nebulosus</i>	0.00	0.00	0.00	0.00	0.25 (0.25)	0.08 (0.08)	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ictalurus punctatus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ictalurus platycephalus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Noturus gyrinus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Labidesthes sicculus</i>	5.25 (3.09)	4.25 (1.36)	7.42 (3.17)	9.75 (5.94)	1.00 (0.58)	9.25 (3.42)	1.75 (0.85)	2.00 (2.00)	3.25 (2.21)	5.00 (3.54)	0.50 (0.29)	7.42 (5.06)
<i>Gambusia affinis</i>	0.00	0.00	0.08 (0.08)	0.00	0.00	0.17 (0.17)	0.00	0.00	0.00	0.00	0.00	0.00
<i>Fundulus lineolatus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aphredoderus sayanus</i>	0.25 (0.25)	0.25 (0.16)	1.00 (0.33)	1.00 (0.71)	1.25 (1.25)	0.00	0.25 (0.25)	1.75 (1.44)	0.25 (0.18)	0.00	0.00	0.33 (0.22)
<i>Amia calva</i>	0.00	0.38 (0.38)	0.25 (0.18)	0.00	0.00	0.33 (0.14)	0.00	0.50 (0.50)	0.08 (0.08)	0.00	0.25 (0.25)	0.17 (0.11)
<i>Anguilla rostrata</i>	0.00	0.13 (0.13)	0.50 (0.23)	0.50 (0.50)	0.50 (0.29)	0.25 (0.13)	0.50 (0.29)	0.00	0.42 (0.19)	0.25 (0.25)	1.50 (0.65)	0.08 (0.08)
<i>Lepisosteus osseus</i>	2.00 (1.41)	1.00 (1.00)	3.25 (2.25)	0.25 (0.25)	0.00	0.58 (0.31)	0.25 (0.25)	0.50 (0.29)	0.00	2.00 (1.35)	0.00	1.00 (0.52)
<i>Lepisosteus platyhincus</i>	0.25 (0.25)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.17 (0.17)
<i>Esox niger</i>	0.00	0.50 (0.33)	0.50 (0.23)	0.25 (0.25)	0.25 (0.25)	0.58 (0.23)	0.00	0.00	0.25 (0.13)	0.00	0.00	0.33 (0.19)
<i>Esox americanus</i>	0.00	0.00	0.00	0.00	0.00	0.17 (0.17)	0.00	0.00	0.00	0.00	0.00	0.00
<i>Dorosoma cepedianum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25 (0.25)	0.00	0.00
<i>Alosa mediocris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25 (0.25)	0.00	0.00	0.00	0.00
<i>Mugil cephalus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Umbra pygmaea</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Chologaster cornuta</i>	0.00	0.13 (0.13)	0.08 (0.08)	0.00	0.25 (0.25)	0.08 (0.08)	0.00	0.00	0.00	0.00	0.00	0.00

>90% of the fish abundance at the twelve sites within the SRSS; they were the most widely distributed and occurred the most frequently. These 17 species belonged to 11 families with six additional families represented by the remaining species. For the entire fish assemblage, cyprinids and centrarchids together comprised the greatest number of species (19) and largest numerical proportion (>55%) of the fish fauna. Seventeen species were collected infrequently, with fewer than 10 individuals collected; only eight were found at single locations. Species represented in the long-term collections in Steel Creek not included in Tables 3.3 and 3.4 include blueback herring Alosa aestivalis, American shad Alosa sapidissima, needlefish Strongylara marina, pumpkinseed Lepomis gibosus, and flier Centrarchus macropterus. None were consistently found and were generally represented by less than twenty individuals in total for the entire study period.

Spatial distribution of fishes within the SRSS

Results of the normal classification analysis (species as attributes of the sites) provided evidence for spatial differentiation in the composition of the fish communities (Figure 3.3). Eight major site groups were distinguished. Among these groups, only the four sites from the Four Mile Creek system exhibited regional affinity, but included in this site group (A) were also three seasonal collections from Steel Creek (SC1) and Stave Island (SI2, SI4). In the remaining seven site groups (B-H), differing numbers of site-season collections from different geographic locations within the SRSS grouped together. Patterns of species richness and relative abundance differed significantly between the different site groups (ANOVA: richness, $F_{7,354} = 67.7$, $p < 0.0001$; abundance, $F_{7,354} = 69.3$, $p < 0.0001$; Table 3.5). The 15 seasonal collections comprising site group A had the most depauperate assemblage with total species richness (cumulative number of species from all monthly samples) ranging from 0-11 species ($\bar{x} = 2.1$) and the lowest fish abundance

Table 3.5. Summary of univariate analysis of variance testing for differences in mean site species richness and mean site abundance (per 50 m transect) between the eight site groups identified through normal classification methods (species as attributes of sampling locations) within the Savannah River Swamp System.

Species Richness:

	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Site Group	7	152.6	21.8	67.7	<0.0001
Error	<u>354</u>	<u>114.0</u>	0.3		
Total	361	266.6			

Relative Abundance:

	<u>df</u>	<u>SS</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Site Group	7	372.9	53.3	69.3	<0.0001
Error	<u>354</u>	<u>272.2</u>	0.8		
Total	361	645.2			

with an average relative abundance of 2.0 individuals per transect (Table 3.6). Compared to site group A, species richness and abundance were higher in the remaining groups. Mean total species richness for groups B-H varied from 10.7 to 18.3 species, mean species richness (per 50 m transect) ranged from 4.1 to 8.3, and mean assemblage abundance was as high as 48.4 individuals per transect. Results from Student-Newman-Keuls (SNK) tests, however, indicated no distinct subsets for site groups for either species richness or fish abundance; only site group A was consistently different than the other seven cluster groups. Rather, there was a trend for complexity (number of species) and numerical abundance of the assemblage to increase across groups A-H. Based on site/season collections within the different clusters, temporal variability in assemblage composition was minor compared to spatial differentiation of the groupings. In the majority of cases (>70%), two or more of the seasonal collections (1 = spring, 2 = summer, 3 = fall) from the same site were found in the same site group, indicating short-term similarities in assemblage composition across the SRSS.

The inverse classification of fish assemblage and construction of the two-way coincidence table summarized species and site relationships for the seasonal collections at each site (Table 3.7). Using sites as attributes of the species (inverse classification), eight taxa groups were recognized (Table 3.7). The first seven groupings contained either single taxa or groups of three species representing the most common species across the SRSS. The largest group (VIII) consisted of taxa that were generally not abundant at any locations.

No site group had a unique fish fauna emphasizing the wide distributional patterns of most species, but there were major compositional differences between site groups. In group A, a total of 24 species were captured. Unlike the other site groups where relatively few species were the numerical dominants, 11 species were abundant in site group A. Composition of the assemblage was dominated by

Table 3.6 Patterns of species richness and assemblage abundance for site groups A-H in the Savannah River Swamp System. Mean total site group richness is based on the cumulative number of species collected each month at a site in a season; numbers in parentheses are the range of species in a site group. Mean site group richness and abundance are the average number of species and individuals per transect \pm 1 SE. Breaks in the horizontal lines for mean site group richness and abundance indicate significant differences between site groups as determined by SNK tests.

		Site Group							
		A	B	C	D	E	F	G	H
I.	Mean Total Site Group Richness	2.1 (0-11)	11.6 (8-18)	13.8 (10-17)	10.7 (7-16)	18.3 (13-27)	13	15	12.5 (12-13)
II.	Mean Site Group Richness	0.9 \pm 0.1	4.4 \pm 0.2	4.1 \pm 0.4	5.0 \pm 0.5	7.9 \pm 0.5	4.8 \pm 1.5	8.3 \pm 0.9	7.0 \pm 0.4
III.	Mean Site Group Abundance	2.0 \pm 1.4	14.5 \pm 3.5	9.6 \pm 1.6	23.5 \pm 4.6	31.7 \pm 3.8	32.5 \pm 4.6	40.8 \pm 8.3	48.4 \pm 10.2

Table 3.7 Two-way coincidence table comparing site groups and fish species associations within the Savannah River Swamp System. Values in the table represent mean species abundances (per 50 m transect) for each site group. Underlined numbers indicate species contributing at least 5% to the numerical abundance within a site group.

Taxa Group	SITE GROUP							
	A	B	C	D	E	F	G	H
I. Coastal shiner	<u>0.2</u>	<u>3.9</u>	<u>0.7</u>	<u>11.8</u>	<u>3.7</u>	<u>7.8</u>	1.3	<u>2.1</u>
II. Brook silversides	<u>0.1</u>	<u>4.0</u>	<u>0.7</u>	<u>3.1</u>	<u>5.6</u>	<u>9.8</u>	<u>6.5</u>	<u>6.6</u>
III. Ironcolor shiner	0	<u>0.9</u>	<u>3.5</u>	<u>1.9</u>	<u>8.6</u>	<u>4.0</u>	<u>22.0</u>	<u>28.3</u>
IV. Longnose gar	<u>0.2</u>	<u>0.9</u>	0.1	0.9	<0.1	0.3	0	0.0
V. Largemouth bass	<u>0.1</u>	<u>1.0</u>	0.4	<u>1.4</u>	<u>2.2</u>	0.8	0.3	0.4
VI. Lake chubsucker	<0.1	0.1	<u>0.6</u>	0.2	<u>2.7</u>	0	0.3	1.4
Pirate perch	<0.1	0.3	<u>0.2</u>	0.6	<u>1.9</u>	1.0	0.5	0.4
Spotted sunfish	<u>0.1</u>	0.3	<u>0.6</u>	<u>1.2</u>	<u>2.6</u>	0.8	0.8	0.9
VII. Golden shiner	<0.1	0.2	<u>0.6</u>	0.1	0.7	0	1.5	<u>2.6</u>
Mosquitofish	<0.1	<0.1	<u>0.1</u>	0.1	0.5	0	<u>3.8</u>	<u>1.1</u>
Bowfin	<u>0.2</u>	0.4	<0.1	0.4	0.4	0	<u>0.5</u>	<u>3.0</u>
VIII. Dusky shiner	0	0.2	0.3	0.2	0.2	<u>4.0</u>	1.0	0
Pugnose minnow	0	0.1	0	0.1	0	0	0	0
Taillight shiner	0	<0.1	0	<0.1	0	<u>1.5</u>	0	0
Spotted sucker	<u>0.1</u>	0.3	0.2	0.1	0.3	0	0	0.3
Lined topminnow	0	0	0.2	0	<0.1	0	0.5	0.6
Yellow bullhead	0	0	<0.1	0	0.1	0	0	0
Tadpole madtom	0	<0.1	<0.1	0	<0.1	0	0	0
Flat bullhead	0	<0.1	0	<0.1	<0.1	0	0	0
Brown bullhead	0	<0.1	0	<0.1	0.1	0	0	0
Swampfish	<0.1	0.2	0	<0.1	0.5	0	0	0
Redbreast sunfish	<u>0.1</u>	0.2	0	0.1	<0.1	0	0	0
Dollar sunfish	0	<0.1	0	0	0	<u>1.5</u>	0	0
Redear sunfish	<0.1	0.2	0.1	0.4	0.1	0	0.5	0
Bluegill	<0.1	<0.1	<0.1	0	0.1	0	0	0
Bluespotted sunfish	0	0	<0.1	<0.1	0.1	0	0.5	0.3
Warmouth	<0.1	0.1	0	<0.1	0.1	0.3	0	0
Black crappie	0	0.1	0.1	0	0	0	0	0
Banded pygmy sunfish	0	0	0	<0.1	0.4	0	0	0
Blackbanded darter	<0.1	0.2	<0.1	0.1	0.1	0	0	0
Tessellated darter	0	<0.1	0	<0.1	<0.1	0	0	0
Yellow perch	0	0.2	0	0.1	0.1	0	0	0
Swamp darter	0	0	0	0.1	0.1	0	0	0
American eel	<u>0.2</u>	0.2	0	0.3	0.1	0.5	0	0
Florida gar	<0.1	0.1	0.1	0	0	0	0	0
Striped mullet	<0.1	0.1	0	<0.1	0.1	0	0	0
Chain pickerel	<0.1	0.1	<u>0.7</u>	0.3	0.2	0.5	1.0	0.5
Redfin pickerel	0	0	<u>0.1</u>	0	0.2	0	0	0
Gizzard shad	<u>0.3</u>	0.2	0	0	<0.1	0	0	0
Sawcheek darter	0	0	0	0	0	0	0	0
Spottail shiner	0	<0.1	0	0	0	0	0	0
Eastern mudminnow	0	0	<0.1	0	0	0	0	0
Hickory shad	<0.1	0	0	0	0	0	0	0
Carp	0	<0.1	0	0	0	0	0	0
Yellowfin shiner	0	0	0	<0.1	0	0	0	0
Channel catfish	<0.1	<0.1	0	0	0	0	0	0

large-bodied species such as largemouth bass, longnose gar, bowfin, and gizzard shad, but smaller-bodied species such as coastal shiners and brook silversides constituted approximately 15% of the individuals. Faunal composition at the Four Mile Creek sites was the most variable of all the regions with many collections yielding no fish when heated conditions prevailed (Table 3.4). Only during periods of reduced discharge and regionally ambient water temperatures (associated with a cessation in reactor operations) were fish captured within this region of the SRSS. Largemouth bass, bowfin, longnose gar, and gizzard shad were among the early invaders.

In the remaining groups, approximately the same number of species (3-7) were the numerical dominants in each site group. Several species, particularly ironcolor shiners, brook silversides, and coastal shiners, frequently recurred in many of the groups as key components of the assemblage. Identity of the additional species, however, was variable between site groups. For example, largemouth bass, lake chubsucker, spotted sunfish, longnose gar, chain pickerel, golden shiner, and pirate perch were numerical dominants in one or more groups from B-E. From groups F-H, the number of species comprising most of the assemblage decreased and several species of cyprinids generally were the most abundant. Thus, in addition to richness and abundance changes between the different clusters, shifts in species composition as well as the general body size of the assemblage from large to small-sized individuals changed among site groups A-H (Figure 3.4). It was not possible from the cluster analysis, however, to rigorously infer which combinations of physical factors contributed to the observed differences among sites or site groups.

To explore relationships between fish assemblage patterns and environmental characteristics (Table 3.1), sites within the SRSS were classified by site group, and canonical discriminant analysis was applied to the limnological and habitat parameters measured at the different sites. Although the sites represented a

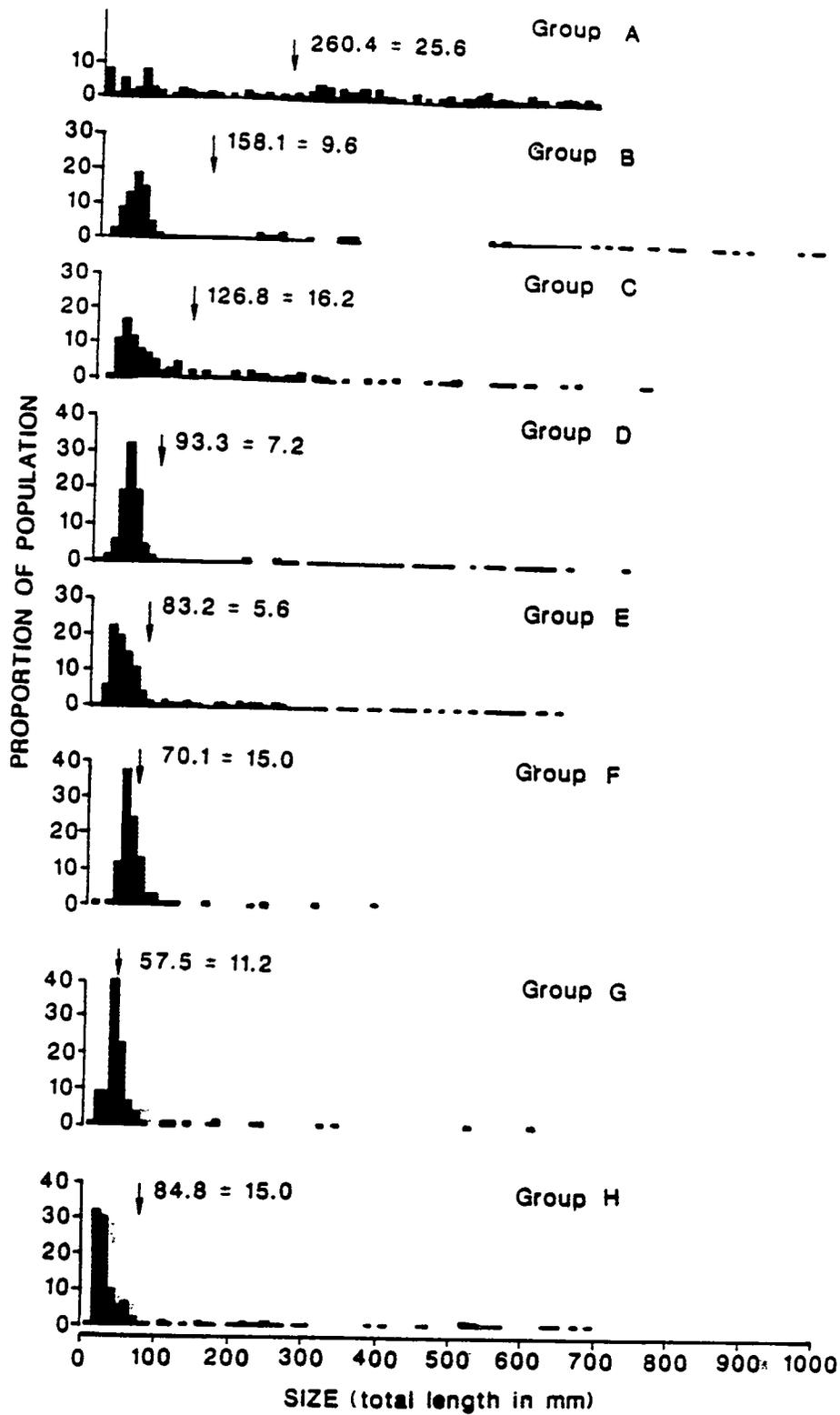


Figure 3.4. Size structure of the fish assemblages in the eight site groups identified through cluster analysis. Mean total length \pm 95% CI are given for each group.

continuum in environmental space, separation of the fish assemblages along the axes was evident (Figure 3.5), and 81% of the sites were correctly classified.

The first two discriminant functions accounted for 95% of the total variance. The first axis, responsible for 77% of the variance, tended to locate sites according to the abundance of aquatic macrophytes and current velocity. The second axis, accounting for 18% of the variance, separated sites on the basis of water temperature and degree of overstory canopy closure. Thus, sites located near the top of Figure 3.5 were generally those with little or no overstory canopy and water temperatures slightly higher than regional ambient values either because of insolation effects or reactor discharges. Sites toward the bottom of the plot tended to have a relatively closed forest canopy of cypress-tupelo and cooler water temperatures. Sites on the right were characterized as areas with extensive herbaceous marshes of emergent and submergent macrophytes and slow current velocities; those to the left were comprised mostly of flowing, open water habitats. The consistency of association with site group B (4 of 6 seasonal collections) for SI3 and SI4 strongly suggests that subtle increases in water temperature of 2-5°C alone probably does not affect fish assemblage organization (Table 3.1; Figure 3.3). The physical conditions emphasizing current and past perturbation regimes of the sites, therefore, exert a strong local influence on the fish species assemblage present at a location. Changes in species richness, abundance, and compositional shifts from large to a mixture of species to predominantly small-bodied forms were associated with gradients in habitat structural complexity. The distinction of faunal characteristics between areas dominated by long-lived trees compared to areas of perennial marshes also suggested that changes may also be associated with productivity of a habitat.

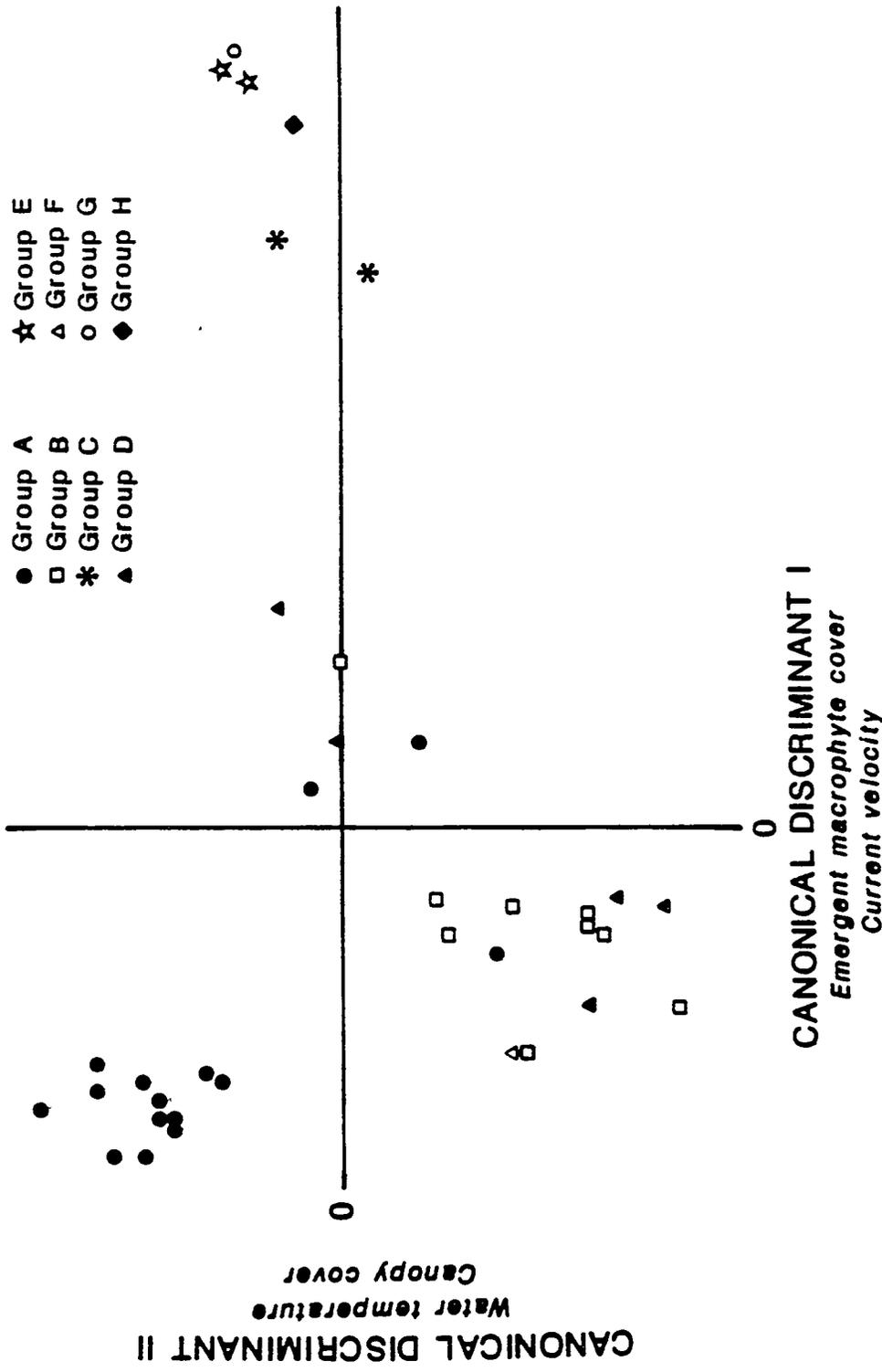


Figure 3.5. Canonical discriminant analysis of the 12 study sites with the SRSS based on environmental data. Axis 1 is related to macrophyte cover and current velocity; axis 2 is related to water temperature and degree of canopy cover.

Temporal persistence in assemblage composition

Water levels fluctuated greatly over the course of this investigation (Figure 3.6). During most of 1983 and 1984, water levels within the SRSS were high with periodic floods in spring, summer, and fall, but then declined in 1985 coinciding with a prolonged drought in the southeastern United States. In contrast to 1983 and most of 1984, the decline in water levels in 1985 exposed large areas of vegetated and mud bank habitat; in many areas, water was present only in the shallow channels that meander through the swamp. Because the two disturbed sites (SC1 and SC2) were not as deep as the undisturbed cypress-tupelo forest site (SC3), loss of habitat was greater in the disturbed regions of the SRSS. Areal estimates of habitat loss for utilization by fishes were approximately 30-60% depending on the site.

Because of the long-term data collections within Steel Creek, analyses of temporal variability in numbers of species and individuals as well as compositional changes in assemblage structure were possible. As summary measures of assemblage attributes comparing 1983 and 1984 when all seasons were sampled, two-way analysis of variance applied to the collection data for numbers of species and individuals per transect (pooling months within the same season as replicates) indicated species richness and fish abundance differed across seasons, among sites, and between years (Figure 3.7; Tables 3.8 and 3.9). Seasonal changes in number of species and abundance were significantly correlated at all locations ($r = 0.66$ to 0.95 , $df = 8$, $p < 0.05$); both were low during the winter and peaked in summer-fall following spring-summer reproduction (see Chapters I and II for details of reproductive phenology). Changes in either attribute of assemblage structure were not correlated with mean seasonal water depth ($r = -0.15$ to -0.63 , $df = 8$, $p > 0.05$) nor with mean water depth the previous season ($r = 0.02$ to 0.61 , $df = 7$, $p > 0.05$). Student-Newman-Keuls analysis of the seasonal differences, however, showed no

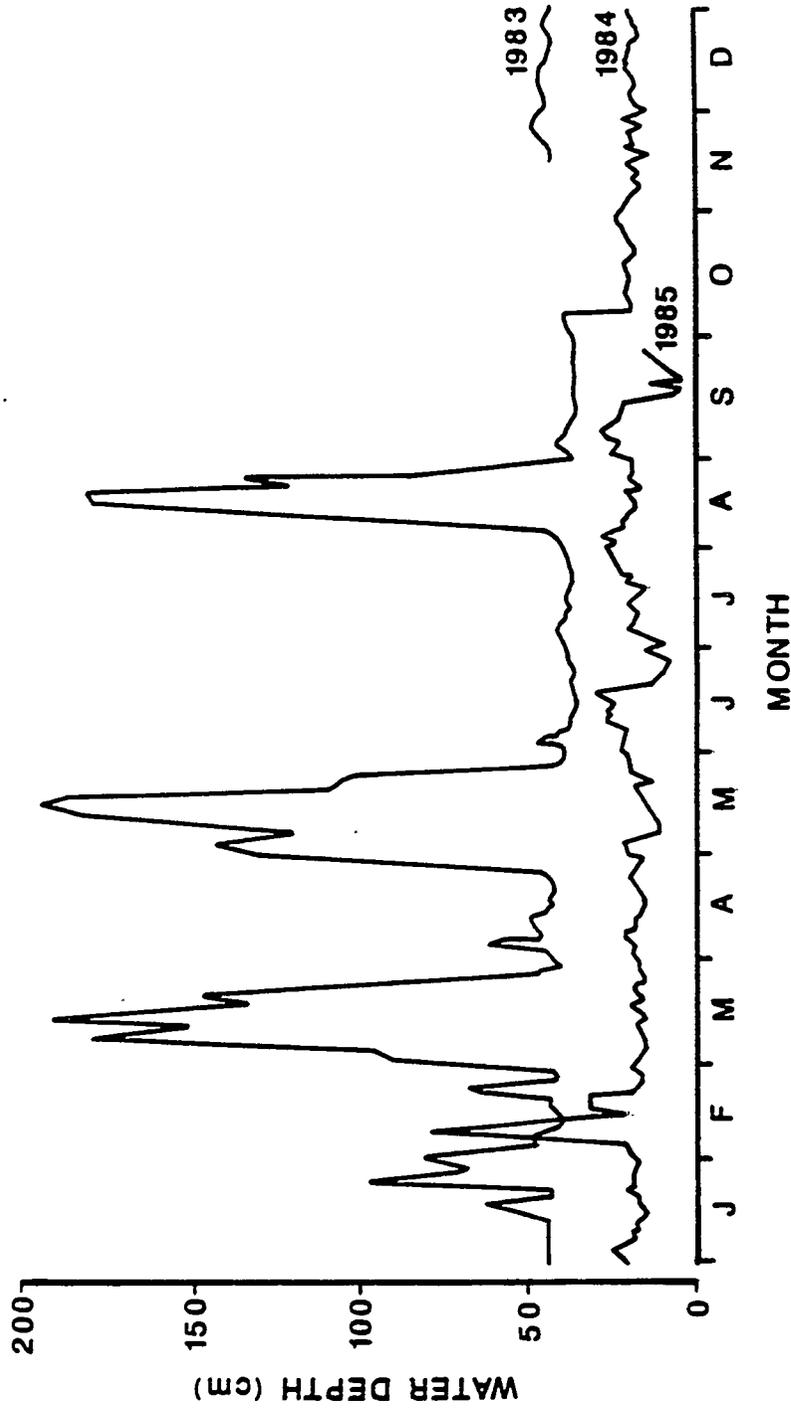


Figure 3.6. Fluctuations in water level within the Steel Creek region of the Savannah River Swamp System from November 1983 through September 1985. Values were determined from a gauge in the disturbed area of the SRSS.

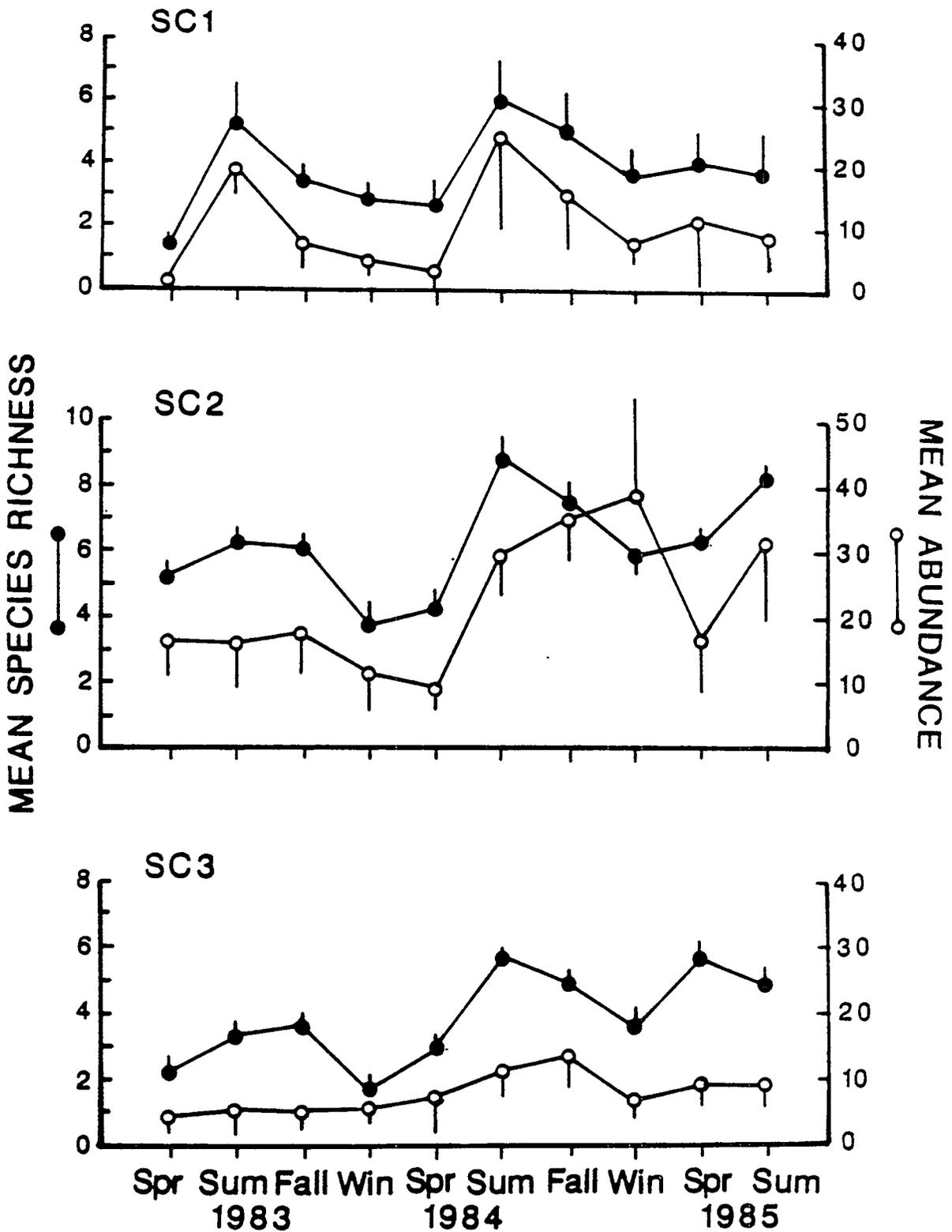


Figure 3.7. Seasonal changes in the mean number of species and mean total fish abundance (mean abundance) per 50 m transect for sites within the Steel Creek delta region of the SRSS. Vertical bars represent the 95% confidence interval.

Table 3.8 Analysis of variance of temporal and spatial variation in (A) number of fish species and (B) number of individuals per 50 m transect present on three sites in the Steel Creek delta (data was $\log_{10}(x + 1)$ transformed prior to analysis).

Factor	df	SS	MS	F	p
A. Species richness					
Location	2	9.58	4.79	16.52	0.0001
Season	3	18.05	6.02	20.75	0.0001
Year	1	6.54	6.54	22.55	0.0003
Location*Season	6	0.84	0.14	0.48	NS ^a
Season*Year	3	1.26	0.42	1.45	NS
Location*Year	2	2.27	1.13	3.91	0.037
Location*Season*Year	6	1.18	0.19	0.68	NS
Error	<u>306</u>	<u>91.31</u>	0.29		
Total	329	131.03			
B. Fish Abundance					
Location	2	44.91	22.46	27.38	0.0001
Season	3	42.47	14.16	17.27	0.0001
Year	1	20.51	20.51	25.01	0.0001
Location*Season	6	6.14	1.02	1.25	NS
Season*Year	3	6.87	2.29	2.79	NS
Location*Year	2	2.65	1.33	1.62	NS
Location*Season*Year	6	3.17	0.53	0.65	NS
Error	<u>306</u>	<u>250.95</u>	0.82		
Total	329	377.67			

^a No significant difference.

Table 3.9 Seasonal changes and results of multiple comparison tests (Student-Newman-Keuls) for mean number of species and mean assemblage abundance \pm 95% CI (per 50 m transect) for three sites in the Steel Creek delta region of the Savannah River Swamp System.

A. Seasonal changes in mean species richness and abundance in Steel Creek delta.

	SC1		SC2		SC3	
	<u>Mean Richness</u>	<u>Mean Abundance</u>	<u>Mean Richness</u>	<u>Mean Abundance</u>	<u>Mean Richness</u>	<u>Mean Abundance</u>
Spring 1983	1.3 \pm 0.6	1.7 \pm 0.6	5.3 \pm 2.3	16.0 \pm 10.7	2.3 \pm 1.5	4.5 \pm 3.0
Summer	5.2 \pm 2.1	19.3 \pm 13.5	6.3 \pm 1.7	15.7 \pm 6.0	3.3 \pm 0.9	5.0 \pm 1.7
Fall	3.3 \pm 1.1	6.7 \pm 4.0	6.1 \pm 1.4	17.7 \pm 8.4	3.5 \pm 0.9	5.3 \pm 1.7
Winter	2.9 \pm 0.9	4.8 \pm 2.5	3.7 \pm 1.4	11.7 \pm 6.1	1.6 \pm 0.8	5.6 \pm 4.1
Spring 1984	2.9 \pm 1.1	4.3 \pm 2.2	3.9 \pm 0.9	9.3 \pm 3.6	2.9 \pm 0.8	6.4 \pm 4.0
Summer	5.7 \pm 2.3	21.0 \pm 16.1	8.5 \pm 1.7	28.9 \pm 9.9	6.1 \pm 0.8	11.8 \pm 3.5
Fall	5.1 \pm 2.3	14.8 \pm 8.6	7.3 \pm 1.2	34.8 \pm 5.7	5.6 \pm 0.9	14.1 \pm 4.0
Winter	3.6 \pm 1.4	7.8 \pm 5.0	5.8 \pm 1.7	39.4 \pm 23.6	3.6 \pm 0.7	6.2 \pm 1.7
Spring 1985	4.1 \pm 1.8	11.2 \pm 8.4	6.3 \pm 1.2	16.5 \pm 6.1	5.4 \pm 1.2	9.7 \pm 3.0
Summer	3.8 \pm 2.2	8.5 \pm 5.3	8.0 \pm 1.8	31.0 \pm 12.9	4.8 \pm 1.2	9.8 \pm 2.8

B. Results of SNK tests for multiple comparison of location, season, and year effects. Underlined values are not significantly different.

Species Richness

Location	<u>SC1</u>	<u>SC3</u>	<u>SC2</u>
Season	<u>Winter</u>	<u>Spring</u>	<u>Summer</u> <u>Fall</u>
Year	<u>1983</u>	<u>1984</u>	

Assemblage abundance

Location	<u>SC1</u>	<u>SC3</u>	<u>SC2</u>
Season	<u>Winter</u>	<u>Spring</u>	<u>Summer</u> <u>Fall</u>
Year	<u>1983</u>	<u>1984</u>	

significant difference between either winter-spring or summer-fall collections, but there were differences between these two periods of time for both numbers of species and individuals (Table 3.9). Among locations within Steel Creek, assemblage richness and size was always greatest at one of the disturbed, post-thermal recovery sites, SC2; no difference was detected among the remaining two sites. Collections made during 1984 had both greater numbers of species and individuals than 1983. There was, however, a significant interaction between location and year for the number of species.

Although richness and abundance varied temporally, persistence of both the total assemblage and the species representing $>1\%$ of the seasonal composition was relatively high at all three sites (Table 3.10). There was, however, some differences among sites with SC1 having the lowest PR value. Across all sites and seasons, only two species (coastal shiner and largemouth bass) were always present suggesting local colonizations and extinctions were more common at SC1 (Tables 3.11, 3.12 and 3.13). An additional six and two species were always present at SC2 and SC3, respectively. Concordance of ranks for the common species were significant at all three sites, rejecting the null hypothesis and supporting a conclusion of assemblage stability over time. The stability of the assemblage at SC1 was, however, much lower than the other two sites and may be influenced by the higher current velocity found in this site (Table 3.1).

Discussion

The type of fish assemblage present at a location within the Savannah River Swamp System is largely determined by the site's position along two major environmental gradients: (1) degree of environmental harshness reflecting current perturbation events (e.g., elevated water temperatures and increased discharge rates) and (2) habitat structural characteristics (e.g., degree of canopy closure,

Table 3.10. Analysis of fish assemblage persistence and assemblage stability using an index of persistence (PR) and Kendall's Coefficient of Concordance (W) for three sites within the Steel Creek delta region of the SRSS. W indicates level of overall concordance from 0 (no correlation) to 1 (complete concordance). P = probability of a Type I error.

Site	PR	W	P
SC1	0.69 (0.58)*	0.39	<0.001
SC2	0.94 (0.74)	0.72	<0.001
SC3	0.81 (0.72)	0.55	<0.001

* Presented is PR value for truncated species list with PR for total assemblage in parentheses.

Table 3.11. Seasonal changes in the percent relative abundance of fishes from SC1 within the Steel Creek delta region of the Savannah River Swamp System.

Fish species	Season									
	1*	2	3	4	5	6	7	8	9	10
Coastal shiner	0	37.1	29.9	6.9	29.4	44.4	27.1	15.7	6.8	50.9
Ironcolor shiner	0	27.6	0	0	0	17.9	21.8	5.7	11.9	1.9
Dusky shiner	0	0	0	0	0	0.5	3.0	1.4	7.9	0
Golden shiner	0	6.5	6.9	0	1.1	0.8	0	0	0	0
Lake chubsucker	0	0.9	0	6.9	0	1.6	0.8	0	0.9	1.9
Spotted sucker	60.0	0.9	3.2	30.2	9.8	1.1	1.5	7.1	9.8	0
Mosquitofish	0	0	0	0	1.9	1.1	1.5	0	0	3.9
Brook silverside	0	7.8	3.9	0	1.9	2.1	10.5	4.3	0	0
Pirate perch	0	0.9	0	4.7	1.9	3.7	6.0	5.7	5.9	5.9
Bowfin	0	0.9	3.9	6.9	1.9	2.6	4.5	15.7	5.9	3.9
Largemouth bass	20.0	7.8	20.8	20.9	3.9	9.5	5.3	8.6	18.8	11.8
Spotted sunfish	0	2.6	1.3	2.3	1.9	9.5	7.5	22.9	19.8	7.8
Redear sunfish	0	0	0	0	5.9	1.1	0.8	1.4	0	1.9
Black-banded darter	0	0	3.9	0	1.9	1.1	1.5	4.3	3.9	5.9
Yellow perch	0	1.7	2.6	2.3	3.9	0	0.8	2.9	0	0
American eel	0	1.7	0	0	5.9	0.5	1.5	0	0.9	0
Longnose gar	0	0	0	2.3	9.8	0	0	0	0.9	1.9
Striped mullet	0	5.1	0	0	5.9	0	0	0	0	0
Chain pickerel	20.0	0	1.3	0	7.8	0.5	1.5	0	0.9	0
Number of fish	5	116	77	43	51	189	133	70	101	51
Number of collections per season	1	2	3	3	3	3	3	3	3	2

*1,5,9 = spring 1983, 1984, 1985; 2,6,10 = summer 1983, 1984, 1985; 3,7 = fall 1983, 1984; 4,8 = winter 1983, 1984.

Table 3.12. Seasonal changes in the percent relative abundance of fishes from SC2 within the Steel Creek delta region of the Savannah River Swamp System.

Fish species	Season									
	1*	2	3	4	5	6	7	8	9	10
Coastal shiner	12.1	13.0	2.0	45.3	10.5	17.6	8.5	12.1	7.7	15.5
Ironcolor shiner	51.5	31.0	42.4	11.8	33.0	18.7	36.9	60.6	15.5	15.1
Dusky shiner	0	0	0	0	0	1.3	0	0.8	11.7	0.6
Golden shiner	6.1	6.2	8.4	3.4	9.5	3.7	1.5	0.6	2.6	3.5
Lake chubsucker	3.0	4.9	4.0	5.9	8.5	8.3	9.9	6.4	8.4	8.2
Spotted sucker	0	3.1	3.4	2.9	3.5	1.7	0.2	0	1.5	2.5
Mosquitofish	3.0	0.6	5.4	2.5	0.5	1.1	2.2	0	0.7	0
Brook silverside	6.1	6.8	8.1	14.3	8.0	13.9	22.7	8.9	4.3	29.5
Pirate perch	0	1.2	4.4	0.4	2.5	10.6	3.5	0.9	6.6	5.4
Bowfin	1.5	0.6	2.7	0.4	1.0	1.3	1.3	0.8	2.9	1.6
Largemouth bass	7.6	11.2	10.5	5.9	10.0	10.7	4.9	3.1	15.7	13.2
Spotted sunfish	9.1	14.3	5.4	3.9	8.0	10.0	7.8	5.0	17.9	44.2
American eel	0	0.6	0.6	0.4	0	0	0.3	0.4	3.6	6.3
Chain pickerel	0	1.2	2.3	2.5	5.0	1.1	0.2	0.4	1.1	0.3
Number of fish	66	161	295	203	200	460	603	654	274	317
Number of collections per season	1	2	3	3	3	3	3	3	3	2

*1,5,9 = spring 1983, 1984, 1985; 2,6,10 = summer 1983, 1984, 1985; 3,7 = fall 1983, 1984; 4,8 = winter 1983, 1984.

Table 3.13. Seasonal changes in the percent relative abundance of fishes from SC3 within the Steel Creek delta region of the Savannah River Swamp System.

Fish species	Season									
	1*	2	3	4	5	6	7	8	9	10
Coastal shiner	7.4	15.3	14.9	1.0	8.8	30.2	30.3	20.5	15.7	17.8
Ironcolor shiner	0	18.5	14.9	1.0	14.2	9.6	7.8	13.4	0.6	0
Dusky shiner	0	6.8	2.1	1.0	0	0.5	0	0.9	10.8	13.1
Golden shiner	0	0	2.1	0	2.7	4.3	12.4	0	0.6	7.5
Lake chubsucker	0	0	4.3	1.0	0	0.9	1.3	3.6	1.8	0
Spotted sucker	7.4	5.1	12.8	5.1	5.4	5.8	11.0	6.3	14.5	10.3
Mosquitofish	0	0	0	4.0	0	0	1.8	0	0	0
Brook silverside	59.3	11.9	13.8	70.7	22.3	11.5	11.9	14.3	15.1	11.2
Pirate perch	0	0	0	0	0	0.5	3.2	3.6	1.2	2.8
Bowfin	0	10.2	11.7	0	0.7	4.3	14.7	6.3	3.6	0.9
Largemouth bass	11.1	15.3	15.9	3.0	9.5	7.7	2.8	7.1	6.0	8.4
Spotted sunfish	3.7	3.4	0	5.1	1.4	2.4	2.8	7.1	6.0	2.8
Redbreast sunfish	3.7	0	0	0	1.4	0.9	0.9	1.8	0.6	0
Black banded darter	0	1.7	0	1.0	1.4	0.5	1.4	7.1	2.4	0.9
Yellow perch	0	8.5	10.6	3.0	7.4	4.3	5.0	13.4	6.6	0.9
American eel	0	0	3.2	2.0	2.0	2.4	1.8	0.9	0	0
Longnose gar	3.7	10.2	4.2	2.0	14.2	4.3	1.8	0	13.3	17.8
Striped mullet	0	3.4	2.1	0	0.7	7.6	1.4	0	0	1.8
Gizzard shad	3.7	0	0	0	8.1	1.9	0	0	0.6	3.7
Number of fish	27	59	94	99	148	208	218	112	166	107
Number of collections per season	1	2	3	3	3	3	3	3	3	2

*1,5,9 = spring 1983, 1984, 1985; 2,6,10 = summer 1983, 1984, 1985; 3,7 = fall 1983, 1984; 4,8 = winter 1983, 1984.

vegetative abundance and architectural type, flow rates). Physical conditions along these gradients have a direct and predictable effect on the structure of the fish assemblages within the SRSS. Areas experiencing high levels of thermal loading, independent of other habitat conditions, generally are depauperate assemblages. Only when cool-water conditions return to these sites can a fish assemblage develop, and initially the assemblage would appear to be dominated by large-bodied fish such as largemouth bass and longnose gar. Large-bodied species are, however, not necessarily the most mobile as many small species of fish have been found reinvading the thermal stream channel draining into the SRSS when conditions permit (Aho and Anderson, unpublished data; see Chapter V of this report). For many sites within the SRSS, habitat features reflect prior disturbance regimes associated with reactor operations by creating open canopied habitats characterized by extensive herbaceous wetlands and slow current velocities. In these locations, as well as natural openings in the forest canopy, several species of minnows and brook silversides are dominant species in the assemblage. However, when an overstory canopy of cypress/tupelo forest exists and areas of open water are common in an area, many of the same species are again found, but larger-bodied species such as largemouth bass, longnose gar, and spotted sucker are relatively common. Although sites do not have a unique fish fauna due to their wide distribution within the river-swamp, the assemblages are distinct and respond to the availability of habitat.

In areas not currently experiencing high thermal loading ($>5^{\circ}\text{C}$ above ambient) or elevated discharge rates, there are several factors that may contribute to the contrast in species richness and abundance between open and closed canopy areas. Habitat complexity has often been implicated as an important determinant of species richness in aquatic habitats. Werner et al. (1978) in a comparison of centrarchid lakes with similar structural complexity from Michigan and Florida

suggest assemblages are 'saturated' and that habitat structure and lake morphometry strongly influence the number of species of fish that could coexist. Keast (1978) came to similar conclusions about many of the small, glacier-formed lakes in North America. Niche segregation and complementarity have been observed in other centrarchid systems (Werner et al., 1977, 1978; Keast et al., 1978; Werner et al., 1983) and cyprinid-dominated assemblages (Mendelson, 1975; Baker and Ross, 1981; Surat et al., 1982; McNeeley, 1987). Since species exhibit niche differentiation with respect to one or more habitat features, the number of fish species should increase with increased habitat complexity and heterogeneity. Species diversity in several stream fish assemblages is also closely related to habitat complexity (Sheldon, 1968; Gorman and Karr, 1978; Schlosser, 1982).

If the habitat complexity/niche complementarity/species richness relationship applies to fish assemblages within the SRSS, vegetation characteristics should be identified as a major factor related to species richness. Benthic substrate composition and depth of the water probably were not important determinants because of the limited range of these habitat features over the sites selected. Thus, if habitat complexity contributed to species richness, vegetation cover should represent the primary habitat dimension along which segregation and species packing occur. The parallel increase in submergent and emergent macrophyte cover and number of species and individuals per transect was the observed trend across the SRSS. The greatest number of species was found in the post-thermal recovery area in Steel Creek (SC2-site group E); while not different between site groups E-H, abundance was greatest at DP1, an undisturbed, vegetated site in the SRSS. Variations in the assemblage structure among sites with some extent of canopy closure may also reflect subtle differences either in the amount of plant cover available or in the architectural characteristics (e.g., simple vs. complex leaf types). Investigations in estuarine and other freshwater systems (Heck and Orth,

1980; Coen et al., 1981; Rozas and Odum, in press) indicated plant structural complexity as a major factor influencing habitat complexity. Thus, even at low levels of macrophyte abundance, characteristics of the plants may impart enough structural complexity to increase assemblage richness. The occurrence of macrophyte growth may also be an important refuge from predators contributing to both increased species richness and abundance. Numerous studies have shown that small fish are associated with vegetation in the presence of predators even though suitable food is available in less structured environments (e.g., Werner and Hall, 1979; Keast, 1978; Laur and Ebling, 1983; Werner et al., 1983). However, habitat use patterns can shift as individuals reach a larger and less vulnerable size.

More productive habitats should also permit the development of greater diet specialization under conditions of evolutionary equilibrium (MacArthur, 1972). The distribution and abundance of macrophytes probably contributes to differences in productivity (e.g., food availability) by increasing the amount of substrate available for secondary production of aquatic invertebrates (Benke, 1984; Minshall, 1984), the dominant prey category for most fishes within the SRSS (Bennett and McFarlane, 1983). Although no estimates of invertebrate production are available in the SRSS, species richness, abundance, and biomass of macroinvertebrates differ between thermally disturbed localities, sites with closed forest canopies, and areas of herbaceous marshes. Values for all assemblage attributes were generally highest in the herbaceous marshes (Kondratieff and Kondratieff, 1985). Productivity, particularly associated with increased planktonic and benthic food webs, has been related to species richness in a Canadian lake system (Nakashima et al., 1977). Although the differences in food availability may contribute to the greater number of species and individuals in the herbaceous marshes, there is an optimum amount of vegetative cover that maximizes measures of population performance (e.g., growth, abundance, survival, and body size-fecundity relations) (Cooper and

Crowder, 1979; Crowder and Cooper, 1982). It is unclear, however, where the tradeoffs in community development and population demographic characteristics as a function of habitat complexity actually occur in the SRSS.

Characterization of many fish species within the SRSS as lithophils or phytolithophils (Balon, 1975, 1984) suggests that the lack of a firm substrate potentially limits spawning success. If macrophytes increase the amount of substrate not associated with the sediments, recruitment success may be greater in the open canopy areas. Thus, lower species richness and population densities in the closed canopy areas may also represent the outcome of low spawning success.

In addition to physical aspects of the environment which structure the fish assemblages, biotic interactions appear to be important. Despite extreme fluctuations in water levels and temporal variability in species richness and abundance within the Steel Creek region, assemblage composition was persistent and stable. Prior studies have indicated that long-term persistence is evidence that assemblage structure is organized through some interactive mechanism (Grossman, 1982; Grossman, 1985; Moyle and Vondracek, 1985). Four studies dealing with freshwater systems suggest that boreal and midwestern lacustrine and southeastern stream fish assemblages may be determined by biotic interactions (Adams and Olver, 1977; Werner 1977; Gatz, 1979; Werner and Hall, 1979). Other studies of river-swamp or stream fishes, however, imply the assemblages are influenced by stochastic events (e.g., floods, droughts) (Starrett, 1951; Larimore, 1954; Paloumpis, 1958; Kushlan, 1976; Carlson and Duever, 1976; Whitaker, 1976; Moyle and Li, 1979; Grossman et al., 1982). Supporting evidence of the role of predation or partitioning of food, space, or time in the SRSS is equivocal at present. However, for at least the lake chubsucker (*Erimyzon sucetta*), field growth rates were significantly lower than fish fed ad libitum in the laboratory at comparable water temperatures (Aho and Anderson, unpublished data). The differential in growth rates between field and

laboratory studies suggests food limitation may be important. Additional long-term studies are therefore necessary to determine the application of these findings and whether the assemblage within the SRSS is persistent or in long-term succession.

However, Connell and Sousa (1983) argue that temporal analyses of assemblage structure are only meaningful if the system experiences disturbance regimes that potentially disrupt structure, and the time period of analysis should cover more than one generation. If these conditions are not met, patterns indicative of equilibrium may simply result from an unchallenging environment or the presence of long-lived animals. Both conditions are met in this study. The reduction in water level during 1985 affected physical conditions within the swamp by exposing areas of aquatic vegetation and reducing habitat availability to the fish. While the study covered only ten months, major components of the fish assemblage were short-lived (generally less than two years) and turnover of at least one generation should have occurred.

Dynamics of the fish assemblages are therefore determined by a variety of factors. Environmental perturbation can be a major factor in degraded habitats and can reduce assemblage structure. Natural disturbance events such as storms could also influence fish community structure by creating open patches in a closed canopy forest. The presence of riparian vegetation acts as a template around which the fish assemblage is structured, but vegetation characteristics are ultimately determined by the interaction of hydroperiod, water movement patterns and discharge, and nutrient availability. Hydroperiod influences forest regeneration and growth potential. Patterns of water movement and discharge variability determine rates of establishment or dispersal of seeds that colonize new habitats. Nutrient availability from either primary production or leaf fall influences secondary production of the food base and the trophic organization of the fish community.

Conclusions

Juvenile and adult fish were collectively studied in representative habitat types in the SRSS. The objective of the study was to identify patterns in fish distribution and abundance in the SRSS adjacent to the SRP and determine the influence of habitat structure, physical disturbance (natural and anthropogenic from the operation of nuclear production reactors), and season on assemblage structure. Conclusions of the study are summarized below.

- Based on the capture of almost 12,000 fish, at least 51 species of 17 families are found in the SRSS.
- Most fish species of the SRSS are year-round residents, but both anadromous and catadromous species also utilize the system.
- Seventeen species of 11 families constitute >90% of the ichthyofauna of the SRSS. Seventeen fish species can be considered rare, based on the capture of fewer than 10 individuals. Eight of these species were represented by specimens from only single locations.
- No sampling site had a unique fish fauna. There were widespread distribution patterns of fish within the SRSS. However, species composition of fish assemblages did vary within the SRSS as a consequence of habitat. Aquatic areas receiving thermal effluents >5°C above regional ambient temperatures are the most depauperate in numbers of fish species and individuals. Areas of overstory canopy (cypress/tupelo) and moving water are inhabited by both large and small-bodied species. Herbaceous marshes with low flow have primarily small-bodied species. The numbers of species and individuals tend to increase from closed-canopy to open-canopy habitats.
- Differences in assemblage richness, abundance, and compositional characteristics are determined by several environmental factors. Of greatest

importance to fish assemblage structure are water temperature reflecting current disturbance events within the SRSS, degree of canopy closure, flow rates, and abundance of aquatic vegetation.

- The SRSS is a highly complex, fluctuating environment in which the overall relative abundance of fish species varies naturally, both seasonally and annually. Fish assemblage structure within Steel Creek, however, was highly persistent with many of the same species repeatedly found over census periods. Stability of fish assemblage structure was also high with many species remaining in the same rank order of abundance.
- Modification of the SRSS from SRP operations (e.g. thermal discharges, high flow rates) could have major impacts on fish assemblages in a direct manner through habitat alteration. Indirect effects in contiguous areas could result from changes in species composition (prey, predators, and fish species) in affected habitats, although the potential for recolonization from more distant areas would persist.
- The fish assemblage found in the SRSS represents a major and valuable source pool of fish for tributary streams of the SRP, the Savannah River, and contiguous swamp habitats.

Literature Cited

- Adams, G.F. and C.H. Olver. 1977. Yield properties and structure of boreal percid communities in Ontario. *Journal of the Fisheries Research Board of Canada* 34:1613-1625.
- Baker, J.A. and S.T. Ross. 1981. Spatial and temporal resource utilization by southeastern cyprinids. *Copeia* 1981:178-189.
- Balon, E.K. 1975. Reproductive guilds of fishes: a proposal and definition. *Journal of the Fisheries Research Board of Canada* 32:821-864.
- Balon, E.K. 1984. Patterns in the evolution of reproductive styles in fishes. In: *Fish Reproduction* (eds. G.W. Potts and R.J. Wootton), pp. 35-54. Academic Press: London. 410 pp.
- Benke, A.C. 1984. Secondary production of aquatic insects. In: *Ecology of aquatic insects* (eds. V.H. Resh and D.M. Rosenberg), pp. 289-322. Praeger Scientific: New York. 625 pp.
- Benke, A.C., T.C. Van Arsdall, D.M. Gillespie, and F.K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. *Ecological Monographs* 54:25-63.
- Bennett, D.H. and R.W. McFarlane. 1983. Fishes of the Savannah River Plant: National Environmental Research Park. National Environmental Research Park Report SRO-NERP-12. Savannah River Ecology Laboratory, Drawer E, Aiken, SC. 152 pp.
- Bennett, G.W. 1958. Aquatic Biology. In: *A century of biological research*, (eds. H.B. Mills, G.C. Decker, H.H. Ross, J.C. Carter, B.B. East, G.W. Bennett, T.G. Scott, J.S. Ayars, and R.R. Warwick. Illinois Natural History Survey Bulletin 27:1-234.
- Brinson, M.M., H.D. Bradshaw, R.N. Holmes, and J.B. Elkins, Jr. 1980. Litterfall, stemflow, and throughfall nutrient fluxes in an alluvial swamp forest. *Ecology* 61:827-835.
- Brinson, M.M., A.E. Lugo, and S. Brown. 1981. Primary productivity, decomposition, and consumer activity in freshwater wetlands. *Annual Reviews of Ecology and Systematics* 12:123-161.
- Brinson, M.M., H.D. Bradshaw, and R.H. Holmes. 1983. Significance of floodplain sediments in nutrient exchange between a stream and its floodplain. In: *Dynamics of Lotic Ecosystems* (eds. T.D. Fontaine, III and S.M. Bartell), pp. 199-221. Ann Arbor Science: Ann Arbor. 494 pp.
- Brown, S. 1981. A comparison of the structure, primary production, and transpiration of cypress ecosystems in Florida. *Ecological Monographs* 51:403-427.

- Carlson, J.E. and M.J. Duever. 1976. Seasonal fish population fluctuations in South Florida swamp. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies. 31:603-611.
- Christensen, E.J., M.E. Hodgson, J.R. Jensen, H.E. Mackey, Jr., and R.R. Sharitz. 1984. Pen Branch Delta Expansion. DPST-83-1087. E.I. duPont de Nemours and Co., Aiken, S.C. 19 pp.
- Clifford, H.T. and W. Stephenson. 1975. An introduction to numerical classification. Academic Press:New York. 229 pp.
- Coen, L.D., K.L. Heck, Jr., and L.G. Abele. 1981. Experiments on competition and predation among shrimps of seagrass meadows. Ecology 62:1484-1493.
- Connell, J.H. and W.P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. American Naturalist 121:789-824.
- Connor, W.H. and J.W. Day, Jr. 1976. Productivity and composition of a bald cypress-water tupelo site and a bottomland site in a Louisiana swamp. American Journal of Botany 63:1354-1364.
- Cooper, W.E. and L.B. Crowder. 1979. Structural complexity and fish-prey interactions in ponds: a point of view. In: Responses of fish to habitat structure in standing water (eds. D.L. Johnson and R.A. Stein), pp. 2-10. Special Publication Number 6, North Central Division, American Fisheries Society.
- Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interactions between bluegills and their prey. Ecology 63:1802-1813.
- Day, F.P. 1982. Litter decomposition rates in the seasonally flooded Great Dismal Swamp. Ecology 63:670-678.
- Diamond, J.M. 1978. Niche shifts and the rediscovery of interspecific competition. American Scientist 66:322-331.
- Diamond, J.M. and R. M. May. 1977. Species turnover rates on islands: dependence on census interval. Science 197:266-270.
- Dunn, C.P. and R.R. Sharitz. 1987. Revegetation of Taxodium-Nyssa forested wetland following complete vegetation destruction. Vegetatio 72:151-157.
- Emery, A.R. 1978. The basis of fish community structure: marine and freshwater comparisons. Environmental Biology of Fishes 3:33-47.
- Ewel, K.C. and H.T. Odum. 1978. Cypress domes: nature's tertiary treatment filter. In: Cypress wetlands for water management, recycling, and conservation (eds. H.T. Odum and K. C. Ewel), pp. 35-60. Fourth Annual Report to NSF-RANN and the Rockefeller Foundation. Gainesville, FL.
- Finger, T.R. and E.M. Stewart. In press, 1987. Responses of fish to flooding regime in lowland hardwood wetlands. In: Evolutionary and community ecology of North American stream fishes (eds. W.J. Matthews and D.C. Heins). University of Oklahoma Press: Norman, OK.

- Forbes, S.A. 1925. The lake as a microcosm. Illinois Natural History Survey Bulletin 15:537-550.
- Freeman, B.J. and M.C. Freeman. 1985. Production of fishes in a subtropical blackwater ecosystem: The Okefenokee Swamp. Limnology and Oceanography 30:686-692.
- Frey, D.G. 1951. The fishes of North Carolina's Bay lakes and their intraspecific variation. Journal of the Elisha Mitchell Science Society 67:1-44.
- Gatz, J. 1979. Community organization in fishes as indicated by morphological features. Ecology 60:711-718.
- Gee, J.H., R.F. Tallman, and H.J. Smart. 1978. Reactions of some Great Plains fishes to progressive hypoxia. Canadian Journal of Zoology 56:1962-1966.
- Gorman, O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507-515.
- Grossman, G.D., P.B. Moyle, and J.O. Whitaker. 1982. Stochasticity in structural and functional characteristics of an Indiana stream fish assemblage: a test of community theory. American Naturalist 120:423-454.
- Grossman, G.D. 1982. Dynamics and organization of a rocky intertidal fish assemblage: The persistence and resilience of taxocene structure. American Naturalist 119:611-637.
- Grossman, G.D. 1985. Long-term persistence in a rocky intertidal fish assemblage. Environmental Biology of Fishes 15:315-317.
- Guillory, V. 1979. The utilization of an inundated floodplain by Mississippi River fishes. Florida Scientist 42:222-228.
- Heck, K.L., Jr. and R.J. Orth. 1980. Seagrass habitats: the role of habitat complexity, competition, and predation in structuring associated fish and macroinvertebrate assemblages. In: Estuarine Perspectives (ed. V.S. Kennedy), pp. 449-464. Academic Press: New York.
- Jarvinen, O. 1979. Geographical gradients of stability in European land bird communities. Oecologia 38:51-69.
- Jumars, P.A. 1980. Rank correlation and concordance tests in community analyses: an inappropriate null hypothesis. Ecology 61:1553-1554.
- Keast, A. 1978. Trophic and spatial interrelationships in the fish species of an Ontario temperate lake. Environmental Biology of Fishes 3:7-31.
- Keast, A., J. Harker, and D. Turnbull. 1978. Nearshore fish habitat utilization and species associations in Lake Opinicon, Ontario. Environmental Biology of Fishes 3:173-184.

- Kondratieff, P. and B.C. Kondratieff. 1985. A lower food chain community study: thermal effects and post-thermal recovery in the streams and swamps of the Savannah River Plant. Report ECS-SR19, DPST-85-376. Environmental and Chemical Sciences, Inc., Aiken, SC.
- Kushlan, J.A. 1976. Environmental stability and fish community diversity. *Ecology* 57:821-825.
- Laerm, J., B.J. Freeman, L.J. Vitt, J.P. Meyers, and L. Logan. 1980. Vertebrates of the Okefenokee Swamp. *Brimleyana* 4:47-73.
- Laur, D.R. and A.W. Ebling. 1983. Predator-prey relationships in surfperches. *Environmental Biology of Fishes* 8:217-229.
- Larimore, R.W. 1954. Minnow productivity in a small Illinois stream. *Transactions of the American Fisheries Society* 84:110-116.
- MacArthur, R.H. 1972. *Geographical Ecology*. Harper and Row: NY.
- McLachlan, A.J. and S.M. McLachlan. 1975. The physical environment and bottom fauna of a bog lake. *Archiv für Hydrobiologie* 76:198-217.
- McNeely, D.L. 1987. Niche relations within an Ozark stream cyprinid assemblage. *Environmental Biology of Fishes* 18:195-208.
- Mendelson, J. 1975. Feeding relations among species of *Notropis* (Pisces, Cyprinidae) in a Wisconsin stream. *Ecological Monographs* 45:199-230.
- Menhinick, E.F. 1975. *The freshwater fishes of North Carolina*. University of North Carolina Press: Charlotte, NC.
- Minshall, G.W. 1984. Aquatic insect-substratum relationships. In: *The ecology of aquatic insects* (eds. V.H. Resh and D.M. Rosenberg), pp. 358-400. Praeger Scientific: New York. 625 pp.
- Moyle, P.B. and H.W. Li. 1979. Community ecology and predator-prey relations in warmwater streams. In: *Predator-prey systems in fisheries management* (ed. H. Clepper), pp. 171-180. Sport Fishing Institute: Washington, D.C.
- Moyle, P.B. and B. Vondracek. 1985. Persistence and structure of the fish assemblage in a small California stream. *Ecology* 66:1-13.
- Mulholland, P.J. 1981. Organic carbon flow in a swamp-stream ecosystem. *Ecological Monographs* 51:307-322.
- Nakashima, B.S., D. Gascon, and W.C. Leggett. 1977. Species diversity of littoral zone fishes along a phosphorus production gradient in Lake Memphremagog, Quebec-Vermont. *Journal of the Fisheries Research Board of Canada*. 34:167-170.
- Newman, M.J. 1986. Water Quality. In: *Comprehensive Cooling Water Report. Volume 2, Water Quality*. Savannah River Ecology Laboratory, Division of Wetlands Ecology, Drawer E, Aiken, SC.

- Paloumpis, A.A. 1958. Responses of some minnows to flood and drought conditions in an intermittent stream. *Iowa Journal of Science* 32:547-561.
- Pflieger, W.L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 pp.
- Rahel, F.J. and J.J. Magnuson. 1983. Low pH and the absence of fish species in naturally acidic Wisconsin lakes: inferences for cultural acidification. *Canadian Journal of Fisheries and Aquatic Sciences* 40:3-9.
- Repaske, W.A. 1981. Effects of heated water effluents on the swamp forest at the Savannah River Plant, South Carolina. M.A. thesis, University of Georgia: Athens. 81 pp.
- Ross, S.T. and J.R. Baker. 1983. The response of fishes to periodic spring floods in a southeastern stream. *American Midland Naturalist* 109:1-14.
- Rozas, L.P. and W.E. Odum. In press, 1987. Fish and macrocrustacean use of submerged plant beds in tidal freshwater marsh creeks. *Marine Ecology-Progress Series*.
- SAS. 1985. SAS User's Guide, Statistics. Version 5. Statistical Analysis Institute. Cary, NC.
- Schindler, D.W., K.H. Mills, D.F. Malley, D.L. Findlay, J.A. Shearer, I.J. Davies, M.A. Turner, G.A. Linsey, and D.R. Cruikshank. 1985. Long-term ecosystem stress: the effects of experimental acidification on a small lake. *Science (Washington, D.C.)* 228:1395-1401.
- Schlesinger, W.H. 1978. Community structure, dynamics, and nutrient cycling in the Okefenokee cypress swamp-forest. *Ecological Monographs* 48:43-65.
- Schlosser, I.J. 1982. Fish community structure and function along two habitat gradients in a freshwater stream. *Ecological Monographs* 52:395-414.
- Seigel, S. 1956. *Nonparametric Statistics*. McGraw-Hill Book Company:New York. 312 pp.
- Sharitz, R. R., J. E. Irwin, and E. J. Christy. 1974. Vegetation of swamps receiving reactor effluents. *Oikos* 25:7-13.
- Sharitz, R.R., K.W. Dyer, N.C. Martin, C.E. Mitchell, and R.L. Schneider. 1986. Effects of SRP Cooling Water Discharges on Regeneration of Floodplain Forests. In: *Comprehensive Cooling Water Report, Volume 1. Wetlands*. Savannah River Ecology Laboratory, Division of Wetlands Ecology, Drawer E, Aiken, SC. pp. 8-94.
- Sheldon, A.L. 1968. Species diversity and longitudinal succession in stream fishes. *Ecology* 49:193-198.
- Smith, M.H., R.R. Sharitz, and J.B. Gladden. 1981. An evaluation of the Steel Creek ecosystem in relation to the proposed restart of L-Reactor. Report prepared by the Savannah River Ecology Laboratory, Aiken, SC. SREL-9.

- Sousa, W.P. 1984. The role of disturbance in natural communities. *Annual Reviews of Ecology and Systematics* 15:353-392.
- Starrett, W.C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. *Ecology* 32:13-27.
- Surat, E.M., W.J. Matthews, and J.R. Bek. 1982. Comparative ecology of *Notropis albeolus*, *N. ardens*, and *N. cerasinus* in the upper Roanoke River drainage, Virginia. *American Midland Naturalist* 107:13-24.
- Thorp, J.H., E.M. McEwan, M. Flynn, and F.R. Hauer. 1985. Invertebrate colonization of submerged wood in a cypress-tupelo swamp and blackwater stream. *American Midland Naturalist* 113:56-68.
- Weiner, J.G. and J.P. Geisy, Jr. 1979. Concentrations of Cd, Cu, Mn, Pb, and Zn in fishes in a highly organic softwater pond. *Journal of the Fisheries Research Board of Canada* 36:270-279.
- Werner, E.E. 1977. Species packing and niche complementarity in three sunfishes. *American Naturalist* 111:553-578.
- Werner, E.E., D.J. Hall, D.R. Laughlin, D.J. Wagner, L.A. Wilsmann, and F.C. Funk. 1977. Habitat partitioning in a freshwater fish community. *Journal of the Fisheries Research Board of Canada* 34:360-370.
- Werner, E.E., D.J. Hall, and D.M. Werner. 1978. Littoral zone fish communities of two Florida lakes and a comparison with Michigan lakes. *Environmental Biology of Fishes* 3:163-172.
- Werner, E.E. and D.J. Hall. 1979. Foraging efficiency and habitat switching in competing sunfishes. *Ecology* 60:256-264.
- Werner, E.E., G.G. Mittlebach, D.J. Hall, and J.F. Gillam. 1983. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. *Ecology* 64:1525-1539.
- Wetzel, R.G. 1975. *Limnology*. W.B. Saunders Publishers: Philadelphia.
- Wharton, C.H., W.M. Kitchens, E.C. Pendelton, and T.W. Sipe. 1982. The ecology of bottomland hardwood swamps of the southeast: a community profile. U.S. Fish and Wildlife Service, Biological Sciences Program, Washington, D.C. FWS/OBS-81/37. 133 pp.
- Whitaker, J.O. 1976. Fish community changes at one Vigo County locality over a twelve year period. *Proceedings of the Indiana Academy of Science* 85:191-207.

IV. Structure of Fish Communities in the SRP Streams

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Introduction

A central goal of community ecology is to understand mechanisms and processes responsible for differences and similarities among communities. One approach to identify determinants of community organization is through comparative studies that examine communities occurring along environmental gradients such as physiological stress or resource availability. While providing valuable basic data, such an approach encourages the development of testable hypotheses eventually leading to more definitive studies of community structure, including experimental manipulations.

Existing models for the structure and dynamics of stream communities are largely based on patterns observed in forested temperate streams. For example, the River Continuum Concept relates changes in community structure along stream gradients to changes in physical characteristics of stream habitats (Vannote et al., 1980; Minshall et al., 1985). The concept suggests that physical aspects of stream morphology are relatively predictable from upstream to downstream areas resulting in consistent patterns of lotic community organization along the lengths of rivers. Prior studies of stream fishes have provided supportive evidence for a consistent pattern of community organization associated with spatial or temporal changes in channel morphology and resource availability (e.g., Horwitz, 1978; Schlosser, 1982a,b). It has been hypothesized that fish assemblage structure in headwater reaches is generally unstable with natural variation in community composition resulting from temporal fluctuations in reproductive success and chance recolonization from downstream refugia. The more stable environmental conditions present in downstream habitats presumably allow biotic interactions (i.e., competition, predation) to become important

determinants of how species exploit food resources and space. Under this conceptual model, persistence (continued presence of species), stability (relative constancy of numbers), and trophic complexity should be greater in downstream reaches of streams.

Because of the limited database and geographic perspective used to develop stream models, tests are needed in other regions. In this paper, the relative importance of physical and biological factors in shaping stream fish community structure along upstream-downstream gradients is examined in three coastal plain streams from South Carolina. The streams selected are useful in this comparative approach because each has historically experienced different perturbation regimes from thermal effluents released by two nuclear production reactors. These disturbances have resulted in changes in riparian vegetation characteristics, and lower food chain dynamics as well as isolating each stream to different degrees from downstream refugia. Specifically, the following questions were addressed: (1) Do patterns of fish species richness, diversity, abundance, and trophic composition change along upstream-downstream habitat gradients and between streams? (2) Do particular locations within streams exhibit greater compositional variability over time?, and (3) Is upstream migration important to community persistence and stability? Our long-term goal is to identify basic patterns as a first step in investigating the organizational processes of streams and their biotic communities. These findings also relate to, and should be invaluable in, assessing the impact perturbation regimes associated with reactor operations impose on stream systems and eventually lead to identification of appropriate management programs.

Study Areas

The three stream systems selected for study are located on the U.S. Department of Energy's Savannah River Plant (SRP) near Aiken, South Carolina (Figure 4.1). Pen Branch, Meyer's Branch, and Steel Creek are typical of other SRP, and coastal plain streams in general, by having a low gradient (0.2 - 3 m/km, maximum 8 m/km) and flowing through predominantly sandy sediments. Water is normally clear except during flooding, but is lightly to intensely colored by organic compounds. Past and present disturbances caused by the operation of three nuclear production reactors differentiate the three streams making them useful systems for evaluating hypotheses about factors controlling community organization.

Channel morphology and riparian vegetation were altered along most of Steel Creek from 1954 through 1968 when thermal effluents from two nuclear production reactors were periodically discharged into the stream. During periods of reactor activity, water temperatures exceeded 40°C, and discharge rates were approximately 11.3 m³/s along the length of Steel Creek. On occasion, discharge rates were as high as 22 m³/s (Ruby et al., 1981). The stream has been undergoing post-thermal recovery since 1968 with mean daily water temperatures now ranging from 7-25°C and discharge rates typically <2 m³/s. However, the composition of the riparian vegetation and organic matter processing dynamics of Steel Creek still differ from other blackwater streams on the SRP (e.g., greater seston concentration and larger particle size during base flow and slower leaf decomposition rates; Hauer, 1985). The abundance and diversity of macroinvertebrates is also reduced in Steel Creek compared to other local stream systems (Kondratieff and Kondratieff, 1985). Differences between these streams is probably related to reduced availability of woody snags, a major site of invertebrate secondary

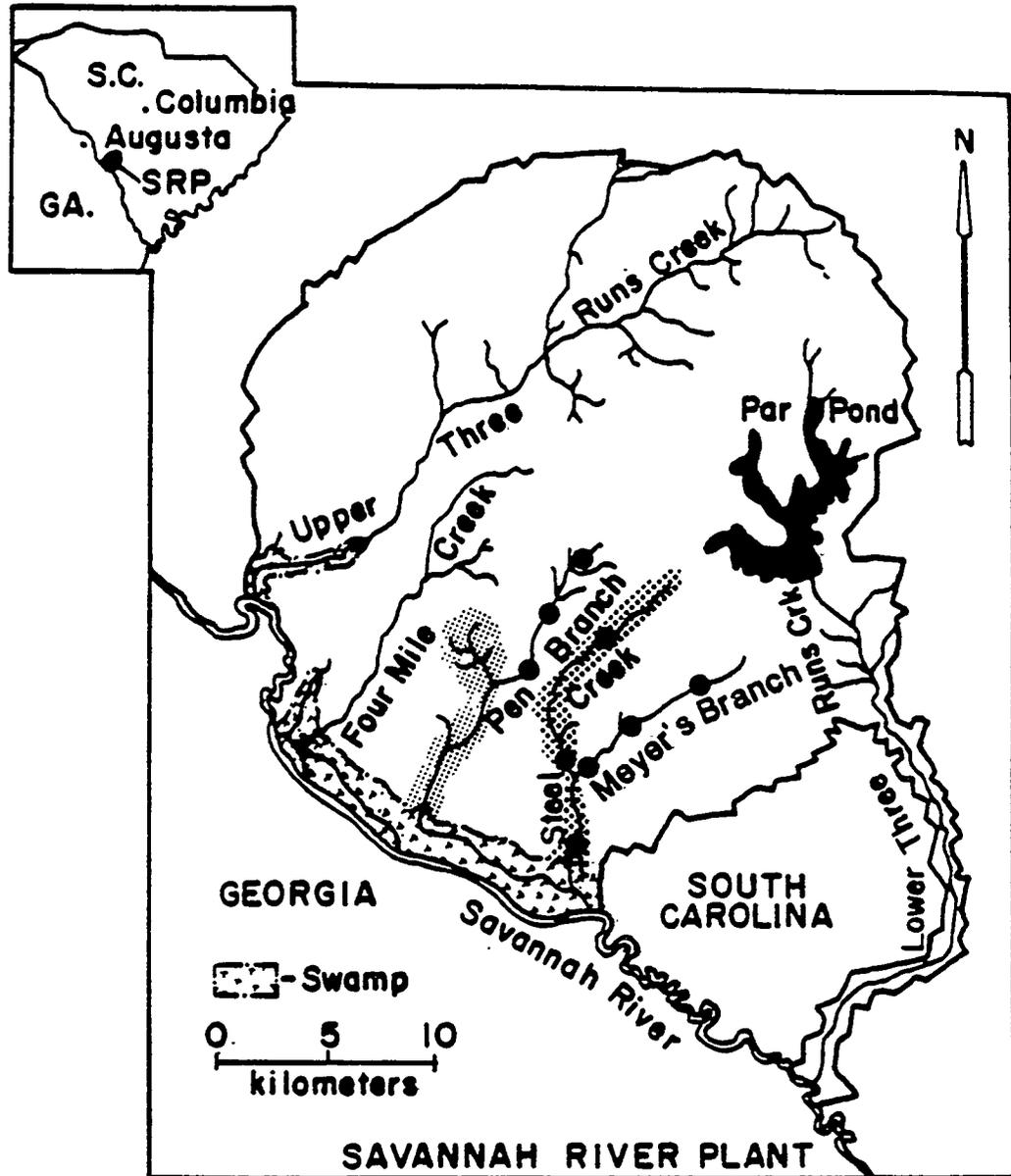


Figure 4.1. Location of study sites in three streams on the Savannah River Plant, South Carolina. Shading on Pen Branch depicts thermally impacted regions. Shading on Steel Creek indicates post-thermal recovery areas. Unshaded portions of Pen Branch and Meyer's Branch show regions unimpacted by thermal effluents. Sites are numbered sequential in a downstream direction.

production in southeastern streams (Benke et al. 1984; Smock et al., 1985), because of the previous high flow rates in Steel Creek. Changes in riparian vegetation, as an energy source, may also be an important determinant of changes in invertebrate community dynamics (Webster and Waide, 1982).

Where collections were made (i.e., upstream of reactor discharges), Pen Branch and Meyer's Branch had never been directly subjected to increased water temperatures and flow rates associated with reactor operations. Both are heavily shaded with a well developed riparian vegetation of bottomland hardwoods or cypress forests that contribute woody material and shape channel form around stumps and roots of living trees. Each stream, however, has historically been isolated from downstream regions for varying lengths of time. Since the early 1950s, thermal effluents have functioned as a barrier isolating the upper reaches of Pen Branch from downstream reaches except for brief periods of time, generally 3-5 days each month, when regional ambient water temperatures and flows ($< 2 \text{ m}^3/\text{s}$) are reestablished and fish may potentially move upstream. As a tributary of Steel Creek, Meyer's Branch had been isolated until 1968 when reactor operations ceased and flow and temperature returned to approximately pre-disturbance conditions. Thus, Meyer's Branch, Pen Branch, and Steel Creek represent a 'natural experiment' because the streams differ in degree of isolation from downstream reinvasion and prior disturbance regimes altering trophic dynamics.

Methods

The importance of physical and biological factors controlling fish assemblage structure was assessed by examining changes of community attributes between, and longitudinally within, streams. Fish populations were sampled quarterly beginning March 1984 at seven sites: three along

Pen Branch (PB), three along Steel Creek (SC), and one on Meyer's Branch (MB2) (Figure 4.1). Sites in each stream were sequentially numbered (1 to 3) in a downstream direction. Collections continued through December 1985 with the following exceptions: PB1 after spring 1985 when this site completely dried and all sites on Steel Creek after October 1985 accompanying the creation of a new reservoir to receive thermal discharges from the restart of a reactor (L-Reactor) facility on the SRP. Quarterly collections at two additional sites in Meyer's Branch (MB1 and MB3) were begun in spring 1985. The sites selected were representative of major macrohabitat characteristics in each drainage system.

At each site, a 100 m section of stream was selected for sampling. Block nets (6 mm mesh) were placed across the stream at 50 m intervals to prevent fishes from escaping from an area. Three sequential passes were made within a subsection using a backpack or portable electroshocker (D.C. pulsed). All fish collected were identified, measured for total length (TL), enumerated, and then released into the section of stream where they were captured. Total numbers of fish collected at each site were used to calculate the Shannon-Weiner diversity index, $H' = - \sum p_i \ln(p_i)$ (Southwood, 1978) where p_i is the numerical proportion of species i in the assemblage. Kruskal-Wallis one-way analysis of variance by ranks was used to detect differences in diversity, species richness, and relative abundance (calculated as number of individuals per 100 m²) between stream systems and sites within the different streams. Correlation analyses were used to examine relationships of species richness to stream width. All analyses followed procedures outlined in Sokal and Rohlf (1981) or Daniel (1978). An alpha level of 0.05 was used to indicate significance.

Persistence of the species assemblage (continued presence or absence of species at a site) was measured using a modification of a faunal turnover index (Diamond and May, 1977; Jarvinen, 1979; Meffe and Minckley, 1987). Turnover between any two samples was calculated by the formula $T = (C + E)/(S_1 + S_2)$ where C and E are the number of species appearing or disappearing between sample periods, and S_1 and S_2 are the total number of species in each sample. An index of persistence (PR) was then calculated from $1 - \bar{T}$ where \bar{T} is the mean turnover for the assemblage from all adjacent sample periods. Persistence values range from 0 (complete turnover of the assemblage) to 1.0 (complete persistence).

Assemblage stability was tested by analyzing concordance of ranked relative abundances over the study period. This procedure tests the null hypothesis that rankings of species abundance change randomly over time. Rejection of the null hypothesis supports the alternative hypothesis that the assemblage has some degree of temporal consistency. Kendall's coefficient of concordance (W), after correcting for ties, is a nonparametric procedure to test the significance of changes in species composition over time (Conover, 1971). Significance of W was tested using χ^2 values following suggestions by Conover (1971).

For the concordance analysis, only species representing at least 1% of the numerical abundance in any seasonal collection at a site were included. This omits rare or infrequently captured species whose capture might not accurately reflect their abundance, or presence or absence, at a locality. Recently, Jumars (1980) pointed out that statistical tests for rank correlation were, in general, suspect since they are based on the null hypothesis that all rankings are equally likely to occur. Because these analyses were done on a truncated species list, virtually all of the species included were thought to be

able to achieve moderate to high abundance ranks. Thus, it is felt that our use of statistical tests for rank correlation were appropriate.

To compare distributions of fish species within the stream systems, classification analyses were used to group sites on the basis of their similarity in species abundances. Relative abundances of species collected at a site were converted to standardized data ($\bar{x} = 0, s = 1.0$). This standardization weights all species equally, and prevents domination of results by abundant species. Cluster analysis (average linkage) was done using the Statistical Analysis System (SAS, 1985).

Habitat characteristics at each site were surveyed each season when fish collections were made by recording stream width, depth, current velocity, and substrate composition (Table 4.1). Line transects positioned at 5 m intervals in the stream sections were used to determine habitat structure by estimating the percent each substrate type (e.g., sand, mud, snags) comprised relative to transect length. Depth and current velocities were measured at 3-5 positions on each transect, the number of measurements being dependent on stream width. Canopy cover was the estimated areal coverage of riparian vegetation overhanging the stream channel. Measurements of stream discharge were obtained from U.S. Geological Survey gauging stations located on Pen Branch (PB3) and Steel Creek (SC1 and SC3). No gauge was present on Meyer's Branch; stream discharge estimates were obtained by the differential between the two gauges on Steel Creek. Although discharge rates presented are only from October 1983 through August 1985, they are typical of the entire study period.

Fish were classified into one of four trophic groups based on personal observations (Aho et al., unpublished data) and published sources (Carlander, 1969, 1977; Smith, 1979; Bennett and McFarlane, 1983). Surface water

Table 4.1 Selected habitat characteristics of sites on three SRP streams. Values were calculated over all available samples.

	Pen Branch 1	Pen Branch 2	Pen Branch 3	Steel Creek 1	Steel Creek 2	Steel Creek 3	Meyer's Branch 1	Meyer's Branch 2	Meyer's Branch 3
Mean width (m)	1.5	2.2	4.4	4.5	3.5	8.8	3.8	5.0	8.5
Area (m ²)	150	220	440	450	350	880	380	500	850
Mean depth (cm)	28	18	20	25	22	43	24	39	36
Gradient (m/km)	3.1	2.9	2.8	4.6	3.0	1.3	3.5	2.3	1.3
Character:									
% pool	50	10	5	10	0	5	10	5	10
% canopy cover	90	80	90	30	50	10	95	90	90
Substrate:									
% sand and mud	55	85	85	90	90	95	60	80	85
% gravel	20	5	0	0	5	0	15	0	0
% cobble	0	0	5	5	0	0	5	0	0
% hard structure*	25	10	10	5	5	5	20	20	15
% leaf & detritus cover**	35	25	5	<5	<5	<5	5	5	5
Mean velocity (cm/s)*** range	25.0 (15-80)	26.3 (15-100)	26.3 (21-100)	57.8 (21-115)	54.6 (26-90)	43.8 (25-55)	26.4 (5-55)	27.1 (12-49)	31.4 (15-70)
Water temperature (°C)									
Mean	12.8	13.1	13.5	17.2	15.9	15.4	15.5	15.4	16.7
Max	22.0	22.0	22.1	27.5	26.0	25.4	25.2	24.9	25.5
Min	1.4	1.9	1.4	4.6	6.4	6.9	3.2	3.0	3.1

* Represented by snags, exposed roots, and rooted vegetation.

** Present primarily only during fall; estimated coverage overlying mineral substrate.

*** Only values from mid-channel measurements presented.

invertivores (SWI) fed on drift in the water column and terrestrial insects at the water surface. Generalized invertivores (GI) ingested a range of animal and plant material, including terrestrial and aquatic insects, and small fish; <25% of their diet was plant matter or detritus. Benthic invertivores (BI) ingested predominantly immature benthic macroinvertebrates. Invertivore-piscivores (IP) fed on a variety of aquatic invertebrates and small fish; species ranged from almost complete piscivory (Esox americanus) to lesser degrees of piscivory and increased ingestion of invertebrates (e.g., Lepomis gulosus). Species captured in all streams, and their assignment to trophic groups, are listed in Table 4.2. Temporal variability in trophic composition at each site was examined using X^2 tests.

Results

Habitat structure

Temporal variation in discharge was similar in all three streams during the two-year sample period (Figure 4.2). Flow rates were generally highest from October 1983 through May 1984 and quite variable within a month. This was particularly evident in Steel Creek where daily fluctuations in natural stream flow were also periodically augmented by tertiary treated wastewater from one of the reactor sites. Discharge rates then declined and remained at low levels for the remainder of the period data was available and for the duration of the study. For portions of Steel Creek and Pen Branch, water levels changed sufficiently that some stream sections remained completely dry for portions of the study (PB1) or were temporarily dewatered for ca. 3 weeks in June 1985 (SC2). The prolonged period of reduced discharge was associated with a severe drought in the southeastern U.S.

Table 4.2. Names and trophic classification of fish species collected from Pen Branch, Steel Creek, and Meyer's Branch. Trophic groups: surface-water invertivore (SWI), generalized invertivore (GI), benthic invertivore (BI), and invertivore-piscivore (IP).

Scientific name	Common name	Trophic classification
<i>Notropis lutipinnis</i>	Yellowfin shiner	SWI
<i>Nocomis leptcephalus</i>	Bluehead chub	GI
<i>Notropis chalybaeus</i>	Ironcolor shiner	SWI
<i>Notropis cummingsae</i>	Dusky shiner	SWI
<i>Notropis emiliae</i>	Pugnose minnow	SWI
<i>Notemigonus crysoleucas</i>	Golden shiner	SWI
<i>Hybopsis rubrifrons</i>	Rosyface chub	SWI
<i>Notropis leedsii</i>	Bannerfin shiner	SWI
<i>Semotilus atromaculatus</i>	Creek chub	SWI
<i>Notropis petersoni</i>	Coastal shiner	SWI
<i>Hypentelium nigricans</i>	Northern hogsucker	BI
<i>Erimyzon suzefta</i>	Lake chubsucker	BI
<i>Erimyzon oblongus</i>	Creek chubsucker	BI
<i>Minytrema melanops</i>	Spotted sucker	BI
<i>Ictalurus natalis</i>	Yellow bullhead	BI
<i>Ictalurus nebulosus</i>	Brown bullhead	BI
<i>Ictalurus platycephalus</i>	Flat bullhead	IP
<i>Ictalurus brunneus</i>	Snail bullhead	GI
<i>Noturus leptacanthus</i>	Speckled madtom	IP
<i>Noturus insignis</i>	Margined madtom	IP
<i>Noturus gyrinus</i>	Tadpole madtom	IP
<i>Micropterus salmoides</i>	Largemouth bass	IP
<i>Acantharchus pomotis</i>	Mud sunfish	IP
<i>Lepomis marginatus</i>	Dollar sunfish	GI
<i>Lepomis auritus</i>	Redbreast sunfish	GI
<i>Lepomis punctatus</i>	Spotted sunfish	GI
<i>Centrarchus macropterus</i>	Flier	GI
<i>Lepomis gulosus</i>	Warmouth	IP
<i>Lepomis macrochirus</i>	Bluegill	GI
<i>Enneacanthus chaetodon</i>	Blackbanded sunfish	GI
<i>Enneacanthus gloriosus</i>	Bluespotted sunfish	GI
<i>Elassoma zonatum</i>	Banded pygmy sunfish	GI
<i>Esox americanus</i>	Redfin pickerel	IP
<i>Esox niger</i>	Chain pickerel	IP
<i>Amia calva</i>	Bowfin	IP
<i>Labidesthes sicculus</i>	Brook silverside	SWI
<i>Anguilla rostrata</i>	American eel	IP
<i>Aphredoderus sayanus</i>	Pirate perch	GI
<i>Umbra pygmaea</i>	Eastern mudminnow	GI
<i>Chologaster cornuta</i>	Swampfish	BI
<i>Gambusia affinis</i>	Mosquitofish	SWI
<i>Fundulus lineolatus</i>	Lined topminnow	SWI
<i>Fundulus chrysotus</i>	Gold topminnow	SWI
<i>Perca flavescens</i>	Yellow perch	IP
<i>Etheostoma fricksium</i>	Savannah darter	BI
<i>Etheostoma olmstedii</i>	Tessellated darter	BI
<i>Etheostoma fusiforme</i>	Swamp darter	BI
<i>Etheostoma serriferum</i>	Sawcheek darter	BI
<i>Percina nigrofasciata</i>	Blackbanded darter	BI

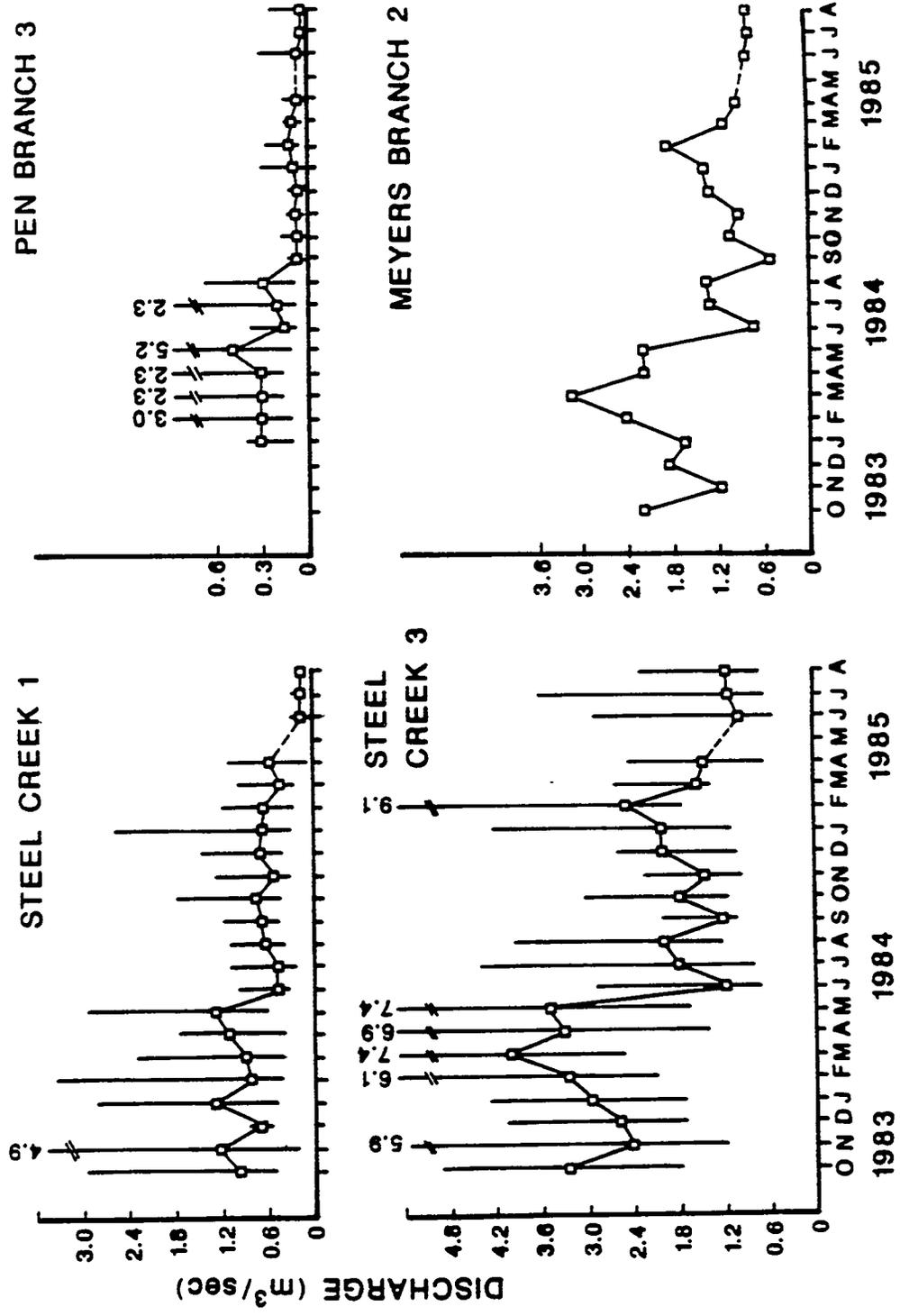


Figure 4.2. Temporal variation in mean monthly discharge during the 2-year sample at the USGS gauging stations on Steel Creek (SC1 and SC3) and Pen Branch (PB3). The values for Meyer's Branch were the differential between SC1 and SC3. Vertical bars represent the range in mean daily flow rates in the stream channel.

Habitat heterogeneity within and between streams was limited (Table 4.1). Substrate composition was similar between streams being dominated by erosional sand. Sites in Steel Creek generally had the lowest substrate heterogeneity (approximately 5% hard structure and 5% leaf/detrital cover) and the highest mean current velocities although the range was comparable among all sites. Habitat structure was similar at comparable sites within each stream with greater substrate variability in the headwater reaches and domination by sand in the downstream most sites. Pen Branch 1 differed slightly in being the only site having well-defined run-pool sequences. Pool habitats were present in other sites, but were formed primarily in the vicinity of a bend in the channel. Of the other physical variables measured, channel width and canopy closure differed most between sites, but these differences were characteristic of the particular site rather than the watershed. Habitat structure fluctuated seasonally, but was more influenced by temporal changes in habitat volume than in significant shifts in substrate composition.

Fish assemblage structure

Fish community diversity differed slightly between stream systems. Steel Creek had the highest diversity followed by slightly lower values for Pen Branch and Meyer's Branch (Table 4.3). The differences between stream drainages were, however, not significant (Kruskal-Wallis ANOVA, $H = 1.16$, $p > 0.10$). Significant changes in assemblage diversity were nevertheless apparent between sites (Kruskal-Wallis ANOVA, $H = 16.68$, $df = 8$, $p < 0.05$). Within each stream, diversity was greatest at the downstream sites, and except for PB1, increased in a downstream direction. No consistent temporal pattern of variation in assemblage diversity was observed along the

Table 4.3 Species diversity (H'), species richness, and mean relative abundance (individuals per 100 m²) of fish assemblages from nine stream sites on the Savannah River Plant from March 1984 through December 1985.

	Stream Sites								
	Pen Branch			Steel Creek			Meyer's Branch		
	PB1	PB2	PB3	SC1	SC2	SC3	MB1	MB2	MB3
Diversity	1.85	1.77	1.93	1.64	2.03	2.16	1.53	1.80	1.95
Spring 1984	1.85	2.18	2.13	1.74	2.09	1.86	-	1.67	-
Summer	1.88	1.94	2.11	2.07	2.49	2.08	-	1.99	-
Fall	1.94	1.64	2.15	1.45	2.31	2.14	-	2.07	-
Winter	1.74	1.34	1.91	1.79	1.30	1.49	-	1.44	-
Spring 1985	1.83	1.68	2.19	1.59	2.22	2.41	1.42	1.55	1.90
Summer	*	1.97	1.58	1.43	2.15	2.59	1.36	1.77	2.26
Fall	-	1.79	1.76	1.41	1.67	2.54	1.61	1.91	1.93
Winter	-	1.63	1.59	-	-	-	1.72	2.01	1.71
Species Richness	8.4	15.1	17.3	15.9	17.9	25.0	17.3	18.8	19.5
Spring 1984	10	18	16	15	18	24	-	16	-
Summer	8	12	18	19	22	26	-	17	-
Fall	8	13	17	12	17	23	-	15	-
Winter	6	16	18	16	14	21	-	25	-
Spring 1985	10	13	16	12	20	26	20	14	18
Summer	-	18	21	17	16	29	16	20	19
Fall	-	17	18	20	18	26	18	24	20
Winter	-	14	14	-	-	-	15	19	21
Relative Abundance	41.2	87.5	51.7	80.3	47.9	62.3	104.5	70.6	44.2
Spring 1984	50.7	45.0	32.9	69.1	42.3	34.2	-	78.4	-
Summer	26.0	50.5	29.3	40.2	55.1	55.5	-	43.4	-
Fall	45.3	100.9	25.0	26.4	53.4	25.5	-	25.8	-
Winter	36.7	121.8	66.6	50.0	33.1	57.0	-	127.0	-
Spring 1985	47.3	68.2	38.2	32.7	44.6	67.5	101.8	48.6	38.4
Summer	-	91.8	91.6	122.7	40.6	98.5	97.9	85.6	28.4
Fall	-	119.1	74.8	221.3	66.3	49.9	129.7	102.0	67.0
Winter	-	102.5	55.2	-	-	-	88.4	53.6	42.8

* Indicates no data available. Pen Branch 1 had dried up due to extended drought conditions. Steel Creek sites were either in, or immediately downstream of, a newly constructed reservoir after October 1985. Meyer's Branch 1 and 3 were not sampled until after the study had been underway for a year.

upstream-downstream gradient, but was generally greatest in Steel Creek. Seasonal patterns of change were comparable between sites with values usually being lowest in winter.

The pattern of mean species richness across streams was similar to that of diversity (Table 4.3). Overall, species richness ranged from 8.4 to 25.0. Although the number of species was slightly higher in Steel Creek, there were no significant differences between stream systems (Kruskal-Wallis ANOVA, $H = 3.80$, $p > 0.10$). Changes in species richness between sites (Kruskal-Wallis ANOVA, $H = 33.71$, $df = 8$, $p < 0.005$) were, however, observed in all streams. Richness was considerably lower in the upstream reaches and progressively increased in downstream regions. Stream size had a significant effect on species richness (Spearman rank correlation, $r = 0.83$, $df = 7$, $p < 0.05$). Temporal variability in the number of species was observed at all sites, but like diversity, there was no consistent trend in the extent of variation observed either along the upstream-downstream gradient within streams or between stream systems. Numbers of species at a site varied over time, but exhibited no consistent pattern of change. Variability in assemblage complexity within a site was influenced by the periodic inclusion of infrequently captured species (see Table 4.5).

Between Pen Branch, Meyer's Branch, or Steel Creek, there were no significant differences in the mean relative abundance (number of individuals per 100 m² of stream) of fish (Kruskal-Wallis ANOVA, $H = 0.28$, $p > 0.50$). For each stream, however, fish abundance was highly variable both temporally and spatially. There was no consistent overall pattern either within or between seasons for abundance changes along the upstream-downstream gradient. In Pen Branch, abundance was greatest at the middle reach station (PB2) whereas in Steel Creek, the middle site (SC2) generally had the fewest

fish. Progressive declines in abundance were observed in Meyer's Branch in the downstream regions. Temporal changes within sites emphasize variability in recruitment success, but there was no obvious association with flow regime (Figure 4.2).

Total richness (the total number of species recorded over all collections from each stream-site category) changed longitudinally within each stream system (Table 4.4). Proceeding downstream from the headwaters, changes in fish composition were associated with the gradual addition of species. There were few cases of species replacement. Shifts in compositional abundance between sites occurred for most species, declining in all directions (upstream, downstream, or mixed being either least or most abundant at mid-stream sites). Of the 49 recorded species representing 16,660 individuals, nine were ubiquitous in occurrence across all sites and eight of these (yellowfin shiner Notropis lutipinnis, bluehead chub Nocomis leptcephalus, speckled madtom Noturus leptacanthus, redbreast sunfish Lepomis auritus, spotted sunfish L. punctatus, pirate perch Aphredoderus sayanus, redbfin pickerel Esox americanus, and tessellated darter Etheostoma olmstedi) alone accounted for >80% of all the individuals collected. Yellowfin shiners were the single most abundant fish representing >40% of the total numerical abundance in any stream. An additional eleven species were present at seven or eight of the sites. No unique species were associated with the headwater reaches of any stream. The proportion of the total richness of species in each stream that was ubiquitous in occurrence tended to decrease in a downstream direction. Values ranged from 83 to 35% in Pen Branch, 46 to 31% in Meyer's Branch, but were lower and more variable in Steel Creek (SC1-33%, SC2-39%, SC3-23%). Overall, the pattern suggests increasing faunal uniqueness of the fish assemblage in a downstream direction.

Table 4 4 Distribution and percent composition of the fish assemblages collected from streams on the Savannah River Plant.

	Stream Sites									
	PB1	PB2	PB3	SC1	SC2	SC3	MB1	MB2	MB3	
<i>Notropis lutipinnis</i>	-	51.7	50.9	53.8	41.1	9.6	59.4	54.7	43.9	
<i>Nocomis leptoccephalus</i>	-	9.7	3.0	13.6	13.2	0.2	8.9	8.0	2.0	
<i>Hypentelium nigricans</i>	-	-	-	11.3	1.7	0.4	0.6	1.0	1.6	
<i>Ictalurus nebulosus</i>	11.7	1.6	0.3	<0.1	0.1	0.2	0.1	0.1	0.5	
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	13.0	1.6	1.1	0.9	1.5	0.5	1.6	3.2	1.9	
<i>Ictalurus natalis</i>	3.2	0.7	0.3	0.1	0.6	0.5	-	0.1	0.8	
<i>Ictalurus platycephalus</i>	-	1.5	0.8	2.0	1.2	0.3	0.1	0.5	0.3	
<i>Noturus insignis</i>	-	1.1	4.2	0.6	0.4	0.2	1.0	2.2	0.1	
<i>Noturus lepacanthus</i>	-	-	4.8	2.6	3.2	2.3	1.7	1.8	3.1	
<i>Noturus gyrinus</i>	-	0.7	0.1	0.7	1.4	0.4	0.9	0.1	0.3	
<i>Lepomis marginatus</i>	19.4	0.7	0.1	0.2	1.5	0.5	1.4	0.5	0.1	
<i>Lepomis auritus</i>	0.9	1.5	5.4	7.2	2.7	3.8	2.2	4.0	1.9	
<i>Lepomis punctatus</i>	-	4.4	4.4	4.4	5.9	14.6	1.5	2.4	4.9	
<i>Micropterus salmoides</i>	-	0.1	0.5	0.4	0.8	2.5	-	0.2	0.1	
<i>Anguilla rostrata</i>	0.7	1.3	0.4	1.2	1.2	3.8	0.4	0.9	10.9	
<i>Aphredoderus sayanus</i>	7.8	11.5	8.8	0.2	6.4	11.2	10.6	8.9	9.3	
<i>Gambusia affinis</i>	-	-	0.5	0.8	5.0	0.4	-	0.2	0.1	
<i>Esox niger</i>	-	0.3	0.6	0.2	1.7	0.4	1.4	0.6	1.4	
<i>Esox americanus</i>	12.3	5.9	0.6	0.2	0.2	0.9	-	0.2	0.1	
<i>Acantharchus pomotis</i>	27.2	1.5	-	<0.1	-	<0.1	-	<0.1	0.1	
<i>Notropis chalybaeus</i>	-	0.1	-	0.3	0.4	0.3	2.7	1.8	1.1	
<i>Etheostoma frickium</i>	-	3.4	3.5	2.3	2.3	1.9	0.3	0.7	1.3	
<i>Percina nigrofasciata</i>	-	-	0.1	2.3	0.4	<0.1	-	0.1	-	
<i>Fundulus lineolatus</i>	-	-	4.6	0.2	4.3	8.6	1.4	4.8	8.8	
<i>Etheostoma olmstedii</i>	-	0.5	0.4	0.1	1.2	23.8	3.5	1.9	4.4	
<i>Notropis cummingsae</i>	1.9	-	0.1	-	-	-	-	-	-	
<i>Amia calva</i>	-	-	-	-	-	-	-	-	-	
<i>Semotilus atromaculatus</i>	-	-	-	0.1	0.3	-	0.2	-	-	
<i>Notropis petersoni</i>	-	-	-	<0.1	1.9	7.2	-	-	-	
<i>Lepomis gulosus</i>	-	-	0.1	<0.1	-	0.2	0.1	0.1	-	
<i>Enneacanthus gloriosus</i>	-	-	-	0.1	-	0.1	-	0.1	-	
<i>Elassoma zonatum</i>	-	-	0.1	-	-	<0.1	-	-	-	
<i>Etheostoma serriferum</i>	-	-	-	-	-	0.2	-	-	-	
<i>Notropis emiliae</i>	-	-	-	-	-	0.2	-	0.1	0.1	
<i>Percia flavescens</i>	-	-	-	0.2	-	<0.1	-	0.1	-	
<i>Notemigonus crysoleucas</i>	-	-	-	0.2	-	<0.1	-	<0.1	0.1	
<i>Centrarchus macropterus</i>	-	-	-	-	-	<0.1	-	<0.1	0.1	
<i>Chologaster cornuta</i>	-	0.1	-	-	-	0.9	-	<0.1	-	
<i>Ictalurus brunneus</i>	-	-	-	-	-	-	-	<0.1	-	
<i>Umbra pygmaea</i>	-	-	0.1	-	0.1	0.1	-	-	0.1	
<i>Minytrema melanops</i>	-	-	-	0.8	-	0.8	-	-	-	
<i>Etheostoma fusiforme</i>	-	-	0.1	-	-	0.3	-	-	-	
<i>Hybopsis rubrifrons</i>	-	-	-	-	-	<0.1	-	-	-	
<i>Notropis leedsi</i>	-	-	-	-	-	<0.1	-	-	-	
<i>Labidesthes sicculus</i>	-	-	-	-	-	0.2	-	-	-	
<i>Enneacanthus chaetodon</i>	-	-	-	-	-	<0.1	-	<0.1	-	
<i>Lepomis macrochirus</i>	-	0.1	-	-	-	<0.1	-	-	0.2	
<i>Fundulus chrysotus</i>	-	-	-	-	-	-	-	-	-	
Number of collections	5	8	8	7	7	7	4	8	4	
Total number of individuals	309	1519	1809	2531	1174	3415	1579	2823	1501	
		417	875	517	803	479	623	1045	706	442

Despite the widespread occurrence of most species, the cluster analysis effectively displayed spatial variation in the fish communities (Figure 4.3). It indicated a low level of similarity between the assemblages at PB1 and SC3 and those of the remaining sites. Common to both these sites was either the absence, or low abundance, of yellowfin shiners. While sites from the same stream system are occasionally grouped together providing evidence of faunal affinity, the inclusion of the remaining seven sites within the same major group suggests a high degree of similarity (low distance separating sites) within and between streams regardless of prior disturbance regimes.

The consistency in assemblage composition was also demonstrated in the trophic structure of the fish assemblages. Community trophic structure was considered stable across both seasons and sites. Only at two Meyer's Branch sites (MB1 and MB3) and one Steel Creek site (SC1) were significant shifts in composition observed ($\chi^2 = 50.1$, $df = 9$; $\chi^2 = 58.2$, $df = 9$; $\chi^2 = 100.7$, $df = 18$, respectively, all $p < 0.01$). The direction of compositional change was similar in all three locations with greater recruitment success of generalized invertivores (e.g., bluehead chub) in association with the low flow regime in 1985 (Table 4.5). These temporal differences, however, did not influence the pattern of essentially no difference in trophic structure across stream sites except at PB1 (Figure 4.4). Surface water invertivores were the dominant feeding group at most sites. Representation by generalist invertivores and benthic invertivores were similar and invertivore-piscivores were least numerous. In contrast, the trophic structure at PB1 was strongly dominated by invertivore-piscivores. Contributions of generalist and benthic invertebrate feeding fishes to the entire assemblage were similar to other sites.

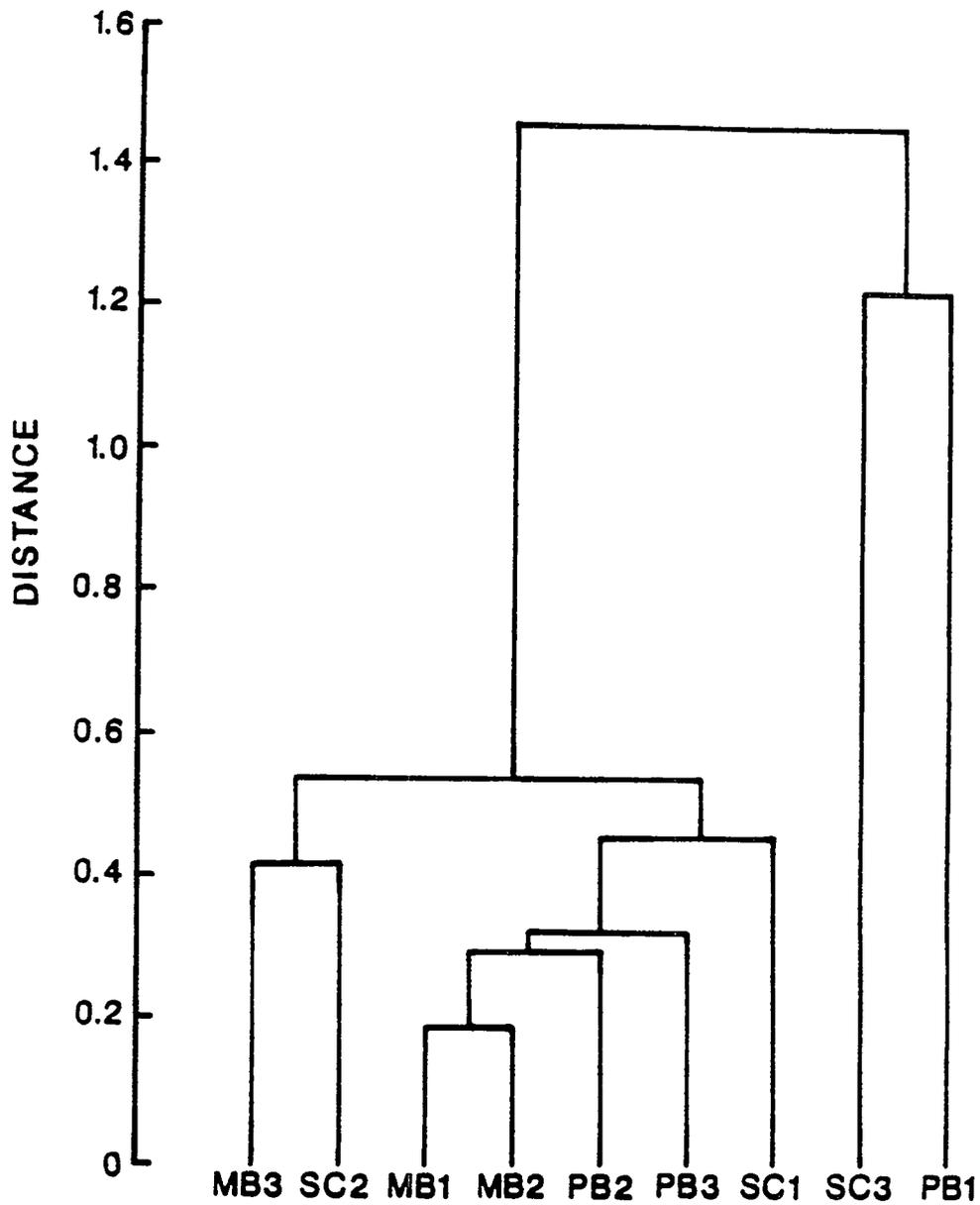


Figure 4.3. Classification analysis of the nine stream sites on the Savannah River Plant using average linkage clustering. Stream site abbreviations are Pen Branch (PB-13), Steel Creek (SC1-3), and Meyer's Branch (MB1-3).

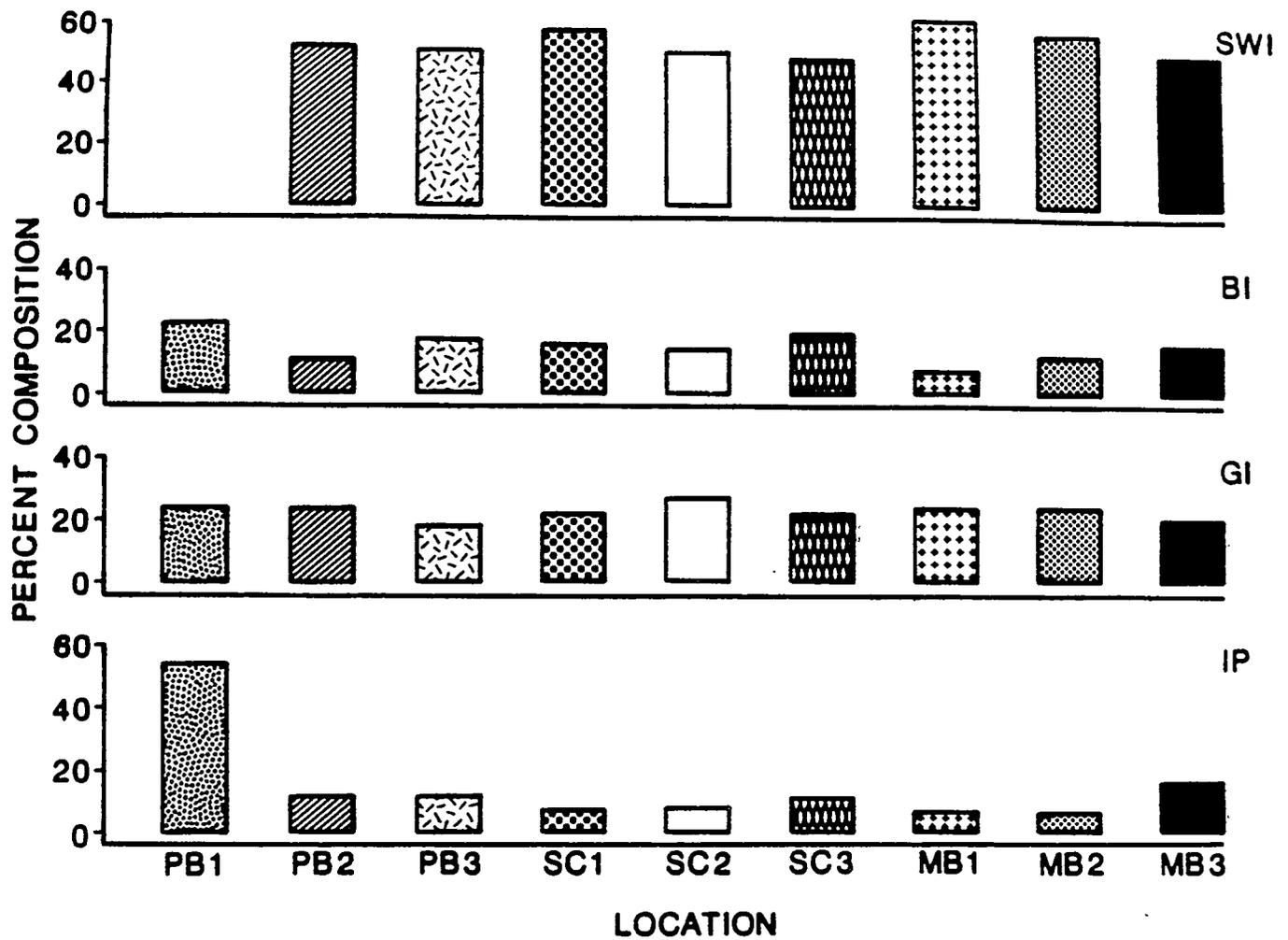


Figure 4.4. Between site variation in the trophic guild composition of the fish assemblage in three streams on the Savannah River Plant. Stream site abbreviations are Pen Branch (PB1-3), Steel Creek (SC1-3), and Meyer's Branch (MB). Trophic groups are surface-water invertivore (SWI), generalized invertivore (GI), benthic invertivore (BI), and invertivore-piscivore (IP).

Most individual fishes captured were less than 100 mm total length (TL). Size composition in the populations varied little with longitudinal position in a stream. Length-frequency analysis was performed on the eight most abundant species. Longitudinal shifts in size distribution were observed only for yellowfin shiners (Figure 4.5), and were particularly striking in Steel Creek with size within a year class progressively decreasing in a downstream direction. The presence of small fish at all sites indicated differences were not necessarily a breeding preference for the smaller reaches of the stream. Instead, the temporal consistency of the pattern suggests that actual conditions within the stream (e.g., width, habitat volume) were responsible for the observed shifts in body size between sites. Changes in size distribution also paralleled changes in yellowfin shiner abundance. Similar patterns for shifts in size structure of Notropis lutipinnis were also observed in Pen Branch and Meyer's Branch.

Based on seasonal collections, ichthyofaunal composition and rank order of species abundances varied only slightly over the study period regardless of site or stream system (Tables 4.5 and 4.6). Persistence values determined for all sites indicated no trend for greater compositional variability within upstream reaches compared to downstream sites. There was also no pattern of a gradual increase in compositional consistency from Pen Branch, Steel Creek, or Meyer's Branch. Values were high (>0.70) indicating that local immigration and emigration occurred infrequently in these small streams. Concordance of species rank order of abundance over time were also significant (Tables 4.5 and 4.6). Hence, the null hypothesis is rejected, and a view of assemblage stability across all sites is supported. Similar to persistence values, there was no obvious trend for concordance

Steel Creek

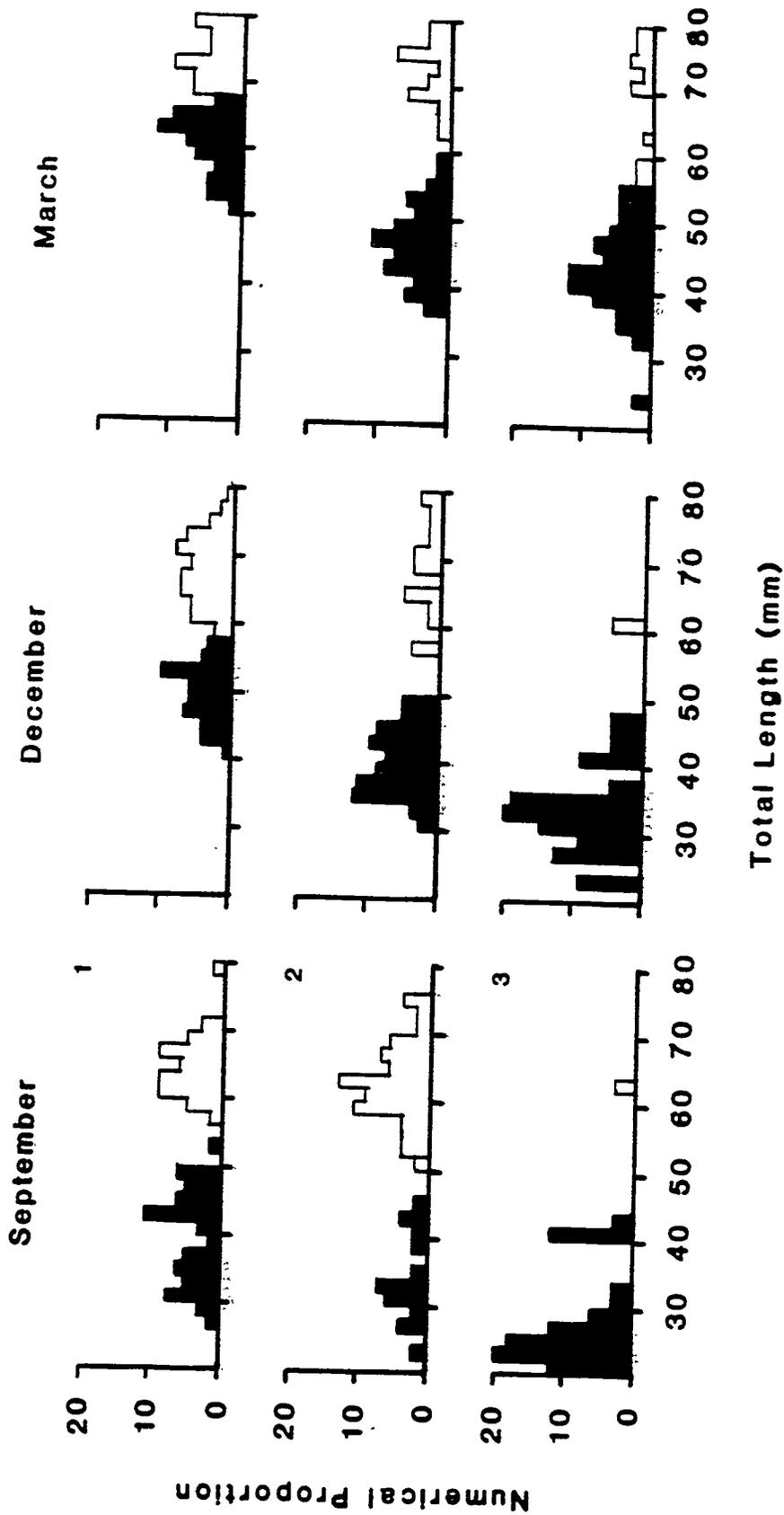


Figure 4.5. Length frequency distributions for collections of *Notropis lutipinnis* from three sample stations and three seasons in Steel Creek. Darkened histograms represent one-year fish. Open histograms represent two-year and older fish.

Table 4.5 Seasonal changes in the percent relative abundance of fishes from sites in Pen Branch, Steel Creek, and Meyer's Branch.

		Stream Site: Pen Branch 1				
		Spring 1984	Summer	Fall	Winter	Spring 1985
<i>Ictalurus nebulosus</i>	Brown bullhead	17.1	12.8	11.8	10.9	5.6
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	Lake and creek chubsucker	15.8	2.6	16.2	16.4	9.9
<i>Ictalurus natalis</i>	Yellow bullhead	5.3	7.7	0.0	0.0	4.2
<i>Lepomis marginatus</i>	Dollar sunfish	15.8	23.1	20.6	20.0	19.7
<i>Lepomis auritus</i>	Redbreast sunfish	1.3	0.0	2.9	0.0	0.0
<i>Lepomis punctatus</i>	Spotted sunfish	0.0	5.1	4.4	0.0	1.4
<i>Anguilla rostrata</i>	American eel	1.3	0.0	0.0	0.0	1.4
<i>Aphredoderus sayanus</i>	Pirate perch	10.5	7.7	8.8	9.1	2.8
<i>Esox americanus</i>	Redfin pickerel	2.6	25.6	16.2	18.2	7.0
<i>Acantharchus pomotis</i>	Mud sunfish	30.3	15.4	19.1	25.5	39.4
<i>Notropis cummingsae</i>	Dusky shiner	0.0	0.0	0.0	0.0	8.4
Total number of fish		76	39	68	55	71
Mean relative abundance		50.7	26.0	45.3	36.7	47.3

Table 4.5 Continued

		Stream Site: Pen Branch 3											
		Spring 1984		Winter		Spring 1985		Summer		Fall		Winter	
		Summer	Fall	Summer	Winter	Spring 1985	Summer	Summer	Fall	Winter	Summer	Fall	Winter
<i>Notropis lutipinnis</i>	Yellowfin shiner	40.0	36.4	48.5	32.7	64.3	56.2	59.7					
<i>Nocomis leptocephalus</i>	Bluehead chub	2.1	0.0	2.1	1.8	5.2	3.7	3.9					
<i>Ictalurus nebulosus</i>	Brown bullhead	0.0	1.6	0.7	0.6	0.0	0.0	0.0					
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	Lake and creek chubsucker	1.4	0.8	2.7	0.0	1.2	0.9	0.0					
<i>Ictalurus natalis</i>	Yellow bullhead	0.0	0.8	0.0	0.0	0.5	0.9	0.0					
<i>Ictalurus platycephalus</i>	Flat bullhead	4.1	0.0	0.3	2.4	0.5	0.0	0.0					
<i>Noturus insignis</i>	Margined madtom	7.6	5.4	1.7	5.4	3.7	4.3	3.4					
<i>Noturus leptacanthus</i>	Speckled madtom	4.8	2.3	5.1	13.1	2.9	3.9	2.6					
<i>Noturus gyrinus</i>	Tadpole madtom	1.4	1.6	1.0	0.6	0.3	0.3	0.9					
<i>Lepomis marginatus</i>	Dollar sunfish	0.0	0.0	0.3	0.0	0.0	0.0	0.0					
<i>Lepomis auritus</i>	Redbreast sunfish	11.7	7.8	4.1	4.8	2.5	4.6	5.2					
<i>Lepomis punctatus</i>	Spotted sunfish	4.8	8.5	3.4	5.9	2.7	3.0	3.9					
<i>Micropterus salmoides</i>	Largemouth bass	0.0	0.0	0.3	0.6	0.5	0.9	0.4					
<i>Anguilla rostrata</i>	American eel	0.0	0.8	1.0	0.6	0.0	0.0	0.4					
<i>Aphredoderus sayanus</i>	Pirate perch	7.6	17.8	13.3	11.3	5.5	6.7	3.4					
<i>Esox niger</i>	Chain pickerel	2.8	0.8	0.0	0.0	0.0	0.6	0.0					
<i>Esox americanus</i>	Redfin pickerel	0.7	2.3	0.3	0.6	0.7	0.3	0.0					
<i>Etheostoma fricksium</i>	Savannah darter	4.8	0.8	5.5	5.9	1.7	2.1	5.6					
<i>Percina nigrofasciata</i>	Blackbanded darter	4.8	8.5	4.8	6.6	3.7	3.3	2.6					
<i>Fundulus lineolatus</i>	Lined topminnow	0.7	0.0	0.0	0.0	0.0	0.0	0.0					
<i>Etheostoma olmstedi</i>	Tesselated darter	0.7	2.3	4.8	7.1	2.2	7.3	7.7					
<i>Notropis cummingsae</i>	Dusky shiner	0.0	0.0	0.0	0.0	0.7	0.9	0.4					
<i>Amia calva</i>	Bowfin	0.0	0.8	0.0	0.0	0.0	0.0	0.0					
<i>Lepomis gulosus</i>	Warmouth	0.0	0.0	0.0	0.0	0.3	0.0	0.0					
<i>Elassoma zonatum</i>	Banded pygmy sunfish	0.0	0.0	0.0	0.0	0.3	0.0	0.0					
<i>Umbra pygmaea</i>	Eastern mudminnow	0.0	0.0	0.0	0.0	0.3	0.0	0.0					
<i>Etheostoma fusiforme</i>	Swamp darter	0.0	0.0	0.0	0.0	0.3	0.0	0.0					
Total number of fish		145	129	293	168	403	329	232					
Mean relative abundance		32.9	29.3	66.6	38.2	91.6	74.8	55.2					

Table 4.5 Continued

Stream Site: Steel Creek 1

	Spring 1984	Summer	Fall	Winter	Spring 1985	Summer	Fall
<i>Notropis lutipinnis</i>	45.9	41.9	61.3	51.6	57.1	51.1	58.9
<i>Nocomis leptocephalus</i>	9.0	9.4	7.6	6.7	5.4	23.9	13.5
<i>Hypentelium nigricans</i>	8.0	8.3	5.9	2.7	9.5	14.1	14.1
<i>Ictalurus nebulosus</i>	0.0	0.0	0.0	0.4	0.0	0.0	0.0
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	1.9	1.7	0.0	0.0	0.0	0.0	1.5
<i>Ictalurus natalis</i>	0.0	0.6	0.0	0.4	0.0	0.0	0.0
<i>Ictalurus platycephalus</i>	6.1	4.4	2.5	8.4	0.0	0.0	0.2
<i>Noturus insignis</i>	0.3	1.1	0.0	1.8	4.8	0.2	0.1
<i>Noturus leptacanthus</i>	4.5	2.8	10.1	5.8	6.1	1.1	0.6
<i>Noturus gyrinus</i>	0.3	0.0	0.0	0.9	0.7	0.0	0.0
<i>Lepomis marginatus</i>	0.0	0.6	0.0	0.4	0.0	0.0	0.3
<i>Lepomis auritus</i>	18.7	13.8	5.0	8.9	1.4	3.6	5.1
<i>Lepomis punctatus</i>	0.3	3.9	0.8	0.0	0.0	0.0	0.0
<i>Micropterus salmoides</i>	0.0	0.0	0.8	0.0	0.0	0.5	0.7
<i>Anguilla rostrata</i>	2.3	3.9	0.8	1.3	3.4	1.1	0.2
<i>Aphredoderus sayanus</i>	0.0	0.0	0.0	0.0	0.0	0.7	0.2
<i>Gambusia affinis</i>	0.6	0.0	1.7	2.7	0.0	0.4	0.7
<i>Esox americanus</i>	0.0	1.7	0.0	0.0	0.0	0.2	0.1
<i>Notropis chalybaeus</i>	0.0	0.6	0.0	0.0	0.0	0.0	0.0
<i>Etheostoma fricksium</i>	0.0	0.0	0.0	0.9	2.7	0.2	0.0
<i>Percina nigrofasciata</i>	1.3	1.1	2.5	6.7	7.5	2.2	1.0
<i>Etheostoma olmstedi</i>	0.3	0.0	0.8	0.4	0.7	0.2	0.1
<i>Notropis cummingsae</i>	0.0	0.6	0.0	0.0	0.7	0.2	0.0
<i>Semotilus atromaculatus</i>	0.3	0.0	0.0	0.0	0.0	0.0	0.1
<i>Lepomis gulosus</i>	0.0	0.0	0.0	0.0	0.0	0.2	0.0
<i>Enneacanthus gloriosus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.2
<i>Perca flavescens</i>	0.0	0.6	0.0	0.0	0.0	0.2	0.3
<i>Notemigonus crysoleucas</i>	0.0	3.3	0.0	0.0	0.0	0.0	0.0
<i>Minytrema melanops</i>	0.0	0.0	0.0	0.0	0.0	0.0	2.1
Total number of fish	311	181	119	225	147	552	996
Mean relative abundance	69.1	40.2	26.4	50.0	32.7	122.7	221.3

Table 4.5 Continued

Stream Site: Steel Creek 2

	Spring 1984		Summer		Fall		Winter		Spring 1985		Summer		Fall	
<i>Notropis lutipinnis</i>	45.3	21.2	29.9	68.1	41.0	33.1	55.2							
<i>Nocomis leptcephalus</i>	13.5	11.9	16.0	12.1	12.8	14.1	12.1							
<i>Hypentelium nigricans</i>	0.0	1.0	2.7	0.9	0.6	5.6	1.3							
<i>Ictalurus nebulosus</i>	0.0	0.5	0.0	0.0	0.0	0.0	0.0							
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	1.4	5.7	0.0	0.0	1.3	1.4	0.0							
<i>Ictalurus natalis</i>	0.0	1.0	0.0	0.9	0.0	2.1	0.4							
<i>Ictalurus platycephalus</i>	1.4	1.6	3.2	0.0	1.3	0.0	0.4							
<i>Noturus insignis</i>	1.4	0.5	0.0	0.0	1.3	0.0	0.0							
<i>Noturus leptacanthus</i>	3.4	5.2	5.9	3.5	3.2	1.4	0.4							
<i>Noturus gyrinus</i>	2.0	2.1	1.6	0.9	1.9	0.7	0.4							
<i>Lepomis marginatus</i>	2.7	0.5	2.7	0.9	4.5	0.0	0.4							
<i>Lepomis auritus</i>	4.7	5.7	2.7	0.9	4.5	0.0	0.4							
<i>Lepomis punctatus</i>	4.1	13.5	6.4	1.7	3.2	6.3	3.9							
<i>Micropterus salmoides</i>	0.0	0.5	0.5	0.0	0.0	4.9	0.0							
<i>Anguilla rostrata</i>	2.0	1.6	0.5	1.7	1.9	0.0	0.9							
<i>Aphredoderus sayanus</i>	3.4	9.3	6.4	1.7	4.5	9.9	7.3							
<i>Gambusia affinis</i>	1.4	2.1	8.6	0.9	1.3	11.9	7.3							
<i>Esox americanus</i>	0.7	5.2	2.7	0.9	0.6	0.7	0.4							
<i>Etheostoma fricksium</i>	0.0	2.1	0.0	0.0	0.6	0.0	0.0							
<i>Percina nigrofasciata</i>	2.0	4.2	1.6	0.0	1.9	1.4	3.5							
<i>Etheostoma olmstedii</i>	4.1	1.0	7.5	4.3	5.1	4.9	3.9							
<i>Notropis cummingsae</i>	2.7	0.0	0.0	0.0	3.9	0.7	1.3							
<i>Semotilus atromaculatus</i>	0.0	0.0	1.1	0.0	0.0	0.7	0.0							
<i>Notropis petersoni</i>	4.1	3.6	0.0	0.0	6.4	0.0	0.0							
<i>Umbra pygmaea</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.4							
Total number of fish	148	193	187	116	156	142	232							
Mean relative abundance	42.3	55.1	53.4	33.1	44.6	40.6	66.3							

Table 4.5 Continued

		Stream Site: Steel Creek 3									
		Spring 1984		Winter		Spring 1985		Summer		Fall	
		Spring	Summer	Fall	Winter	Spring	Summer	Summer	Summer	Fall	Fall
<i>Notropis lutipinnis</i>	Yellowfin shiner	10.9	0.2	14.3	4.8	4.4	14.9	18.7			
<i>Nocomis leptocephalus</i>	Bluehead chub	0.7	0.0	0.0	0.2	0.2	0.1	0.0			
<i>Hypentelium nigricans</i>	Northern hogsucker	0.0	0.0	0.0	0.0	0.0	1.7	0.0			
<i>Ictalurus nebulosus</i>	Brown bullhead	0.7	0.6	0.5	0.2	0.0	0.0	0.2			
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	Lake and creek chubsucker	0.7	0.4	0.5	0.6	0.5	0.4	0.9			
<i>Ictalurus natalis</i>	Yellow bullhead	0.3	0.4	0.0	0.0	0.5	1.2	0.2			
<i>Ictalurus platycephalus</i>	Flat bullhead	0.0	0.0	0.9	0.0	0.5	0.4	0.5			
<i>Noturus insignis</i>	Margined madtom	0.0	0.0	0.0	0.0	1.0	0.0	0.0			
<i>Noturus leptacanthus</i>	Speckled madtom	4.9	1.2	3.1	1.2	4.7	0.7	2.7			
<i>Noturus gyrinus</i>	Tadpole madtom	0.0	0.6	1.8	0.0	1.0	0.2	0.0			
<i>Lepomis marginatus</i>	Dollar sunfish	1.0	0.6	0.5	0.0	0.0	0.7	0.9			
<i>Lepomis auritus</i>	Redbreast sunfish	2.3	2.3	0.9	1.2	4.7	5.3	6.6			
<i>Lepomis punctatus</i>	Spotted sunfish	3.7	24.6	33.0	6.4	13.5	14.5	12.8			
<i>Micropterus salmoides</i>	Largemouth bass	0.3	2.1	0.9	0.8	1.2	5.7	2.9			
<i>Anguilla rostrata</i>	American eel	2.9	3.9	0.5	1.2	5.9	4.5	4.8			
<i>Aphredoderus sayanus</i>	Pirate perch	0.0	38.1	20.9	7.6	6.1	6.5	4.6			
<i>Gambusia affinis</i>	Mosquitofish	0.3	0.4	0.0	0.2	1.2	4.4	3.9			
<i>Esox niger</i>	Chain pickerel	1.0	0.2	0.5	0.4	0.2	0.2	0.5			
<i>Esox americanus</i>	Redfin pickerel	0.0	2.7	0.5	0.8	0.2	1.2	0.7			
<i>Acantharchus pomotis</i>	Mud sunfish	0.0	0.2	0.0	0.0	0.0	0.0	0.0			
<i>Notropis chalybaeus</i>	Ironcolor shiner	0.0	4.3	0.0	0.6	0.2	0.0	0.0			
<i>Etheostoma fricksium</i>	Savannah darter	0.0	0.0	1.3	0.0	0.2	0.2	0.7			
<i>Percina nigrofasciata</i>	Blackbanded darter	1.0	0.8	1.8	0.6	5.1	1.0	3.2			
<i>Fundulus lineolatus</i>	Lined topminnow	0.3	0.0	0.0	0.0	0.0	0.0	0.0			
<i>Etheostoma olmstedi</i>	Tesselated darter	3.9	0.6	2.2	3.8	7.9	14.5	18.5			
<i>Notropis cummingsae</i>	Dusky shiner	50.5	6.2	10.3	64.9	29.8	8.4	7.3			
<i>Notropis petersoni</i>	Coastal shiner	11.9	3.7	2.2	3.6	9.1	9.9	6.6			
<i>Lepomis gulosus</i>	Warmouth	0.3	0.4	0.5	0.0	0.0	0.0	0.7			
<i>Enneacanthus gloriosus</i>	Bluespotted sunfish	0.3	0.0	0.0	0.2	0.0	0.1	0.0			
<i>Elassoma zonatum</i>	Banded pygmy sunfish	0.3	0.0	0.0	0.0	0.0	0.0	0.0			
<i>Etheostoma serriferum</i>	Sawcreek darter	0.3	0.0	0.9	0.2	0.0	0.1	0.0			
<i>Notropis emiliae</i>	Pugnose minnow	0.7	0.0	0.0	0.0	0.3	0.0	0.2			
<i>Percia flavescens</i>	Yellow perch	0.0	0.0	0.0	0.0	0.0	0.1	0.2			
<i>Centrarchus macropterus</i>	Flier	0.3	0.0	0.0	0.0	0.0	0.0	0.0			
<i>Chologaster cornuta</i>	Swampfish	0.0	4.1	0.9	0.0	0.0	1.2	0.0			
<i>Umbra pygmaea</i>	Eastern mudminnow	0.0	0.0	0.0	0.0	0.0	0.5	0.0			
<i>Minytrema melanops</i>	Spotted sucker	0.0	0.0	0.0	0.6	1.5	1.2	0.9			
<i>Etheostoma fusiforme</i>	Swamp darter	0.0	1.0	1.3	0.0	0.2	0.0	0.0			
<i>Hybopsis rubrifrons</i>	Rosyface chub	0.0	0.2	0.0	0.0	0.0	0.0	0.0			
<i>Notropis leedsi</i>	Bannerfin shiner	0.0	0.0	0.0	0.0	0.2	0.0	0.0			
<i>Labidesthes sicculus</i>	Brook silversides	0.0	0.0	0.0	0.0	0.0	0.2	0.7			
<i>Enneacanthus chaetodon</i>	Blackbanded sunfish	0.0	0.2	0.0	0.0	0.0	0.0	0.0			
<i>Lepomis macrochirus</i>	Bluegill	0.0	0.0	0.0	0.0	0.0	0.0	0.2			
Total number of fish		301	488	224	502	594	867	439			
		317	555	255	570	675	985	499			

Table 4.5 Continued.

		Stream Site: Meyer's Branch 1			
		Spring 1985	Summer	Fall	Winter
<i>Notropis lutipinnis</i>	Yellowfin shiner	66.7	69.1	53.9	48.0
<i>Nocomis leptocephalus</i>	Bluehead chub	4.7	5.1	12.6	12.5
<i>Hypentelium nigricans</i>	Northern hogsucker	0.3	0.5	0.2	1.8
<i>Ictalurus nebulosus</i>	Brown bullhead	0.3	0.0	0.0	0.0
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	Lake and creek chubsucker	0.8	1.9	3.0	0.3
<i>Ictalurus platycephalus</i>	Flat bullhead	0.0	0.0	0.2	0.0
<i>Noturus insignis</i>	Margined madtom	0.3	0.8	1.2	1.8
<i>Noturus lepiacanthus</i>	Speckled madtom	2.6	2.9	0.4	0.9
<i>Noturus gyrinus</i>	Tadpole madtom	0.5	1.6	0.2	1.5
<i>Lepomis marginatus</i>	Dollar sunfish	1.0	1.9	1.4	1.2
<i>Lepomis auritus</i>	Redbreast sunfish	0.5	1.3	3.5	3.1
<i>Lepomis punctatus</i>	Spotted sunfish	0.8	1.1	2.4	1.2
<i>Anguilla rostrata</i>	American eel	0.5	0.5	0.6	0.0
<i>Aphredoderus sayanus</i>	Pirate perch	7.5	6.5	15.4	11.6
<i>Esox americanus</i>	Redfin pickerel	0.8	2.4	1.6	0.6
<i>Etheostoma fricksium</i>	Savannah darter	6.5	1.6	1.4	1.2
<i>Percina nigrofasciata</i>	Blackbanded darter	0.8	0.0	0.4	0.0
<i>Etheostoma olmstedi</i>	Tesselated darter	2.1	2.4	1.0	0.0
<i>Notropis cummingsae</i>	Dusky shiner	2.6	0.0	0.0	13.8
<i>Semotilus atromaculatus</i>	Creek chub	0.3	0.0	0.4	0.3
<i>Lepomis gulosus</i>	Warmouth	0.3	0.0	0.0	0.0
Total number of fish		387	372	493	336
Mean relative abundance		101.8	97.9	129.7	88.4

Table 4.5 Continued

		Stream Site: Meyer's Branch 2											
		Spring 1984		Winter 1985		Spring 1985		Summer		Fall		Winter	
		Summer	Fall	Winter	Spring 1985	Summer	Fall	Winter	Spring 1985	Summer	Fall	Winter	Winter
<i>Notropis lutipinnis</i>	Yellowfin shiner	59.2	32.7	68.5	59.3	57.2	48.8	46.3	59.3	57.2	48.8	46.3	46.3
<i>Nocomis leptocephalus</i>	Bluehead chub	7.9	6.5	2.8	4.5	7.5	15.7	10.8	4.5	7.5	15.7	10.8	10.8
<i>Hypentelium nigricans</i>	Northern hogsucker	1.3	0.0	0.5	0.8	0.7	1.8	1.9	0.8	0.7	1.8	1.9	1.9
<i>Ictalurus nebulosus</i>	Brown bullhead	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	Lake and creek chubsucker	0.5	4.2	1.3	2.9	6.1	5.3	0.8	2.9	6.1	5.3	0.8	0.8
<i>Ictalurus natalis</i>	Yellow bullhead	0.0	0.0	0.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.4
<i>Ictalurus platycephalus</i>	Flat bullhead	1.3	0.9	0.2	0.0	0.0	0.9	0.0	0.0	0.0	0.9	0.0	0.0
<i>Noturus insignis</i>	Margined madtom	3.1	1.4	2.7	1.7	1.4	1.6	3.7	1.7	1.4	1.6	3.7	3.7
<i>Noturus leptacanthus</i>	Speckled madtom	2.6	3.2	1.1	2.5	1.6	1.2	1.9	2.5	1.6	1.2	1.9	1.9
<i>Noturus gyrinus</i>	Tadpole madtom	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0	0.2	0.4	0.0	0.0
<i>Lepomis marginatus</i>	Dollar sunfish	0.0	0.0	0.0	0.0	1.4	0.4	2.6	0.0	1.4	0.4	2.6	2.6
<i>Lepomis auritus</i>	Redbreast sunfish	4.6	10.1	1.7	4.1	4.2	2.9	5.9	4.1	4.2	2.9	5.9	5.9
<i>Lepomis punctatus</i>	Spotted sunfish	3.3	4.6	1.4	0.0	0.9	1.8	0.4	0.0	0.9	1.8	0.4	0.4
<i>Micropterus salmoides</i>	Largemouth bass	0.0	0.0	0.2	0.0	0.0	0.6	0.4	0.0	0.0	0.6	0.4	0.4
<i>Anguilla rostrata</i>	American eel	2.0	0.0	0.8	1.2	0.5	0.8	1.1	1.2	0.5	0.8	1.1	1.1
<i>Aphredoderus sayanus</i>	Pirate perch	5.4	28.1	8.2	7.8	4.4	7.7	7.1	7.8	4.4	7.7	7.1	7.1
<i>Gambusia affinis</i>	Mosquitofish	0.0	0.9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0
<i>Esox niger</i>	Chain pickerel	0.0	0.9	0.5	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.4
<i>Esox americanus</i>	Redfin pickerel	0.8	0.9	0.2	0.0	1.6	0.6	0.0	0.0	1.6	0.6	0.0	0.0
<i>Acantharchus pomotis</i>	Mud sunfish	0.0	0.0	0.0	0.0	0.2	0.2	0.4	0.0	0.2	0.2	0.4	0.4
<i>Notropis chalybaeus</i>	Ironcolor shiner	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Etheostoma fricksium</i>	Savannah darter	1.5	1.4	2.2	4.1	1.6	1.8	0.8	4.1	1.6	1.8	0.8	0.8
<i>Percina nigrofasciata</i>	Blackbanded darter	1.3	0.5	0.5	2.1	0.5	0.2	0.8	2.1	0.5	0.2	0.8	0.8
<i>Fundulus lineolatus</i>	Lined topminnow	0.0	0.5	0.3	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
<i>Etheostoma olmstedei</i>	Tesselated darter	5.1	2.8	3.3	7.8	4.4	5.5	7.5	7.8	4.4	5.5	7.5	7.5
<i>Notropis cummingsae</i>	Dusky shiner	0.0	0.0	2.5	0.0	5.1	0.9	4.9	0.0	5.1	0.9	4.9	4.9
<i>Lepomis gulosus</i>	Warmouth	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Enneacanthus gloriosus</i>	Bluespotted sunfish	0.3	0.5	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0
<i>Perca flavescens</i>	Yellow perch	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0
<i>Centrarchus macropterus</i>	Flier	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Ictalurus brunneus</i>	Snail bullhead	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Umbra pygmaea</i>	Eastern mudminnow	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<i>Enneacanthus chaetodon</i>	Blackbanded sunfish	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total number of fish		392	217	635	243	428	510	268	243	428	510	268	268
Mean relative abundance		78.4	43.4	127.0	48.6	85.6	102.0	53.6	48.6	85.6	102.0	53.6	53.6

Table 4.5 Continued.

Stream Site: Meyer's Branch 3		Spring 1985	Summer	Fall	Winter
<i>Notropis lutipinnis</i>	Yellowfin shiner	43.6	27.4	47.9	49.2
<i>Nocomis leptocephalus</i>	Bluehead chub	1.8	1.2	2.6	1.6
<i>Hypentelium nigricans</i>	Northern hogsucker	0.0	0.4	2.9	1.6
<i>Ictalurus nebulosus</i>	Brown bullhead	0.9	0.4	0.7	0.0
<i>Erimyzon</i> spp. (<i>oblongus</i> and <i>sucetta</i>)	Lake and creek chubsucker	0.3	2.5	0.4	5.2
<i>Ictalurus natalis</i>	Yellow bullhead	0.6	0.0	1.1	1.1
<i>Ictalurus platycephalus</i>	Flat bullhead	0.0	0.0	0.9	0.0
<i>Noturus insignis</i>	Margined madtom	0.0	0.0	0.2	0.0
<i>Noturus leptacanthus</i>	Speckled madtom	2.8	4.2	4.2	1.1
<i>Noturus gyrinus</i>	Tadpole madtom	0.0	1.2	0.2	0.0
<i>Lepomis marginatus</i>	Dollar sunfish	0.0	0.0	0.0	0.5
<i>Lepomis auritus</i>	Redbreast sunfish	1.8	1.7	2.1	1.6
<i>Lepomis punctatus</i>	Spotted sunfish	2.8	7.5	5.6	4.7
<i>Micropterus salmoides</i>	Large-mouth bass	0.0	0.8	0.0	0.0
<i>Anguilla rostrata</i>	American eel	9.8	18.3	8.9	10.2
<i>Aphredoderus sayanus</i>	Pirate perch	6.1	14.5	10.0	7.4
<i>Gambusia affinis</i>	Mosquitofish	0.3	0.0	0.4	0.0
<i>Esox niger</i>	Chain pickerel	0.3	0.0	0.0	0.0
<i>Esox americanus</i>	Redfin pickerel	0.3	4.9	1.4	0.0
<i>Acantharchus potomis</i>	Mud sunfish	0.3	0.0	0.0	0.0
<i>Notropis chalybaeus</i>	Ironcolor shiner	0.0	0.0	0.0	0.3
<i>Etheostoma trichsium</i>	Savannah darter	1.2	2.1	0.5	1.1
<i>Percina nigrofasciata</i>	Blackbanded darter	2.2	2.1	1.2	0.3
<i>Etheostoma olmstedi</i>	Tesselated darter	7.7	7.9	8.6	10.7
<i>Notropis cummingsae</i>	Dusky shiner	17.2	2.1	0.0	1.4
<i>Perca flavescens</i>	Yellow perch	0.0	0.0	0.2	0.0
<i>Centrarchus macropterus</i>	Flier	0.0	0.4	0.0	0.0
<i>Chologaster cornuta</i>	Swampfish	0.0	0.0	0.0	0.3
<i>Umbra pygmaea</i>	Eastern mudminnow	0.0	0.0	0.0	0.5
<i>Etheostoma fusiforme</i>	Swamp darter	0.0	0.4	0.0	0.3
<i>Fundulus chrysotus</i>	Gold topminnow	0.0	0.0	0.0	0.8
Total number of fish		326	241	570	364
Mean relative abundance		38.4	28.4	67.0	42.8

Table 4.6. Analysis of fish assemblage persistence and assemblage stability using an index of persistence (PR) and Kendall's Coefficient of Concordance (W) for nine stream sites on the Savannah River Plant. W indicates a level of overall concordance from 0 (no correlation) to 1 (complete concordance). P = probability of a Type 1 error.

Site	PR	W	P
PB1	0.78	.*	
PB2	0.79	0.67	< 0.01
PB3	0.80	0.62	< 0.01
SC1	0.70	0.74	< 0.01
SC2	0.76	0.58	< 0.01
SC3	0.76	0.60	< 0.01
MB1	0.76	-	
MB2	0.83	0.68	< 0.01
MB3	0.73	-	

*No estimate of assemblage stability calculated because of limited collected period.

values to change in a consistent longitudinal pattern or between stream systems.

Discussion

For the three coastal plain streams on the SRP, predictions formulated from pre-existing models of stream fish community structure were: (1) Pen Branch should have the least number of species because of its isolation, have a simple trophic structure of generalized invertivores, and exhibit low temporal persistence and stability in species composition; (2) Steel Creek should have greater species richness, persistence, and assemblage stability than Pen Branch because of greater recolonization potential but should show changes in species composition and guild organization that reflect changes in habitat and organic matter processing because of prior thermal disturbance and high flow rates; and (3) Meyer's Branch should have the most species, the most complex trophic organization, and should exhibit the least temporal fluctuations in assemblage persistence and stability. It was anticipated that all streams would also exhibit longitudinal changes, with headwater areas having the fewest species, simplest trophic organization, and reduced persistence and stability compared to downstream reaches.

Our observations, however, contrast with several of the predicted patterns. Perturbation regimes associated with high temperatures and flows in these headwater streams have modified channel morphology, trophic dynamics, and openness of habitats to recolonization. Seasonal fluctuations in discharge regimes produce a physically active stream channel whose substrate is dominated by erosional sand. Yet, species composition, trophic structure, and persistence/ stability of the assemblage does not appear to reflect the importance of these physical factors in structuring the fish

assemblage within each drainage as identified in other studies (e.g., Schlosser, 1982a; Horwitz, 1978; Grossman et al., 1982). Determining the reasons for these differences is important for both generating theories for understanding fish community dynamics and for establishing ecologically sound management strategies (Karr and Schlosser, 1978; Karr and Dudley, 1981; Murphy et al., 1981).

Changes in assemblage richness and diversity were observed in all three stream systems with species additions being more pronounced than species replacements and concurrent shifts in relative abundance occurring between the upstream and downstream portions of each stream system. In several studies, channel morphology, and flow regime have been shown to be important determinants of habitat stability and a broad range of fish community attributes (Schlosser, 1982a; Angermeier and Karr, 1983; Matthews, 1985). Successional changes in the number of fish species, diversity, age structure, and trophic structure along longitudinal gradients have been related to environmental harshness and physical habitat diversity that change with increasing distance from the headwaters (Harrel et al., 1967; Sheldon, 1968; Whiteside and McNatt, 1972; Lotrich, 1973; Hocutt and Stauffer, 1975; Echelle and Schnell, 1976; Gorman and Karr, 1978; Evans and Noble, 1979; Barila et al., 1981; Guillory, 1982; Schlosser, 1982a,b; Angermeier and Karr, 1983).

From a macrohabitat perspective, changes in fish community characteristics in Pen Branch, Steel Creek, and Meyer's Branch occurred despite a lack of spatial and temporal variation in substrate composition between sites. While substrate composition may be a determinant in other systems (Gorman and Karr, 1978), results from these stream systems suggest habitat volume is probably the most important physical factor influencing

species richness and diversity with changes in depth occurring along a stream size gradient. The high faunal similarity among sites probably reflects the overall comparable habitat characteristics at each site. The observed dissimilarity between the downstream site on Steel Creek and other sites indicates the contribution species usually associated with river-swamp habitats can have toward the fish assemblage structure. Differences in the fish fauna in the upper reaches of Pen Branch compared to other sites probably reflects the change in habitat structure to a nonsand substrate, more hard structural cover, and greater pool habitat. Similar observations about the importance of velocity and habitat size (primarily depth and width) as factors influencing assemblage composition in SRP streams have also been made by Meffe and Sheldon (1986).

Alteration of the riparian vegetation and channel morphology has resulted in differences in the dynamics of organic matter processing in Steel Creek compared to other SRP streams (Hauer, 1985). Organic inputs from riparian vegetation are relatively predictable in natural headwater streams in the eastern United States (Bell et al., 1978). Autochthonous production is usually a minor component of the organic matter budget. Removal of vegetation and exposure to greater sunlight usually shifts the energy base toward autochthonous sources and the period of maximum abundance from fall and winter to spring and summer; responses by the fish assemblage to these modifications usually results in increased composition of herbivore-detritivore feeding groups. However, there was no accompanying shift in trophic structure of the fish assemblage. Dietary groups were relatively unspecialized in the three streams studied with all four groups depending on insects or other invertebrates as sources of prey. In coastal plain streams, specialized diets may be unreliable if the distribution and abundance of

invertebrate prey is being affected by shifting sand substrates. While most fish species have habitat preferences that determine patterns of distribution and abundance, they are widespread in SRP streams and are probably food generalists.

Persistence and stability of the fish assemblage were high in all sites and did not reflect the placement of a site along either an upstream/downstream gradient. Prior studies have indicated that the demonstration of long-term compositional persistence and stability is evidence that interactive mechanisms (e.g., competition or predation) may be important determinants of assemblage structure (Moyle and Vondracek, 1985; Ross et al., 1985; Grossman, 1982, 1985). While not directly tested using either controlled laboratory experiments or field manipulations, the consistent change in size structure and abundance of yellowfin shiners along the stream gradient is also regarded as supportive evidence for the operation of biotic interactions in assemblage dynamics. Because of increased abundance of other surface water invertivores in downstream sites, yellowfin shiners could be food limited which could lead to lower growth rates, fecundity, and densities. Predation pressure could also change the length distributions and densities of yellowfin shiners if birds, or other predators, which select larger prey sizes are more effective or common where streams are larger. Changes in size structure, fecundity, and density along stream gradients in response to biotic changes in prey availability and predation risk have been shown to occur in several environmentally stable warm water streams (Anderson, 1985). The application of these observations, and importance to stream dynamics, however, needs further examination particularly in light of predictions based on the River Continuum Concept.

However, Connell and Sousa (1983) indicated that temporal analyses of assemblage structure are only meaningful if the system experiences disturbances of a magnitude that could disrupt structure, and cover at least one cohort generation. If not met, equilibrium patterns may simply indicate a lack of environmental change or the presence of long-lived species. Both conditions are met in this study. All sites experienced large fluctuations in water levels, and thus reducing habitat volume, with reaches of stream, such as SC2 or PB1, either being temporarily dewatered or drying up completely during the study because of the drought. While showing a high faunal persistence while water was present, conditions at PB1 reflect the environmental uncertainty associated with small, headwater stream reaches, and in that respect is similar to other studies. The study period is short in comparison to other investigations, but limiting concordance tests to only sites where collections had been made for more than 18 months, it was felt comparisons were genuine because many of the species (e.g. yellowfin shiners) live less than two years (Carlander, 1969, 1977). However, baseline survey observations made for many of the streams on the SRP in the early 1950s (Freeman, 1954) indicate many of the same species have been present in these drainages for more than 30 years indicating that persistence of the fish fauna is high.

Recolonization dynamics were important in the repopulation of Steel Creek following abatement of high water temperatures and discharge rates. The presence of eels in Pen Branch also suggests some upstream migration can periodically occur when reactor operations cease for varying lengths of time. The contribution immigration makes to the assemblage, however, is thought to be only minor for several reasons. These include observations indicating that many of the species captured moving upstream from an

extensive river-swamp system, were either larger than species regularly found or are species not regularly found in the streams (Aho and Anderson, unpublished data; see Chapter V). Although the potential exists for fish to move widely within the streams, few fish actually move long distances within the streams and no species marked from a downstream location were ever caught in any of these stream sites. Finally, in situ recruitment has been observed for most of the major families of fish in these streams (Paller, 1985). Thus, the high persistence and stability of the assemblage regardless of prior history of isolation indicates recolonization/extirpation cycles are not a major force influencing the stream fish community dynamics. Colonization of PB1 will occur when water levels rise, but will be from predominantly internal sources and not external to the tributary itself. Faunal similarity will probably be high compared to pre-drought characteristics, and will occur within a short period of time as observed in other stream systems (Gunning and Berra, 1969).

Our observations, therefore, suggest that fish assemblages in southeastern streams are less influenced by flood events (Minckley and Meffe, in press), temporary droughts, or prolonged periods of cold temperatures than fish communities in midwestern and mountain systems. Physical factors are important determinants of assemblage structure, but biotic interactions apparently are assuming greater importance in these stream systems than expected. Recolonization dynamics are important following major disturbance events, but the persistence and stability of the assemblage suggests southeastern streams are approaching their carrying capacity. The dominant role of habitat structure (habitat volume) suggests that modifications such as channelization could have adverse effects on assemblage properties. Although small in overall habitat configuration, snag

removal could also be important to fish assemblage structure and function. Snag habitat has been identified as a major site for invertebrate secondary production (Benke et al., 1984; Smock et al., 1985).

Conclusions

Fish communities were sampled in three SRP stream systems, Pen Branch, Meyer's Branch, and Steel Creek. The objectives of the study were: (1) to determine the kinds, relative abundance, species diversity, and trophic composition of fishes in selected stream systems on the SRP and assess utilization patterns within different portions of each stream, (2) to determine whether particular locations within streams exhibit greater compositional variability over time, and (3) to determine the importance of upstream migration to community persistence and stability. Patterns in fish species composition, distribution, and abundance within and between stream systems are also important in evaluating past and current effects of reactor operation on fish community organization. Conclusions of the study are summarized below.

- Based on the capture of more than 16,000 individuals, at least 49 species of fishes inhabit stream systems (Steel Creek, Meyer's Branch, Pen Branch) on the SRP.
- Species diversity was similar in each of the streams sampled, with Steel Creek having slightly higher values in most instances. Diversity progressively increased in a downstream direction for each stream.
- Nine species of fishes were common to all sampling areas and 11 others were found at most sites. These 20 species represented >80% of the captures.
- Mean species richness ranged from 8.4 to 25.0. Steel Creek had slightly greater species richness probably because of its greater habitat size (e.g., depth, stream width) and not necessarily because of prior perturbation regimes. Progressive increases in numbers of species increased from headwater reaches to downstream.

- Trophic composition of the assemblage was dominated by surface water invertivores. Generalized and benthic invertivores were similar in abundance and invertivore-piscivores were the least abundant except in the headwater reaches of Pen Branch. There was no obvious change within or across stream systems.
- Assemblages abundance was temporally and spatially variable. There was no consistent overall pattern either within or between seasons for abundance changes along the upstream/downstream gradient except in Meyer's Branch.
- Persistence and stability of the fish assemblage was high at all sites within a stream system.
- Persistence and stability of the fish assemblages did not differ between streams isolated for most of the year from downstream reaches (Pen Branch), undergoing post-thermal recovery (Steel Creek), and those that have been open for upstream migration for approximately 20 years (Meyer's Branch).
- From a macrohabitat perspective, following a cessation in reactor operations and subsequent return to regionally typical water temperatures and flow rates, development of the fish community in previously thermally impacted streams will eventually approach characteristics (e.g., richness, trophic composition) found in other streams on the SRP of comparable size and habitat features.

Literature Cited

- Anderson, C. S. 1985. The structure of sculpin populations along a stream size gradient. *Environmental Biology of Fishes* 13:93-102.
- Angermeier, P. L. and J. R. Karr. 1983. Fish communities along environmental gradients in a system of tropical streams. *Environmental Biology of Fishes* 9:117-135.
- Barila, T. Y., R. D. Williams, and J. R. Stauffer, Jr. 1981. The influence of stream order and selected stream bed parameters on fish diversity in Raystown Branch, Susquehanna River drainage, Pennsylvania. *Journal of Applied Ecology* 18:125-131.
- Bell, D. T., F. L. Johnson, and A. R. Gilmore. 1978. Dynamics of litterfall, decomposition, and incorporation in the streamside forest ecosystem. *Oikos* 30:76-82.
- Benke, A. C., T. C. Van Arsdall, Jr., D. M. Gillespie, and F. K. Parrish. 1984. Invertebrate productivity in a subtropical blackwater river: the importance of habitat and life history. *Ecological Monographs* 54:25-63.
- Bennett, D. M. and R. W. McFarlane. 1983. *The Fishes of the Savannah River Plant: National Environmental Research Park. Savannah River Ecology Laboratory, National Environmental Research Park Program, Department of Energy, Aiken, SC. SRO-NERP-12. 152 pp.*
- Carlander, K. D. 1969. *Handbook of freshwater fishery biology. Volume 1. Iowa State University Press: Ames, IA. 752 pp.*
- Carlander, K. D. 1977. *Handbook of freshwater fishery biology. Volume 2. Iowa State University Press: Ames, IA. 431 pp.*
- Connell, J. H. and W. P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. *American Naturalist* 121:789-824.
- Conover, W. J. 1971. *Practical nonparametric statistics. Wiley. NY.*
- Daniel, W. W. 1978. *Applied nonparametric statistics. Houghton Mifflin Co.: Boston. 505 pp.*
- Diamond, J. M. and R. M. May. 1977. Species turnover on islands: dependence on census interval. *Science* 197:266-270.
- Echelle, A. A. and G. D. Schnell. 1976. Factor analysis of species associations among fishes of the Kiamichi River, Oklahoma. *Transactions of the American Fisheries Society* 105:17-31.
- Evans, J. W. and R. L. Noble. 1979. The longitudinal distribution of fishes in an East Texas stream. *American Midland Naturalist* 101:333-343.

- Freeman, H. W. 1954. An ecological study of the land plants and cold-blooded vertebrates of the SRP areas. Part II. Fishes of the SRP area. University of South Carolina Publication Series III, Biology 1:117-156.
- Gorman, O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. *Ecology* 59:507-515.
- Grossman, G. D. 1982. Dynamics and organization of a rocky intertidal fish assemblage: the persistence and resilience of taxocene structure. *American Naturalist* 119:611-637.
- Grossman, G. D. 1985. Long-term persistence in a rocky intertidal fish assemblage. *Environmental Biology of Fishes* 15:315-317.
- Grossman, G. D., P.B. Moyle, and J.O. Whitaker. 1982. Stochasticity and assemblage organization in an Indiana stream fish assemblage. *American Naturalist* 126:275-285.
- Guillory, V. 1982. Longitudinal gradients of fishes in Thompson Creek, Louisiana. *Southwestern Naturalist* 27:107-115.
- Gunning, G. E. and T. M. Berra. 1969. Fish repopulation of experimentally decimated segments in the headwaters of two streams. *Transactions of the American Fisheries Society* 98:305-308.
- Harrel, R., B. Davis, and T. Dorris. 1967. Stream order and species diversity of fishes in an intermittent stream. *American Midland Naturalist* 78:428-436.
- Hauer, F. R. 1985. Aspects of organic matter transport and processing within Savannah River Plant streams and the Savannah River floodplain swamp. Savannah River Ecology Laboratory. Division of Wetlands Ecology, Aiken, SC. SREL-18, UC-66e. 157 pp.
- Hocutt, C. H. and J. R. Stauffer. 1975. Influence of gradient on the distribution of fishes in Conowingo Creek, Maryland and Pennsylvania. *Chesapeake Scientist* 16:143-147.
- Horwitz, R. J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. *Ecological Monographs* 48:307-321.
- Jarvinen, O. 1979. Geographical gradients of stability in European land bird communities. *Oecologia* 38:51-69.
- Jumars, P. A. 1980. Rank correlation and concordance tests in community analyses: an inappropriate null hypothesis. *Ecology* 61:1553-1554.
- Karr, J. R. and Dudley, D. R. 1981. Biological perspectives on water quality goals. *Environmental management* 5:55-68.
- Karr, J. R. and I. J. Schlosser. 1978. Water resources and the land-water interface. *Science* 201:229-234.
- Kondratieff, B. C. and P. Kondratieff. 1985. A lower food chain community study: Thermal effects and post-thermal recovery in the streams and

- swamps of the Savannah River Plant. November 1983-May 1984. Report ECS-SR-15, DPST-85-218. Environmental and Chemical Sciences, Aiken, SC.
- Lotrich, V. A. 1973. Growth, production, and community composition of fishes inhabiting a first-, second-, and third-order stream of eastern Kentucky. *Ecological Monographs* 43:377-397.
- Matthews, W. J. 1985. Distribution of midwestern fishes on multivariate environmental gradients, with emphasis on Notropis lutrensis. *American Midland Naturalist* 113:225-237.
- Meffe, G. K. and A. L. Sheldon. 1986. Habitat associations of fish assemblages in small streams of the SRP. In: *Savannah River Ecology Laboratory Annual Report, 1986* (eds. W.D. McCort and R.B. Wolf), pp. 104-110. Savannah River Ecology Laboratory, Aiken, SC. 170 pp.
- Meffe, G. K. and W. L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran desert stream. *American Midland Naturalist* 117:177-191.
- Minckley, W. L. and G. K. Meffe. In press. Selection for native fishes by flooding in aquatic communities of the arid American southwest. In: *Evolutionary and Community Ecology of North American Stream Fishes* (eds. W.J. Matthews and D.C. Heins). University of Oklahoma Press: Norman, OK. 1987.
- Minshall, G. W., K. W. Cummins, R. C. Petersen, C. E. Cushing, D. A. Bruns, J. R. Sedell, and R. L. Vannote. 1985. Developments in stream ecosystem theory. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1045-1055.
- Murphy, M. L., C. P. Hawkins, and N. H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. *Transactions of the American Fisheries Society* 110:469-478.
- Moyle, P. B. and B. Vondracek. 1985. Persistence and structure of the fish assemblage in a small California stream. *Ecology* 66:1-13.
- Paller, M. 1985. Report of the ichthyoplankton sampling data from the creeks and swamps of the Savannah River Plant, March 14-1984 to July 31, 1984. ECS-SR-16, DPST-85-391. E.I. duPont de Nemours and Company, Savannah River Laboratory, Aiken, SC.
- Ross, S. T., W. J. Matthews, and A. A. Echelle. 1985. Persistence of stream fish assemblages: Effects of environmental change. *American Naturalist* 126:24-40.
- Ruby, C. H., P. J. Reinhart, and C. L. Reel. 1981. Sedimentation and erosion trends of the Savannah River Plant reactor discharge creeks. Research Planning Institute, Inc., Columbia, SC. Prepared for E.I. duPont de Nemours and Co., Aiken, SC. 54 pp.

- SAS. 1985. Statistical Analysis Institute. Version 5, Statistics. Statistical Analysis Institute: Cary, NC.
- Schlosser, I. J. 1982a. Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs* 52:395-414.
- Schlosser, I. J. 1982b. Trophic structure, reproductive success, and growth rates of fishes in a natural and modified headwater stream. *Canadian Journal of Fisheries and Aquatic Sciences* 39:968-978.
- Sheldon, A. L. 1968. Species diversity and longitudinal succession in stream fishes. *Ecology* 49:194-198.
- Smith, P. W. 1979. The fishes of Illinois. University of Illinois Press: Urbana, IL. 314 pp.
- Smock, L. A., E. Gilinsky, and D. L. Stoneburner. 1985. Macroinvertebrate production in a southeastern United States blackwater stream. *Ecology* 66:1491-1503.
- Southwood, T. R. E. 1978. *Ecological Methods*. Chapman and Hall: London. 524 pp.
- Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:130-137.
- Webster, J. R. and J. B. Waide. 1982. Effects of forest clearcutting on leaf breakdown in a southern Appalachian stream. *Freshwater Biology* 12:331-344.
- Whiteside, B. and R. McNatt. 1972. Fish species diversity in relation to stream order and physiographic conditions in the Plum Creek drainage basin. *American Midland Naturalist* 88:90-101.

**V. Recolonization Patterns of Fish in Streams
Receiving Thermal Effluents
From Nuclear Production Reactors**

John M. Aho and Charles S. Anderson

Introduction

Streams are periodically exposed to natural catastrophes, such as floods and drought, that can influence faunal population dynamics and assemblage structure. An important aspect of recovery following perturbation is the pathway and rate of repopulation. The patterns of disturbance and reinvasion affect community composition, and faunal responses may suggest common selective forces on the life histories of the species present.

Stream fishes repopulate disturbed habitats either by the active movement of juvenile or adult fish or by passive downstream drift of larvae. Of the two, within stream movement (upstream, downstream, or lateral) of juvenile and adult stages has received the greatest attention, but observations on the degree, timing, and extent of fish movement has varied among studies. Some investigations have emphasized limited longitudinal dispersal of many species (Bangham and Bennington, 1939; Larimore, 1952; Gerking, 1959; Brown, 1961; Berra and Gunning, 1972) whereas others have recognized the existence of three different components (sedentary, semi-mobile, and mobile) of fish assemblages (Funk, 1957; Hall, 1972; Whitehurst, 1981). Utilization of areas along stream margins (e.g., floodplain habitats) is also variable, being dependent upon channel morphology and fish behavioral patterns (Starrett, 1951; Guillory, 1979; Ross and Baker, 1983). Downstream drift of larval stages (Gerlach and Kahnle, 1981) as a source of colonists has received less attention, but may be analogous to invertebrate drift serving as the main pathway of recolonization in permanent streams (Townsend and Hildrew, 1976; Williams and Hynes, 1976). Thus, species-specific behavioral, morphological, life history, and physiological characteristics may all be important in determining community structure and dynamics. The complexity of these features and spatio-temporal

heterogeneity of the disturbance regime probably account for the variety of responses seen in lotic habitats. Some stream systems exhibit high resilience while others show little similarity between pre- and post-environmental impact (Gerking, 1950; John, 1964; Elwood and Waters, 1969; Rinne, 1975; Harrell, 1978; Grossman et al., 1982 and references therein; Ross et al., 1985).

Reestablishment processes are integral to stream fish dynamics in areas periodically inundated with heated effluents discharged from fossil fuel or nuclear power generating facilities. Duration of the thermal influence is variable with periods extending from days to months before water temperatures typical of surrounding aquatic habitats may again be established. During periods when temperatures return to normal ambient levels for the region, fish can potentially reinvade stream channels from upstream or downstream refugia. Dynamics of reinvasion and development of the fish assemblage provide model systems to examine patterns and processes in ecosystem recovery. Repopulation of these habitats by fish, however, may lead to their entrapment and the production of fish kills when high temperatures resume.

This study examines patterns of fish reinvasion of stream channels that periodically receive thermal effluents from nuclear production reactors. Particular attention is focused on the importance of upstream migration, but inferences are made regarding contributions from other sources of colonists. Specific questions addressed were: (1) Does upstream migration occur, and if so, does it vary seasonally and with respect to the length of time ambient water temperatures prevail? (2) Do patterns of utilization differ between streams of different heat loads and varying distances from source pools? and (3) Is the composition of fish recolonizing the streams temporally constant, or does it change seasonally?

Study Areas

Since the early 1950s, two streams (Pen Branch and Four Mile Creek) on the Department of Energy's Savannah River Plant (SRP) near Aiken, SC, have continued to periodically carry heated effluents from two nuclear production reactors into an extensive river-swamp system (Figure 5.1). Prior to where the streams enter the river-swamp, both are similar in discharge (ca. 11.3 m³/s during operation), and degree of thermal alteration (40-50°C), although Pen Branch was typically 3-5°C warmer than Four Mile Creek at the specific study sites. The streams differed, however, in the scheduling of reactor production activities. Discharge of effluents into Pen Branch occurred approximately on a monthly cycle. Over a 3-7 day period, discharge rates decline (to ca. 2-5 m³/s), water levels drop (by ca. 0.5 m), and seasonally ambient water temperatures are reestablished; for the remainder of time, the stream receives heated effluents. Longer periods of reactor operation and shutdown occurred in Four Mile Creek. Within a year, Four Mile Creek will cycle up and down 3 to 4 times and have periods of seasonally ambient water temperature and reduced discharge rates usually extending > 20 days. Although these are typical yearly patterns, operation schedules varied and limited the development of a regular fixed sampling design.

Methods

Fyke nets (13 mm stretched mesh, 5.5 m body length with three throats and 7.6 m wings) were used to examine patterns of migration into, and movement within, the two stream channels. In Pen Branch, six nets were set during each reactor outage; four were located where the stream channel enters the Savannah River Swamp System (SRSS) and the other two were ca.

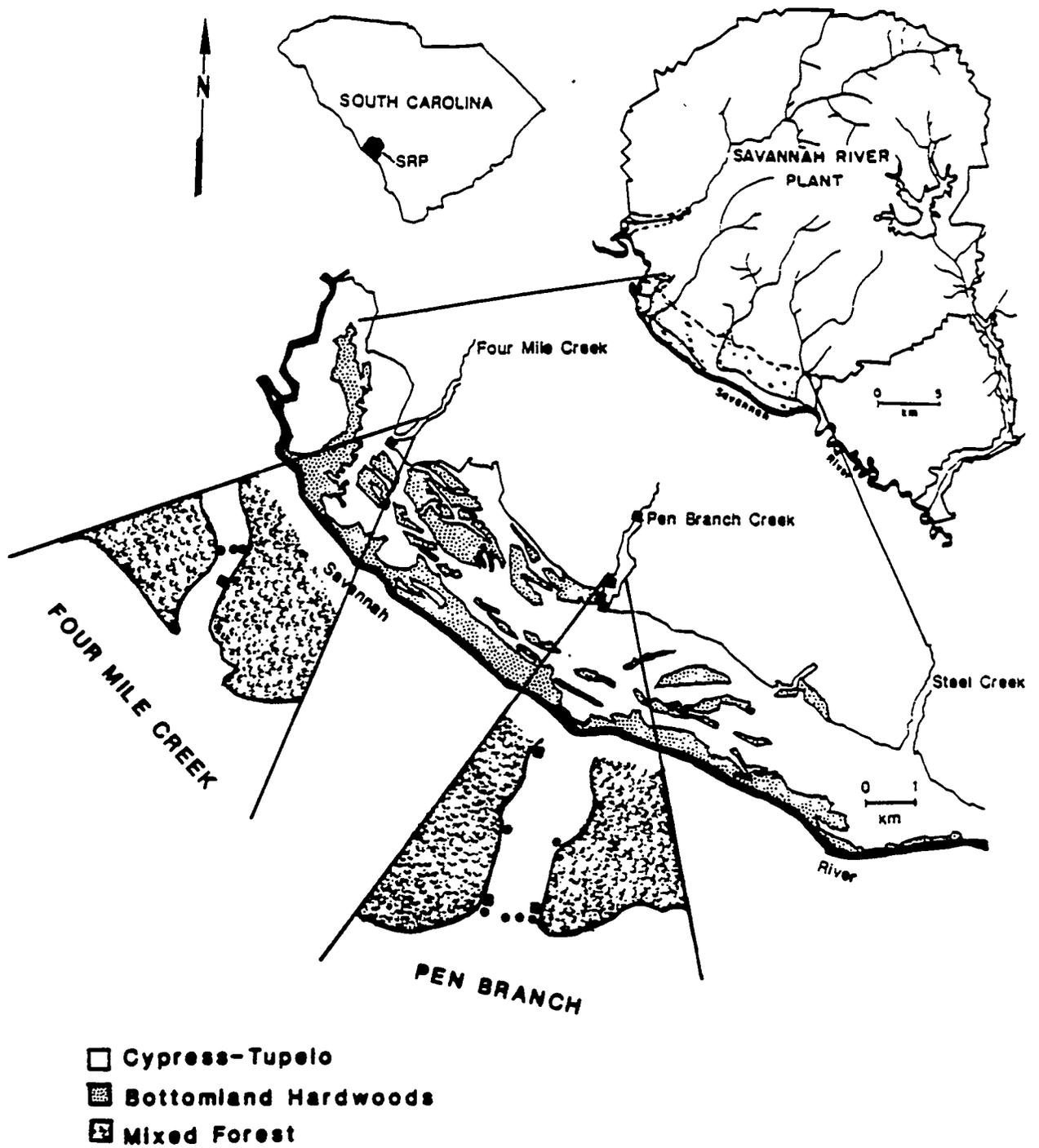


Figure 5.1. Map of the Savannah River Plant with highlights of the Savannah River Swamp System and location of the fyke nets (●) and location of backwater habitats (■) sampled by electrofishing, within Four Mile Creek and Pen Branch.

1.0 km upstream and positioned along the stream bank (Figure 5.1). An additional two nets were used twice to monitor the extent of long distance movement and were located ca. 3 and 6.5 km upstream of the downstream nets. Only three nets were used in Four Mile Creek; access to the stream limited placement to a site ca. 1.5 km above its deltaic fan in the SRSS. Thus, water temperatures at collection sites and distances that fish must move before capture differed between the two streams.

More nets were necessary to cover the wider (ca. 300 m) and braided Pen Branch channel. Four Mile Creek fyke nets stretched bank to bank, while in Pen Branch, only the four main low water channels, as depicted by aerial remote sensing imagery, that drain into the river-swamp were sampled. Additional small channels offered opportunity for upstream movement into Pen Branch, but were likely not important as most were either dry or shallow (<10 cm) during periods when regional ambient temperatures prevailed. Attempts to use paired upstream and downstream facing nets to determine flux rates of individuals or biomass were unsuccessful. On several occasions, variability in discharge rates associated with reactor operations resulted in the destruction of the upstream net. Fyke nets used in both streams were, therefore, situated parallel to the stream channel and only captured fish moving upstream.

From September 1983 through December 1985, 19 reactor cycles were investigated on Four Mile Creek (n = 3) and Pen Branch (n = 16). Upon notification of a planned cessation in reactor operations, nets were placed in the stream channels 1-2 days in advance of the shutdown, and then checked daily for the presence of fish in order to provide estimates of the timing and extent of reinvasion. Each fish caught was identified, measured for total length (TL), and weighed. Prior to being released upstream of the capture

site, each individual was either marked by clipping different combinations of fins if < 150 mm TL or given an individually numbered anchor tag. Records from recaptures would be used to assess the extent and direction of movement within the stream and determine whether individuals repeatedly migrated into the streams. Following reestablishment of heated conditions with the start of a new reactor cycle, nets were removed from the stream and observations stopped. Thus, all phases of reactor operation were examined for recolonization. The last outage on Four Mile Creek (> 180 days) was an exception to this schedule. After ten days, the nets were checked at two, and at most five, day intervals (mean = 2.6 days).

Five adjacent, backwater sloughs in Pen Branch ($n = 4$) and Four Mile Creek ($n = 1$) were also electrofished during June-July 1984 (Figure 5.1). Observations were made to determine whether fish used these habitats as refugia during periods of reactor operation and, if so, what species were present and their relative abundance. Daily occurrence of fish kills was also recorded when nets were examined, and notes were kept on the number of dead fish seen along the shoreline or floating downstream in a 10 to 15 minute time period (i.e., few--less than 10, moderate--10 to 100 individuals; and many--greater than 100) and species killed.

Statistical analyses were done using the Statistical Analysis System (SAS, 1985 a,b). Two-way analysis of variance (ANOVA) was used to test for differences in fish utilization of these streams among reactor cycles and for a preferred route (stream bank or mid-channel) of reinvasion. For this analysis, only a time period common to all reactor cycles (6 and 20 days for Pen Branch and Four Mile Creek, respectively) was used, and numbers of fish species and individuals caught at net locations (bank or mid-channel) were summed to provide daily values on the number of species and individuals; only the

downstream four nets in Pen Branch were used in the analysis. Timing of reinvasion and daily variability in the utilization of the streams by fishes within reactor cycles were tested using univariate ANOVA. For all parametric analyses, data on the number of species and individuals was $\log(x + 1)$ transformed since the assumption of homogeneity of variance was not originally met. The influence of water temperature on recolonization dynamics and variation in the relationship of species richness and total number of fishes captured were examined using rank correlation analyses. Chi-square tests were used to detect differences in stream movement patterns based on positional changes of marked fish in Pen Branch. The percent similarity index (equation 1 in Hurlbert, 1978) was used as a quantitative method of comparing similarity of the fish assemblages reinvading the two stream systems. Percent similarity was calculated as

$$PS = 100 (\text{minimum } p_{ia}, p_{ib})$$

where p_{ia} and p_{ib} are the proportion of taxon i in samples a and b , respectively. Analytical methods follow procedures outlined in Sokal and Rohlf (1981) and significance of all tests is $p \leq 0.05$.

Results

Temporal patterns of stream use

During periods of reactor operation on either Pen Branch or Four Mile Creek, fish use was minimal. No fish were ever captured when elevated water temperatures and discharge rates prevailed. Following cessation of production activities and a return to seasonally ambient water temperatures, however, fish were consistently captured moving upstream from the SRSS into both streams. Overall, a total of 3750 fish were captured in the fyke nets in Pen Branch ($n = 2636$, 27 species) and Four Mile Creek ($n = 1114$, 34 species).

Despite regular use of these habitats by fishes, patterns of repopulation varied over time (Figure 5.2, Table 5.1). In Pen Branch, assemblage richness and the total number of individuals entering the stream fluctuated temporally (Two-way ANOVA, time treatment, richness, $F_{15, 158} = 3.55$, $p < 0.001$; abundance, $F_{15, 158} = 3.29$, $p < 0.001$; Table 5.2). Patterns of fish reinvasion were similar between years. Species richness and number of individuals entering the stream were lowest during winter and progressively increased over spring before a decreased usage occurred throughout summer and fall (Figure 5.2, Table 5.1). Although the number of species and overall abundance varied slightly between months from different years, there were no detectable within-season differences in either assemblage richness or number of individuals entering Pen Branch (ANOVA, spring, summer, fall, or winter comparisons, $p > 0.05$). Upstream movement, however, differed between net location (Two-way ANOVA, position treatment, richness, $F_{1, 158} = 11.29$, $p < 0.001$; abundance, $F_{1, 158} = 11.46$, $p < 0.001$; Table 5.2) and was predominantly along the stream bank (>60% species, ca 65% individuals) (Figure 5.2, Table 5.1). Route of reinvasion shifted periodically (Two-way ANOVA time*position interaction, richness, $F_{15, 158} = 2.03$, $p < 0.01$; abundance $F_{15, 158} = 3.66$, $p < 0.001$; Table 5.2) with catch in mid-channel nets being higher on several occasions. The significance of the shift, however, as a response to water temperature or variation in stream flow is questioned as there was no consistent pattern in occurrence. Both temperature and flow are known to fluctuate within and between cycles (H. E. Mackey, Savannah River Laboratory, Environmental Monitoring Group, E. I. Dupont de Nemours and Company, personal communication).

Although observations were limited to three reactor cycles, reinvasion dynamics in Four Mile Creek were similar to patterns found in Pen Branch

FOUR MILE CREEK

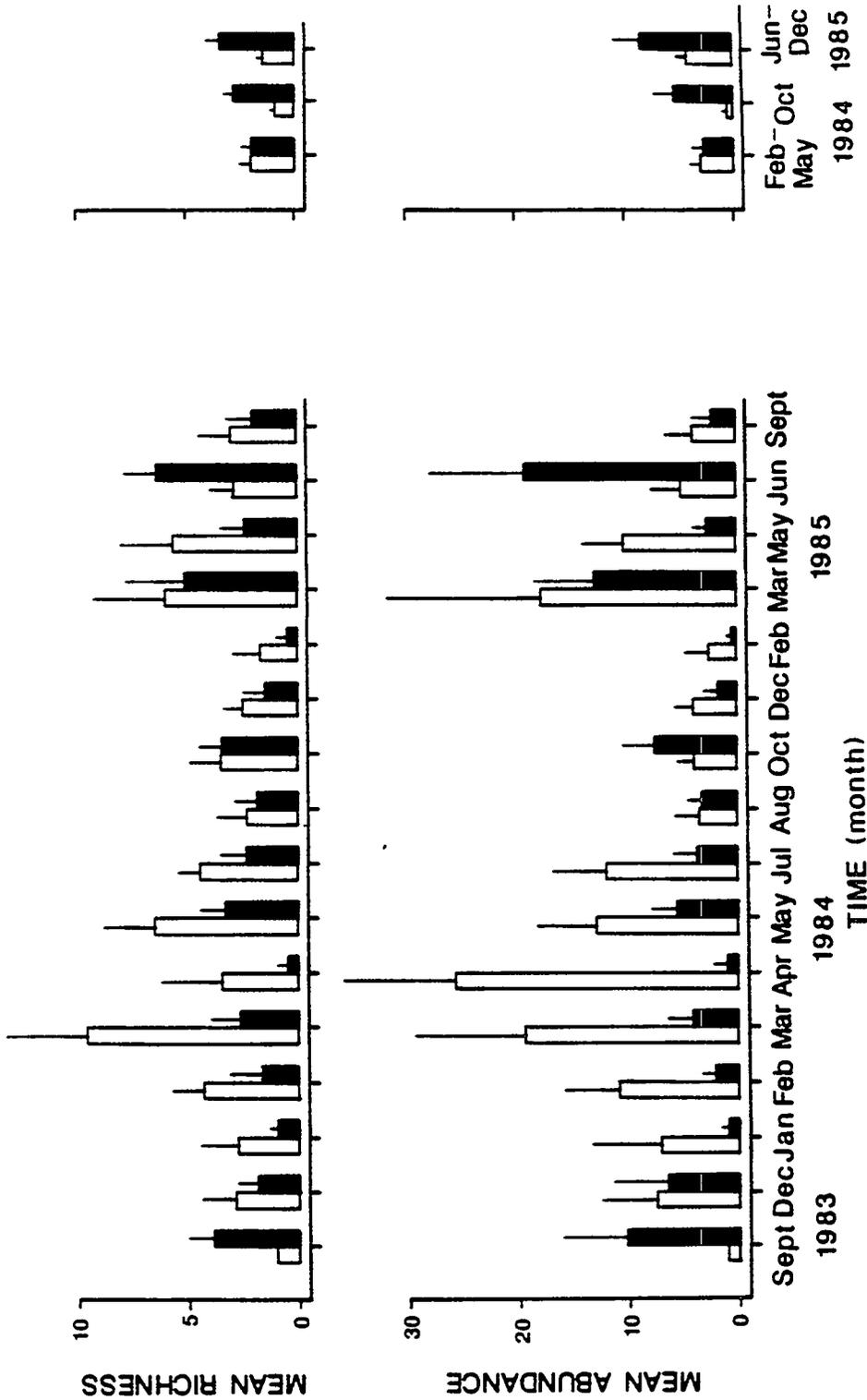


Figure 5.2. Temporal and positional changes in the mean number of species (richness) and mean total number of individuals (abundance) captured per day in the fyke nets during each reactor cycle on Pen Branch and Four Mile Creek. Open histograms represent nets placed along the streambank; black histograms represent nets located in mid-channel. Vertical bars indicate the 95% confidence interval. Assignment to a time class was based on the month with the greatest number of observations.

Table 5.1. Changes in the mean number of species per day (richness) and mean total number of individuals (abundance) per day ($\pm 95\%$ CI) over time and position of the fyke nets for fishes caught during each reactor cycle on Pen Branch and Four Mile Creek. Sample sizes for each time period and net position were $n = 6$ in Pen Branch and $n = 20$ in Four Mile Creek.

	<u>Mean number of species</u>		<u>Mean number of individuals</u>	
	<u>Streambank</u>	<u>Mid-channel</u>	<u>Streambank</u>	<u>Mid-channel</u>
<u>Pen Branch</u>				
September 1983	1.0 \pm 0.0	3.8 \pm 1.3	1.0 \pm 0.0	10.2 \pm 6.4
December	2.8 \pm 1.9	1.8 \pm 1.1	7.3 \pm 5.2	6.5 \pm 5.1
January 1984	2.8 \pm 1.9	1.0 \pm 0.5	7.2 \pm 6.9	1.0 \pm 0.7
February	4.3 \pm 1.6	1.7 \pm 1.7	10.8 \pm 5.0	1.8 \pm 1.8
March	9.7 \pm 4.1	2.7 \pm 1.4	19.5 \pm 9.1	4.2 \pm 2.4
April	3.5 \pm 3.0	0.5 \pm 0.5	25.8 \pm 30.2	0.8 \pm 1.3
May	6.5 \pm 2.5	3.3 \pm 1.1	12.8 \pm 5.3	5.3 \pm 2.7
July	4.5 \pm 1.0	2.3 \pm 1.3	11.8 \pm 5.4	3.5 \pm 2.4
August	2.3 \pm 1.3	1.8 \pm 0.9	3.5 \pm 2.3	3.2 \pm 1.4
October	3.5 \pm 1.5	3.5 \pm 1.1	3.7 \pm 1.7	7.3 \pm 3.3
December	2.5 \pm 0.9	1.5 \pm 1.1	3.8 \pm 1.7	1.7 \pm 1.2
February 1985	1.7 \pm 1.3	0.5 \pm 0.4	2.5 \pm 2.3	0.5 \pm 0.4
March	6.0 \pm 3.4	5.2 \pm 2.8	17.8 \pm 15.1	12.8 \pm 8.5
May	5.6 \pm 2.9	2.2 \pm 1.3	10.2 \pm 5.8	2.6 \pm 1.5
June	2.8 \pm 1.1	6.3 \pm 1.5	5.0 \pm 0.8	19.2 \pm 8.6
September	3.0 \pm 1.5	2.0 \pm 1.3	4.0 \pm 2.3	2.3 \pm 1.6
<u>Four Mile Creek</u>				
February-May 1984	1.9 \pm 0.9	2.0 \pm 0.7	2.9 \pm 1.0	2.7 \pm 1.1
October 1984	0.4 \pm 0.3	2.7 \pm 0.8	0.4 \pm 0.2	5.4 \pm 1.8
June-December 1985	1.5 \pm 0.4	3.2 \pm 1.0	3.5 \pm 1.6	8.6 \pm 2.9

Table 5.2. Results of analysis of variance examining for differences in the number of species and relative abundance of fish caught in fyke nets in Pen Branch between reactor cycles and position of the nets in the stream channel. Data was $\log_{10}(x + 1)$ transformed prior to analysis.

	df	SS	MS	F	p
Species Richness:					
Reactor Cycle	15	20.25	1.35	3.55	0.0001
Net Position	1	4.29	4.29	11.29	0.0010
Cycle x Position	15	11.51	0.77	2.03	0.02
Error	<u>158</u>	<u>59.93</u>	0.38		
Total	189	95.98			
Relative Abundance:					
Reactor Cycle	15	36.58	2.44	3.29	0.0001
Net Position	1	8.48	8.48	11.46	0.0009
Cycle x Position	15	40.69	2.71	3.66	0.0001
Error	<u>158</u>	<u>116.97</u>	0.74		
Total	189	206.72			

(Figure 5.2, Table 5.1). Species richness and total number of individuals caught moving into the stream differed between reactor cycles (Two-way ANOVA, richness, $F_{2, 114} = 12.74$, $p < 0.0001$; Table 5.3). Upstream movement of fish was low during winter, intermediate in fall, and while reinvasion was greatest during late spring to early summer (early in the third cycle), it declined over the course of the summer months typical of the movement pattern observed in Pen Branch. Differences in the route of reinvasion were also detected (Two-way ANOVA, richness, $F_{1, 114} = 25.96$, $p < 0.001$; abundance, $F_{1, 114} = 33.76$, $p < 0.001$; Table 5.3). In Four Mile Creek, however, mid-channel was the preferred route. The low usage of the stream bank channels by fish accompanied declining water levels that produced channels which were either shallow (< 10 cm) and slow (< 15 cm/s), or deep (ca. 1 m) and fast (25-40 cm/s).

Regardless of the time of year, recolonization into either stream was rapid with individuals captured within 12 hours of a cessation in reactor operations (Figure 5.3). Intensity of upstream movement at the onset of a cycle was typically low, and not correlated with mean water temperature in the first week of a cycle (Spearman rank correlation, $r = 0.19$, $df = 17$, $p > 0.10$), suggestive that fish entered the streams at approximately the same rate throughout the year. Species richness and individual abundance then increased and reinvasion continued for the remainder of the cycle. There was, however, considerable daily variation in both the number of species and individuals moving into Pen Branch (ANOVA, richness, $F_{41, 1109} = 2.09$, $p < 0.001$; abundance, $F_{41, 1109} = 1.96$, $p < 0.001$; Table 5.4), but no consistent pattern of change either within or between cycles was evident (Figure 5.3). Although daily variability in movement of fish into Four Mile Creek was observed, the differences were not as pronounced as found in Pen Branch

Table 5.3. Results of analysis of variance examining for differences in the number of species and relative abundance of fish caught in fyke nets in Four Mile Creek between reactor cycles and position of the nets in the stream channel. Data was log (x + 1) transformed prior to analysis.

	df	SS	MS	F	p
Species Richness:					
Reactor Cycle	2	2.55	1.28	5.12	0.007
Net Position	1	6.49	6.49	25.96	0.0001
Cycle x Position	2	4.46	2.23	8.92	<0.001
Error	<u>114</u>	<u>27.98</u>	0.25		
Total	119	41.48			
Relative Abundance:					
Reactor Cycle	2	10.70	5.35	12.74	0.0001
Net Position	1	14.18	14.18	33.76	0.0001
Cycle x Position	2	10.46	5.23	14.45	0.0001
Error	<u>114</u>	<u>47.35</u>	0.43		
Total	119	82.69			

Table 5.4. Results of analysis of variance examining for daily differences in the number of species and relative abundance of fish caught in fyke nets in Pen Branch and Four Mile Creek. The temporal analysis considers only captures on specific fish were able to reinvade the stream channel.

	df	SS	MS	F	p
<u>Pen Branch</u>					
Species Richness:					
Days in Cycle	41	31.73	0.77	2.01	<0.001
Error	<u>1109</u>	<u>427.59</u>	0.39		
Total	1150	459.32			
Relative Abundance:					
Days in Cycle	41	58.96	1.44	1.96	<0.001
Error	<u>1109</u>	<u>812.14</u>	0.73		
Total	1150	871.09			
<u>Four Mile Creek</u>					
Species Richness:					
Days in Cycle	101	39.06	0.39	0.94	>0.60
Error	<u>330</u>	<u>135.39</u>	0.41		
Total	431	174.45			
Relative Abundance:					
Days in Cycle	101	65.16	0.65	0.83	>0.85
Error	<u>330</u>	<u>256.59</u>	0.78		
Total	431	321.76			

(Figure 5.3, Table 5.4). Some variability in reinvasion was associated with the increase in discharge rates prior to a resumption of reactor activities, particularly for the cycles of less than 14 days duration. For longer periods of reactor inactivity, decreased upstream migration was also associated with seasonal changes in fish activity.

Within stream movement patterns

In Pen Branch, representatives of all species and greater than 75% of all individuals were initially caught and marked in the nets adjacent to the SRSS. While the capture of unmarked fish at the upstream nets prevented estimation of either the total number of fish or biomass entering the stream, their presence, plus five additional fish (one marked) caught in two nets located further upstream, indicated movement within the stream could be widespread. The extent of upstream movement within the stream, however, was not influenced by the duration of ambient water temperature and low discharge conditions. Fish moved upstream in all periods of observation, but there was no apparent change in the proportion of fish captured at the upstream nets between reactor cycles of differing length (Spearman rank correlation, $r = 0.20$, $df = 14$, $p > 0.05$). Although movement throughout the stream was possible (except for a man-made riffle > 8 km from the SRSS), comparatively few fish moved great distances upstream over periods of time when conditions were hospitable in Pen Branch.

Instead, based on positional changes made by marked individuals within the stream, most fish exhibited a combination of directional movement patterns (Table 5.5). Many fish continued upstream from the lower nets, but others were subsequently recaptured after making local movements (i.e., the same individual was recaptured multiple times at the

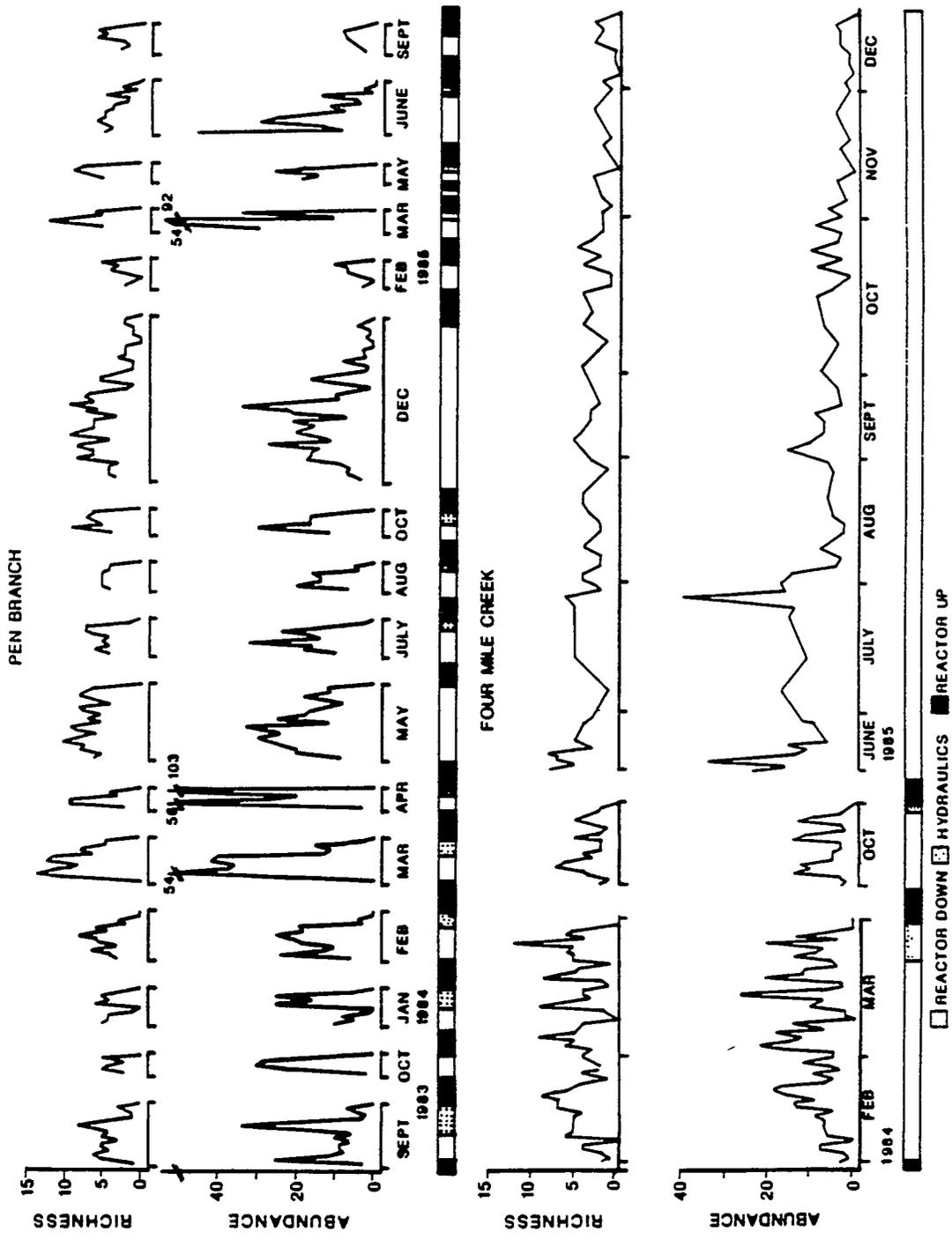


Figure 5.3. Daily variability in the number of species and individuals entering Pen Branch and Four Mile Creek in 1983 through 1985. Solid bars indicate periods when thermal effluents were discharged into the streams, open bars were periods of reduced water temperatures and discharge, and stippled bars identify times when increased discharge rates occurred, but water temperatures were seasonally ambient. Assignment to a time class was based on the month with the greatest number of observations.

Table 5.5 Direction of continued movement of fish within Pen Branch based on mark-recapture studies.

Direction moved:	Upstream ¹	Downstream ²	Lateral ³	Local ⁴
Number of observations:	25	18	16	30
			$\chi^2 = 5.61$	$p > 0.10$

¹Fish caught upstream of initial capture

²Fish caught downstream of initial capture

³Fish having shifted lateral position between net locations

⁴Fish recaptured only at the same net of initial capture; multiple recaptures of same individual only counted once

same net), shifting position laterally in the stream channel, or moving downstream. As no significant difference was detected between frequencies of these different behavioral patterns ($\chi^2 = 5.61$, $df = 3$, $p > 0.10$), movement of fish within the stream was apparently random. Recapture of marked individuals between cycles was also limited. On only two occasions were single individuals of longnose gar (Lepisosteus osseus) later recaptured upon reinvading the streams. A bowfin (Amia calva) and a warmouth (Lepomis gulosus), which had been previously marked in other portions of the SRSS (Aho and Anderson, unpublished data), were also captured moving into Pen Branch. The bowfin had moved ca. 7 km in 31 days, and the warmouth had moved ca. 3 km in 10 days.

Within Four Mile Creek, continued upstream migration was limited by a spillway dam located approximately 1 km above the nets, but our observations indicated fish were present at the base of this barrier on several occasions. No fish marked in a prior reactor cycle or a different region of the SRSS were recaptured in Four Mile Creek.

Species composition

Similarity of the fish assemblage repopulating Four Mile Creek and Pen Branch was high (75% similarity). Of the fish captured, centrarchids were the most numerous and dominant taxa with >30% of all species recorded and > 60% of the individuals (Figure 5.4; Table 5.6). Fifteen species were considered as common (> 1% of numerical abundance), but five species (spotted sunfish Lepomis punctatus, lake chubsucker Erimyzon sucetta, golden shiner Notemigonus crysoleucas, redbreast sunfish Lepomis auritus, and longnose gar) represented more than 50% of the fish entering the streams. Although frequently observed in the streams, the absence of other cyprinids (e.g. coastal shiner Notropis petersoni) and mosquitofish (Gambusia

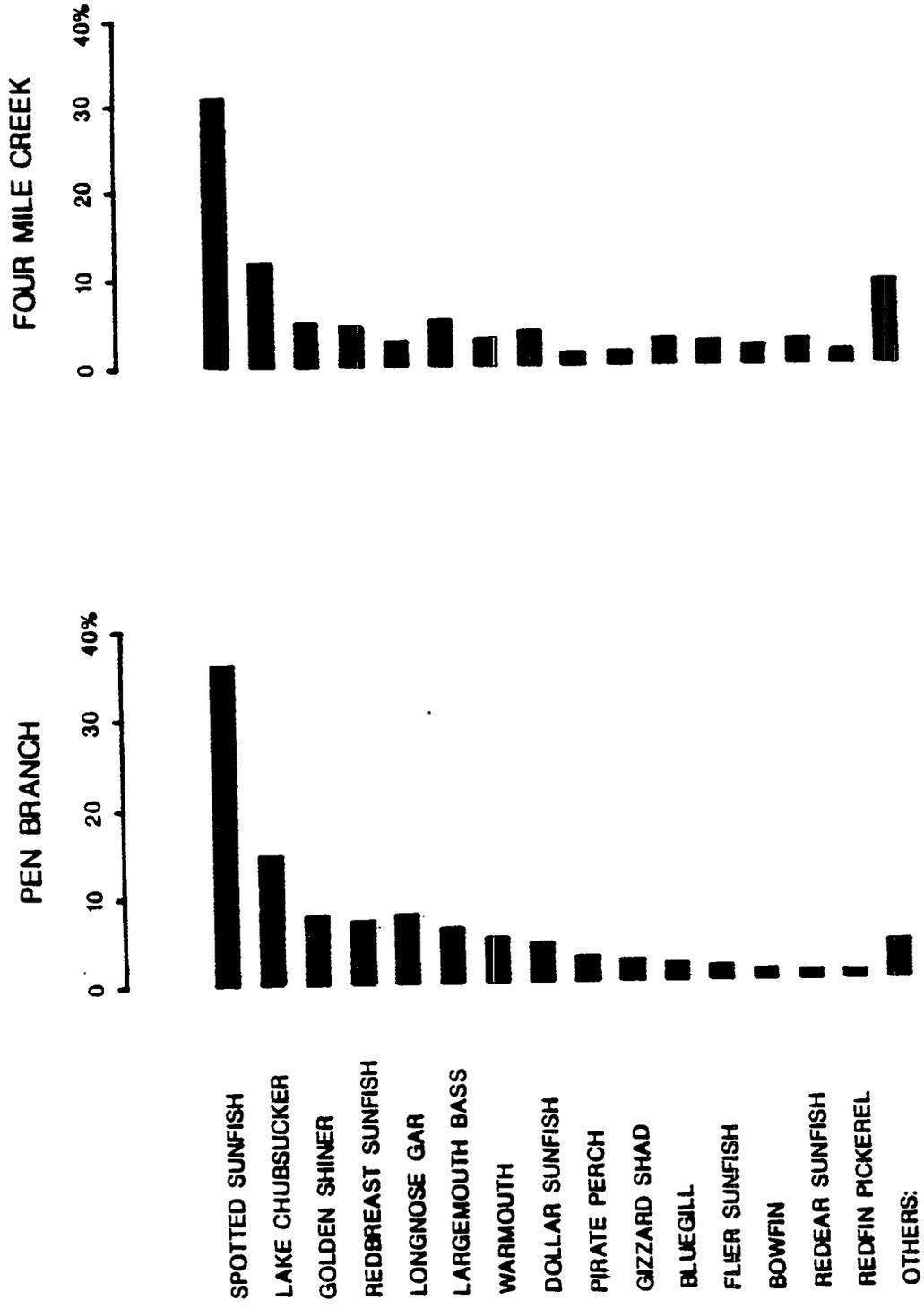


Figure 5.4. Overall numerical percentage composition of the fish assemblage caught in fyke nets in Pen Branch (n = 2636) and Four Mile Creek (n = 1114).

Table 5.6. Summary of the frequency of occurrence (%) and mean abundance (\bar{x}) of fishes captured in each reactor cycle in Pen Branch and Four Mile Creek and species group designations (1 = rare, 2 = intermediate, 3 = common). Assignment of a species to a group was based on its frequency of occurrence in both streams.

	Pen Branch (n = 16)		Four Mile (n = 3)		Group
	%	\bar{x}	%	\bar{x}	
Amiidae					
<u>Amia calva</u>	43.7	2.1	100.0	7.7	2
Anguillidae					
<u>Anquilla rostrata</u>	25.0	0.5	33.3	1.0	1
Aphredoderidae					
<u>Aphredoderus sayanus</u>	50.0	4.5	33.0	10.7	2
Catostomidae					
<u>Erimyzon sucetta</u>	93.7	24.4	100.0	45.7	3
<u>Minytrema melanops</u>	18.7	0.3	33.3	1.7	1
<u>Moxostoma anisurum</u>			33.3	0.3	1
Centrarchidae					
<u>Lepomis auritus</u>	100.0	12.1	100.0	17.3	3
<u>Lepomis gulosus</u>	75.0	8.	100.0	11.7	3
<u>Lepomis gibbosus</u>	12.5	0.3	33.3	0.3	1
<u>Lepomis macrochirus</u>	56.2	3.4	100.0	11.0	2
<u>Lepomis marginatus</u>	81.2	7.5	100.0	26.3	3
<u>Lepomis microlophus</u>	37.5	1.8	100.0	6.7	2
<u>Lepomis punctatus</u>	100.0	50.8	100.0	140.7	3
<u>Enneacanthus gloriosus</u>	37.5	0.9	66.7	3.0	2
<u>Pomoxis nigromaculatus</u>	50.0	1.1	66.7	2.0	2
<u>Centrarchus macropterus</u>	43.7	2.8	66.7	10.0	2
<u>Micropterus salmoides</u>	100.0	10.8	100.0	20.3	3
<u>Acantharchus pomotis</u>	6.3	<0.1	33.3	0.3	1
Clupeidae					
<u>Dorosoma cepedianum</u>	56.2	3.6	66.7	6.3	2
<u>Alosa mediocris</u>			33.3	0.7	1
<u>Alosa aestivalis</u>			33.3	0.3	1

Table 5.6. Continued

	Pen Branch (n = 16)		Four Mile (n = 3)		Group
	%	\bar{x}	%	\bar{x}	
Cyprinidae					
<u>Notemigonus crysoleucas</u>	93.7	12.6	100.0	19.3	3
<u>Cyprinus carpio</u>			33.3	0.3	1
Esocidae					
<u>Esox americanus</u>	37.5	1.6	66.7	5.0	2
<u>Esox niger</u>	6.3	0.1	33.3	3.7	1
Ictaluridae					
<u>Ictalurus nebulosus</u>	25.0	0.3	33.3	1.3	1
<u>Ictalurus natalis</u>	25.0	0.6	66.6	1.0	2
<u>Ictalurus punctatus</u>	6.3	<0.1	33.3	1.0	1
<u>Noturus gyrinus</u>			33.3	0.3	1
<u>Ictalurus platycephalus</u>			66.7	0.7	1
Lepisosteidae					
<u>Lepisosteus osseus</u>	37.5	12.9	100.0	11.0	2
<u>Lepisosteus platyrhinchus</u>	12.5	1.6	33.3	1.3	1
Percidae					
<u>Perca flavescens</u>	6.3	<0.1	33.3	0.3	1
Umbridae					
<u>Umbra pygmaea</u>			33.3	0.3	1

affinis) reflected the bias of the nets against collecting small, elongate fishes. In addition to fish, alligators (Alligator mississippiensis) and turtles (Trachemys scripta, T. floridana, T. concinna, Chelydra serpentina, and Trionyx spiniferus) were caught moving into both streams over the period of study.

For the common species of fish captured moving into either stream, size range was broad ranging from a spotted sunfish of 34 mm total length to a longnose gar having a total length of 913 mm (Table 5.7). Based on size distribution patterns of the common species, both juvenile and adult fish were caught moving upstream, regardless of the time of year. Some species, however, were primarily only captured as adults. These included bowfin Amia calva, gizzard shad Dorosoma cepedianum, spotted sucker Minytrema melanops, and longnose and Florida gar Lepisosteus platyrhincus.

Based on patterns of species utilization among reactor cycles for both Pen Branch and Four Mile Creek, three groups of species were identified reinvading the streams (Table 5.6; Figure 5.5). The first had the most species, but was composed of rare and infrequently encountered taxa (occurring in <30% of the reactor cycles) that exhibited no consistent pattern in either time of appearance or peak abundance. The second group included 11 species that occurred in 30-70% of the reactor cycles and had peak activity primarily during spring to early summer, with many individuals reproductively active. Representatives of this group included pirate perch Aphredoderus sayanus; longnose gar, redbfin pickerel Esox americanus, flier Centrarchus macropterus, and warmouth. The last group (seven species) was found reinvading the streams in >70% of the reactor cycles with five species (spotted sunfish, golden shiner, lake chubsucker, redbreast sunfish, and largemouth bass Micropterus salmoides) consistently (>90% of the cycles)

Table 5.7. Summary of the mean length (± 1 SE) and range of sizes for fishes caught in Pen Branch and Four Mile Creek.

Species	Pen Branch	Four Mile Creek
Amiidae		
Bowfin <u>Amia calva</u>	499.9 \pm 25.6 (110-656)	512.9 \pm 19.2 (349-780)
Anguillidae		
American eel <u>Anquilla rostrata</u>	398.1 \pm 35.8 (301-603)	390.5 \pm 94.5 (296-485)
Aphredoderidae		
Pirate perch <u>Aphredoderus sayanus</u>	84.7 \pm 2.0 (53-102)	85.0 \pm 1.3 (66-100)
Catostomidae		
Lake chubsucker <u>Erimyzon sucetta</u>	163.2 \pm 2.1 (63-317)	170.9 \pm 4.4 (83-306)
Spotted sucker <u>Minytrema melanops</u>	355.5 \pm 99.3 (109-480)	371.0 \pm 49.7 (248-520)
Silver redhorse <u>Moxostoma anisurum</u>		127
Centrarchidae		
Redbreast sunfish <u>Lepomis auritus</u>	129.9 \pm 2.7 (60-223)	94.9 \pm 5.2 (44-170)
Warmouth <u>Lepomis gulosus</u>	182.1 \pm 3.2 (70-250)	148.8 \pm 7.8 (66-248)
Pumpkinseed <u>Lepomis gibbosus</u>	146.3 \pm 9.7 (133-175)	86
Bluegill <u>Lepomis macrochirus</u>	133.7 \pm 6.0 (91-224)	116.4 \pm 10.8 (62-205)
Dollar sunfish <u>Lepomis marginatus</u>	76.7 \pm 0.9 (56-103)	75.9 \pm 0.9 (54-93)
Redear sunfish <u>Lepomis microlophus</u>	168.5 \pm 6.3 (91-224)	116.4 \pm 10.8 (62-205)
Spotted sunfish <u>Lepomis punctatus</u>	90.3 \pm 0.7 (34-160)	87.3 \pm 0.9 (55-145)

Table 5.7. Continued

Species	Pen Branch	Four Mile Creek
Centrarchidae - continued		
Bluespotted sunfish <u>Enneacanthus gloriosus</u>	66.9 ± 1.4 (55-79)	66.7 ± 2.2 (60-80)
Flier <u>Centrarchus macropterus</u>	135.5 ± 3.4 (66-177)	136.1 ± 3.7 (99-185)
Mud sunfish <u>Acantharchus pomotis</u>	94	85
Black crappie <u>Pomoxis nigromaculatus</u>	163.4 ± 10.7 (95-254)	150.5 ± 30.0 (80-263)
Largemouth bass <u>Micropterus salmoides</u>	124.9 ± 3.8 (72-368)	129.3 ± 8.3 (72-575)
Clupeidae		
Blueback herring <u>Alosa aestivalis</u>		272.0 ± 2.0 (270-274)
Hickory shad <u>Alosa mediocris</u>		290
Gizzard shad <u>Dorosoma cepedianum</u>	292.5 ± 6.0 (147-370)	201.1 ± 24.5 (85-375)
Cyprinidae		
Golden shiner <u>Notemigonus crysoleucas</u>	149.9 ± 2.1 (64-234)	142.7 ± 3.7 (101-246)
Carp <u>Cyprinus carpio</u>		750
Esocidae		
Chain pickerel <u>Esox niger</u>	190	228.2 ± 19.5 (146-380)
Redfin pickerel <u>Esox americanus</u>	177.9 ± 10.6 (89-282)	160.4 ± 7.8 (133-212)

Table 5.7. Continued

Species	Pen Branch	Four Mile Creek
Ictaluridae		
Yellow bullhead <u>Ictalurus natalis</u>	130.3 ± 9.7 (97-180)	128.0 ± 12.2 (112-152)
Brown bullhead <u>Ictalurus nebulosus</u>	201.0 ± 30.6 (113-253)	166.5 ± 37.9 (135-255)
Flat bullhead <u>Ictalurus platycephalus</u>		148.5 ± 5.5 (143-154)
Channel catfish <u>Ictalurus punctatus</u>	271	413.8 ± 44.1 (150-595)
Tadpole madtom <u>Noturus gyrinus</u>		64
Lepisosteidae		
Longnose gar <u>Lepisosteus osseus</u>	577.2 ± 7.1 (196-906)	579.6 ± 22.7 (267-913)
Florida gar <u>Lepisosteus platyrhinchus</u>	594.3 ± 23.9 (409-935)	496.5 ± 24.9 (430-546)
Percidae		
<u>Perca flavescens</u>	285	278
Umbridae		
<u>Umbra pygmaea</u>		89

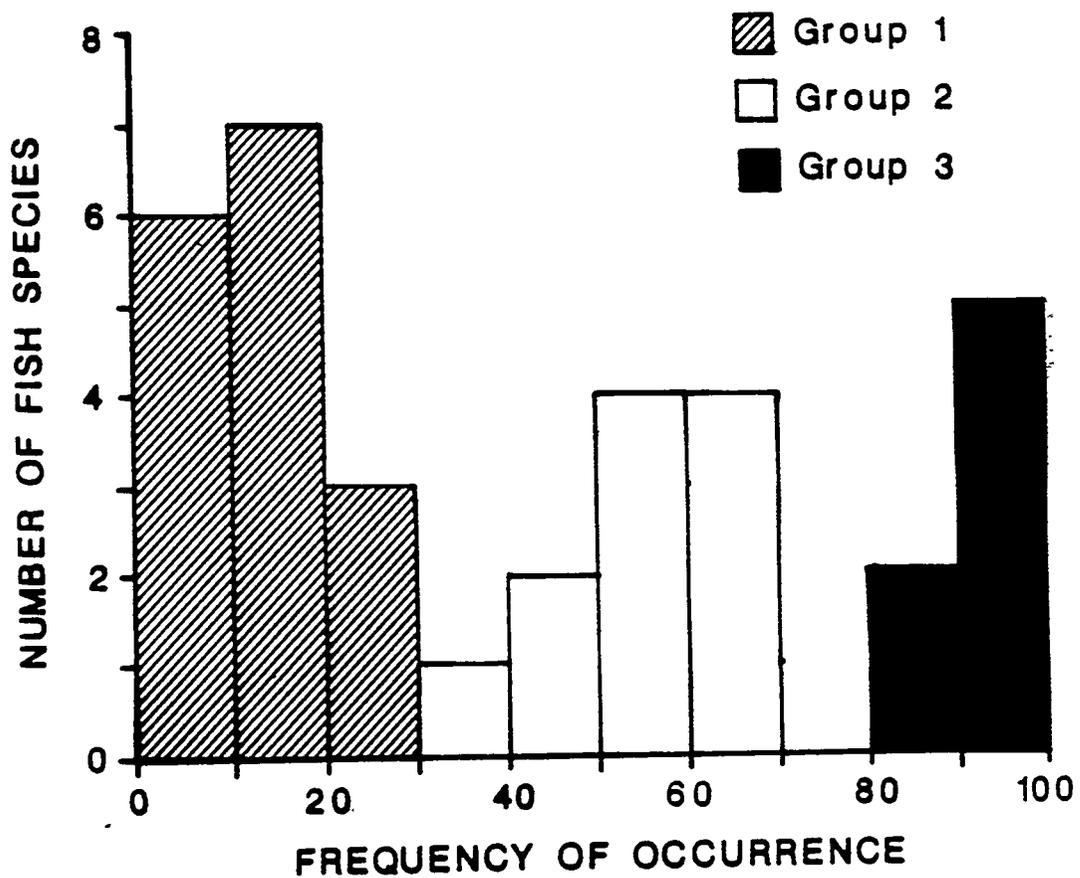


Figure 5.5. Frequency distribution of the occurrence of fish species moving into Pen Branch and Four Mile Creek during periods of reactor shutdown. Group number refers to the species group listed in Table 5.6.

moving into the stream channels upon a cessation of reactor operations. While arbitrarily defined from species utilization patterns of the streams, the distinction between rare, intermediate, and common components in the fish assemblage is important to community development as frequency of species occurrence and its abundance were positively correlated (Spearman rank correlation, $r = 0.91$, $df = 32$, $p < 0.01$).

Occurrence of fish kills

Following a reestablishment of thermal conditions in either stream channel, fish kills were infrequently observed and usually only few to moderate in size. Most individuals killed were mosquitofish or coastal shiners, although sunfishes of several species, including largemouth bass, and lake chubsuckers were seen on occasion. Only after the restart of the October 1984 reactor cycle on Four Mile Creek was a large fish kill observed; >200 individuals of 9 different species (mosquitofish, coastal shiners, spotted sucker, lake chubsucker, largemouth bass, redbreast sunfish, bluegill, spotted sunfish, and dollar sunfish) were counted in ca. 5 minutes. The observation of low mortality following resumption of heated conditions suggested that fish responded quickly to increased flow rates and water temperature and moved downstream into the SRSS. Some potential refuge areas existed along the stream margin (e.g., marshes, isolated groundwater seepage areas), but most were either ephemeral or too small to provide sufficient shelter for the number of fish migrating upstream. Fish were only captured in the two lowermost backwater sloughs in Pen Branch and the single site in Four Mile Creek. Water temperatures ranged from 24-36°C where fish were present; maximal temperatures exceeded 40°C in sites where no fish were captured. When fish were found in backwater areas adjacent to the main channel, assemblage composition was dominated by mosquitofish (>90% numerical

abundance) (Table 5.8). Onset of assemblage recovery from internal sources of colonists would, therefore, seem to be minimal and utilization of backwater areas as refuge areas is limited.

Discussion

The stream channels of Pen Branch and Four Mile Creek are areas of open habitat regularly exploited by fishes following cessation of reactor operations. Species composition and number of individuals migrating upstream varies seasonally, the greatest influx occurring during spring. Movement into the streams is rapid, usually occurring within 24 hours of a shutdown and is continuous for as long as ambient temperatures and low flow conditions exist. Although the species pool available for reinvasion and distances moved prior to entering the stream are currently unknown, the fishes recolonizing both streams represent a major subset of the greater than 60 species of resident and migratory fish recorded from the SRSS (Bennett and McFarlane, 1983). Differences in either reactor scheduling or distance from the SRSS had only minor influence on the fish assemblage as the same 15 species were the numerical dominants in both stream systems. The presence of two anadromous species, blueback herring *Alosa aestivalis* and hickory shad *Alosa mediocris*, suggests that Four Mile Creek may also receive migrants from the Savannah River.

Three hypotheses are recognized that may account for the observed patterns in fish utilization of these streams. The first suggests upstream movement may be a direct response by fish either to changes in current velocity or water level (Funk, 1957; Hall, 1972; Whitehurst, 1981). If the stimulus for movement is either of these, or some combination, the predicted response would be for an initial rapid increase followed by a decline within a short period of time. Changes in water temperature may also influence fish

Table 5.8. Species composition and percentage relative abundance of fish in backwater regions on Pen Branch and Four Mile Creek during periods of reactor discharge of heated effluents. Fish were collected from two backwater sites in Pen Branch and one site in Four Mile Creek.

	Pen Branch Four Mile Creek	
<u>Species</u>	<u>Common Name</u>	<u>Percent Composition</u>
Poeciliidae		
<u>Gambusia affinis</u>	Mosquitofish	95 90
Centrarchidae		
<u>Lepomis auritus</u>	Redbreast sunfish	1 1
<u>Lepomis macrochirus</u>	Bluegill	1 1
<u>Lepomis marginatus</u>	Dollar sunfish	<1
<u>Lepomis microlophus</u>	Redear sunfish	1 7
<u>Lepomis punctatus</u>	Spotted sunfish	1 1
Cyprinodontidae		
<u>Fundulus lineolatus</u>	Lined topminnow	<1
Total Number of Individuals		189 113

movement (Stauffer et al., 1976), and during the summer and early fall when the areal coverage of the thermal plume in the SRSS is greatest (H. E. Mackey, Savannah River Ecology Laboratory, Environmental Monitoring Group, E. I. du Pont de Nemours & Co., personal communication), fish may be further from the streams and require a longer period of time to migrate upstream. Conversely, behavioral thermoregulation could increase use of the thermal plumes as overwintering areas and, therefore, increase the numbers of fish captured in winter. As neither of these movement patterns, or the short pulse in catch rate, were observed, it is unlikely that changes in physical factors are directly causing the movement.

Movement into the streams might alternatively be a response to large-scale spatial variations in food resource availability established by the thermal plumes. Fish moving into the streams represent a variety of trophic guilds, but most are generalist invertebrate feeders (Bennett and McFarlane, 1983). Standing stocks of benthic macroinvertebrates, principally aquatic insects, are low in comparison to adjacent cool-water regions (O'Hop et al., 1986). Recolonization of the channels occurs rapidly with vagile insects, such as chironomids, reaching densities of $>1000/m^2$ within 10 days on artificial substrates. Populations of larger-bodied macroinvertebrates (e.g., mayflies, and caddisflies) are present, but abundance is low due to lower mobility and longer generation times. With reduced temperature and flow conditions normally in existence for less than 10 days, particularly in Pen Branch, food availability should remain limited. While instream primary production is high in both streams, most is either transported downstream into the SRSS or is of low food quality to higher trophic levels because of being dominated by several taxa of blue-green algae (Hauer, 1985). Thus, it seems unlikely fish respond to gradients in food resources, but interrelationships between

foraging and habitat availability, utilization, and profitability need to be examined to support or refute this idea.

A third hypothesis appears the most parsimonious. Recolonization of Pen Branch and Four Mile Creek may be the outcome of fish randomly moving into the stream channels from the SRSS whenever conditions permit. Invertebrate colonization of new substrates or habitats represent analogous systems to the thermal stream systems on the SRP; habitats with larvae contribute to empty habitats until once-empty sites contain enough individuals to provide a balancing counterflow and reach densities appropriate to the local environment (Sheldon, 1984). Movement may be an adaptive response to food availability, predators, or competitors. However, colonization of new habitats also has a large random component, and factors such as water temperature, current velocity, and size of the animal are important determinants of timing, numbers of individuals, and how far an organism moves.

The absence of marked individuals reinvading the streams between reactor cycles suggests that individuals within the SRSS are probably continuously mixing, and whenever conditions permit, they move into these previously unavailable habitats. Initiation of movement into the streams does not appear to differ throughout the year, but the intensity of recolonization is likely influenced by water temperature effects on activity levels and the distance fish must move prior to entering the stream. This is particularly evident during summer and fall with the decline in utilization coinciding with the thermal plume having its greatest areal coverage (Christiansen et al., 1984). Inclusion of both juvenile and adult fish for most species also indicates that size is not a determinant of movement. Although individuals had the potential for widespread dispersal, distance moved was

independent of the length of time ambient temperature/discharge conditions were in existence. Most individuals exhibited limited changes in position in the areas adjacent to the SRSS. The lack of pronounced directional movement within the stream is also suggestive of a random movement pattern.

Species composition also appears to be a random subset of the fish in the swamp as ca. 50% of the species recorded from the SRSS (Bennett and McFarlane, 1983) were captured during the study. Where species are absent, notably the cyprinids, size selectivity of the nets restricted their inclusion as many of the species (e.g. coastal shiner, dusky shiner Notropis cummingsae) were observed to be present in the vicinity of the nets. Seasonal changes in the composition of the fish assemblage moving into the streams, therefore, may reflect behavioral differences between species in their dispersal potential. For the centrarchids, exploitation of these habitats is not too surprising as numerous studies have shown them to be generalists in habitat use (Keast, 1965; Keast and Webb, 1966; Werner and Hall, 1976; Werner et al., 1977; Keast, 1978; Keast et al., 1978). In contrast, species known to be more selective in habitat requirements (e.g., darters - Matthews et al., 1982) might not be expected to move appreciable distances. Differential responsiveness by fishes to move onto floodplain habitats during periods of inundation have also been observed by Ross and Baker (1983). Species-specific patterns of habitat selection may, therefore, be an important determinant of Funk's (1957) observation that stream fishes can be classified either as mobile, semi-mobile, or sedentary, and may change movement patterns during their life history.

There may also be a directed component to upstream movement as several species of fish (e.g., pirate perch, longnose gar) were only captured

while reproductively active. Several studies have shown a spring peak in movement corresponding to spawning activity (Funk, 1957; Holder, 1970; Hall, 1972; Whitehurst, 1981; Currie and Spacie, 1984), including many of the species observed here. Upstream movement by adults into smaller streams and headwaters has been hypothesized to provide more favorable conditions for larval development, growth and population persistence through increased amounts of energy for prey productivity, decreased interactions for food, and less predation pressure (Hall, 1972; Schlosser, 1982). While seemingly a maladaptive behavior in these particular streams because of temperature/flow effects on food availability and habitat characteristics (e.g., reduction in the amount of cover in the stream), the observed movement coinciding with reproduction potentially represents an evolutionary response exhibited by many species of fish.

Consequences of a reestablishment of thermal conditions in either Pen Branch or Four Mile Creek differ according to the life history stage of the fish. As few juvenile and adult fish have been found dead, most individuals reinvading the streams are thought to elicit a reactive response by leaving the stream channel and moving back into the SRSS. Several small backwaters exist on both streams, but their importance as refugia (McFarlane, 1976) for survival is apparently limited probably because increased water temperature during the summer-fall months reduces their effective habitat size. For spawning fish, depending upon the extent of dispersal, their reproductive guild (Balon, 1984), and thermal responsiveness of the larvae (Ehrlich et al., 1979), a restart in operations could have an impact on year class success. While directly affecting early developmental stages in the stream, a change in environmental conditions could also reduce reproductive success in adjacent areas of the SRSS either through thermal effects, increased current velocity,

or elevated sediment loads influencing nest integrity and larval development. Similarly, cessation of reactor operations during spring might affect spawning success in the swamp by reducing water levels and exposing nests or eggs on vegetation, or by direct cold shock of larvae. Regardless, winter through late spring are critical periods in the life histories of these species.

Thermal effluents, therefore, represent a major environmental perturbation to the development of the fish fauna in these streams, and repopulation of these habitats is a dynamic process. From the perspective of stream recovery, there exists a 'core' (Hanski, 1982) group of species (group 3, see Table 5.6) which will be among the early colonists and should numerically dominate the assemblage at least in its early stages. Depending on the time of year recovery commences, composition of the fish assemblage will vary as different suites of species (groups 1 and 2, see Table 5.6) move out of the swamp and into the stream channels. Two additional sources of fish, adult and juvenile fish in nonthermal, upstream tributaries, as well as downstream drift of larval stages, may also be important in community development. No information currently exists to evaluate the extent of downstream movement. However, the presence of yellowfin shiner (*Notropis lutipinnis*), one of the most common fish species in the tributary streams in the upstream portions of both Pen Branch and Four Mile Creek, soon after a reactor shutdown commences indicates some downstream movement must occur (McFarlane, 1976). Drifting larval stages of several species of fish have also been collected in both Pen Branch and Four Mile Creek (Paller, 1984), but numbers were generally low and where they originated and how far they had drifted are not known. Thus, additional sources of colonists are potentially available to contribute to reestablishment of the fish community in both streams. How the system develops, therefore, will initially be

dependent on the timing of reactor shutdown. The importance of environmental characteristics (e.g., current velocity, depth, substrate composition) in structuring the community will then further influence community establishment and development. Habitat complexity and food web structure has been altered compared to other streams in the area because of prior thermal/flow conditions. As succession and development of these attributes change, we would anticipate that assemblage structure would also change according to the resources available.

Conclusions

Patterns of fish reinvasion were examined in stream channels that periodically receive thermal effluents from nuclear production reactors. The objectives of the study were: (1) to determine the extent of upstream migration of fishes into the thermal stream channels during reactor shutdown and (2) to assess variability in the abundance and species composition as a function of season, period of reactor shutdown, temperature conditions, and distance from the SRSS as a source pool of fish. Conclusions of the study are presented below.

- In general, fishes do not invade or inhabit thermal streams on the SRP upstream from the Savannah River Swamp System during periods of reactor operation.
- Thirty-four species of fishes representing a major subset of the available species pool entered the effluent streams during reactor operation.
- Regardless of stream, fishes reinvaded Four Mile Creek and Pen Branch within 24 hours of reactor shutdown and continued to enter and move upstream as long as normal temperature waters were present.

- Invasion of streams varied seasonally and among years, but was usually highest during spring.
- Based on patterns of species utilization among reactor cycles, three groups of species were identified reinvading the streams: (1) rare and infrequently encountered taxa, <30% occurrence, (2) 11 species that occurred in 30-70% of the reactor cycles, and (3) seven species that were present in greater than 70% of the reactor cycles.
- Few fish, especially individuals of larger species, were killed during reactor restart indicating a rapid and effective retreat response to rising temperatures.
- Recolonization and inhabitation of an entire stream system by a major portion of the fish species living in the SRSS would be expected following the permanent termination of thermal effluents.

Literature Cited

- Balon, E.K. 1984. Patterns in the evolution of reproductive styles in fishes. In: Fish Reproduction (eds. G.W. Potts and R.J. Wootton), pp. 35-54. Academic Press: London. 410 pp.
- Bangham, R.V. and N.L. Bennington. 1939. Movement of fish in streams. Transactions of the American Fisheries Society 68:256-262.
- Bennett, D.H. and R.W. McFarlane. 1983. The fishes of the Savannah River Plant. National Environmental Research Park. SRO-NERP Document No. 12. 152 pp.
- Berra, T.M. and G.E. Gunning. 1972. Seasonal movements and home range of longear sunfish, Lepomis megalotis (Rafinesque) in Louisiana. American Midland Naturalist 88:363-376.
- Brown, E.H., Jr. 1961. Movement of native and hatchery reared fish in a warmwater stream. Transactions of the American Fisheries Society 90:449-456.
- Christiansen, E. J., M. E. Hodgson, J. R. Jensen, H. E. Mackey, Jr., and R. R. Sharitz. 1984. Pen Branch Delta Expansion. DPST-83-1087. E. I. du Pont de Nemours & Co., Aiken, SC. 19 pp.
- Currie, K.D. and A.E. Spacie. 1984. Differential use of stream habitat by spawning catostomids. American Midland Naturalist 111:267-279.
- Ehrlich, K.F., J.M. Hood, G. Muszynski, and G.E. McGowen. 1979. Thermal behavioral responses of selected littoral fishes. Fishery Bulletin 76:837-849.
- Elwood, J.W. and T.F. Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population. Transactions of the American Fisheries Society 98:253-262.
- Funk, J.L. 1957. Movement of stream fishes in Missouri. Transactions of the American Fisheries Society 85:39-57.
- Gerking, S.D. 1950. Stability of stream fish populations. Journal of Wildlife Management 14:194-202.
- Gerking, S.D. 1959. The restricted movement of fish populations. Biological Reviews 34:221-242.
- Gerlach, J.M. and A.W. Kahnle. 1981. Larval drift in a warmwater stream. In: The Warmwater Streams Symposium (ed. L.A. Krumholz), pp. 154-162. Southern Division, American Fisheries Society: Lawrence, KS.
- Grossman, G.D., P.B. Moyle, and J.O. Whitaker, Jr. 1982. Stochasticity in structural and functional characteristics of an Indiana stream: a test of community theory. American Naturalist 120:423-454.

- Guillory, V. 1979. Utilization of an inundated floodplain by Mississippi River fishes. *Florida Scientist* 42:222-228.
- Hall, C.A.S. 1972. Migration and metabolism in a temperate stream ecosystem. *Ecology* 53:585-604.
- Hanski, I. 1982. Dynamics of regional distribution: The core and satellite species hypothesis. *Oikos* 38:210-221.
- Harrell, H.L. 1978. Response of the Devil's River (Texas) fish community to flooding. *Copeia* 1978:60-68.
- Hauer, F.R. 1985. Aspects of organic matter transport and processing within Savannah River Plant streams and the Savannah River floodplain swamp. Report number SREL-18, UC-66e, Savannah River Ecology Laboratory, Wetlands Division: Aiken, SC. 157 pp.
- Holder, D.R. 1970. A study of fish movements from the Okefenokee Swamp into the Suwanee River. *Proceedings of the Annual Conference of the Southeastern Association of Game and Fish Commissioners* 24:591-608.
- Hurlbert, S.H. 1978. The measurement of niche overlap and some relatives. *Ecology* 59:67-77.
- John, K.R. 1964. Survival of fish in intermittent streams of the Chiricahua Mountains, Arizona. *Ecology* 45:112-119.
- Keast, A. 1965. Resource subdivision amongst cohabitating fish species in a bay, Lake Opinicon, Ontario. *Great Lakes Research Division, University of Michigan Publication* 13:106-132.
- Keast, A. 1978. Trophic and spatial interrelationships in the fishes of an Ontario temperate lake. *Environmental Biology of Fishes* 3:7-31.
- Keast, A. and D. Webb. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake, Lake Opinicon, Ontario. *Journal of the Fisheries Research Board of Canada* 23:1845-1874.
- Keast, A., J. Harker and D. Turnbull. 1978. Nearshore fish habitat utilization and species associations in Lake Opinicon (Ontario, Canada). *Environmental Biology of Fishes* 3:173-184.
- Larimore, R.W. 1952. Home pools and homing behavior of smallmouth black bass in Jordan Creek. *Illinois Natural History Survey Bulletin Notes* 28:3-12.
- McFarlane, R.W. 1976. Fish diversity in adjacent ambient, thermal, and post-thermal freshwater streams. In: *Thermal Ecology II* (eds. G.W. Esch and R.W. McFarlane), pp 268-271. ERDA Symposium Series (CONF-750425). National Technical Information Service: Springfield, VA.
- Matthews, W.J., J.R. Bek, and E. Surat. 1982. Comparative ecology of the darters *Etheostoma podostemone*, *E. flabellare*, and *Percina roanoka* in the upper Roanoke River drainage, Virginia. *Copeia* 1982:805-814.

- O'Hop, J., B.C. Kondratieff, and B.G. Coler. 1986. Recolonization of Four Mile Creek by stream invertebrates following the cessation of heated water discharge. *Bulletin of the North American Benthological Society*. pp. 82 (abstract).
- Paller, M. 1984. Summary of the ichthyoplankton sampling data from the creeks and swamps of the Savannah River Plant. Interim Report. ECS-SR-10. Prepared for E.I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, S.C.
- Rinne, J.N. 1975. Changes in minnow populations in a small desert stream resulting from naturally and artificially induced factors. *Southwest Naturalist* 20:185-195.
- Ross, S.T. and J.A. Baker. 1983. The response of fishes to periodic spring floods in a southeastern stream. *American Midland Naturalist* 109:1-14.
- Ross, S.T., W.J. Matthews, and A.A. Echelle. 1985. Persistence of stream fish assemblages: effects of environmental change. *American Naturalist* 126:24-40.
- SAS. 1985a. *SAS Users Guide, Basics*. Version 5. Statistical Analysis Institute: Cary, NC.
- SAS. 1985b. *SAS Users Guide, Statistics*. Version 5. Statistical Analysis Institute: Cary, NC.
- Schlosser, I. J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. *Ecological Monographs* 52:395-414.
- Sheldon, A.L. 1984. Colonization dynamics of aquatic insects. In: *Ecology of Aquatic Insects* (eds. V.H. Resh and D.M. Rosenberg), pp. 401-429. Praeger:New York. 625 pp.
- Sokal, R.R. and F.J. Rohlf. 1981. *Biometry*. Second edition. W.H. Freeman and Co: San Francisco, CA. 859 pp.
- Starrett, W.C. 1951. Some factors affecting the abundance of minnows in the Des Moines River, Iowa. *Ecology* 32:13-27.
- Stauffer, J.R., K.L. Dickson, J. Cairns, Jr., and D.S. Cherry. 1976. The potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. *Wildlife Monographs* 50:5-40.
- Townsend, C.R. and A.G. Hildrew. 1976. Field experiments on the drifting, colonization, and continuous redistribution of stream benthos. *Journal of Animal Ecology* 45:759-772.
- Williams, D.D. and H.B.N. Hynes. 1976. The recolonization mechanisms of stream benthos. *Oikos* 27:265-272.
- Werner, E.E. and D.J. Hall. 1976. Niche shifts in sunfishes: experimental evidence and significance. *Science* 191:404-406.

Werner, E.E., D.J. Hall, D.R. Laughlin, D.J. Wagner, L.A. Wilsmann, and F.C. Funk. 1977. Habitat partitioning in a freshwater fish community. *Journal of Fisheries Research Board of Canada* 34:360-370.

Whitehurst, D.K. 1981. Seasonal movements of fishes in an eastern North Carolina swamp system. In: *The Warmwater Streams Symposium* (ed. L.A. Krumholz), pp. 182-190. Southern Division, American Fisheries Society. Bethesda, MD. 422 pp.

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