2001 Savannah River Biological Surveys
for
Westinghouse Savannah River Company

Report No. 03-08F

THE
ACADEMY
OF NATURAL
SCIENCES

South Carolina DHEC Laboratory I.D. #89011

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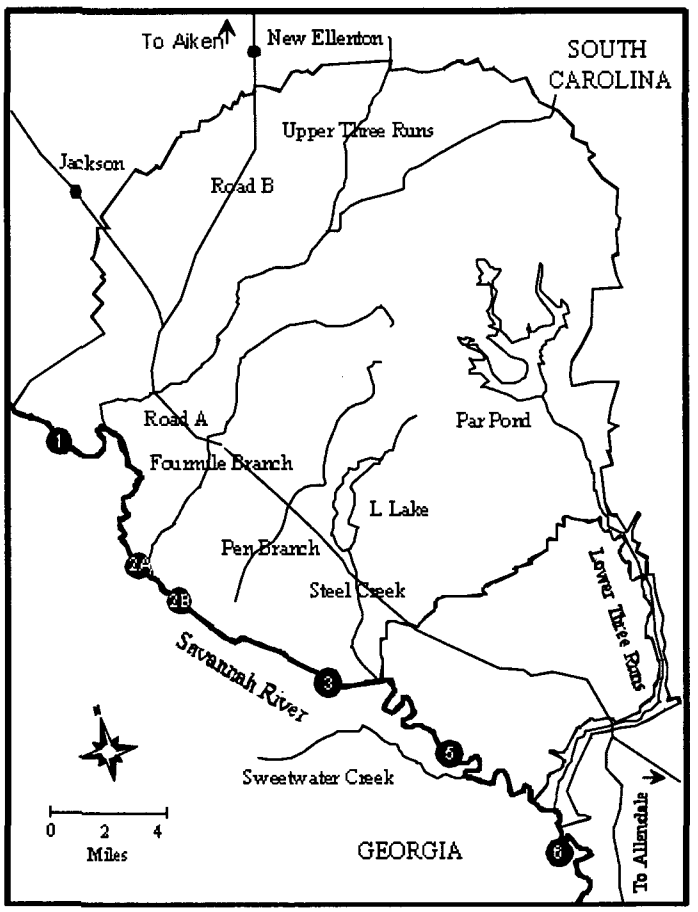
NON-TECHNICAL SYNTHESIS

Overview and Rationale

The Academy's monitoring program, conducted since 1951, assesses the effects of the Savannah River Site on the health of the Savannah River ecosystem.

The Academy of Natural Sciences of Philadelphia has been conducting biological and water quality studies of the Savannah River since 1951. These studies are designed to assess potential effects of Savannah River Site (SRS) contaminants and warm-water discharges on the general health of the river and its tributaries. They therefore look for spatial patterns of biological disturbance that are geographically associated with the site, and for temporal patterns of change that indicate improving or deteriorating conditions.



Components of the Academy's Savannah River studies have included basic water chemistry, diatoms, other attached algae, aquatic macrophytes (mosses and rooted aquatic plants), protozoa, aquatic insects, non-insect macroinvertebrates, and fish. The study design includes multiple biological groups spanning a broad range of ecological roles, both because no single group is the best indicator of every component of water quality and because there is widespread agreement that protecting the entire system is important.

Cursory versus Comprehensive Surveys

Cursory

- Conducted Every Year
- Four Sampling Periods
- Fewer Study Components
- Fewer Sampling Stations

Comprehensive

- Roughly Every Four Years
- Two Sampling Periods
- All Study Components
- All Sampling Stations

Prior to 1997, four basic types of studies were conducted by the Academy: Comprehensive Surveys, Cursory Surveys, Diatometer Studies, and Plant Vogtle Surveys. Comprehensive Surveys included the largest number of study components, were carried out roughly every four years, and included two sampling periods during the year. Cursory Surveys included a reduced set of study components—typically attached algae, insects, and fish—but were conducted annually, with four sampling periods per year (except in years with Comprehensive Surveys, which substituted for two of the usual Cursory sampling periods). Thus, Cursory Surveys provided more narrowly focused information, but on a more frequent basis. Diatometer Studies addressed only the diatom flora but provided year-round annual monitoring. Plant Vogtle Surveys, which included the same components as Comprehensive Surveys but different sampling stations, were initiated in 1985 in order to assess potential impacts of Georgia Power and Light's Vogtle Nuclear Power Plant so that these could be separated from potential SRS impacts.

Beginning with the 1997 study and continuing through the 2000 study, several changes were made in the monitoring program in order to reduce the number of types of studies conducted. Aspects of the Diatometer Study and the Cursory, Comprehensive, and Plant Vogtle Surveys were combined into a single, comprehensive study. The number of study components was reduced by eliminating assessments of water chemistry and protozoa. The scale of the diatometer component was also reduced, with both the number of sampling stations and the number of exposure periods being decreased. Components of this study design included diatoms (diatometer sampling using artificial substrates), attached algae and aquatic macrophytes (hand collections from natural substrates), aquatic insects, non-insect macroinvertebrates, and fish. Diatometers were deployed for one two-week exposure period in each month of the year. Four sampling stations were employed in each study component, including one reference station (Station 1) and three exposed stations (Stations 2B, 5, and 6).

In 2003, the Savannah River biomonitoring program will be further modified as follows. Diatometers will be deployed monthly at the same four stations as in 2000, but only a

three-month se ries in the spring and an other three-month series in late sum mer will be an a lyzed from Sta tions 1, 5, and 6; the re main ing sam ples will be ar chived for pos si ble fu ture use. Hand col lec tions of at tached al gae and aquatic macrophytes will be dis con tin ued. The non-in sect macroinvertebrate study will be con ducted in late sum mer and will sam ple only Sta tions 1 and 6, ex cept that mus sels will also be col lected at Sta tion 5. Like the diatometers, in sect ar ti fi cial sub strates will be de ployed at Sta tions 1, 5, and 6 in spring and late sum mer, but only the late sum mer sam ples from Sta tions 1 and 6 will be an a lyzed, the re main ing sam ples be ing ar chived for pos si ble fu ture use. In sect hand col lec tions will be con ducted only in late sum mer. The fish study will be con ducted in late sum mer and will in clude boat electrofishing at Sta tions 1, 5, and 6, and seining at Sta tions 1 and 6.

The 2001 study de sign is tran si tional and in cludes as pects of both the 2000 and 2003 de signs. The diatometer com po nent in cludes anal y sis of monthly sam ples from Sta tions 1, 5, and 6 for Jan u ary through Oc to ber, and from Sta tion 2B for Jan u ary through Au gust. No for mal anal y sis of al gal or aquatic macrophyte hand col lec tions was con ducted. The non-in sect macroinvertebrate com po nent in cludes anal y sis of mus sel sam ples from all four sta tions (Sta tions 1, 2B, 5, and 6), and anal y sis of col lec tions of all other groups from Sta tions 1 and 6. The in sect com po nent in cludes anal y sis of late-sum mer sam ples from Sta tions 1 and 6, in clud ing both hand col lections and ar ti fi cial-sub strate sam ples. The fish com po nent includes anal y sis of boat electrofishing, walk-along electrofishing, and seining sam ples from Sta tions 1 and 6.

The 2002 Sa van nah River biomonitoring study em ployed monthly diatometer sam pling and in sect ar ti fi cial sub strates in spring and late sum mer, all at Sta tions 1, 2B, 5, and 6. These sam ples have not been an a lyzed; they have been ar chived for pos si ble fu ture use.

De pending on the study com po nent, two to four sam pling stations were em ployed in the 2001 study. These sta tions serve the fol low ing pur poses. Sta tion 1, which was em ployed in all study com po nents, is lo cated next to the SRS but near its upstream bound ary, up stream from all SRS trib u tar ies. It is not ex pected to be sig nif i cantly ex posed to SRS in flu ence and

there fore serves as the ref er ence sta tion. Sta tions 2B, 5, and 6 are all lo cated down stream from at least two of the trib u tar ies that flow through or orig i nate within the SRS, and these stations are there fore ex pected to be ex posed to SRS in flu ence. (See map on pre vi ous page.) Mul ti ple ex posed sta tions are em ployed be cause of the com plex pat tern of SRS in puts along the river.

As in pre vi ous Acad emy stud ies on the Sa van nah River, po ten tial im pacts of the SRS are as sessed in the new study design by de ter min ing whether dif fer ences ex ist be tween the ex posed and ref er ence sta tions that are ei ther greater or of a dif fer ent char ac ter than would be ex pected if they were due merely to nat u ral dif fer ences among sam pling sites. For example, the char ac ter of dif fer ences among sta tions is judged in part by com par ing the in di vid ual spe cies col lected. Ev i dence of im pact ex ists if a sta tion shows el e vated abun dances of spe cies known to be mod er ately or highly tol er ant of pol lution and de pressed abun dances of spe cies known to be in tol erant of pol lu tion. If this pat tern is de tected at the ex posed sta tions but not at the ref er ence sta tion, then there is ev i dence that the im pact orig i nates within the study area and fur ther stud ies would be rec om mended to de ter mine the ex act type and source of pol lu tion. If, how ever, the pat tern is seen at the ref er ence sta tion, then the im pact must be due to sources upstream from the study area.

Other po ten tial types of ev i dence for im pact in clude decreased num bers of spe cies, de creased num bers of in di vid uals, and nu mer i cal dom i nance by a small pro por tion of the spe cies pres ent. These pat terns arise be cause pol lu tion tends to re duce pop u la tion sizes in a ma jor ity of spe cies, while a few tol er ate or thrive in such con di tions.

De ter mining whether ex posed and ref er ence sta tions dif fer is com pli cated by the fact that con sid er able vari a tion ex ists even among sam ples col lected at the same time from the same loca tion. Ap par ent dif fer ences may there fore be spu ri ous if each sta tion is char ac ter ized by only a sin gle sam ple. For this reason, sev eral com po nents of the Acad emy's stud ies col lect mul ti ple sam ples from each sta tion, mak ing it pos si ble to separately quan tify two im por tant com po nents of vari a tion: within and among sta tions. Com pel ling ev i dence for sta tion

differences exists if average variation among samples from different stations is significantly greater than average variation among samples from the same station, as judged by appropriate statistical techniques (e.g., analysis of variance).

When statistically significant biological differences among stations are found, it is advisable to determine whether these might be caused by differences in physical characteristics of the stations rather than pollution. For example, the fish fauna at a station with shallow, fast-moving water is likely to differ from that at a station with deep, slow-moving water. The possible role of differences in physical characteristics such as water depth, current speed, and substrate type can be investigated using a statistical technique called analysis of covariance. The basic idea is to determine a simple statistical relationship between the measured physical and biological characteristics, then use this relationship to remove the effect of station differences in physical characteristics from the biological data. If station differences persist after this adjustment, they probably are caused by something other than the measured physical factors.

Another type of variation that the Academy's studies address is variation over time. Important components of temporal variation include seasonal trends, multiyear trends, and trendless (random) variation. All of these components can be assessed using the unique dataset generated by the Academy's long-term monitoring program in the Savannah River. Regular sampling has continued with relatively little change in methods since the early 1950s, making this one of the most comprehensive ecological datasets available for any of the world's rivers.

Such long-term records of biological change are valuable for several reasons. Since they allow the normal degree of year-to-year variability at a site to be quantified, changes observed from one survey to the next can be assessed to determine whether they fall within the normal range, much as one would use a control chart. Changes that are outside this range provide evidence of altered conditions at the study site.

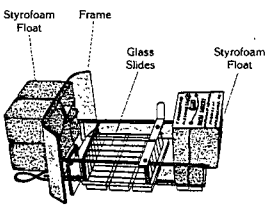
These datasets are also useful in distinguishing between potential impacts of the Savannah River Site and variation caused by other factors. For example, part of the biological

vari a tion ob served over time is caused by doc u mented changes in river flow, wastewater treat ment meth ods, dredging ac tiv i ties, and so on. Iden tifying cor re la tions be tween the known his tory of such changes on the one hand, and com ponents of vari a tion in long-term datasets on the other, pro vides ev i dence that these com po nents of bi o log i cal vari a tion are not at trib ut able to SRS op er a tions.

Finally, long-term datasets can pro vide com pel ling ev i dence for multiyear trends of im prove ment or de te ri o ra tion in ecosys tem health. The Acad emy's long-term data sug gest, for exam ple, that there has been a rel a tively steady in crease in the num ber of spe cies of aquatic in sects liv ing in the river dur ing the last 15 years. Since aquatic in sect di ver sity is be lieved to be a sen si tive mea sure of en vi ron men tal qual ity, this pat tern may in di cate a long-term trend of im prov ing wa ter qual ity in the Sa van nah River.

Summary of Results

Diatometer Study



Catherwood diatometers were de ployed at Sta tions 1, 2B, 5, and 6 for 12 monthly 2-week ex po sure pe ri ods, with re trieval dates span ning 30 Jan u ary to 4 De cem ber 2001. Di a toms were iden ti fied to spe cies and va ri ety. Ex cept for Sta tion 2B, slides from one diatometer per station were an a lyzed for the first ten ex po sure pe ri ods (Jan u ary through Oc to ber); slides for Sta tion 2B were an a lyzed for the first eight ex po sure pe ri ods (Jan u ary through Au gust). Slides not an a lyzed were ar chived for pos si ble fu ture use.

The di a tom flora on diatometer slides was an a lyzed for species rich ness (= num ber of spe cies), per cent dom i nance (= per cent of to tal spec i men count on a slide com pris ing dom i nant spe cies, where a dom i nant spe cies is op er a tion ally defined as one with more than 1024 counted cells), Shan non-Wiener di ver sity (= a joint mea sure of spe cies richness and the sim i lar ity of spe cies abun dances, de rived from in for ma tion the ory), and rel a tive abun dances of dom i nant spe cies. To re move the pro nounced sea sonal vari a tion from

station comparisons, data on species richness at the four stations were ranked for each exposure period, and the ranks were then statistically analyzed via analysis of variance. Data on percent dominance and Shannon-Wiener diversity were analyzed in the same way.

The species composition and pollution tolerance of the diatom assemblage was similar at all stations. The reference station (Station 1) showed significantly higher species-richness rank, significantly lower dominance rank, and significantly higher diversity rank than did the exposed stations (Stations 2B, 5, and 6), but no significant differences among exposed stations were detected. Ecological and pollution tolerances of the dominant species were found to be similar at all stations, with most of the dominant species being characteristic of alkaline waters with moderately high nutrient concentrations.

The fact that the reference station showed higher species-richness rank, lower dominance rank, and higher diversity rank than any of the exposed stations is consistent with an SRS impact, but there was no corresponding pattern in ecological or pollution tolerances of the dominant species. Evidence is therefore equivocal regarding a potential SRS impact on water-quality components to which diatoms are most sensitive.

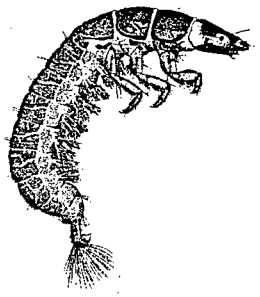
Non-insect Macroinvertebrates

Qualitative samples of non-insect macroinvertebrates were collected at Stations 1, 2B, 5 and 6 during 24-27 August and 7-10 September 2001. Sampling during the August period concentrated on mussel habitats. Mussel samples from all four stations were analyzed. For all other non-insect macroinvertebrate groups, only samples from Stations 1 and 6 were analyzed for this report; the remaining samples were archived for possible future use. All specimens in analyzed samples were identified to the lowest practical taxonomic level.

The main findings of the 2001 study were that, while more species were collected than in the 2000 study, both the numbers of species in the four dominant non-insect macroinvertebrate groups (bivalves, snails, crustaceans, and leeches) and the total number of species overall were lower

than in stud ies con ducted dur ing the mid to late 1990s. These lower num bers con tinue a trend the be gan in 1999 and prob a-bly are mainly due to drought con di tions in the ba sin and the re sult ing lower flows in the Sa van nah River. Ad di tional fac-tors that prob a bly con trib uted to these lower num bers are the re duced num ber of sam pling sta tions com pared to stud ies in 1998 and ear lier and the use of a quadrat sam pling tech nique for mus sels in the 2000 and 2001 stud ies, which tends to yield a wider range of sizes but fewer spe cies. Five more spe cies were col lected at Sta tion 1 (27) than at Sta tion 6 (22), but the spe cies com po si tion was broadly sim i lar and does not ap pear to in di cate an SRS im pact.

Aquatic Insects



Quan ti ta tive and qual i ta tive sam ples of aquatic in sects were col lected at Sta tions 1, 2B, 5, and 6 dur ing 25-28 April and 6-8 Sep tem ber 2001. The quan ti ta-tive sam ples were col lected us ing stan dard ized ar ti fi cial sub-strates, which per mit rep li cate sam ples at each sta tion and rig or ous sta tis ti cal com par i sons. Qual i ta tive sam ples were col lected from a wide va ri ety of nat u ral sub strates and hab i tat types. Only the Sep tem ber sam ples from Sta tions 1 and 6 were an a lyzed for this re port; the re main ing sam ples were ar-chived for pos si ble fu ture use. Spec i mens in an a lyzed sam ples were iden ti fied to the low est prac ti cal tax o nomic level (usu-ally spe cies).

Sta tion and sea son com par i sons were based both on vi sual in-spec tion of data from the qual i ta tive col lec tions and on sta tis-ti cal anal y sis (anal y sis of vari ance) of quan ti ta tive es ti mates of sev eral types of in di ces. These in di ces in clude den si ties of se lected taxa, to tal spe cies rich ness, rich ness of se lected groups of pol lu tion-sen si tive taxa (EPT: Ephemeroptera, Plecoptera, Trichoptera) and pol lu tion-tol er ant taxa (Chironomidae), Shan non-Wiener spe cies di ver sity, rel a tive abun dance of Chi rono mids (% Chironomidae), rel a tive abun-dance of the sin gle most abun dant taxon and the five most abun dant taxa (% Dom i nance-1, % Dom i nance-5), and over-all de gree of pol lu tion tol er ance (HBI: Hilsenhoff Bi otic In-dex, NCBI: North Carolina Bi otic In dex).

Total species richness in the qualitative collections was much higher than in the quantitative samples. Qualitative samples contained 131 taxa while quantitative samples contained only 57 taxa; 76 taxa were unique to the qualitative collections while only 17 taxa were unique to the quantitative samples. These differences probably are due mainly to the fact that qualitative samples were collected from all major habitat types while quantitative samples largely reflect species typical of snag and debris habitats.

The species composition of insect fauna was similar to those in previous years and contained numerous and abundant pollution-sensitive taxa. Of the major insect groups found in qualitative collections, the most species-rich were dipterans (47 taxa, mainly Chironomidae), beetles (28 taxa), dragonflies and damselflies (15 taxa), mayflies (17 taxa), and caddisflies (14 taxa). Total species richness was similar to that in the last several studies.

Statistical analysis of the quantitative samples revealed a few differences among stations and between seasons, but none of these differences was consistent with the pattern expected for an SRS impact. On the contrary, the results indicate that the condition of the aquatic insect assemblage at the exposed stations tends to be as good as, or superior to, the condition at the reference station. Specifically, EPT richness was significantly higher at Station 6, while Chironomidae richness, percent Chironomidae, HBI, NCBI, and 5-taxa percent dominance all were significantly lower at Station 6. The same general pattern was demonstrated by results of the 1999 and 2000 studies.

Overall, results of the 2001 aquatic insect study suggest that differences detected among sites reflect natural spatial variation found in all rivers and streams. The results provide no evidence of a negative SRS impact on the aquatic insect assemblage.

Fish

Fish were sampled at Stations 1, 2B, 5 and 6 during 7-12 September 2001. The main collecting techniques were seining, boat electrofishing in the main channel,

and walk-along electrofishing in back wat ers. Only sam ples from Sta tions 1 and 6 were an a lyzed for this re port. All spec i-mens in an a lyzed sam ples were iden ti fied to spe cies.

Spe cies rich ness, spe cies di ver sity (Shan non-Wiener in dex), and den si ties of in di vid ual spe cies were es ti mated for each quan ti ta tive seine sam ple. These data were an a lyzed us ing anal y sis of vari ance and anal y sis of covariance. Den sities and to tal pop u la tion sizes of fish col lected in back water ar eas via electrofishing were es ti mated sta tis ti cally by a de ple tion tech-nique. A con di tion anal y sis based on length-weight re la tion-ships was also con ducted for se lected spe cies (bannerfin shiner, spottail shiner, blue gill, red breast sun fish, and dol lar sunfish).

In to tal, 48 spe cies of fish were col lected in 2001 sam pling, with two spe cies (spottail shiner and tail light shiner) com pos-ing ap prox i mately half of the to tal catch. A large num ber (ap-prox i mately 17% of the to tal catch) of un iden ti fi able young-of-year min nows was also col lected at both sta tions Spe cies rich ness was sig nif i cantly higher at Sta tion 6 than at Sta tion 1, but nei ther spe cies di ver sity nor the den si ties of com mon spe cies dif fered signficantly be tween sta tions. No con sis tent dif fer ences in con di tion were found, but least-squares mean weight was al ways ei ther sig nif i cantly higher at Sta tion 6 (2 of 5 spe cies) or not sig nif i cantly dif fer-ent be tween sta tions. These re sults are sim i lar to those of the 1999 and 2000 study and pro vide no ev i dence of an SRS im-pact on the fish as sem blage.

Conclusions

As in pre vi ous Sa van nah River stud ies, the 2001 re-sults for diatometer sam ples in di cate nu tri ent en rich-ment at all sta tions, ev i dently due to sources up stream from the study area. Sev eral dif fer ences among sta-tions were de tected in var i ous com po nents of the sur vey. In some cases, these were con sis tent with an SRS im pact (e.g., sig nif i cantly lower spe cies-rich ness and di ver sity ranks and sig nif i cantly higher dom i nance rank in diatometer sam ples at the ex posed sta tions than at the ref er ence sta tion; lower macroinvertebrate taxa rich ness in hand col lec tions at Sta tion

6 than at the ref er ence sta tion). In other cases, the sta tion dif-fer ences were op po site the pat tern ex pected for an SRS im-pact (e.g., sig nif i cantly higher abun dance of may flies and sig nif i cantly lower abun dance of chi rono mids in quan ti ta tive in sect sam ples at Sta tion 6 than at the ref er ence sta tion; sig-nif i cantly higher EPT rich ness at Sta tion 6; sig nif i cantly lower Chironomidae rich ness, per cent Chironomidae, HBI, NCBI, and 5-taxa per cent dom i nance at Sta tion 6; sig nif i-cantly higher fish spe cies rich ness at Sta tion 6 than at the ref-er ence sta tion; least-squares mean weights of se lected fish spe cies con sis tently as great, or sig nif i cantly greater, at Sta-tion 6 than at the ref er ence sta tion). We con clude that these dif fer ences prob a bly re flect nat u rally oc cur ring spa tial vari a-tion along the river, and that re sults of the 2001 Sa van nah River biomonitoring study do not pro vide com pel ling ev i-dence of an SRS im pact on bi o log i cal com mu ni ties in the river.

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QUALITY ASSURANCE STATEMENT

Study Number: 852

Study Title: 2001 Savannah River Biological Surveys for Westinghouse Savannah River Company.

This study was performed under the general provisions of the Patrick Center's Quality Assurance Implementation Plan (Rev. 1, June 1998). The final report was determined to be an accurate reflection of the data obtained.

The dates that Quality Assurance activities on this study were completed are given below.

Data Review:

Diatometer:	7/28/03
Macroinvertebrates:	7/30/03
Aquatic Insects:	7/31/03
Fish:	7/31/03
Report Review:	7/31/03

ARCHIVING: Raw data and the final report are filed in the Patrick Center's archives.

_____ _____

Robin S. Davis Date
Quality Assurance Unit
Patrick Center for Environmental Research
Academy of Natural Sciences

INTRODUCTION

In the longest study of a large river in the U.S., the Academy has monitored the biology and chemistry of the Savannah River Site since 1951 and near Plant Vogtle since 1985, to assess potential effects of those facilities on the river ecosystem.

In 2001, the Academy of Natural Sciences of Philadelphia (ANSP) conducted biological monitoring of the Savannah River for Westinghouse Savannah River Company. The 2001 investigation was the 50th survey year in a series of multiple trophic level biological studies of the river in the vicinity of the Savannah River Site, near Augusta, Georgia. The first surveys were conducted in 1951 and 1952 before the operation of the Savannah River Site (heavy water plant started August 1952) and the construction of Clark Hill Dam "to establish an objective measure of the aquatic life . . . so that any significant effect . . . could be determined in the future" (ANSP, 1953:2). This study was undertaken during each of the spring through winter seasons to establish baseline water quality conditions, as reflected primarily in the diversity of the aquatic biota, in the vicinity of the plant prior to operations. No studies were conducted in 1953 (first of five production reactors started operating December 1953) and a cursory investigation was undertaken in 1954. With all five reactors operating by March 1955, the first postoperational (SRS and Clark Hill Dam) study commenced in 1955 and 1956 "to determine whether any change had occurred . . . in the aquatic life and general environmental factors in the Savannah River" (ANSP, 1957:1). The operation of Clark Hill Dam reduced the wide seasonal variations in discharge and reduced the silt loads, except as determined by local meteorological conditions. Vegetation was able to become more generally established in sheltered areas. Since the first postoperational study, comprehensive river investigations were conducted approximately every four years (1955/56, 1960, 1965, 1968, 1972, 1976, 1980, 1984, 1989 and 1993) to monitor spatial and temporal chemical and biological patterns in the river.

The comprehensive surveys were augmented by less intensive, but more frequent cursory studies. These cursory in-

vestigations were intended to provide a relatively frequent, cost-effective interim assessment of any major change in the biota since the most recent comprehensive survey. Generally, fewer elements of the biota [fishes, algae and macroinverte- brates (primarily insects)] were studied at various times of the year (once, twice and four times a year, respectively) in cursory surveys.

Within the Savannah River study area (Fig. 1), studies have also been conducted in the vicinity of Georgia Power and Light's Vogtle Nuclear Power Plant. The first survey was designed and conducted in 1985 with an additional preoperational study in 1986. The purpose of the 1985 and 1986 studies was to establish baseline water quality conditions, as reflected primarily in the diversity of the aquatic biota, in the vicinity of the plant prior to plant operation. Commercial production of the Vogtle facility commenced in early summer 1987, after which the first operational survey was undertaken. Since that time seven more studies (1988, 1990, 1991, 1993, 1994, 1995 and 1996) have been undertaken to monitor spatial and temporal chemical and biological changes in the river.

The Plant Vogtle survey stations are additional data points in the longest comprehensive study of a large river in the United States.

The Catherwood Diatometer program, conducted for the past 49 years, is designed for continuous biological monitoring of the Savannah River. Diatoms are used as biological indicator organisms because they represent the predominant periphyton (attached algae) in most water bodies and because they are reliable indicators of adverse impact on water quality due to their characteristic patterns of species composition and assemblage structure. These studies consist of analyses of the diatom flora growing on Diatometer substrates (glass slides) in the river. The exposed substrates are retained at the Academy as a permanent record of water conditions.

The results of these various studies (comprehensive, cursory, Plant Vogtle, Diatometer) constitute the primary biological history of the Savannah River in the region of the Savannah River Site from 1951 through 1996. Beginning with the 1997 survey, larger-scale modifications in the pro-

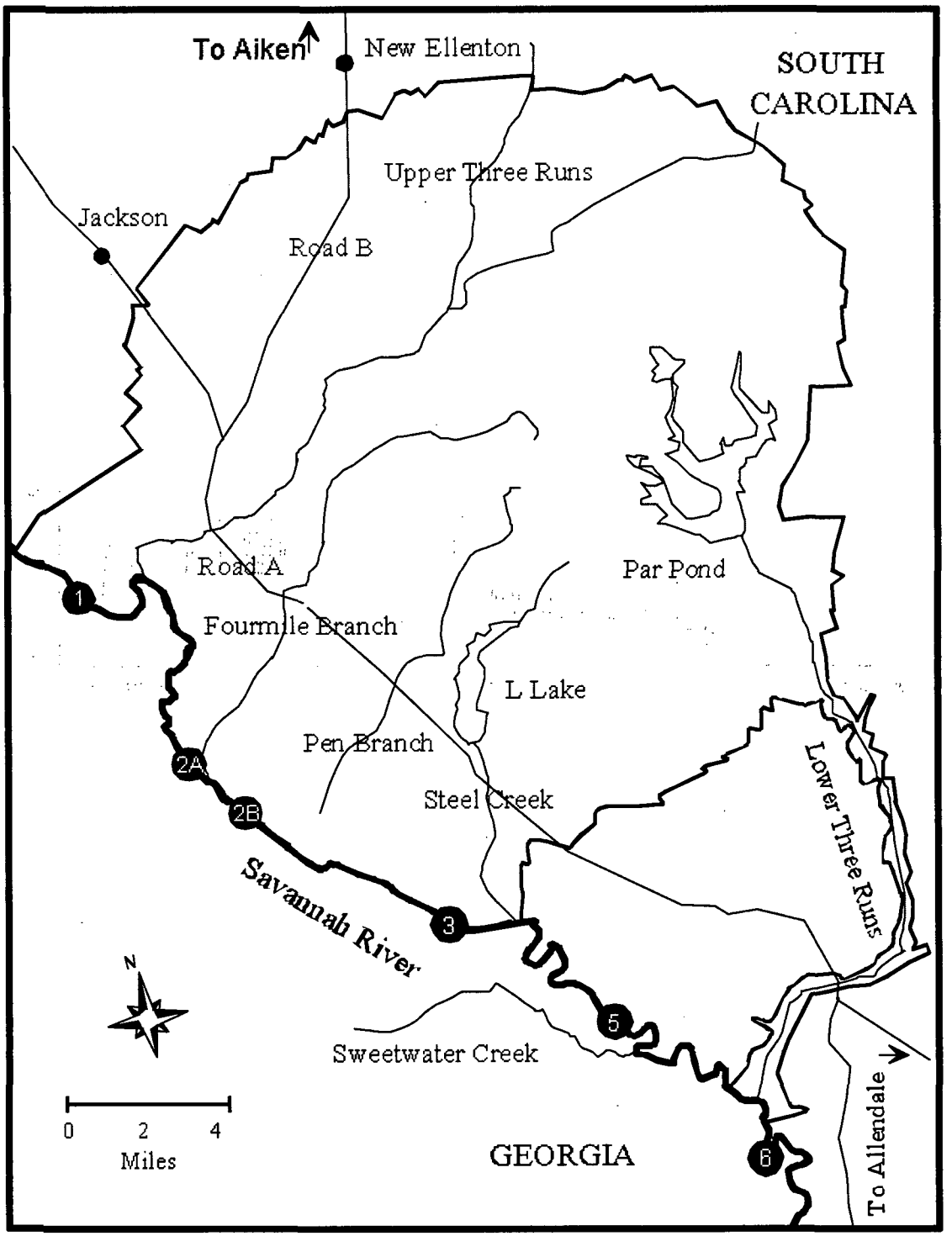

Figure 1. Survey stations on the Savannah River in the vicinity of the Savannah River Site. Stations 1, 2B, 5 and 6 were sampled for the 2001 diatometer studies and Stations 1, 2B, 5 and 6 were sampled for the non-insect macroinvertebrate, aquatic insect and fish studies.

gram were implemented. These changes combined aspects of all four studies into a single program. The primary changes included sampling at Station 2B (formerly Vogtle Station V-2) rather than Station 3, diatometer monitoring monthly (biweekly in 1996 and earlier) including Station 2A (formerly Vogtle Station V-1), qualitative algal and macrophyte studies annually [spring collection in 1996 but late autumn samples not taken (generally biannually in cursory studies and quarterly in comprehensive investigations)], non-insect macroinvertebrate sampling annually (semiannually in comprehensive studies), insect studies semiannually [semiannually (spring and late summer) in 1996 (early summer samples archived and late autumn samples not taken) and quarterly in 1995 and earlier], and fish sampling annually (semiannually in comprehensive studies). The fisheries investigation followed a sampling plan consisting of boat electrofishing (started in 1995 at Station 1 and all stations in 1996 to replace gill netting, trapping and 15.2 m seining), walk-along electrofishing (started in 1995 to replace use of an ichthyocide on the South Carolina side of the river) and 6.1 m seining. Further modifications were made in the program beginning in 1999. These included the qualitative algal study concentrating on filamentous algae (archiving diatom samples) and noting only significant changes in the aquatic vascular plant flora. Protozoan surveys have been omitted from the Academy studies starting in 1999. Beginning in 2001, diatometers were no longer set at Station 2A. The 1998 through 2000 Station 2A diatometer samples have been archived.

Beginning in 2003 the Savannah River biomonitoring program will be modified as follows: diatometers will continue to be deployed monthly at Stations 1, 2B, 5 and 6; however, only a three-month series at Stations 1, 5 and 6 in the spring and late summer, correlating with the incubation of the insect artificial substrates at Stations 1, 5 and 6, will be analyzed (samples from Station 2B and the remaining months will be archived). The comprehensive survey of the algae (filamentous algae analyzed and diatoms archived) and noteworthy changes in the aquatic vascular flora from all habitats will be discontinued. The spring and late summer deployment of insect artificial substrates maintains the recent tem-

poral scale of their study periods. However, only substrates at three study sites (Stations 1, 5 and 6) will be deployed, with only the late summer samples from Stations 1 and 6 analyzed (all spring samples and late summer Station 5 samples will be archived). In addition, only a late summer comprehensive insect survey will be undertaken (no spring comprehensive survey). The non-insect macroinvertebrates investigation will be reduced to Stations 1, 5 (mussels only) and 6. The periodicity (late summer period) of the fisheries program will remain the same but only include boat electrofishing at Stations 1, 5 and 6 (smaller specimens from Station 5 will be archived) and seining at Stations 1 and 6.

The analyzed portion of the 2001 study reflects aspects of the 2001 and 2003 programs. The results from the 2001 diatometer study include Stations 1, 5 and 6 (January through October) and 2B (January through August). The samples and field notes from the 2001 qualitative algal and aquatic vascular plant study will be archived. For the 2001 non-insect macroinvertebrate study, in addition to Stations 1 and 6, some information from Stations 2B and 5 and the conclusions from the mussel survey from all stations are reported. The results of the insect study include quantitative and qualitative studies at Stations 1 and 6 in late summer. For the fisheries investigation, the findings from the boat electrofishing, walk-along electrofishing, and seining collections from Stations 1 and 6 are detailed.

The 2002 Savannah River biomonitoring study utilized diatometers (monthly) and insect artificial substrates (spring and late summer) at Stations 1, 2B, 5 and 6. These samples are or will be archived at the ANSP (diatom slides) and Stroud Water Research Center (insect samples).

Major alterations in the river during the survey years have been due to dredging and the creation of oxbows by cutting off meanders. These modifications have changed base flows and altered or removed sheltered habitats, as well as resulted in spoil deposition and siltation. The increased development of beds of aquatic plants that started with upriver controls of river flows reached their peak by the time of the 1972 survey. At this time luxuriant beds of aquatic vascular plants were present in the river and presumably reflected elevated

organic loadings from effluents emanating from the Augusta, GA, area. By the 1976 survey, improved effluent treatments resulted in an improvement in water quality and a sharp reduction in the extent of the vascular plant beds. Since 1990, submerged aquatic vascular plant beds have been absent from the main stem of the Savannah River.

For 2001, a comprehensive study was conducted in April and September. The impacts of water conditions and vegetation on particular elements or sampling methods are discussed in each section. See the section River Gauge Height for a discussion of river heights and their relevance to the field sampling effort.

PERSONNEL AND ACKNOWLEDGMENTS

These studies were performed under the supervision of Dr. David D. Hart, Director, of the Patrick Center for Environmental Research of the Academy of Natural Sciences of Philadelphia. Dr. Raymond W. Bouchard, Project Leader, was responsible for the professional quality of all field and laboratory work. Robin S. Davis, Scientific Editor, coordinated all the data for the report for this program. The direction and implementation of individual project elements were the responsibility of the Principal Scientific Investigators. The following are the personnel who participated in the 2001 Savannah River studies.

Diatometer Studies

Supervisor: Frank Acker, M.S.
Principal Scientific Investigators:
Frank Acker, M.S. and Donald Charles, Ph.D.
Laboratory Biologist: Erin Hagan
Diatom Analyses: Eduardo Morales, Ph.D.
Taxonomy: Eduardo Morales, Ph.D. and
Charles W. Reimer Ph.D.

Algae Studies

Supervisor and Principal Scientific Investigator:
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Robert Grant, Jr.

Macroinvertebrate Studies

Supervisor and Principal Scientific Investigator:
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Paul Overbeck
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Laboratory Biologists: David H. Funk,
Roberta M. Weber, Sally Peirson, Andrew Byler and
Amy MacCausland

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Kevin O'Donnell, Amanda Kindt and Adam Dewan

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Quality Assurance Officer: Robin S. Davis

Scientific Communications

Scientific Editor: Robin S. Davis
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Graphics: Roger Thomas

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STUDY DESIGN

In studies such as those conducted on the Savannah River since 1951, the biological condition of a river is determined by examining the structure of the whole community of species of all major groups of aquatic organisms and the relationship of these groups to each other. The most conspicuous biological elements include the algae, aquatic macrophytes, macroinvertebrates and fishes. This biological study is based upon the assumption that in most natural streams there is a high diversity of species, most of which are represented by moderate-size populations. Depending upon the degree of pollution, an unfavorable environment will lower the species diversity, change the kinds of species, and alter the relative size of species populations. In many cases, the age structure of populations of individual species also changes.

The methods employed by the Academy to evaluate the conditions of aquatic communities were developed by Dr. Ruth Patrick (1949). Patrick and subsequent biologists have noted that the value of species richness across all the major biological components of an aquatic ecosystem and their relative abundances coupled with known pollution tolerances can provide the strongest, most cost-effective measures of an aquatic environment. These data, along with strong quantitative and ecological measures and analyses of chemical, physical and bacteriological parameters, provide a broad base for evaluation of river health. Such a study not only permits evaluation of the condition of the aquatic community at the time of the study, but it can also detect temporal changes.

The elements examined in the 2001 survey included algae, aquatic macrophytes (i.e., significant concentrations and/or notable changes only), macroinvertebrates and fishes. Algal and macrophyte communities, the major constituents of the

aquatic flora in riverine situations, are important components of an aquatic ecosystem at the base of the food web. The aquatic flora is responsible, through photosynthesis, for the transformation of the sun's energy into forms usable by other organisms. Free oxygen as a by-product of this process is an essential element of most aquatic organisms. Macrophytes and large filamentous algae are important as shelter and habitat for the aquatic fauna. Macroinvertebrates are an eclectic assemblage that provide the main route of energy flow between the primary producers (algae) and particulate organic matter to higher trophic levels such as fishes. Because of the sedentary or near sedentary nature of many species and their wide range of pollution tolerances, they are viewed by state and federal environmental agencies as the most important measures of the health of an aquatic ecosystem. In general, the top carnivores in the ecosystem and those species of greatest interest to the public are the fishes. Because of their value and popularity, they constitute, with invertebrates, the groups of most concern by regulatory agencies in monitoring the health of aquatic ecosystems.

Shallow-water habitats are generally considered to contain the greatest proportion of species in a riverine environment, and therefore these areas were studied most intensively. Benthic organisms which are sessile or which move only relatively short distances give the most accurate indication of conditions in a river over time, while bacterial and chemical studies indicate conditions only at the time of sampling. In addition to the impact of river heights on the biota and the sampling thereof, which are discussed in the section "River Gauge Height," there has been a conspicuous absence of submerged aquatic vascular plant beds beginning with the 1990 study. Loss of these beds and factors that may have led to their sharp reduction (e.g., rapid changes in the hydrodynamics of the river from flooding and shifting substrates and turbidity) are coincident with changes reflected in the biota. In 2001, patches of the shade mudflower (*Micranthemum umbrosum*) were more common, especially in sheltered areas among the rows of pilings, than in recent surveys.

LOCATION AND DESCRIPTION OF STATIONS

Monitoring programs include routine examination of both control and indicator locations to detect impacts.

The areas of a river chosen for comparative study should include stations which have comparable ecological habitats. This assures that the possibility of finding a particular species is equal at all stations. The total area of the station is considered less important than the inclusion of all types of habitats. Among the general conditions considered in selecting stations are:

(1) structure, contour and stability of the riverbed;
(2) current and sedimentation;
(3) type and quantity of debris;
(4) surrounding vegetation;
(5) logistic factors.

To assess the impact of a particular effluent upon its receiving waters, sampling must be conducted in ecologically similar habitats in river segments influenced by various tributary streams and/or discharges and in an area unaffected by specific inputs to the river. In this manner, the effects of the discharge on the aquatic community can be isolated from natural variability. The general survey area is depicted in Figure 1. Typically four stations have been utilized for the comprehensive Savannah River studies. Although each study element of the 2001 survey sampled four stations, only the results from Stations 1 (all groups), 2B (Diatometers), 5 (Diatometers and mussels) and 6 (all groups) have been analyzed. The remaining samples, including the comprehensive algal study, will be archived. Inasmuch as the six most sampled survey stations in the historical Savannah River studies are likely to appear in the discussions of individual study elements, descriptions of each station are included below. Whereas every effort is made to make the stations as comparable as possible in terms of habitat types, Stations and 5 and 6 appear to be more similar physically than the other stations. They occur in a more downriver meandering section

of the river and contain nearby oxbows and sloughs as potential sources of biota. The locations and general habitats of the stations are discussed below. Due to modifications of the river by the US Army Corps of Engineers between the 1955/56 and 1960 studies, Station 5 was stranded in a newly created oxbow. Since the main channel bypassed this station, a new Station 5 was established a short distance away in 1960. This new station has been utilized in all subsequent surveys. Modifications to the river have also changed distances of the stations from the mouth of the Savannah River. Therefore, the river mile (RM) designations for stations herein will not correspond to those in the older studies at all stations in 1951/52 to 1965 and Stations 1, 5 and 6 in 1968. Also the lengths of stations have been designated in certain past studies as slightly smaller or larger than presently depicted. Sampling slightly outside the designated areas has also occurred in order to include a particular biotope among the station samples.

Station 1 (Fig. 1)

This station comprises a section of the river upstream from Upper Three Runs Creek and any potential impacts of the SRS. The area lies approximately between RM 160.35 and RM 160.85, Burke County, Georgia, and Aiken County, South Carolina. The upper limit of the station is about 1.0 river mile downriver from Shell Bluff Landing, Burke County, Georgia. Pilings (#78) are present near the upper limit of the station on the left (oriented downriver) or South Carolina side of the river, and the lower boundary is marked by a rip rap right bank and small tributary on the Georgia side of the river. Sandy beaches are present among the pilings. Electrofishing (rotenone in the past) sites originally consisted of residual pools behind a low levee next to the pilings. Due to siltation of these pools, two new upriver localities were selected. The first appropriate sites occurred downriver from Jackson's Landing, Aiken County, South Carolina. These two areas, associated with oxbows, are located at RM 168.9 in the nearly sedimented upstream arm of an oxbow near the main course of the Sa-

vannah River and in the inconspicuous upstream arm of an oxbow near RM 169.6. This reach of the river is here designated as Station 1A. At higher water levels electrofishing may still occur at Station 1.

Station 3 (Fig. 1)

Station 3 comprises a section of the river downriver from Fourmile Branch and upstream from Steel Creek. This station has only been surveyed during the comprehensive surveys every three to five (usually four) years from 1951 through 1993. Station 3 was not examined in the 1997 comprehensive investigation and is noted herein as a reference when historical comparisons are made of the biota. It lies between RM 143.6 and RM 144.0, Burke County, Georgia, and Barnwell County, South Carolina. The lower limit of the station is near Brigham's Landing, Burke County, Georgia, and beaches on the opposite (South Carolina) side of the river. Pilings (#56A and #58) are present on the South Carolina side of the river with sandy beaches among the set of pilings. Near the lower boundary of the station is a steep rip rap right bank and small tributary on the Georgia side of the river near the landing. Electrofishing (rotenone in the past) areas occur in a backwater portion of the river below the downrivermost (= ultimate) row of pilings and in a residual pool behind a low levee between the penultimate and ultimate sets of pilings. The water level in this latter pool is controlled by a small outlet between the two aforementioned sets of pilings.

Station 5 (Fig. 1)

This station comprises a section of the river downriver from Steel Creek and upstream from Lower Three Runs Creek. It lies between RM 135.35 and RM 135.85, Allendale County, South Carolina, and Burke County, Georgia. The lower end of the station is approximately 0.8 river miles upstream from the oxbow entrance to Little Hell Landing, Allendale County, South

Carolina. Pilings (#55) are present on the Georgia side of the river near the upriver limit of the station. The oxbow at Devil's Elbow, Georgia, and a large sandy beach on the South Carolina side of the river mark the lower end of Station 5. A small outlet stream of the Savannah River occurs on the left bank (referred to as either Wild Horse Slough or Swift Gut) with a steep rip rap bank downriver. Electrofishing (rotenone in the past) sites lie at the entrance of Wild Horse Slough and in an area behind a levee opposite Devil's Elbow. Behind the levee occurs a series of pools and the second downriver one is usually sampled. The present Station 5 was established in 1960 a short distance from its original siting after dredging and removal of river meanders between the 1955/56 and 1960 studies stranded the original station in a newly created oxbow.

Station 6 (Fig. 1)

The downrivermost Savannah River station lies below the confluence with Lower Three Runs Creek, Screven County, Georgia, and Allendale County, South Carolina. The upper end of the station is 1.75 river miles downriver from Johnson's Landing, Allendale County. The station consists of two sections referred to in the 1984 and subsequent studies as reaches. The upper reach, located between RM 123.00 and 123.55, contains a large sand beach on the left (South Carolina) bank near its upper end and another sand beach and large backwater along the right (Georgia) bank. The lower reach ranges from RM 122.85 downstream to RM 122.35. The upper limit of this reach includes a large left (oriented downriver) bank backwater at Ring Jaw Point and the lower extent is marked by a set of pilings (#42) on the same side of the river. A large sand bar extends out and toward the left bank at Ring Jaw Point. Presently electrofishing (rotenone in the past) takes place at the back end of the backwater and along the peninsula behind Ring Jaw Point or, as in 1996, at the back end of the backwater and at the #42 pilings. Rotenone sampling began at Ring Jaw Point in 1968 in conjunction with the traditional Station 6 (large right bank backwater in the upper reach).

From 1972 to 1994, the use of rotenone was confined to the South Carolina side of the river because sampling with rotenone was no longer permitted on the Georgia side. Beginning with the 1981 cursory survey, the pilings at the lower reach of Station 6 were sampled for algae. This same habitat was utilized for the next comprehensive study in 1984 by both the algal and protozoan investigators. In the 1989 comprehensive study, the insect, non-insect macroinvertebrate and fisheries (gill nets at pilings and rotenone at Ring Jaw) sampled the lower reach of Station 6. Prior to 1981, other groups also, at times, extended their sampling from the upper reach into the backwater behind Ring Jaw Point. Currently only the fisheries comprehensive investigation continues to utilize the upper (seining along the sandy left bank beach) and lower reaches of Station 6.

Station 2A (Fig. 1)

This station comprises a section of the river upstream from Plant Vogtle at Mile 151.2, approximately 0.75 mi downstream (east) from Hancock Landing, Burke County, Georgia, across from Barnwell County, South Carolina. Pilings (#72) are present on the South Carolina side of the river and mark the downstream limit of the station. Sandy beaches are present among the pilings, and a sandy beach is present at the upstream limit of the station on the Georgia side of the river. Electrofishing (rotenone in the past) areas occur up- and downriver from the downstreammost row of pilings. Only Diatometer monitoring took place at this station in 1997 through 2000 and a mussel survey in 1998.

Station 2B (Fig. 1)

This station comprises a section of the river at Mile 149.8, approximately 0.25 mi downstream (east) from Blue Bluff, Burke County, Georgia, across from Barnwell County, South Carolina. This station is located approximately 1 mi downstream from the Vogtle Plant

cooling water discharge. Pilings (#68) are present on the South Carolina side of the river and mark the downstream limit of the station. Pilings (#69) are also present on the Georgia side of the river and mark the upstream limit of the station. There are sandy beaches among both sets of pilings. Electrofishing (rotenone in the past) areas occur up- and downriver from the downrivermost row of pilings.

Reference Materials

The locations, mileages and piling numbers in this description are taken from the following sources:

1. United States Army Corps of Engineers (USACE), 1990. Navigation Charts, Savannah River, GA & SC, Savannah to Augusta. USACE. Savannah, GA. 49 pp.
2. Nautical chart 635-SC, Savannah River, Brier Creek to Augusta, South Carolina - Georgia. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Survey.

The pilings themselves are marked with readily visible numbers attached near the top of one piling in each set.

RIVER GAUGE HEIGHT

River discharge levels, both prior to and during surveys, are an important factor to consider when comparing survey results with those of prior years. The extent to which suitable shallow-water habitat is available for the colonization of riverine organisms is often correlated with river stage, as well as with the degree of daily fluctuations in flow. Generally, larger, more diverse populations are collected throughout a study area when flow is low to moderate and has been rather constant for two or more weeks prior to field collections. In contrast, unusually high flow, or large daily fluctuations in discharge just prior to or during a survey can lead to smaller, less diverse population samples. This is often merely a reflection of habitat accessibility to the investigator; however, it may also reflect true differences in habitat availability to the organisms of interest.

Figure 2 displays the estimated mean daily gauge heights for the Savannah River at Augusta, GA, for 2001, with the survey periods highlighted.

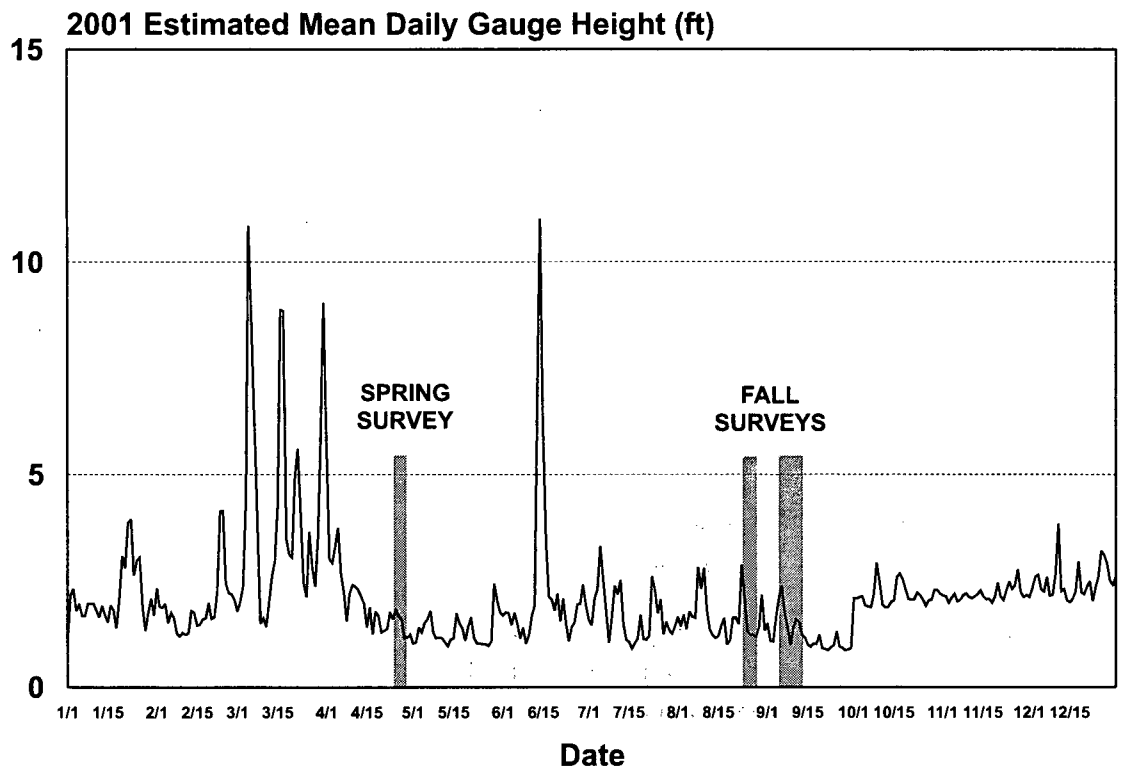


Figure 2. Estimated 2001 mean daily gauge heights of the Savannah River at Augusta, GA. A few original gauge height values were missing from the original USGS dataset. These values were calculated or derived from existing USGS discharge and gauge height data recorded at the same site. Shaded vertical bars indicate the approximate sampling times in April and September. Diatometer monitoring occurred monthly from January through December 2001.

A. DIATOMETER STUDIES

Methods and Procedures

Sampling Method

Diatoms were collected by a device called a Catherwood Diatometer (Fig. A-1), an apparatus designed to sample the diatom flora in a continuous and nonselective manner. Vertically oriented glass slides serve as artificial substrates for colonization by diatoms. The diatometers are designed to float so that the slides remain just below the water's surface. They are secured to anchors by means of nylon cord and, by adjusting the length of this cord, they are kept afloat at all times, regardless of changing water levels.

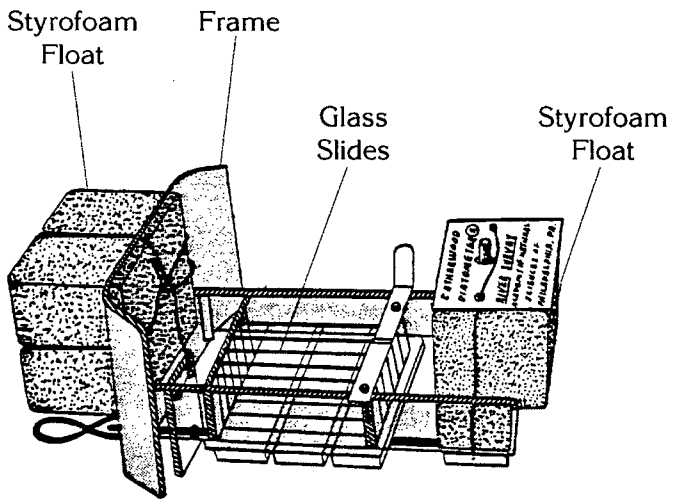


Figure A-1. Diagram of a Catherwood Diatometer.

Diatometers were deployed at four stations (1, 2B, 5 and 6; Fig. 1) along a 59.9-km (37.2-mi) stretch of the Savannah River in the vicinity of the SRS. At each station, two diatometers were placed near the left bank and one diatometer was located near the right bank (by convention, right and left banks are determined by facing downstream). Deployments were made for 12 monthly 2-wk periods. With the exception of Station 2B, slides from 1 diatometer at each station were analyzed for the first 10 exposure periods, January through October; slides for Station 2B were analyzed for the first 8 exposure periods, January through August (slides that were not analyzed were stored for future reference). When possible, slides from a diatometer positioned on the side nearest the SRS (left bank) were analyzed. Previous studies (Patrick, Hohn and Wallace 1954) have determined that an exposure period of two weeks is optimal for the collection of a representative growth of diatoms. Exposure periods for 2001 studies are shown in Table A-1. After exposure, the glass slides are removed from the diatometers and allowed to air dry. The diatometers are replaced by cleaned diatometers and the exposed slides are shipped to The Academy's laboratory in Philadelphia for processing and retention as a permanent record of water conditions.

Table A-1. Dates of Installation and removal of diatometer slides for the report period 16 January through 4 December 2001, Savannah River, South Carolina.

Exposure Period[a]	Installation Date	Removal Date
3	January 16, 2001	January 30, 2001
5	February 14, 2001	February 29, 2001
7	March 13, 2001	March 27, 2001
9	April 17, 2001	May 1, 2001[b]
11	May 15, 2001	May 29, 2001
13	June 19, 2001	July 2, 2001
15	July 24, 2001	August 7, 2001
18	August 22, 2001	September 4, 2001
20	September 18, 2001	October 2, 2001[c]
22	October 23, 2001	November 6, 2001[b, c]
24	November 20, 2001	December 4, 2001[d]

[a]Exposure period refers to the closest approximation to one of the 26 yearly 2-wk exposure periods monitored from 1978 through 1997.

[b]In addition to the semi-detailed reading analysis, the detailed reading analysis was performed during these exposure periods.

[c]Slides from Station 2B were collected and archived for these exposure periods.

[d]All slides were collected and archived for these exposure periods.

Laboratory Techniques

The dried slides are first soaked in distilled water, making it possible to remove the diatoms without breakage by scraping the glass slides. The material is then cleaned by a nitric acid digestion procedure (CEM Model 2000 microwave digestor ANSP SOP P-13-42) and, after rinsing by a repeated sedimentation and decanting process, resuspended in 20 ml of distilled water. This procedure removes all organic material from the sample, leaving the empty siliceous shells (frustules) of the diatoms. A known quantity of the cleaned material is placed on an 18 x 18-mm coverslip, air-dried and mounted in Naphrax (a synthetic mounting medium of refractive index 1.6; ANSP SOP P-13-49) on a glass microscope slide.

Identification and Counts

Specimens on the prepared slides were progressively identified to species and variety, and counted and recorded using a compound microscope with an oil immersion objective and a minimum magnification of 1000x. The semi-detailed reading method (ANSP SOP P-13-09) was employed for all exposure periods, while the detailed reading method (ANSP SOP P-13-39) was also employed for the exposure periods ending 1 May and 6 November 2001. In the detailed readings, between 6,000 and 28,000 specimens were counted and identified until the criteria for a lognormal distribution, as described in Patrick, Hohn and Wallace (1954), were met. In the semi-detailed readings, after an initial count of one row or an approximately 2.5-mm^2 area of the coverslip, the total number of specimens per species was no longer recorded. The coverslip was then scanned for new species over an area determined from previous detailed readings to represent the area of a completed lognormal curve, as described by Hohn (1961). These methods ensured that comparable units of assemblages were compared from station to station and from year to year.

Data Analysis

The underlying assumption of the reading methods is that the relative abundance of diatom species of unpolluted rivers closely follows a lognormal distribution, with a few species very abundant and a few very rare, but the majority of the species represented by populations of moderate abundance. This type of distribution is represented in Figure A-2, with numbers of species in a hypothetical diatom assemblage grouped as a function of the numbers of individuals representing each species. The vertical axis identifies the numbers of species whose respective individuals fall within the log-scaled intervals of the horizontal axis. The mode of an extended count needed to produce such a curve is ideally positioned in the third interval. The body of the curve is composed of the majority of species, which are represented by populations of moderate abundance.

In Figure A-3, a hypothetical diatom assemblage that might be found in a polluted river is represented. Polluted conditions are often indicated by the loss of many species in the system. The body of the curve is composed of many fewer species represented by populations of moderate abundances and the tail of the curve is extended as the abundances of the dominant species become relatively greater.

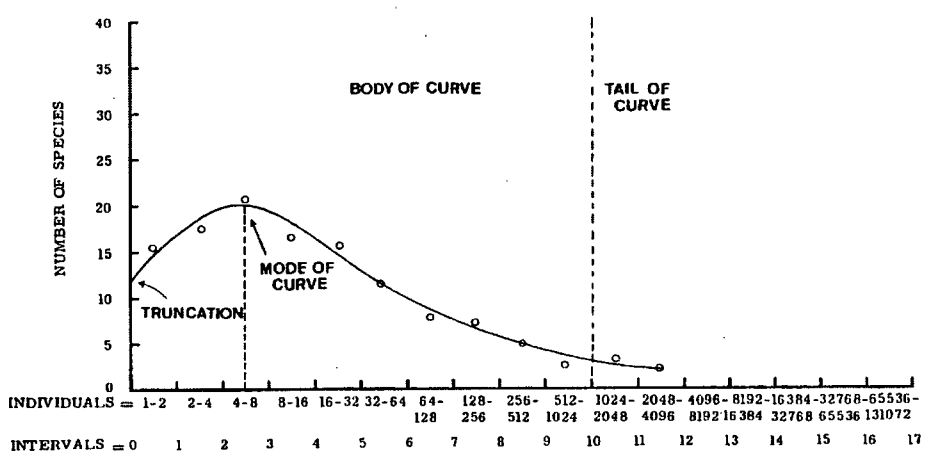


Figure A-2. Example of a lognormal curve fit to the frequency distribution of species within a hypothetical diatom assemblage not affected by pollution.

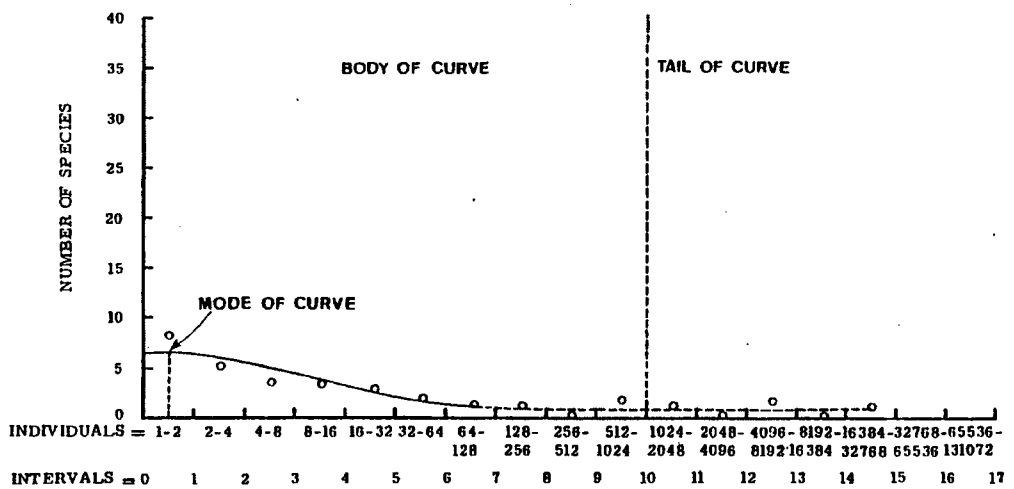


Figure A-3. Example of a lognormal curve fit to the frequency distribution of species within a hypothetical diatom assemblage severely affected by pollution.

The method used to construct these curves was adapted from procedures described by Patrick, Hohn and Wallace (1954), Cohen (1961) and Hendrickson (1998). The model of a truncated normal curve to express the structure of a natural community of organisms was first used by Preston (1948) to express the structure of the communities of birds and moths. Patrick, Hohn and Wallace (1954) found that this method of analysis was excellent to show the structure of natural diatom communities.

Observed Species Number: Richness Parameter

The number of observed species (the number of species recorded at the termination of the count) in an assemblage is used as a direct measure of richness as expressed by species numbers. The termination of the count was based on the area determined from previous detailed readings of Savannah River diatometer slides to represent the area of a completed lognormal curve, as described by Hohn (1961); thus, the numbers of observed species can be compared among stations and reflect the species richness of the sample.

Percent Dominance: Assemblage Dominance Parameter

The degree of assemblage dominance is a measure of unevenness of an assemblage. In the majority of natural situations, most species have medium-sized populations; a few species are more common, and a few more rare. In this report, percent dominance is operationally defined as the percentage of the total specimen count made up of species with abundances greater than 1,024 individuals in a completed detailed reading (those populations falling beyond the 10th interval of a lognormal frequency distribution; Fig. A-3). In assemblages not affected by pollution in soft water rivers, the curve may extend over 12 intervals, thus exhibiting some degree of dominance.

Shannon-Wiener Diversity Index

The Shannon-Wiener Diversity Index (SWDI) is a parameter based on information theory (Shannon and Wiener 1949) that expresses the concept of community diversity. The parameter is composed of both richness and evenness components.

Species Relative Abundances

Relative abundances of the dominant diatom species (a dominant species is defined as one whose abundance is greater than 1,024 individuals in a completed lognormal frequency distribution) were calculated and plotted for the entire study period. Data were examined graphically to determine any seasonal or spatial patterns in the distribution of these species.

Statistical Methods

The parameters tested by statistical analyses (richness, dominance and Shannon-Wiener Diversity) were ranked among the four stations for each exposure period and an analysis of variance (ANOVA) was performed

on these ranked values. A level of $\alpha = 0.05$ was chosen as significant. A multiple range test (Ryan-Einot-Gabriel-Welsch; SAS Institute) was performed to locate any significant pairwise differences found in the ANOVA.

Results

Semi-Detailed Reading Analyses

Diatom Community Parameters

Similar to the previous four study years (1997 to 2000), diatom assemblages were analyzed from more stations (3 in 2001 compared with 2 or 3 prior to 1997) and for fewer exposure periods (10 in 2001 compared to 26 in years prior to 1997) in 2001 than earlier studies (1978 through 1996). There were fewer consistent trends, though a few seasonal and spatial (i.e., station) trends were evident. The results of the statistical analyses (ANOVA; Table A-2) indicate that assemblage richness (number of diatom species), evenness (converse of percent dominance) and diversity (Shannon-Wiener Diversity Index) were consistently higher at the reference station (Station 1) than at the SRS stations (Stations 2B, 5 and 6; $\alpha = 0.05$).

Table A-2. Results of analyses of variance of diatom community parameters of richness, evenness and diversity for the 2001 study year; Savannah River, South Carolina. Stations in the last column are listed in order of decreasing mean for each parameter.

	Degrees of Freedom Error/Station	F	P	Multiple Range Test
Number of Diatom Species	7/3	4.834	0.0002	-- -------- 1 2B 5 6
Percent Dominance	7/3	10.308	0.0021	--------- -- 6 2B 5 1
Shannon-Wiener Diversity Index	7/3	7.968	0.0043	-- --------- 1 5 2B 6

The number of diatom species (a parameter of assemblage species richness; Fig. A-4) was highest at the reference station (means of 107, 82, 80 and 70 and medians of 110, 79, 74 and 66, at Stations 1, 2B, 5 and 6, respectively; Table A-3) with values usually exceeding 100 at Station 1 (for 7 of 10 exposure periods), and exceeding 100 only once at the other stations.

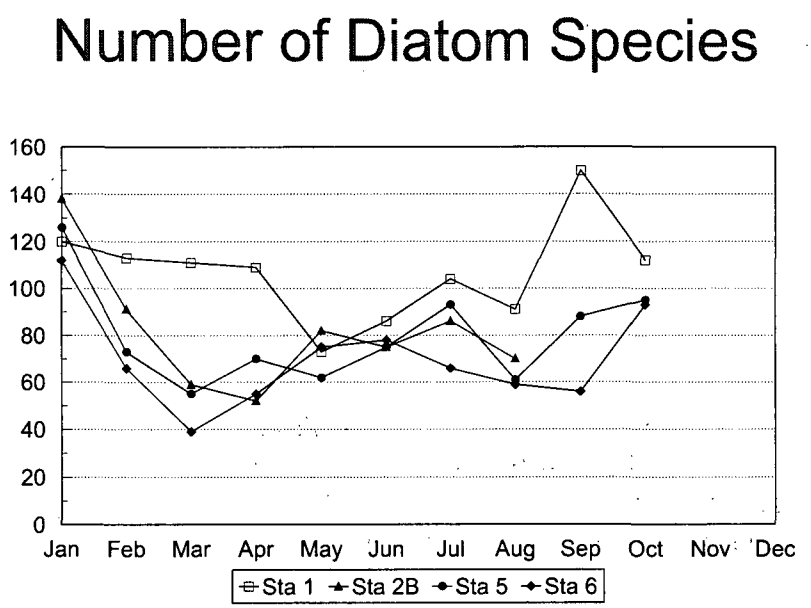


Figure A-4. Number of diatom species from diatometer readings for exposure periods ending 30 January through 6 November 2001; Savannah River, South Carolina. (see Table A-1 for dates of installation and removal of diatometers.)

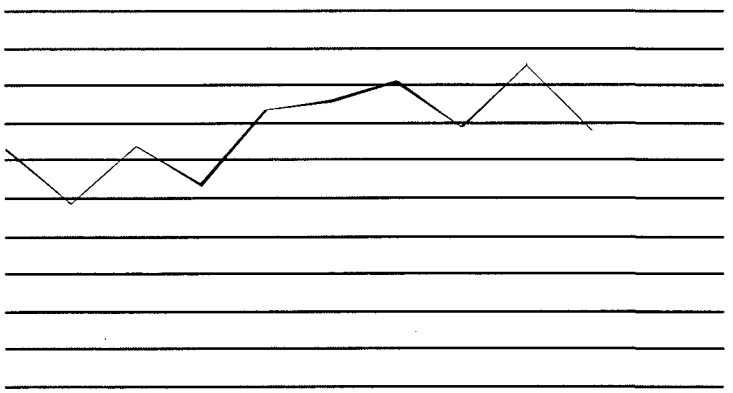
Notable differences (35% or more) between the reference and SRS stations were observed more often at Stations 5 and 6 (5 of the 10 exposure periods). The number of species was usually lower at the upper SRS station (Station 2B) than at the reference station (for 7 of the 8 exposures periods), notably for March and April (there were 47 and 52% fewer species at Station 2B than Station 1 for the March and April exposure periods, respectively. Seasonally, the number of species was higher in the cooler months (9 of the 10 values that exceeded 100 were observed from January through April and September through October).

The assemblage parameter of evenness (converse of percent dominance; Fig. A-5) indicates that assemblages were more

Table A-3. Number of observed diatom species (# Sp.) percent dominance (% Dom.) and Shannon-Wiener Diversity Index (SWDI) from biweekly diatometer readings for the 2001 study year; Savannah River, South Carolina.

Removal	Station 1			Station 2B			Station 5			Station 6		
Date	# Sp.	% Dom.	SWDI	# Sp.	% Dom.	SWDI	# Sp.	% Dom.	SWDI	# Sp.	% Dom.	SWDI
1/30/01	120	10.0	4.981	138	34.5	4.650	126	39.5	4.320	112	63.0	3.400
2/28/01	113	14.2	4.789	91	25.1	4.622	73	40.7	4.271	66	48.5	3.978
3/27/01	111	26.0	4.727	59	73.7	3.041	55	59.7	3.822	39	63.7	3.044
5/1/01	109	17.5	5.054	52	63.4	3.815	70	49.3	3.887	55	53.4	3.710
5/29/01	73	68.4	3.528	82	71.7	3.266	62	77.8	2.956	75	73.4	2.465
7/2/01	86	74.0	3.026	75	74.2	3.132	75	74.3	3.090	78	75.8	2.923
8/7/01	104	57.3	4.158	86	49.8	3.787	93	49.8	4.091	66	80.8	3.001
9/4/01	91	33.6	4.320	70	68.6	3.430	61	55.8	3.559	59	69.0	3.577
10/2/01	150	50.6	4.232	*ND*	*ND*	*ND*	88	57.1	3.741	56	85.3	2.117
11/6/01	112	62.1	4.593	*ND*	*ND*	*ND*	95	67.3	3.574	93	67.9	4.552
Average:	107	41.4	4.341	82	57.6	3.718	80	57.1	3.731	70	68.1	3.277
Median:	110	42.1	4.456	79	66.0	3.609	74	56.5	3.782	66	68.5	3.222
Range:	73-150	10.0-74	3.026-5.054	52-138	25.1-74.2	3.041-4.650	55-126	39.5-77.8	2.956-4.320	39-112	48.5-85.3	2.117-4.552

Percent Dominance



even at the reference station than at the SRS stations (percent dominance means of 41, 58, 57 and 68% and medians of 42, 66, 56 and 68% at Stations 1, 2B, 5 and 6, respectively; Table A-3). The trend was significant (α = 0.05) with the decreased evenness values being most evident below Lower Three Runs (percent dominance values were higher at Station 6 than Station 1 for all 10 exposure periods). Excessive dominance (values greater than 90%) was not observed in 2001, due in large part to a taxonomic change that reduced the abundance of the most dominant species (*Gomphonema parvulum)*. It should be noted that percent dominance values calculated without the taxonomic change exceeded 90% only once, many fewer times than in previous studies. Similar to prior studies, the warmer exposure periods (May through August) had the lowest assemblage evenness (i.e., highest percent dominance values).

Trends in the species diversity parameter (Shannon-Wiener Diversity Index [SWDI]; Fig. A-6) were similar to the evenness parameter with significantly higher (α = 0.05) species diversity at the reference station than at the SRS stations. Values for the SWDI were lowest at the station below

Table A-3. Number of observed diatom species (# Sp.) percent dominance (% Dom.) and Shannon-Wiener Diversity Index (SWDI) from biweekly diatometer readings for the 2001 study year; Savannah River, South Carolina.

Removal	Station 1			Station 2B			Station 5			Station 6		
Date	# Sp.	% Dom.	SWDI	# Sp.	% Dom.	SWDI	# Sp.	% Dom.	SWDI	# Sp.	% Dom.	SWDI
1/30/01	120	10.0	4.981	138	34.5	4.650	126	39.5	4.320	112	63.0	3.400
2/28/01	113	14.2	4.789	91	25.1	4.622	73	40.7	4.271	66	48.5	3.978
3/27/01	111	26.0	4.727	59	73.7	3.041	55	59.7	3.822	39	63.7	3.044
5/1/01	109	17.5	5.054	52	63.4	3.815	70	49.3	3.887	55	53.4	3.710
5/29/01	73	68.4	3.528	82	71.7	3.266	62	77.8	2.956	75	73.4	2.465
7/2/01	86	74.0	3.026	75	74.2	3.132	75	74.3	3.090	78	75.8	2.923
8/7/01	104	57.3	4.158	86	49.8	3.787	93	49.8	4.091	66	80.8	3.001
9/4/01	91	33.6	4.320	70	68.6	3.430	61	55.8	3.559	59	69.0	3.577
10/2/01	150	50.6	4.232	*ND*	*ND*	*ND*	88	57.1	3.741	56	85.3	2.117
11/6/01	112	62.1	4.593	*ND*	*ND*	*ND*	95	67.3	3.574	93	67.9	4.552
Average:	107	41.4	4.341	82	57.6	3.718	80	57.1	3.731	70	68.1	3.277
Median:	110	42.1	4.456	79	66.0	3.609	74	56.5	3.782	66	68.5	3.222
Range:	73-150	10.0-74	3.026-5.054	52-138	25.1-74.2	3.041-4.650	55-126	39.5-77.8	2.956-4.320	39-112	48.5-85.3	2.117-4.552

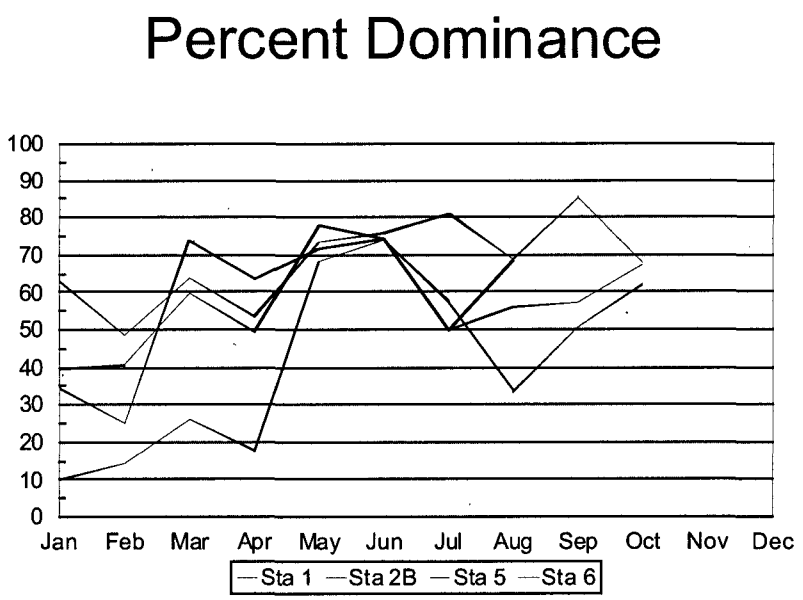


Figure A-5. Percent dominance values for diatom communities from diatometer readings for exposure periods ending 30 January through 6 November 2001; Savannah River, South Carolina. *(See Table A-1 for dates of installation and removal of diatometers.)*

even at the reference station than at the SRS stations (percent dominance means of 41, 58, 57 and 68% and medians of 42, 66, 56 and 68% at Stations 1, 2B, 5 and 6, respectively; Table A-3). The trend was significant ($\alpha = 0.05$) with the decreased evenness values being most evident below Lower Three Runs (percent dominance values were higher at Station 6 than Station 1 for all 10 exposure periods). Excessive dominance (values greater than 90%) was not observed in 2001, due in large part to a taxonomic change that reduced the abundance of the most dominant species (*Gomphonema parvulum*). It should be noted that percent dominance values calculated without the taxonomic change exceeded 90% only once, many fewer times than in previous studies. Similar to prior studies, the warmer exposure periods (May through August) had the lowest assemblage evenness (i.e., highest percent dominance values).

Trends in the species diversity parameter (Shannon-Wiener Diversity Index [SWDI]; Fig. A-6) were similar to the evenness parameter with significantly higher ($\alpha = 0.05$) species diversity at the reference station than at the SRS stations. Values for the SWDI were lowest at the station below

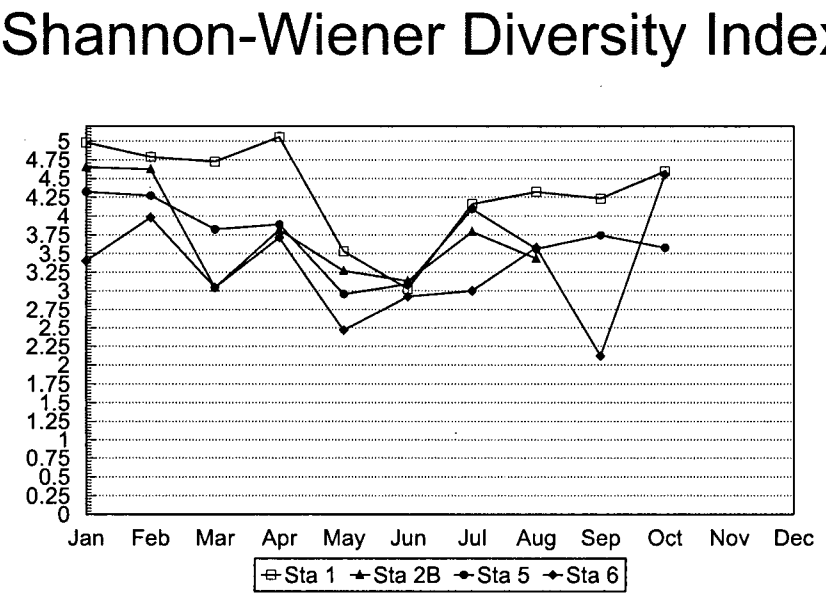


Figure A-6. Shannon-Wiener Diversity Index values for diatom communities from diatometer readings for exposure periods ending 30 January through 6 November 2001; Savannah River, South Carolina. (See Table A-1 for dates of installation and removal of diatometers.)

Lower Three Runs (Station 6; means of 4.341, 3.718, 3.731 and 3.277 and medians of 4.456, 3.609, 3.782 and 3.222 at Stations 1, 2B, 5 and 6, respectively). The highest values of SWDI were observed during the coolest months (January through April).

Diatom Species Relative Abundances

The seasonal and spatial patterns for the dominant diatom species found during the study period 18 January through 4 December 2001 are discussed below. Autoecological data for each species are compiled from several sources (Lowe 1974; Beaver 1981) including the ecology file of the Diatom Herbarium at the Academy of Natural Sciences of Philadelphia (ANSP). Data for comparison with other study periods came from previous reports (ANSP 1982; 1984a; 1984b; 1985a; 1988a; 1988b; 1990b; 1991c; 1992a; 1992b; 1993a; 1994c; 1995; 1996; 1997; 1998; 1999, 2000; 2001). The rating of natural or polluted water species is from Patrick and Palavage (1994). In addition to the discussions of the 2001 study year trends, appendix A discusses the updated taxonomy and ecology of the dominant diatom species from 1978 through 2001.

Cocconeis placentula var. *lineata* (Fig. A-7) – highest relative abundances occurred in late summer and fall (August through October) with a small increase in April. Overall relative abundances were highest at Stations 5 and 6 with peaks of 37% (Station 5 in October) and 20% (Station 6 in September) and lowest at Station 2B (maximum of 2% in April). This species has been observed consistently as a dominant, with low relative abundances (1982 through 1989, 1994,1996 and 1999-2000), usually during warmer exposure periods with few apparent spatial patterns. *Cocconeis placentula* v. *lineata* is characteristic of waters with pH greater than 7 (however, a large range, 4.7-9.0) and is found in natural waters.

Cocconeis placentula var. lineata

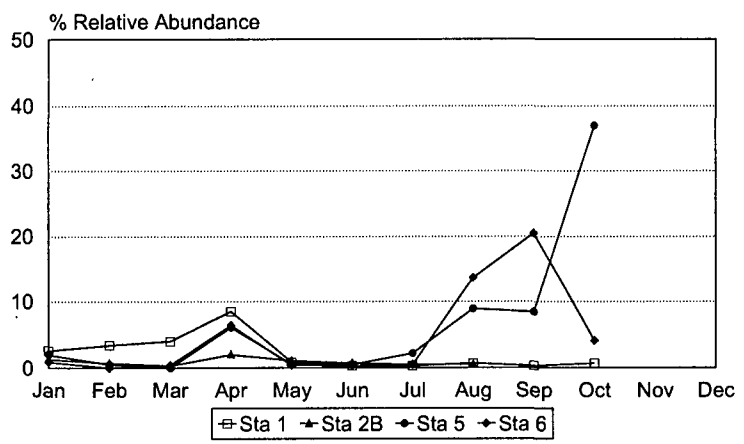


Figure A-7. Relative abundances (%) of *Cocconeis placentula* v. *lineata* for the 2001 study year; Savannah River, South Carolina.

Gomphonema lagenula (previously was a portion of the *Gomphonema parvulum* populations; Fig. A-8) – showed few seasonal trends with peaks in several months, especially June (relative abundances of 44, 35, 40 and 31% at Stations 1, 2B, 5 and 6, respectively). There were few, if any spatial trends as several populations exceeded 20% at each station.

Gomphonema parvulum (the abundances of several species were taken from this large taxon for the 2001 study, see the description in Appendix A; Fig. A-9) -- found seasonally from February through May (abundance exceeded 5% for 15

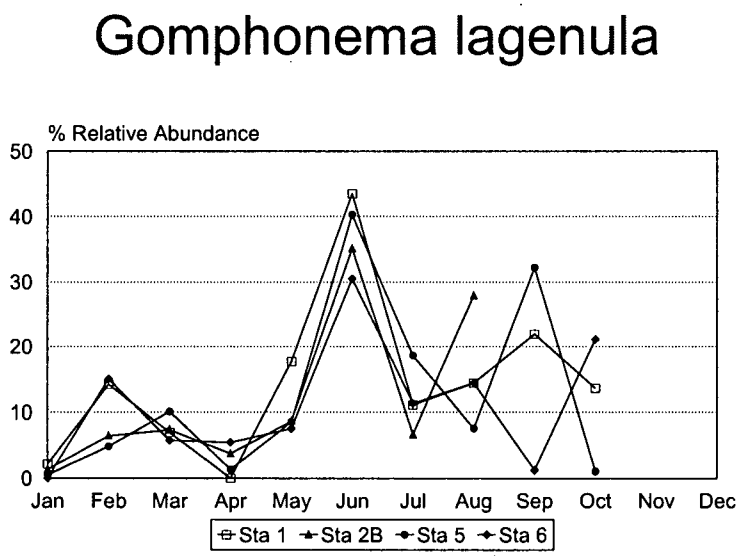


Figure A-8. Relative abundances (%) of *Gomphonema lagenula* for the 2001 study year; Savannah River, South Carolina.

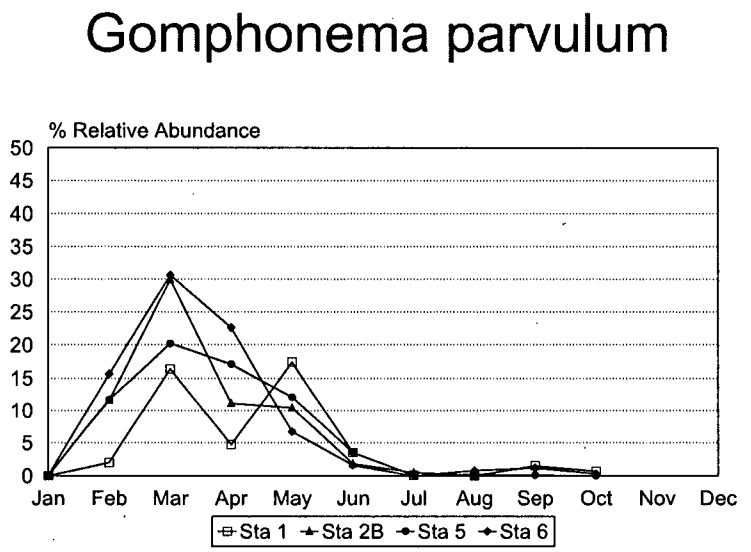


Figure A-9. Relative abundances (%) of *Gomphonema parvulum* for the 2001 study year; Savannah River, South Carolina.

of 16 exposure periods; there were no other values greater than 5% during the 2001 study). Abundances were low during January and July through October (all values less than 2%). No spatial trends were observed as there was at least one population at each station that exceeded 15%. Prior to the taxonomic revisions that separated forms, *Gomphonema*

parvulum had been the most abundant diatom in all recent study periods (1982 through 2000), with highest relative abundances during warmer exposure periods. This species has a large ecological span and is tolerant of a range of pollution conditions, is considered a facultative nitrogen heterotroph, is usually indicative of a large organic load and is found in polluted waters.

Gomphonema sp. 13 Savannah EAM (an undetermined species previously listed as *Gomphonema micropus* and *Gomphonema affine*; Fig. A-10) – overall low in relative abundance (less than 10%) with largest populations at Station 1 observed from July through August (values exceeded 5% only at this station).

Gomphonema sp. 13 Savannah EAM

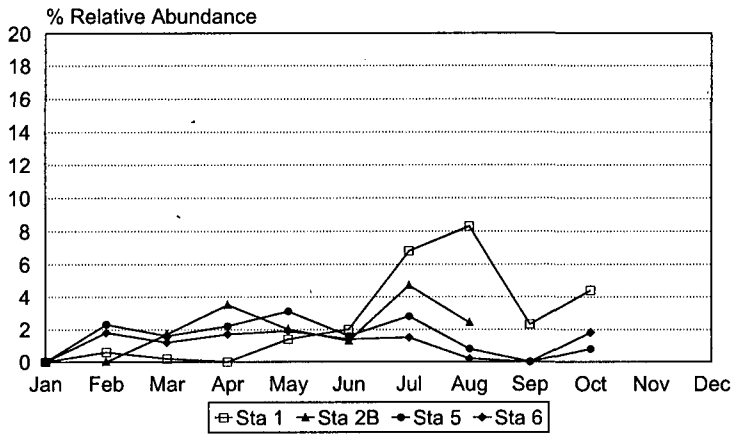


Figure A-10. Relative abundances (%) *of Gomphonema* sp. 13 Savannah EAM for the 2001 study year; Savannah River, South Carolina.

Gomphonema sp. 14 Savannah EAM (previously was a portion of the *Gomphonema parvulum* populations; Fig. A-11) – this was one of the most abundant species observed during the 2001 study, especially from February through June (13 of 20 relative abundance values exceeded 10%; in other exposure periods only 2 of 18 exceeded 10%). Highest values were observed in May (33, 47, 49 and 63% at Stations 1, 2B, 5 and 6, respectively) and March (37 and 33% at Stations 2B and 6, respectively).

Gomphonema sp. 14 Savannah EAM

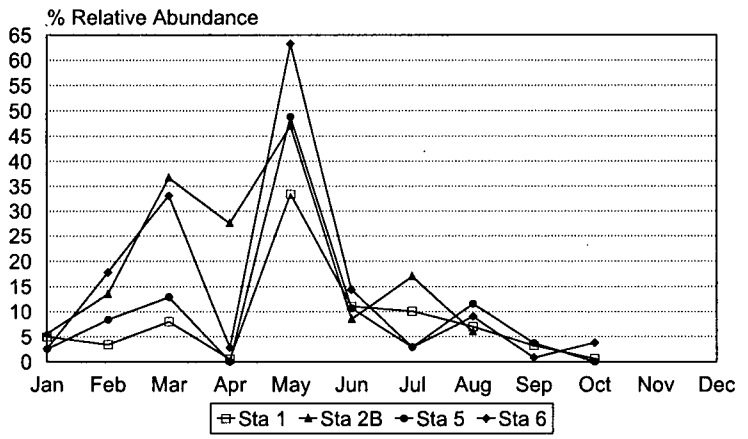


Figure A-11. Relative abundances (%) of *Gomphonema* sp. 14 Savannah EAM for the 2001 study year; Savannah River, South Carolina.

Gomphonema sp. 17 Savannah EAM (previously was a portion of the *Gomphonema parvulum* populations; Fig. A-12) - highest relative abundances occurred in the warmer months, June through August (11 of 12 relative abundance values exceeded 15% in this period; only 1 of 26 values in other exposure periods exceeded 15%). Relative abundances were a little lower at Station 1 (peak of 19% in August) than at the downstream stations (peaks of 33, 31 and 39% at Stations 2B, 5 and 6, respectively for the July exposure period).

Gomphonema sp. 17 NAWQA EAM

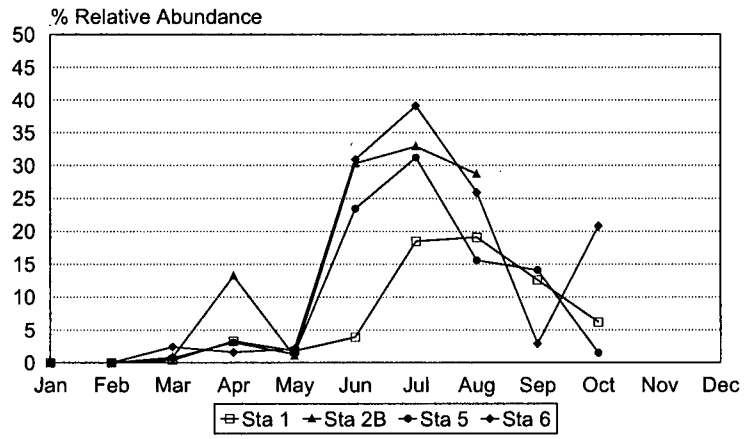


Figure A-12. Relative abundances (%) of *Gomphonema* sp. 17 EAM for the 2001 study year; Savannah River, South Carolina.

Melosira varians (Fig. A-13) - there were few seasonal or spatial trends observed for this species during the 2001 study. Highest relative abundances were observed at Station 1 in October (36%) and Station 5 in April (32%). There was a slight trend of higher relative abundances upstream (Stations 1 and possibly 2B) from June through October. This species has been found consistently in previous studies (1982 through 2000), usually with several large populations and, like previous years (2000 was an exception), with unclear seasonal and spatial trends. *Melosira varians* has a large range of ecological tolerances with pH optimum near 8.0 (7.6-8.2).

Melosira varians

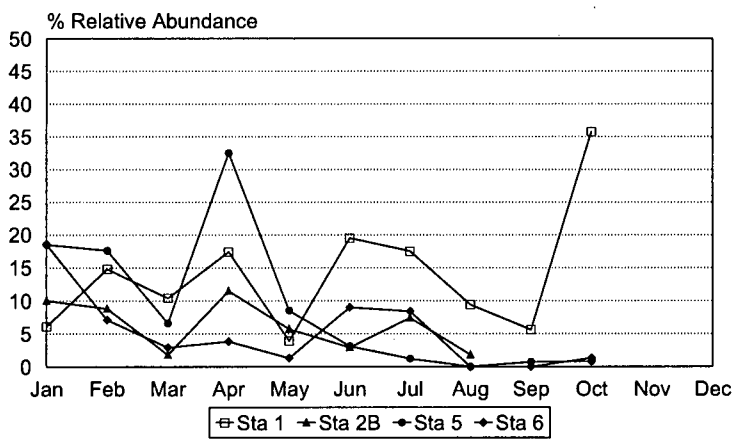


Figure A-13. Relative abundances (%) of *Melosira varians* for the 2001 study year; Savannah River, South Carolina.

Meridion circulare var. *constrictum* (Fig. A-14) - was found only in January (abundances were less than 2% in all other exposure periods) with more abundant populations at Stations 6 and 2B (18 and 10%, respectively). This species has been a dominant in 1993, 1995 and 1996-2000 Savannah River diatometer studies. *Meridion circulare* v. *constrictum* has been found in cooler exposure periods. *Meridion circulare* (nominate variety) has a wide pH range (acid conditions through 9+), but is found mostly at pH 7 (optimum 6.7-9.0) and in nutrient-rich (eutrophic) waters where pollutants have been broken down. This species is found in natural waters.

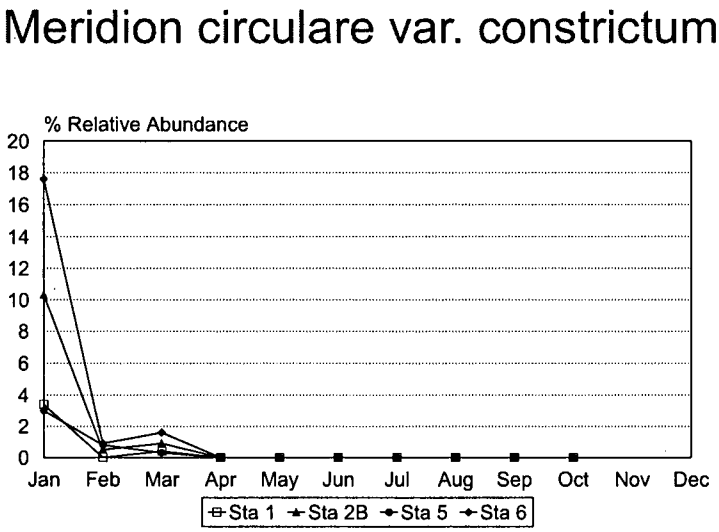


Figure A-14. Relative abundances (%) of *Meridion circulare* v. *constrictum* for the 2001 study year; Savannah River, South Carolina.

Navicula atomus (Fig. A-15) – was found sporadically during the 2001 study, mostly in March and April with a large population (31%) at Station 6 in April.

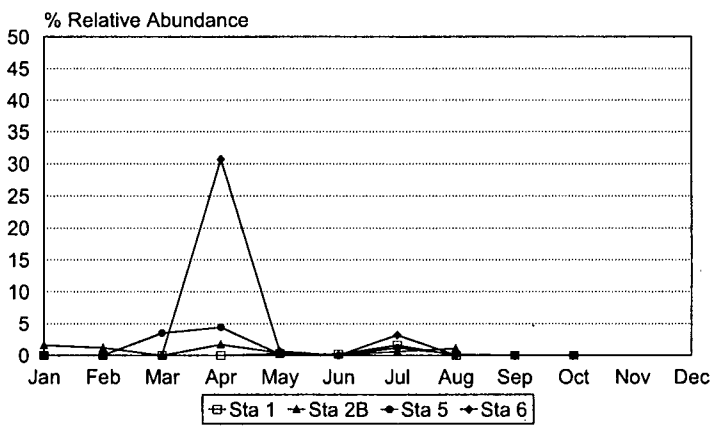


Figure A-15. Relative abundances (%) of *Navicula atomus* for the 2001 study year; Savannah River, South Carolina.

Navicula gregaria (Fig. A-16) – was found only during the cooler exposure periods (values exceeded 2% only in January and February) with higher relative abundances upstream (peaks 10 and 9% at Stations 1 and 2B for the January exposure period).

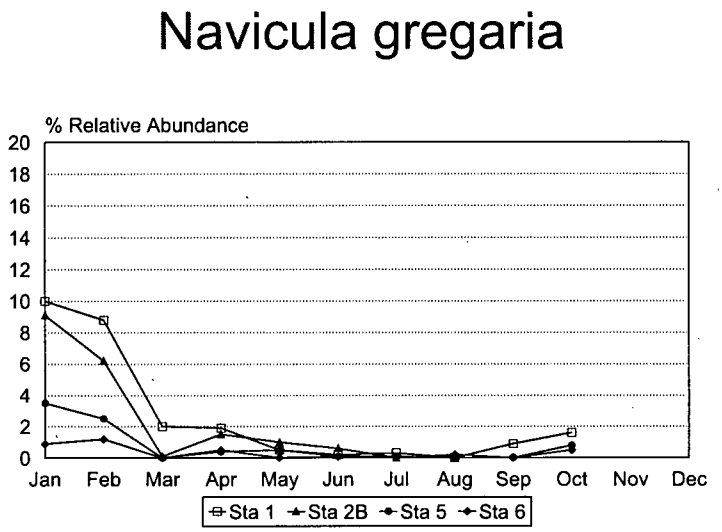


Figure A-16. Relative abundances (%) of *Navicula gregaria* for the 2001 study year; Savannah River, South Carolina.

Planothidium biporomum (previous listed as A. *biporoma*, *A. lanceolata* var. *biporoma* and *Achnanthes lanceolata* subsp. *biporoma*; Fig. A-17) - was abundant only during the warmer months (August through October; relative abundances less than 2% January through July). Lower relative abundances occurred at Stations 1 and 2B (all values less than 2%) with largest populations at Stations 5 (28.6% in

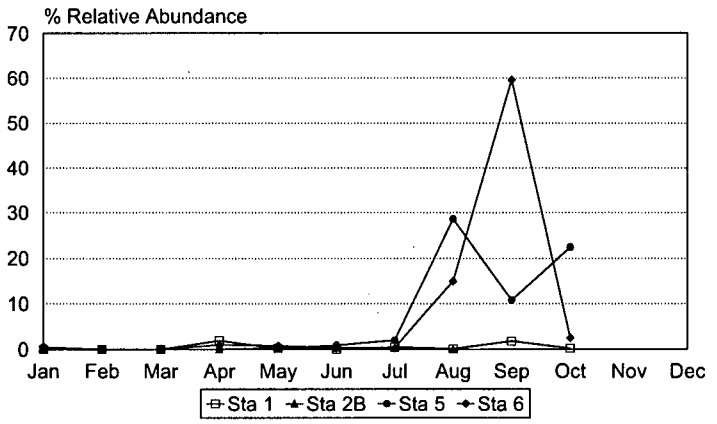


Figure A-17. Relative abundances (%) of *Planothidium biporomum* for the 2001 study year; Savannah River, South Carolina.

August) and 6 (59.6% in September). *Planothidium biporomum* was noted from 1982 through 2000 (except 1992), usually with highest relative abundances in warmer months and highest relative abundances at Station 5 (1983, 1987-1991, 1993-1995 and 1998). This species is characteristic of waters with pH near 7 and is found in natural waters.

Planothidium frequentissimum (Fig. A-18) - showed overall low relative abundances with highest values in the warmer exposure periods (August through October; relative abundance values were less than 2% in the other study months). Populations were most abundant at the downstream stations (5.3% at Station 6 for the September exposure period and 4,8% at Station 5 for the October exposure period).

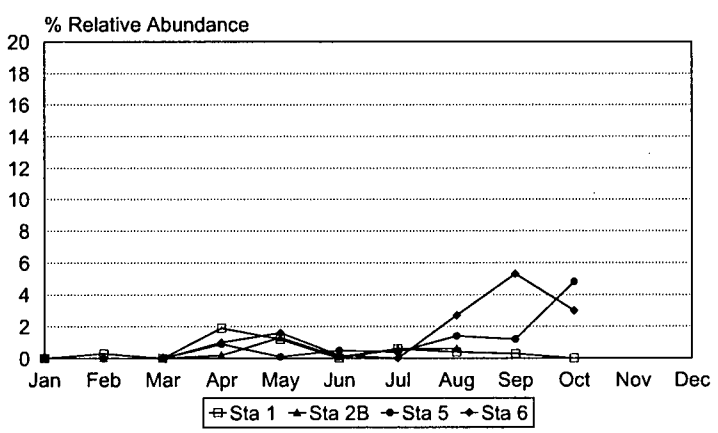


Figure A-18. Relative abundances (%) of *Planothidium frequentissimum* for the 2001 study year; Savannah River, South Carolina.

Synedra rumpens var. *familiaris* (Fig. A-19) - relative abundances were lowest from April though September (all values less than 5%) with highest abundances at downstream stations (27 and 14% at Stations 6 and 2B, respectively for the January exposure period, 16% at Station 5 for the March exposure period and 26% at Station 6 for the October exposure period) compared to the upstream reference station (all values were less than 7% at Station 1).

Synedra ulna (Fig. A-20) - found at the start (January and February) of the study year and in the fall (September

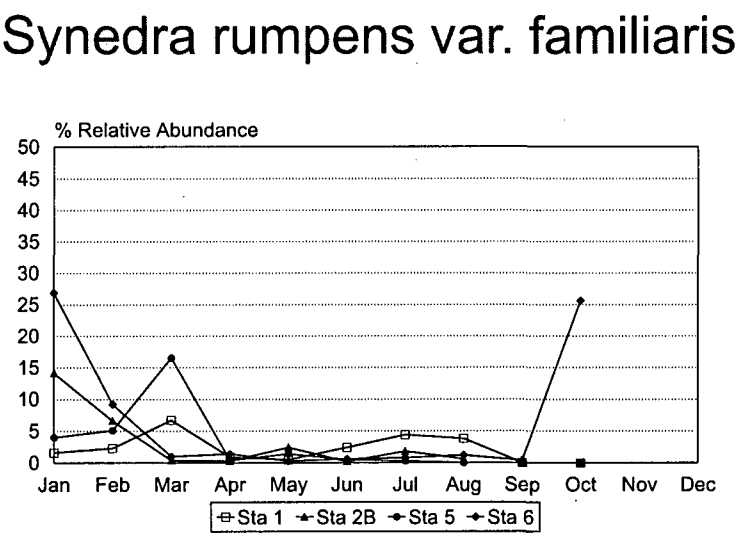


Figure A-19. Relative abundances (%) of *Synedra rumpens* var. *familiaris* for the 2001 study year; Savannah River, South Carolina.

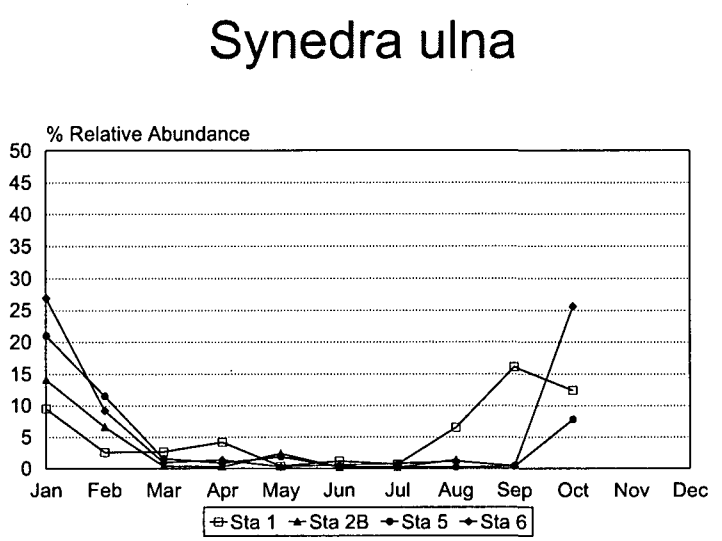


Figure A-20. Relative abundances (%) of *Synedra ulna* for the 2001 study year; Savannah River, South Carolina.

through October) with highest values at different times (peak values of 16 and 12% at Station 1 in September and October, 27 and 26% at Station 6 in January and October, 14% at Station 2B in January and 21 at Station 6 in January). This species showed few, if any, spatial trends (however, the most abundant populations were observed at Station 6). *Synedra ulna* has been found consistently in recent studies (1983, 1986- 1987 and 1989 through 2000) during cooler

exposure periods. This species has a large ecological span, including a pH range of 5.7-9.0 (usually alkaline), and it is found in polluted waters.

Gomphonema parvulum in the "traditional sense" (Fig. A-21) would have been, similar to all recent study periods (1982 through 2000), the most abundant diatom in the 2001 study period. With the exception of generally lower relative abundances in cooler exposure periods (relative abundances were less than 40% for 9 of 11 values in January-February and October but for only 4 of the 27 values from March through September), relative abundance values for *Gomphonema parvulum* in the "traditional sense" (i.e., as it was used prior to the 2001 study) were extremely high, forming nearly half of all assemblages (19 of 38 relative abundance values exceeded 50%).

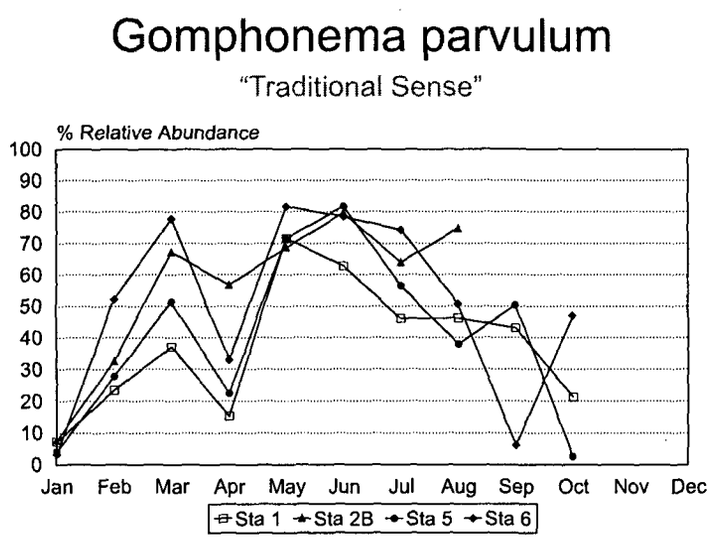


Figure A-21. Relative abundances (%) of *Gomphonema parvulum* in the "traditional sense" for the 2001 study year; Savannah River, South Carolina.

Detailed Reading Analyses

Detailed diatometer readings were carried out for the exposure period ending1 May and 6 November 2001. The modes of the species distribution curves (Figs. A-22 and A-23), are positioned as follows:

	Position of the Mode			
Exposure Period	Sta. 1	Sta. 2B	Sta. 5	Sta. 6
5/2/00	1.060	1.531	2.042	1.332
10/31/00	0.593	no data	0.522	0.243

Comments on the Structure of the Lognormal Curve

The results of the detailed readings for May in the Savannah River indicate that there is little sign of organic pollution. Station 1 in the Savannah River is located above the SRS, but below the city of Augusta. The results of the diatometer reading indicate that there was no sign of organic pollution in May. The height of the mode was about 27 diatoms, and in the second interval. The curve extended over 10 intervals and the number of species in the community was about 175.

In May at Station 2B, below Upper Three Runs and below Plant Vogtle, the height of the mode was about 18 diatoms and the curve extended over 12 intervals. The number of species in the community was roughly 156.

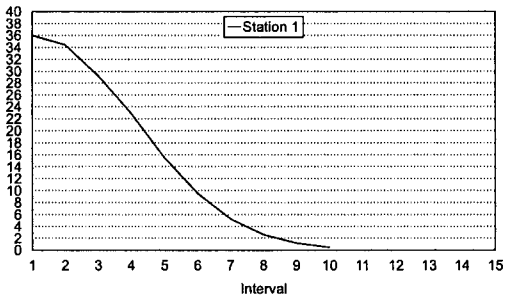
Station 5 in the spring showed signs of a small amount of organic enrichment as the curve extended over 13 intervals. The height of the mode was 18 species and the number of species in the community was about 130 species.

These readings would indicate there was some sign of organic or toxic pollution at these stations (Stations 1, 2B and 5) during the spring (May) exposure period.

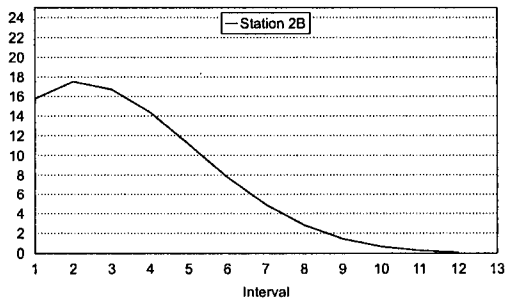
At Station 6, located below Lower Three Runs, the height of the mode was about 20 and the curve extended over 14 intervals. The mode was in interval 2. This indicates that there was some organic pollution present as the curve extended over 14 intervals, rather than 10 to 12, which is typical for normal conditions. The most common species were *Gomphonema lagenula*, *G. parvulum*, and *Mayamaea atomus* (formerly *named Navicula atomus*).

Detailed Readings - 5/1/2001

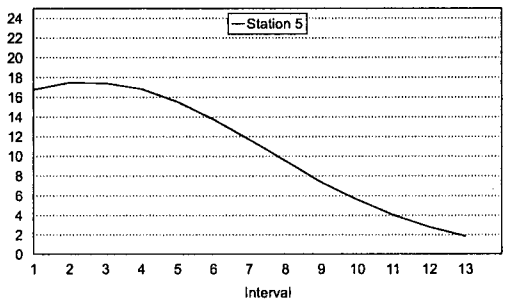
(A)



(B)



(C)



(D)

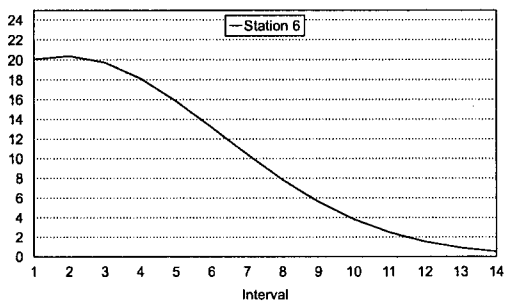


Figure A-22. Frequency distributions of diatom species at (A) Station 1, (B) Station 2B, (C) Station 5 and (D) Station 6 from the detailed reading for the exposure period ending 1 May 2001; Savannah River, South Carolina.

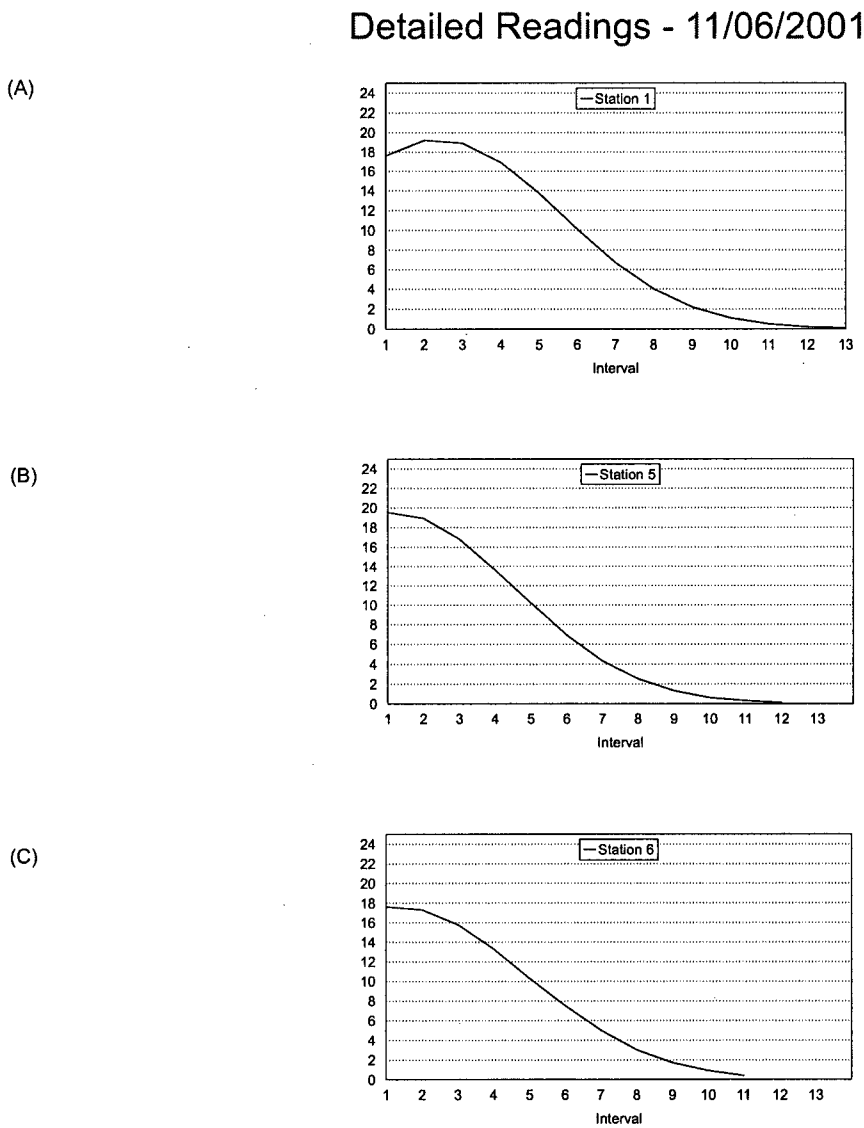


Figure A-23. Frequency distributions of diatom species at (A) Station 1, (B) Station 2B and (C) Station 5 from the detailed reading for the exposure period ending 6 November 2001; Savannah River, South Carolina.

In November at Station 1 above the SRS the curve extended over 13 intervals, indicating some organic pollution. However, the height of the mode was about 19 diatoms and the number of species in the community was 154. The most common species was *Melosira varians*, indicating some organic pollution. This species was found at the 13th interval.

At Station 5 in November the curve extended over 12 intervals, the height of the mode was about 20, and the number of species in the community was 165. There was no sign of

organic pollution. At Station 6, below Lower Three Runs, the height of the mode was 18 species and the total number observed in the community was 158. The curve extended over 12 intervals, indicating that there was no evidence of organic pollution coming out of Lower Three Runs.

From these studies it is evident that the Savannah River was in a natural condition and at times had small amounts of organic pollution. The diatom flora is diversified and what one would expect in a soft water river of this type.

Discussion

The assessment of water quality in the vicinity of the SRS during 2001 (the 49th year of studies) involves comparing diatom assemblages growing on artificial substrates at the reference station (Station 1) with those found at the SRS stations below the Georgia Power and Light's Vogtle Nuclear Power Plant (Station 2B), below Steel Creek (Station 5) and below Lower Three Runs (Station 6), and determining how the assemblages found during 2001 compare with previous studies, over a long period of time. Higher assemblage diversity, as richness (higher number of diatom species) and evenness (lower percent dominance), implies better water quality, or at least a better balanced biota. Small differences, though consistent, might not indicate a difference in water quality, since variation from other sources (physical and seasonal factors) could have a similar effect. Comparisons with previous studies must consider the large number of spatial comparisons (i.e., more stations in 1997 through 2001 than previous years) and fewer seasonal comparisons (10 exposure periods compared with 20-26 in previous Savannah River diatometer studies).

The statistical analyses of diatom assemblage parameter data for 2001 indicate differences between the reference and SRS stations. There was consistently lower richness, higher assemblage evenness (decreased percent dominance) and diversity (Shannon-Wiener Diversity Index) at the reference station than at the SRS stations. A trend of lower richness), diversity and higher unevenness (increased percent dominance) at Station 6 below Lower Three Runs compared to the reference Station 1 was observed consistently in 2001 (as

it was for the study years 1985 through 1996) and the overall means for these parameters were lower at Station 6. The 2001 study year is the fifth year (including 1997 through 2000) with monthly exposure periods and an additional station below Plant Vogtle.

Comparisons were made of diatom assemblage parameters from 2001 studies with means developed from previous studies (ANSP 1978; 1980a; 1981b; 1982; 1984a; 1985a; 1988a; 1988b; 1988c; 1990b; 1991c; 1992a; 1993a; 1994c; 1995; 1996; 1997; 1998; 1999, 2000, 2001) in which semi-detailed readings were used for continuous monitoring (1978-2001 for Stations 1 and 6; 1982-2001 for Station 5; 26 two-week exposure periods per year except 1976, 1997, 1998, 1999, 2000, 2001; Figs. A-24 and A-25). Although more diatom species might be expected because of the taxonomic changes (breaking the dominant *Gomphonema parvulum* into several species), the number of diatom species was lower than the established mean during the 2001 study, especially during warmer exposure periods. At the reference station there were about as many above average as below average numbers of species with the warmer exposure periods (May through August) below the established average. Stations 5 and 6 had consistently below average number of diatom species (9 out 10 exposure periods, by 1 s.d. for 4 exposure periods) except for January. As expected, due to the taxonomic change, the percent dominance values were lower than the established average (29 of the 30 values; 12 by 1 s.d.). However, the taxonomic change does not explain all of the lower than average values (without the change, 22 of the 30 values for percent dominance are below the established average, 7 by 1 s.d.). The comparisons with previous years are mixed as the number of species would represent lower diversity, however lower dominance would indicate the opposite.

Detailed lognormal readings have been made for Stations 1 and 6 in the spring (usually April) and fall (usually October) beginning in 1954 (no fall 1996 or 2000 reading; ANSP, 1974b; 1978; 1980a; 1981b; 1982; 1984a; 1985a; 1988a;1988b; 1990b; 1991c; 1992a; 1992b; 1993a; 1994c; 1995; 1996; 1997; 1998; 1999, 2000; 2001 appendix and original data sheets). The number of species varied considerably (Figs. A-26 and A-27), and for the 2001 studies were higher in the spring exposure period (especially at Station 1).

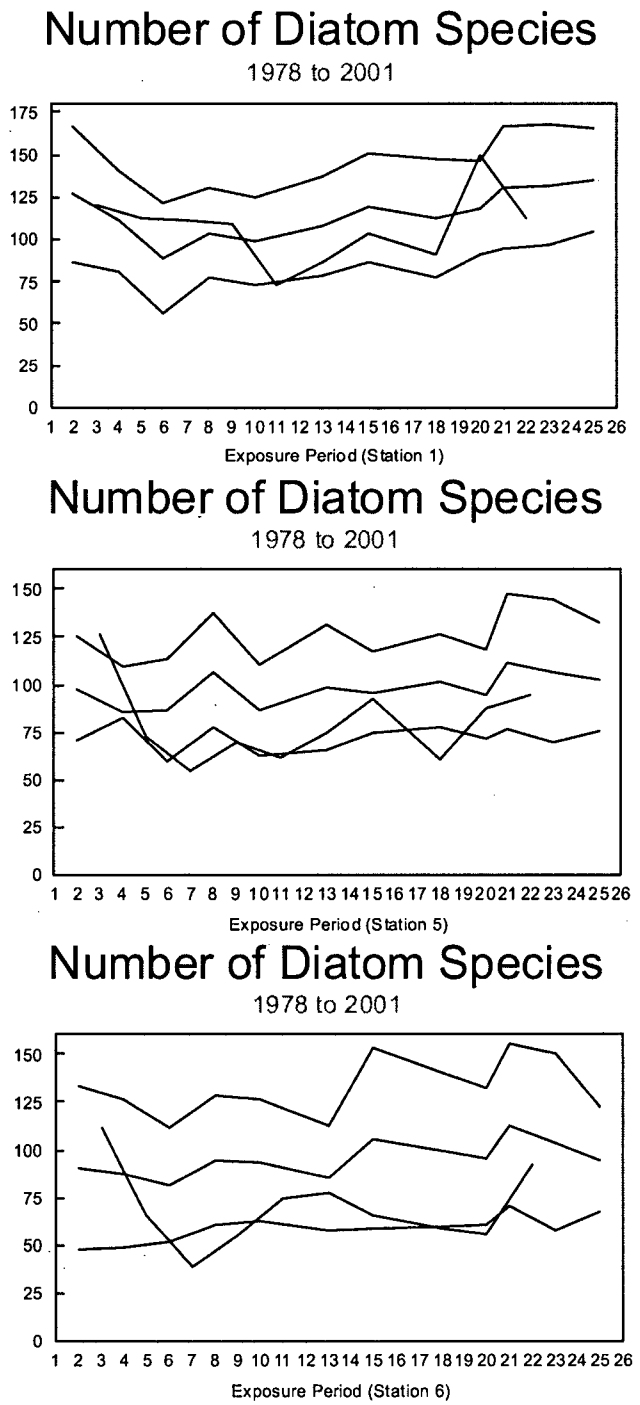


Figure A-24. Number of species from 2001 diatometer studies on the Savannah River, SC (line connecting squares) compared with mean and 1 standard deviation of data from diatometer studies conducted from 1978 through 1997 (lines connecting dashes; Sta tion 5 data are from 1982 through 1997) us ing semi-de tailed read ing method. The heavy line rep re sents the per cent dom i nance if the dom i nant *Gomphonema parvulum* **in its original definition was used, as was done in studies prior to 2001. Exposure periods represent 26 two-week exposures, starting in January and end ing in late De cem ber. Note that only 20 ex po sure pe ri ods were an a lyzed in 1996.**

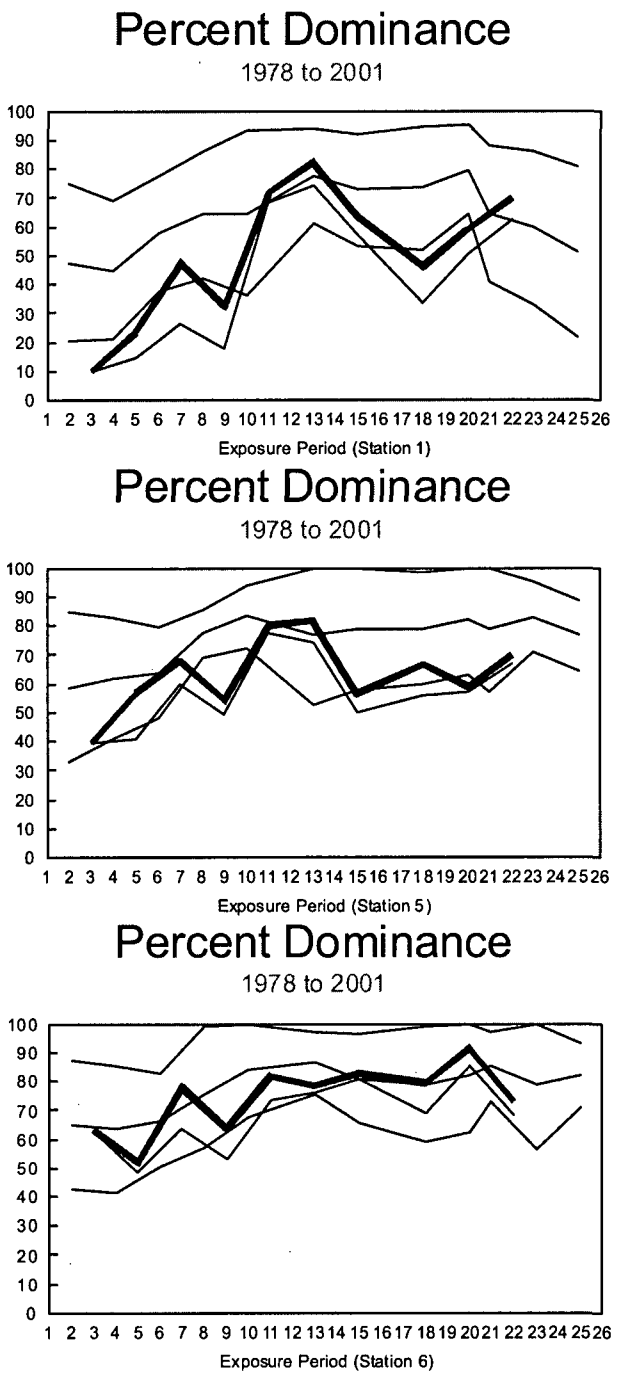


Figure A-25. Percent Dominance from 2001 diatometer studies on the Savannah River, SC (line connecting squares) compared with mean and 1 standard deviation of data from diatometer studies conducted from 1978 through 1997 (lines connecting dashes; Station 5 data are from 1982 through 1997) using semi-detailed reading method. The heavy line represents the percent dominance if the dominant ***Gomphonema parvulum*** **in its original definition was used, as was done in studies prior to 2001. Exposure periods represent 26 two-week exposures, starting in January and ending in late December. Note that only 20 exposure periods were analyzed in 1996.**

Although many distribution patterns were observed for the relative abundances of dominant species, most trends were seasonal, not spatial, nor related to the operation of the SRS. Most species exhibited maximum development during the early, cooler portion of the study year. Because of the overwhelming dominance at all stations of several *Gomphonema* species, and the presence in at least low abundance, of most species at each station, the overall species composition was similar at the four stations in the vicinity of the SRS during 2001 studies. Ecological tolerances of diatom species found on diatometer slides in the Savannah River in the vicinity of the SRS during 2001 studies, determined from a compilation of diatom literature (Lowe 1974; Beaver 1981; ANSP ecolog -ical records), were similar for the dominant species at all stations. Nearly all of the dominant species were characteristic of alkaline waters (optimum growth when pH greater than 7). The abundant diatom *Gomphonema parvulum* is considered pH indifferent, but with an optimum above pH 7. Most of the dominant diatoms are considered characteristic of waters with moderately high nutrient concentrations (i.e., eutrophic; Lowe 1974). The most abundant species (espe-

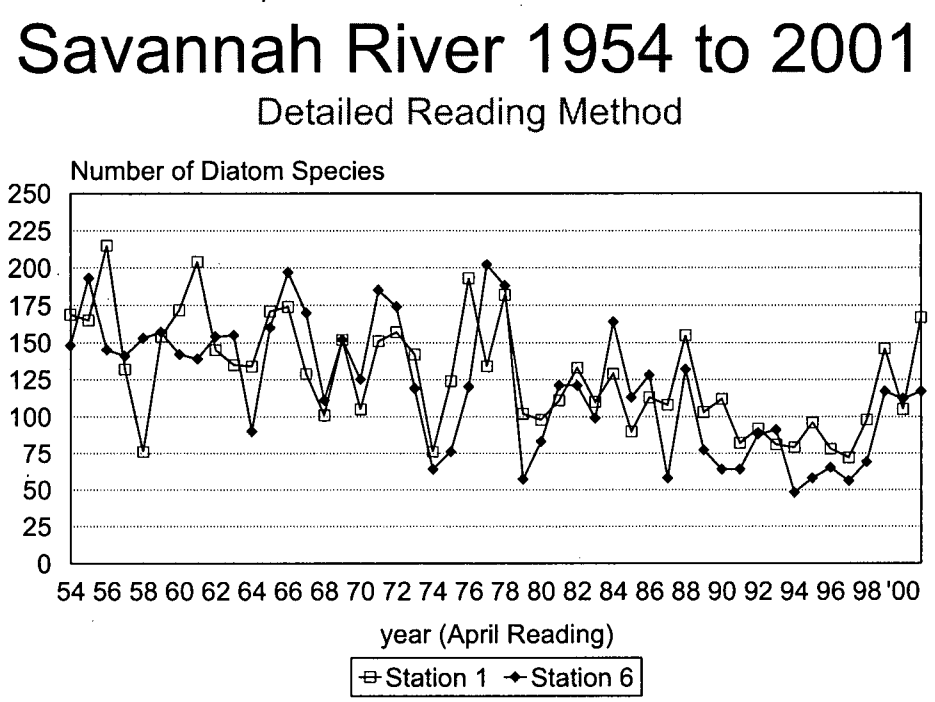


Figure A-26. Total number of diatom species from the fall (usually April) exposure period, 1954 through 2001 using the detailed lognormal reading method; Savannah River, South Carolina.

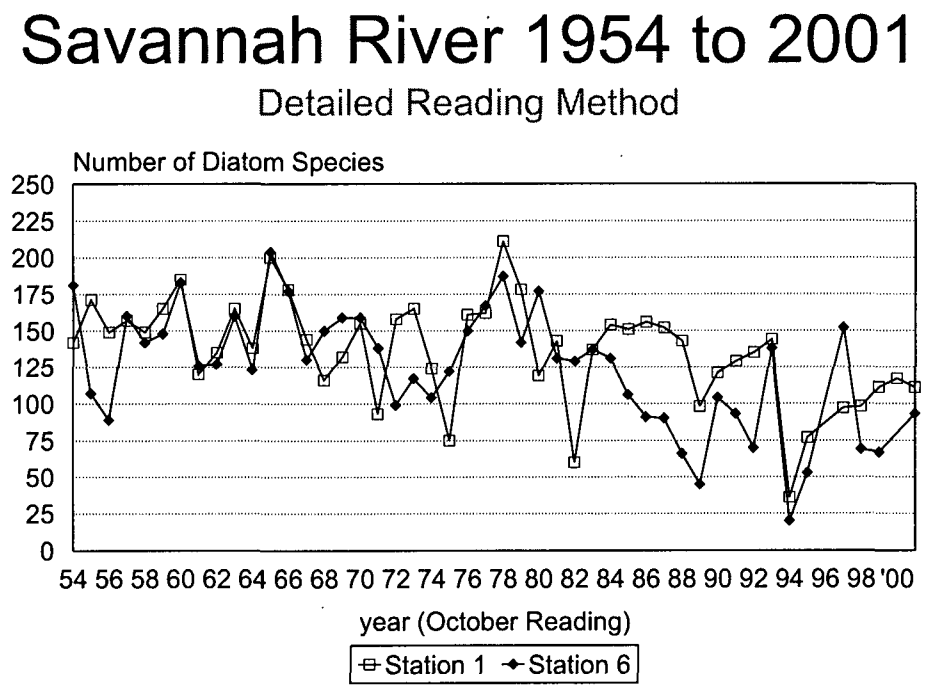


Figure A-27. Total number of diatom species from the spring (usually October) exposure period, 1954 through 2001 using the detailed lognormal reading method; Savannah River, South Carolina.

cially *Gomphonema parvulum* and *Melosira varians*) have wide tolerances and can adjust to a range of conditions; but, they are not usually indicative of severe conditions.

In summary, the composition and tolerances of diatom species in the Savannah River above and below the SRS were similar during the 2001 study. Differences in diatom assemblage structure (lower evenness and diversity at the SRS stations), were not as severe as the lower diversity noted at the station below Lower Three Runs for biweekly studies from 1986 through 1996. The data from 1997 through 2001 (i.e., compared with the earlier 11 years), appear to indicate that deteriorated conditions (as noted by the lower diversity) observed previously on the Savannah River below Lower Three Runs, were not present in 1997 through 2001. However, a less consistent and less severe trend of lowered diversity at the SRS stations (below Plant Vogtle, below Steel Creek and below Lower Three Runs) was noted for at least short periods in the 1998, possibly 1999 and 2000 studies. Most of the dominant species observed in the 2001 study, similar to previous studies, are characteristic of alkaline, nutrient-enriched waters.

APPENDIX A

Taxonomic Changes of Some Dominant Diatom Taxa from the Savannah River

By Eduardo A. Morales

Diatom Taxonomy is in constant flux due to the relatively recent introduction of the scanning electron microscope (SEM) to the study of diatom morphology. This tool, combined with detailed light microscopy (LM) analysis, has revealed a substantial complexity in the morphology of the diatom cell wall. This complexity, in turn, has served to refine the morphologically-based diatom classification system.

The majority of changes in the taxonomy of diatoms are concentrated on the genus level, where more restricted categories have been separated from formerly broadly circumscribed genera. This is the case of *Navicula*, for example, from which genera such as *Craticula*, *Diadesmis*, *Kobayasiella*, *Luticola*, *Placoneis*, *Sellaphora*, etc. have been split (Morales, 2001c).

This Appendix is divided into two parts. The first part is a continuation of Appendix A-1 (Morales, 2001c) presented in the 2000 Savannah River Biological Survey Report, and deals with some additional new genera names that have been adopted for the 2001 analyses. The second part treats some taxonomic changes at the species level in some of the most

abundant taxa reported in the last two Savannah River Biological Reports (complementary to Appendix A-2 of the 2000 report). Especially important are the changes in the nomenclature and circumscription of *Gomphonema* spp. Plates with LM and SEM micrographs are included as supporting material for these taxonomic decisions.

Additional New Genera Names Adopted for the Analysis of 2001 Savannah River Samples

Centric Diatoms

Orthoseira

This taxon contains species formerly included in the genus *Melosira*. *Orthoseira* differs from the latter genus in having one to many wide openings (labiate processes) at the center of the valve. *Melosira* in contrast has the same structures, but they are much smaller and scattered throughout the valve face. Also, *Melosira* has labiate processes at the valve face-mantle junction, whereas *Orthoseira* does not have these structures. The areolae are much finer in *Melosira* and they can not be seen with LM. The areolae in *Orthoseira*, in contrast, are wide and easily seen under LM.

Monoraphid Diatoms

Planothidium

This genus was devised to contain species related to the *Achnanthes lanceolata* species group. At present this genus includes species that do not have all the characteristics included in the protologue of the genus as defined by Round and Bukhtiyarova (1996). One of the most outstanding features that defines the genus is the hoof print ("horse shoe" structure) located on one side of the central area of the pseudoraphe valve. This feature is present, for example, in *P. frequentissimum* and *P. biporomum*. Recently, other taxa that do not possess this hoof print have been included in *Planothidium*. Namely, *P. granum*, *P. lanceolatum*, etc.

Clearly the protologue of the genus needs revision, but in spite of this, its use has become widespread among diatomists. This genus has been adopted for Savannah River sample analysis based on features other than the hoof print. Some of these features include the doubly-punctated striae and characteristics of the raphe and pseudoraphe.

Biraphid Diatoms

Adlafia

This genus was erected in Moser et al. (1998) based on *Navicula muscora*. Under SEM, the striae are composed of round areolae, which remain occluded by a persistent extracellular organic coating even after acid digestion. This is probably due to the fact that this layer is embedded with mineral particles that make it resistant to acids. The structure of the raphe is simple with distal ends conspicuously bent in the same direction. Girdle bands are perforated.

Chamaepinnularia

This genus was based on *C. vyvermanii* (Lange-Bertalot and Metzeltin, 1996) and since then many taxa formerly in *Navicula* and *Pinnularia* have been transferred into it. The striae of the taxon are uniseriate (in contrast to *Pinnularia* in which they are multiseriate), although this feature is not often seen even under SEM due to the fact that the striae seem to be covered by an additional silicon layer. Internally, the striae open through a single transapically elongated opening. Thick costae can be observed. The raphe system is simple (in *Pinnularia* it is complex) and the distal ends bend in the same direction. Internally, the proximal raphe ends bend in the same direction, but contrary to the proximal raphe ends.

Encyonopsis

This genus was split from *Cymbella* and based on *C. cesatii* (Krammer, 1997). In general, species in this genus are characterized by their small sizes, the structure of their areolae and occluding membranes (vela), and the structure of the raphe. The distal ends of the raphe fissure are curved toward the dorsal part of the valve. In the majority of species, the striae are composed by small round or transapically elon-

gated areolae (in *Cymbella* the areolae [lineolae] are apically elongated). Also, most species on *Encyonopsis* lack a stigma.

Geissleria

This taxon was described in Lange-Bertalot and Metzeltin (1996) based on *Geissleria moseri*. Under SEM, species in this group have striae composed of lineolae (slit-like areolae), which are conspicuously widened in striae toward the apical ends of the valve (this is sometimes visible under LM). Some species possess a stigma in the central area. The raphe structure is simple with distal ends always (?) deflected in different directions.

Fistulifera

This genus was described in Lange-Bertalot (1997) to include *Navicula saprophila* and related taxa. All the species included in this genus are difficult to see under the LM. This is due to the small sizes of these diatoms and to the weak silicification of their frustules. In many cases, only the central sternum and valve outline are visible. At the SEM level, the striae are composed by a single row of small round poroids. These poroids are occluded individually and internally by a fine membrane (the occlusion is external in the closely related genus *Mayamaea*). The raphe has a simple structure and lies along a thickened sternum. The bending of distal and proximal raphe ends is variable depending on the species. The girdle bands are very thin and numerous.

Hippodonta

This genus was originally described in Lange-Bertalot et al. (1996) based on *Navicula hungarica* var. *lueneburgensis* (=*Hippodonta lueneburgensis*). Under SEM, the striae are externally composed by lineolae, each of which opens to the interior of the valve internally by two pores, suggesting doubly punctated striae. In general silicification of the valves is heavy in all species which makes them highly refractive under LM. Most of the species have thickened costae, central area and apices. The raphe has a simple structure with distal ends deflected in the same direction.

Mayamaea

This genus was originally described in Lange-Bertalot (1997) based on *Navicula atomus*. At the SEM level, the striae are composed of round areolae, individually occluded by an external (not internal as in *Fistulifera*) fine membrane. The raphe structure is simple with distal and proximal ends deflected in opposite directions. The raphe lies on a thickened sternum, which is conspicuous under LM. The helictoglossae are also very prominent and seen as conspicuous dots toward the valve apices.

Nupela

This taxon was described to contain the species associated with *Nupela giluwensis* (Vyverman and Compère, 1991). Since then many species formerly in the genera *Achnanthes* have been transferred into it. Under SEM, the external surface of the valves is covered by a thin siliceous layer that is lost when the material is thoroughly cleaned with acids. This thin layer does not allow the observation of the striae, which from the internal view can be seen as composed by a single row of round areolae. The raphe system is simple and well developed on one valve, but short and visible or sometimes completely filled with extra silica on the other valve. The raphe is hooked in the same direction at its distal ends, but this may vary from species to species. The proximal ends are directly opposite to each other.

Reimeria

This genus was created by Kociolek and Stoermer (1987) to contain *Cymbella sinuata* and associated taxa. This taxon is different from *Cymbella sensu stricto* in that the striae are formed by two rows of poroids. Also the distal and proximal raphe ends are curved toward the ventral side of the valve. The apical pore fields are split by the raphe fissure at the apex. A clear round stigma can be seen at the central area. This stigma is transapically elongated at the valve's inner surface.

Taxonomic Changes at the Species and Variety Levels of Some Common Taxa Occurring in Savannah River Samples

Species Within the Genera *Encyonema* and *Encyonopsis*

As stated in Morales (2001c), The genus *Encyonema* was created to include many species formerly ascribed to *Cymbella*. Some of the species of this latter genus that were reported for the Savannah River and that are now included in *Encyonema* are: *Encyonema lunatum*, *E. minutum*, and *E. sileciacum*. All of these taxa are easily identifiable and Krammer and Lange-Bertalot (1986) can be used as a reference.

The genus *Encyonopsis* was also split from *Cymbella* (see first part of this Appendix). The species of *Encyonopsis* reported for the Savannah River are: *Encyonopsis microcephala* and *Encyonopsis ruttneri* var. *obtusa*.

Species Within the Genera *Fragilaria* and *Synedra*

There has been a dramatic change in the taxonomy of these two genera in the last twenty years. This is primarily due to detailed analysis using SEM and the study of wider geographical regions, which allowed for a better circumscription of genera and species boundaries. The following outline depicts some this taxonomical history of these two genera:

1) In 1986, Williams (1986) redefines the genus *Synedra* to include *Synedra ulna* and allies.
2) In the same year, the remaining species of *Synedra* are split into five genera by Williams and Round (1986) based ultrastructural features. The five genera are: *Catacombas* (*Synedra gaillonii/S. baltica* group), *Ctenophora* (*S. pulchella* group), *Hyalosynedra* (*Synedra laevigata* group), *Neosynedra* (*Synedra provincialis* group), and *Tabularia* (*Synedra barbatula* group).

3) In 1987 *Fragilaria* was split into five different genera by Williams and Round (1987) based on ultrastructural features. The five genera are: *Fragilaria* sensu stricto (*F. crotonensis* and allies), *Fragilariforma* (*F. virescens* group), *Pseudostaurosira* (*F. brevistriata* group), *Staurosira* (*F. construens* group), *Staurosirella* (*F. pinnata* group).
4) In subsequent years more genera are erected based on other *Fragilaria* species that Williams and Round did not cover: *Stauroforma* (Flower et al., 1995), *Pseudostaurosiropsis* (Morales, 2001a).
5) Although Lange-Bertalot and colleagues do not generally agree with the abovementioned changes, many of the modifications at the species and variety levels presented in Krammer and Lange-Bertalot (1991) can be combined with the work of Williams and Round. As a consequence there is a considerable change in the nomenclature of several taxa. These changes are mainly based on examination of type material under LM, and to a reduced extent by collection of SEM data.

The Appendix Table A-1 shows the changes in the nomenclature of *Fragilaria* and *Synedra* species reported in Savannah River studies prior to 2000.

Additional species of *Fragilaria* reported from the 2000 and 2001 samples are:

Fragilaria bidens

This taxon has a distinctive inflated central area with constrictions above and below it. Also the apices are conspicuously rostrate and the striae are very well defined. In general, the valves of this taxon are more robust and easily distinguishable from the *F. capucina* group, to which it is closely related.

Fragilaria capucina var. *perminuta*

This taxon can be distinguished for the other varieties of the *F. capucina* group by the narrowly linear central sternum and the thickening in the unilaterally clear central area. Also, the valves of this taxon tend to be much smaller than those of other closely related taxa.

Appendix Table A-1.

Name of taxon in counts prior to 2000	Name of taxon in 2000 and 2001 counts
Fragilaria berolinensis	*Staurosirella berolinensis*
Fragilaria brevistriata	*Pseudostaurosira brevistriata*
Fragilaria capucina var. mesolepta	*same*
Fragilaria construens	*Staurosira construens*
Fragilaria construens var. pumila	*Staurosira construens*
Fragilaria construens var. subsalina	*Staurosira construens var. subsalina*
Fragilaria construens var. venter	*Staurosira construens var. venter*
Fragilaria crotonensis	*same*
Fragilaria leptostauron	*Staurosirella leptostauron*
Fragilaria leptostauron var. dubia	*Staurosirella leptostauron var. dubia*
Fragilaria pinnata	*Staurosirella pinnata*
Fragilaria pinnata var. subcapitata	*same, but probably a Staurosirella*
Fragilaria vaucheriae	*same*
Fragilaria virescens	*Fragilariforma virescens*
Synedra acus	*same*
Synedra delicatissima	*same*
Synedra delicatissima var. angustissima	*same*
Synedra famelica	*Fragilaria famelica*
Synedra fasciculata var. truncata	*Tabularia fasciculata*
Synedra goulardi	*same*
Synedra incisa	*not studied, but probably just a teratological for of Fragilaria capucina var. rumpens.*
Synedra minuscula	*Fragilaria famelica*
Synedra parasitica	*same, but probably a Pseudostaurosira*
Synedra pulchella	*Ctenophora pulchella*
Synedra pulchella var. lacerata	*Ctenophora pulchella var. lacerata*
Synedra rumpens	*Fragilaria capucina var. rumpens*
Synedra rumpens var. familiaris	*Fragilaria capucina var. gracilis*
Synedra rumpens var. fragilarioides	*Fragilaria capucina var. distans*
Synedra rumpens var. meneghiniana	*same, but should probably be transferred as a variety of Fragilaria capucina*
Synedra rumpens var. scotica	*Fragilaria capucina var. gracilis*
Synedra socia	*not studied*
Synedra tenera	*Fragilaria tenera*
Synedra ulna	*same*
Synedra ulna var. danica	*same*
Synedra ulna var. oxyrhynchus fo. *mediocontracta*	*Synedra ulna var. contracta*
Synedra ulna var. ramesi	*not studied, but should probably stay the same*

Fragilaria nanana

This taxon produces long and narrow valves, which striae are barely seen under LM. The central sternum is visible and somewhat wide (considering the width of the valves). The central area is mostly clear on both sides and the apices are either rostrate of slightly capitate.

Fragilaria neoproducta/F. nitzschioides

F. neoproducta produces long chains with the aid of spines. It is distinguished from *F. nitzschioides* in that the striae of the valve mantle (as seen in side view) are short. In contrast, *F. nitzschioides*, which also produces long chains, the striae are long and almost seem to be uninterrupted from valve to valve (when only one or two girdle bands are produced).

Fragilaria sp. 5 NAWQA EAM

This taxon was originally found in NAWQA (National Water Quality Assessment Program) material. It is characterized by small frustules, narrow rostrate apical ends, and a long and clear central area. The sternum is somewhat wide and the striae are delicate, but visible under LM. This taxon seems to be related to the *F. capucina* group, but does not fit into any of the described varieties.

Species in the Genus *Gomphonema* with Emphasis on the *G. parvulum* Complex

In an effort to increase accuracy in the identification of diatoms found in preparations from the Savannah River, the taxonomy of the *G. parvulum* (Kützing) Kützing complex was studied under both light microscopy (LM) and scanning electron microscopy (SEM). In the past (up to the year 2000), this taxon has been reported as the most abundant diatom in diatometer samples from the Savannah River, reaching a relative abundance of up to 90% toward the end of the summer period.

Historically, the taxonomy of this taxon has been a challenge for diatomists since its original description by Kützing in (1849). Other investigators subsequently studied and illustrated many additional populations from collections from all

over the world. Such reports often dealt with forms that seemed to intergrade with *G. parvulum* sensu stricto, and thus, were ascribed to this taxon. After some years, the literature presented a wealth of forms that seemed to represent a highly morphologically variable taxon.

Investigations by Geitler on reproduction of cultured strains of *G. parvulum* revealed the existence of what he termed "small tribes," signifying reproductively isolated sectors, and thus, separate species (Geitler, 1932; 1972). Many strains studied by Geitler were morphologically similar, yet their gametes failed to produce offspring probably due to the existence of unidentified reproductive barriers. Geitler also observed that there were differences in the reproductive behavior of these cryptic species. Such differences involved the orientation of the mother cells at the time of copulation, the way the cytoplasm of the mother cells divided to give raise to gametes, and the way the fertilization of gametes took place (Geitler, 1932).

Despite the existence of the evidence presented above, taxonomists took a "lumper" approach to the treatment of *G. parvulum* and morphologically related taxa. Since most of these taxonomic decisions were often presented in widely used regional and continental floras, the lumper view became easily accepted. For example, Wallace and Patrick (1950) concluded that morphs observed in North American samples belonged to a single morphologically variable taxon. The same authors then reduced to synonymy (under the name *G. parvulum*), a great number of varieties found in the literature at that time. Patrick and Reimer (1975) continued with this tradition and their highly influential "Diatoms of the United States" became deeply rooted in the taxonomy of *G. parvulum* in the Americas.

But the lumper approach was not only a characteristic of North American diatomology, European investigators also followed this path. Lange-Bertalot (in Krammer and Lange-Bertalot [1986]) presented a series of morphs under *G. parvulum*, which led to the publication of a number of subsequent ecological and taxonomic papers in which this taxon is treated as highly variable (Cumming et al., 1995; Fallu, et al., 2000; Reavie and Smol, 1998, and many others).

Taxonomists have proposed an alternative view to the taxonomy of *G. parvulum* only recently and based on morphological features of the vegetative cell wall at the light microscopy (LM) and scanning electron microscopy (SEM) levels. Krammer and Lange-Bertalot (1991) and Reichardt (1999), who have concentrated on the examination of larger number of samples and widely distributed populations, champion this new trend. The result has been a return to the use of many "old" names from the literature and the description of new species and varieties. Unfortunately, this splitter approach is primarily based on the characteristics of vegetative cells and no attention has been paid to reproductive data presented by Geitler. Therefore, more changes are expected in the near future.

As far as ecological assessments is concerned, the splitter approach represents a more convenient way to express changes in water conditions. This is because lumping could lead to a reduced usefulness of diatoms as indicators (Morales et al., 2001). Diatom data presented in this Appendix have been collected following the splitter approach. Splitting was possible due to the existence of numerous auxospores and initial valves (the product of sexual reproduction) in Savannah River samples, which provided a rare opportunity to investigate the boundaries of each of the morphs. Hence, the present study represents a step forward in solving the taxonomy of *G. parvulum* using not only the morphological, but also the biological species concept.

Description of Methodology

Counts were done using a compound microscope equipped with DIC at a magnification of 1000X. Some variations in size, valve outline, striation patterns, and morphological characteristics of the initial valves where identified at this level and counts were performed keeping what seemed to be distinct groups separate from each other. Many of these groups where not found in the literature, thus they had to be assigned to "unknown" categories designated as "sp.", "cf." or "aff." following methodology outlined in Morales (2001b). Many digital images of each of the categories were taken to illustrate and support determinations and to ensure that the same category was recognized across all samples.

During LM analyses samples containing high abundance of the different taxa were selected for SEM analyses. Samples for SEM were prepared following methodology outlined in Morales (2001a). Many digital images were also collected using SEM so a cross examination of the different taxa by comparison of LM and SEM data was possible. This cross examination resulted in better characterization of the different taxa and better identification of auxospores. It was then possible to go back to the original LM counts and make some adjustments in the proportions of the taxa found in the samples.

LM and SEM plates presented in this Appendix are based on samples collected in the years 2000 and 2001.

Observations

The gomphonemoid community present in Savannah samples is very diverse. Only 17 taxa had been reported in year 2000 samples using a lumper approach. On the other hand, 26 taxa were identified in 2001 samples using the splitter approach. This latter number represents ca. 10 % of the total number of diatom species (260 taxa) found in 2001 samples. The following table depicts taxa reported in 2001 analyses that do not appear in previous Savannah River records, and the equivalents reported in counts prior to 2001:

* different portions of the total range of variation of these taxa may have been assigned different names.

Name of Taxon in Counts Prior to 2001	Name of Taxon in 2001 Counts
Gomphonema affine	*Gomphonema sp.* 11 *SA VANNA* H *EA* M *pro parte* * *Gomphonema sp.* 13 *SA VANNA* H *EA* M *Gomphonema sp.* 15 *SA VANNA* H *EA* M *Gomphonema sp.* 16 *SA VANNA* H *EA* M
Gomphonema angustatum	*Gomphonema sp.* 9 *NA* W*QA EA* M
Gomphonema grunowii	*Gomphonema sp.* 17 *SA VANNA* H *EA* M *pro parte* * *Gomphonema sp.* 1 *A NS SA VA NNA* H *EA* M *Gomphonema sp.* 11 *SA VANNA* H *EA* M *pro parte* *
Gomphonema parvulum	*Gomphonema aquamineralis* *Gomphonema lagenula* *Gomphonema micropus pro parte* * *Gomphonema parvulum sensu stricto* *Gomphonema parvulum var. parvulum* f. *saprophilum* *Gomphonema parvulum var. parvulius* *Gomphonema sp.* 2 *A NS SA VA NNA* H *EA* M *Gomphonema sp.* 11 *SA VANNA* H *EA* M *pro parte* * *Gomphonema sp.* 12 *SA VANNA* H *EA* M *Gomphonema sp.* 14 *SA VANNA* H *EA* M

As seen in the previous table, of all the gomphonemoid diatoms found in the 2001 samples, the *G. parvulum* group is the most diverse and complex. This is precisely the group that was the most difficult to identify during routine counts for that year. Some of the morphotypes lumped under *G. parvulum* in counts prior to 2001 were not found in the literature and have been assigned temporary names in 2001 counts (e.g. *Gomphonema* sp. 11 SAVANNAH EAM). Some of these taxa may represent new species to science and will require formal description.

All unknown gomphonemoid taxa reported in 2000 and 2001 samples (including those that are not part of the *G. parvulum* group) are informally described in this Appendix and illustrated together with the rest of gomphonemoid taxa present in 2000 and 2001 samples. Many of the known taxa presented in these plates do not require mention of additional details because their identification can be easily complemented by use of specialized literature (Krammer and Lange-Bertalot, 1991; Reichardt, 1999).

Gomphonema aff. *angustatum* ANS SAVANNAH EAM (Plate 5, Fig. 37).

This taxon is rare and co-occurs with *G.* sp. 17 SAVANNAH EAM (Plate 7, Figs. 17-43), suggesting that it might correspond to a teratological form of this latter taxon or a stage immediately after auxospore formation. In general, the width of this taxon is narrower than *G.* sp. 17 SAVANNAH EAM and the striae are much more spaced (resembling slender forms of *G. angustatum* -Reichardt [1999]). The head and foot poles are much more acute than in *G.* sp. 17 SAVANNAH EAM and *G. angustatum*.

Gomphonema aff. *subclavatum* ANS NAWQA EAM (Plate 3, Fig. 1).

This taxon is much smaller than *G. subclavatum* (Plate 3, Figs. 2-14), but its outline is very similar. The head pole is broadly rounded, and the foot pole narrowly rounded. The striae vary from slightly radial at the central area to parallel toward the poles. The axial area is lanceolate and a distinct stigma can be seen situated near the terminations of the raphe at the central area.

Gomphonema aquamineralis (Plate 5, Fig. 29).

The range of distribution of this taxon in North America is unknown due to the fact that there are very few records from samples collected in this continent. In Savannah River studies prior to the analysis of 2001 samples, this taxon was lumped with *G. parvulum* (Plate 10, Figs. 1-8). However, the head pole is substantially different in both taxa. *G. aquamineralis* has a broadly rounded to rostrate head pole. In contrast *G. parvulum* has a rostrate and more acute head pole. Central area and spacing of striae are similar in both taxa.

Gomphonema cf. *coronatum* EAM Ehrenberg (Plate 3, Fig. 15).

This taxon resembles *G. coronatum* (Reichardt, 1999) but the head pole is broadly rounded instead of apiculate. Additionally, the striae are strongly radial at the central area becoming parallel toward the poles.

Gomphonema lagenula (Plate 7, Figs. 1-16, Plate 8, Figs. 1-6).

Specimens found in Savannah River samples resemble those found in the literature (Krammer and Lange-Bertalot, 1991). The initial valves of this taxon were difficult to identify, but the process was facilitated by the presence of at least one mother valve, which in many cases remains attached to the auxospore (Plate 13, Fig. 1).

Gomphonema parvulum (Plate 10, Figs. 1-8, Plate 11, Figs. 1-6).

The restricted concept of this taxon as presented in Reichardt (1999) is being followed for the analysis of Savannah River samples. Apices of cells are rostrate, with the foot pole being narrower than the head pole. The striae are mostly parallel, although they can be slightly radiate from the central area to the foot pole. The central area is reduced and slightly asymmetrical due to the presence of a shorter stria on the side opposite to the stigma. The initial valve of this taxon were also difficult to recognize. Their shape is somewhat rhomboid with blunt apices and in many cases mother valves are still attached (Plate 13, Fig. 2).

Gomphonema parvulum var. *parvulius* (Plate 5, Figs. 30-32).

This taxon fits description and illustrations presented by Krammer and Lange-Bertalot (1991). Specimens in Savannah material are much slender and the apices are more acute than in the nominate variety. Additionally, the striae are much more separated than in *G. parvulum*.

Gomphonema parvulum var. *parvulum* f. *saprophilum* (Plate 5, Fig. 16-25).

Although with some minor variations, this taxon follows the description in Krammer and Lange-Bertalot (1991) and Lange-Bertalot (1993). The main characteristic of this taxon is its rhomboid outline and blunt rostrate head poles. The foot poles are much more acute, but are also rostrate. The striae are more coarse than in *G. parvulum* and are curved around the central area. In smaller specimens, the striae become somewhat radial. The central area has similar characteristics to that in *G. parvulum*.

Gomphonema sp. 1 ANS SAVANNAH EAM (Plate 5, Figs. 33-36).

This taxon resembles *G.* sp. 17 SAVANNAH EAM very closely. However, the latter tends to be slightly wider. Additionally *G.* sp. 1 ANS SAVANNAH EAM has a more acute foot pole and the central area seems to have a depression, as evidenced by dark areas in Figs. 33-36. The stria opposite to the stigma is very reduced and in most specimens can not be seen.

Gomphonema sp. 2 ANS SAVANNAH EAM (Plate 5, Fig. 38).

This taxon is extremely rare and has been observed only once. It might represent a teratological form or an initial valve of *G. lagenula*. The apices are slightly capitate, the foot pole being slender. The striae are dense and radiate. The central area is acute angled.

Gomphonema sp. 9 NAWQA EAM (Plate 10, Figs. 38-43).

This taxon may have been identified as *G. angustatum* var. *sarcophagus* in previous counts of Savannah River material. However, the striae in *G.* sp. 9 NAWQA EAM are much more dense and the valves are wider. Krammer and Lange-Bertalot (1991) present a series of forms that have dense and coarse striae arrangements under *G. sarcophagus* (=*G. angustatum* var. *sarcophagus*). However, the striae density in the Savannah River specimens seems to be more uniform throughout the population. The apices of the valves are broadly rostrate, the foot pole being slender than the head pole. The striae are slightly curved around the central area and the stria opposite to the stigma is shortened, resulting in a displacement of the central area.

It is possible that this taxon is conspecific with the recently described *G. americobtusatum* (Reichardt, 1999). More detailed analysis are necessary to clarify this relationship.

Gomphonema sp. 11 SAVANNAH EAM (Plate 1, Figs. 1-20, Plate 2, Figs. 1-6).

The valves of this taxon are long and lanceolate and can be easily distinguished from other taxa. It is possible that smaller forms of this taxon might have been confused with *G. gracile* in previous Savannah River samples. However, the valves of the latter are much slender. Both apices are narrow and slightly subrostrate. The striae vary from parallel to slightly radiate. The central area is reduced and displaced to one side of the valve due to the presence of a shortened stria on the side opposite to the stigma. The initial valves of this taxon are long and with one pointed end and a large inflated central region (Plate 13, Fig. 5).

Gomphonema sp. 12 SAVANNAH EAM (Plate 10, Figs. 9-11).

The valves of this taxon are small. The shape of the valve is clavate, with broadly rounded apices, the foot pole being more acute than the head pole. The striae vary from slightly radiate at the central area to parallel toward the poles. The central area is displaced to one side of the valve due to the presence of a shortened stria opposite to the stigma. The latter structure is faint and can not be seen in some specimens.

Gomphonema sp. 13 SAVANNAH EAM (Plate 10, Figs. 24-37, Plate 12, Figs. 1-6).

This taxon is also very distinctive. It can be immediately characterized by the coarseness of the valves and the striation pattern. Valves are clavate with the head pole varying from broadly rounded to subrostrate. The foot pole is much narrower and also subrostrate. The striae vary from parallel to slightly radiate (toward the poles). The central area is reduced and there is a short stria located opposite to the stigma. The initial valves of this taxon are conspicuously inflated, which facilitates their recognition (Plate 13, Fig. 6).

Gomphonema sp. 14 SAVANNAH EAM (Plate 5, Figs. 1-15; Plate 6, Figs. 1-6).

This taxon may have been lumped together with *G. parvulum*. However, complete series were found in Savannah River 2001 samples. The apices of the valves are acute and subrostrate becoming more broadly rounded in smaller representatives. The foot pole is slender than the head pole. The striae vary from radiate at the central area to parallel toward the ends. The central area is reduced and displaced to one side due to the presence of a shortened stria opposite to the stigma. The initial valves of this taxon (Plate 13, Fig. 3) have a distinctive rhomboid shape.

Gomphonema sp. 15 SAVANNAH EAM (Plate 1, Figs. 21-27).

This taxon has a clavate shape with short and blunt rostrate head poles and a slender, more acute foot pole. The striae vary from parallel at the central area to curved at the poles. The central area is very reduced and slightly displaced to one side of the valve due to a shortened stria on the side opposite to the stigma.

Gomphonema sp. 16 SAVANNAH EAM (Plate 1, Figs. 28-33).

This taxon is comparatively smaller than *G.* spp. 11 and 15. The shape of the valves is clavate with the head pole being short and subrostrate and the foot pole being more acute. The striae are mostly parallel, although some specimens may

bear slightly radial striae toward of the apices. The central are is reduced and displaced to the opposite side of the stigma, where a short stria lies.

Gomphonema sp. 17 SAVANNAH EAM (Plate 7, Figs. 17-43; Plate 8, Figs. 1-6).

Specimens in the Savannah River samples have acute ends which tend to become rostrate in smaller specimens. The striae are coarse (as compared to *G. parvulum*, for example). The central area is reduced and shifted to the side opposite to the stigma due to the presence of a shortened stria. Some smaller specimens might resemble *G. parvulum* var. *parvulius*, but the apical ends in the latter are much more acute. This taxon resembles G. sp 14 SAVANNAH EAM very much, but the striae in the latter taxon are much more dense. There are also ultrastructural differences in the shape of the areolae between these taxa (compare Plates 6 and 9). Spacing of the striae and characteristics of the areolae can also be used to separate the auxospores produced by these two taxa (compare Figs. 3 and 4 from Plate 13).

Some Transfers From and Within the Genus *Navicula*

The table on the next page shows the different taxa that have been split from *Navicula* and allocated in newly described genera. These new genera have been discussed herein or in Morales (2001c). Also, many changes have been done in the literature concerning the taxonomy of particular taxa within the genus *Navicula*. These changes resulted in a different species epithet instead of a transfer to other genera. Notice that only taxa not cited in Appendix A-2 (2000 Savannah River Biological Survey Report) are included in the table.

Planothidium spp.

The most important species in Savannah River material is *P. biporomum*, previously listed as *Achnanthes biporoma*, *Achnanthes lanceolata* var. *biporoma* and *Achnanthes lanceolata* subsp. *biporoma*. This taxon has rostrate ends and a clear hoof print structure at the central area. These are the two feature that distinguish this taxon from *Planothidium lanceolatum* (in which the hoof print is just a

Taxa Reported Prior to 2000	Taxa Reported in 2000 and 2001 Counts
Navicula agrestis	*Mayamaea agrestis*
Navicula aikenensis	*Geissleria aikenensis*
Navicula atomus	*Mayamaea atomus*
Navicula bryophila	*Adlafia bryophila*
Navicula capitata	*Hippodonta capitata*
Navicula capitata var. lueneburgensis	*Hippodonta lueneburgensis*
Navicula decussis	*Geissleria decussis*
Navicula goeppertiana	*Luticola goeppertiana*
Navicula ignota var. acceptata	*Geissleria acceptata*
Navicula menisculus var. grunowii	*Navicula antonii*
Navicula molestiformis	*Craticula molestiformis*
Navicula subtilissima	*Kobayasiella subtilissima, notice error in Appendix A-2, where N. subtillissima is transferred to Cyclostephanos tholiformis (this is actually a typo).*
Navicula tenera	*Fallacia tenera*
Navicula vandami	*Navicula canalis*
Navicula viridula var. linearis	*Navicula viridulacalcis*
Navicula viridula var. rostellata	*Navicula rostellata*

depression), and *Planothidium frequentissimum* (subrostrate or broadly rounded apices), which also occur in Savannah River samples. Another taxon within this genus is *Planothidium rostratum*, which has similar features than those of *P. biporomum*, but the apices are subcapitate and the valves are smaller. Finally, an additional taxon found in Savannah is *Planothidium granum*, which is similar to *P. rostratum*, but completely lacks the hoof print and has smaller valves.

All the taxa within this genus were previously reported as members of the genus *Achnanthes*. *P. biporomum*, *P. frequentissimum* and *P. rostratum* used to be considered as varieties within *Achnanthes lanceolata*.

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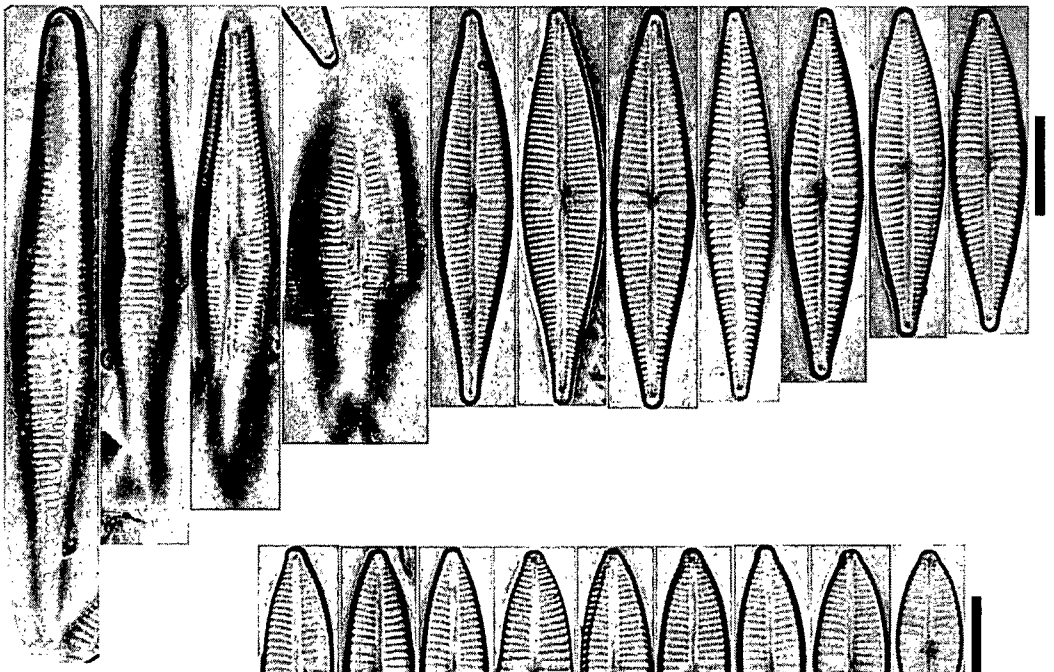
Plate 1

Figures 1-20. *Gomphonema* sp. 11 SAVANNAH EAM

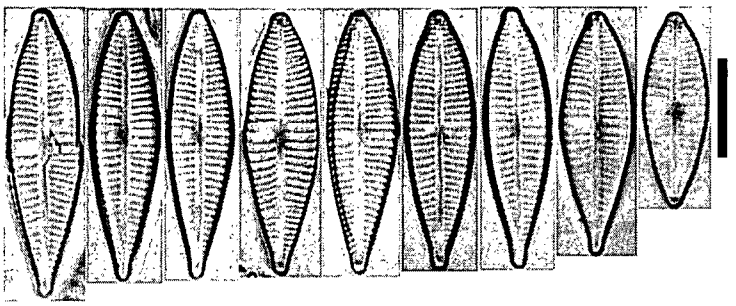
Figures 21-27. *Gomphonema* sp. 15 SAVANNAH EAM

Figures 28-33. *Gomphonema* sp. 16 SAVANNAH EAM

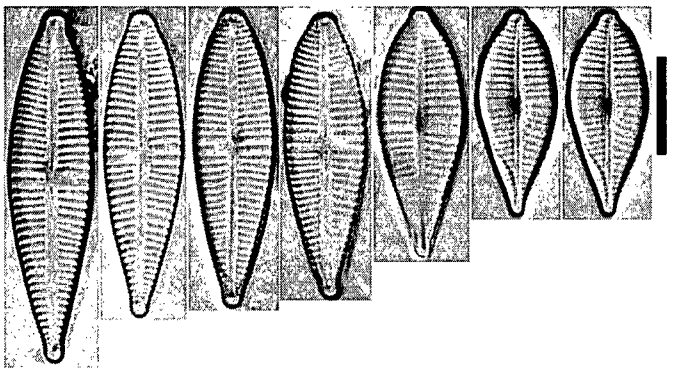
Scale bars: 10 μm.



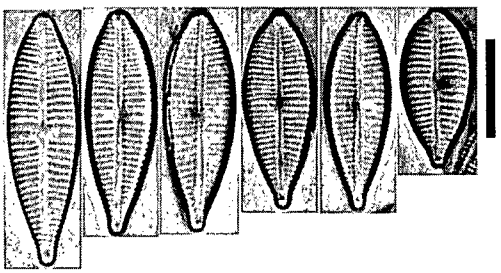
1-11



12-20



21-27

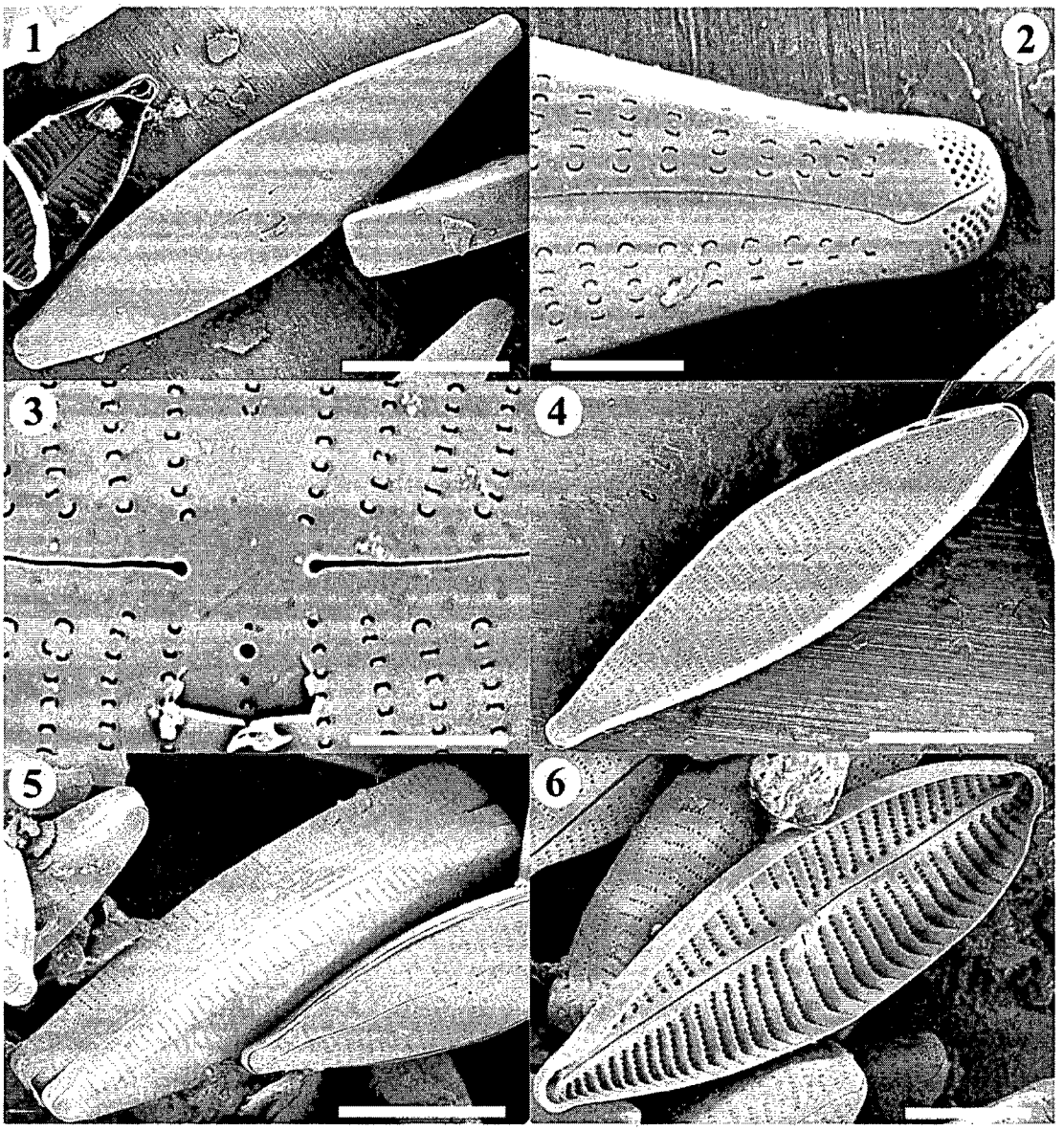


28-33

Plate 2

Figures 1-6. *Gomphonema* sp. 11 SAVANNAH EAM

Scale bars: Figs. 1, 4, and 5: 10 μm; Figs 2 and 3: 2 μm; Fig. 5: 5 μm.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6

Plate 3

Figure 1. *Gomphonema* aff. *subclavatum* ANS NAWQA EAM

Figures 2-14. *Gomphonema subclavatum*

Figure 15. *Gomphonema* cf. *coronatum* EAM Ehrenberg

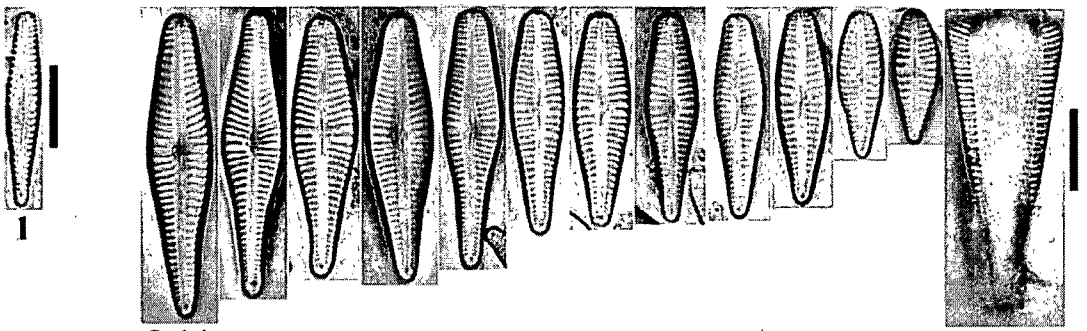
Figures 16-19. *Gomphonema truncatum*

Figures 20-22. *Gomphonema affine*

Figures 23-27. *Gomphonema turris*

Figures 28-30. *Gomphonema carolinense*

Scale bars : 10 μm.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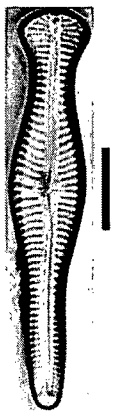
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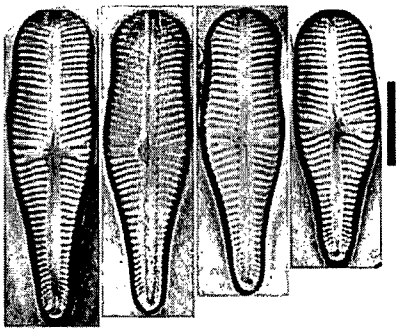
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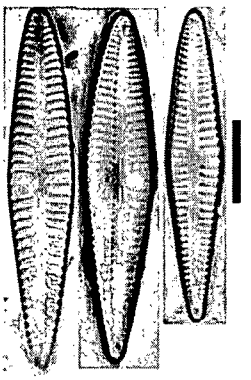
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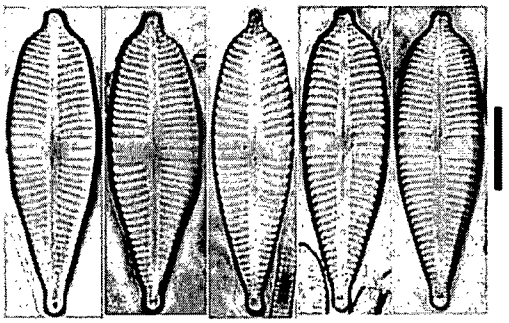
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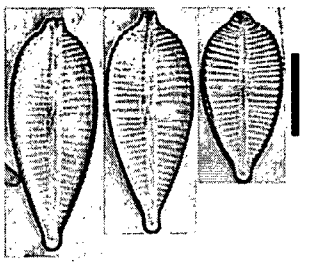
28-30

Plate 4

Figures 1-3. *Gomphonema turris*

Figure 4. *Gomphonema carolinense*

Figures 5-6. *Gomphonema subclavatum*

Scale bars : Fig. 1 : 10 μm ; Figs. 2, 3, and 5: 2 μm ; Figs. 4 and 6: 5 μm.

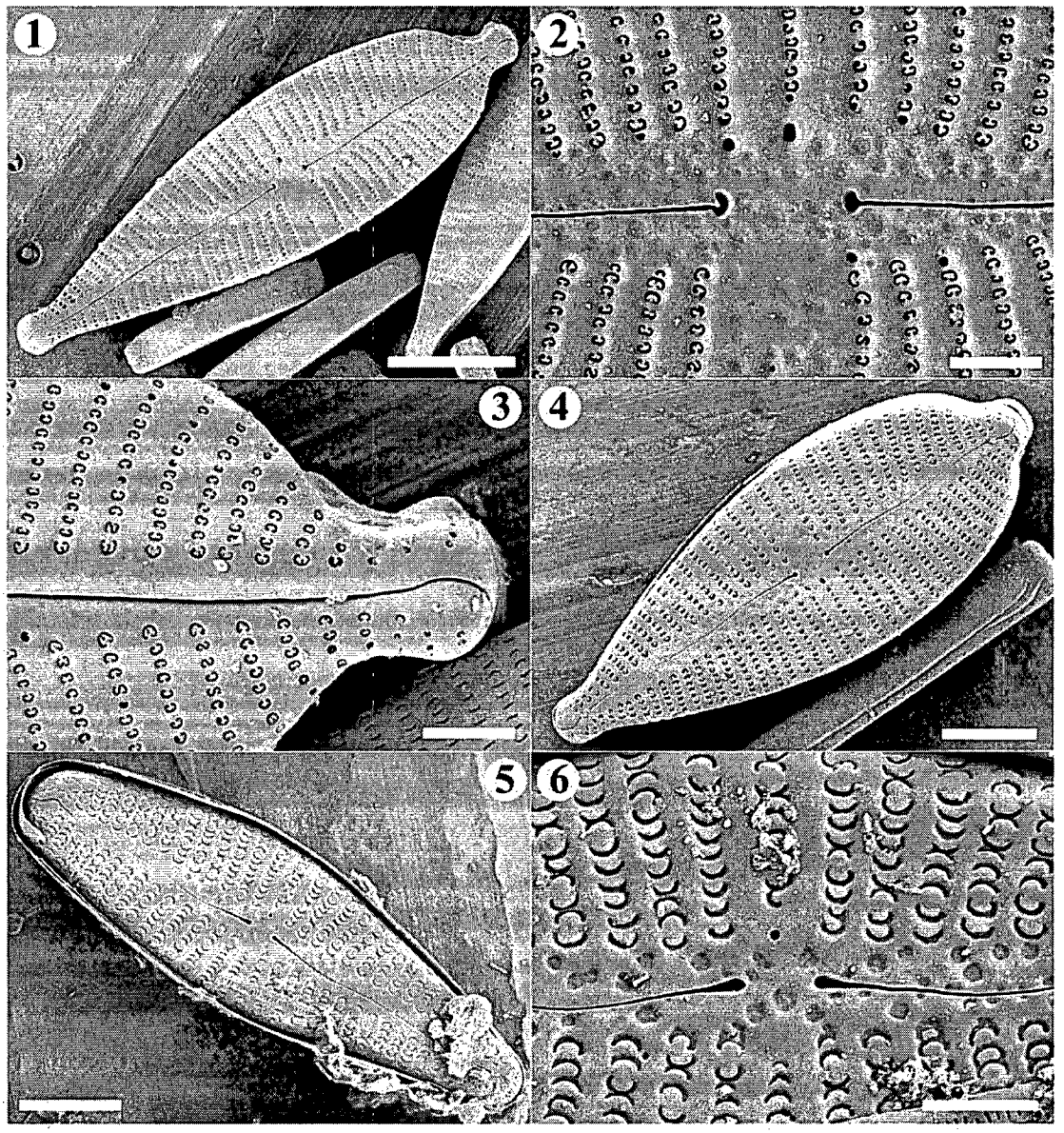
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Plate 5

Figures 1-15. *Gomphonema* sp 14 SAVANNAH EAM

Figures 16-25. *Gomphonema parvulum* var. *parvulum* f. *saprophilum*

Figures 26-28. *Gomphonema gracile*

Figure 29. *Gomphonema aquamineralis*

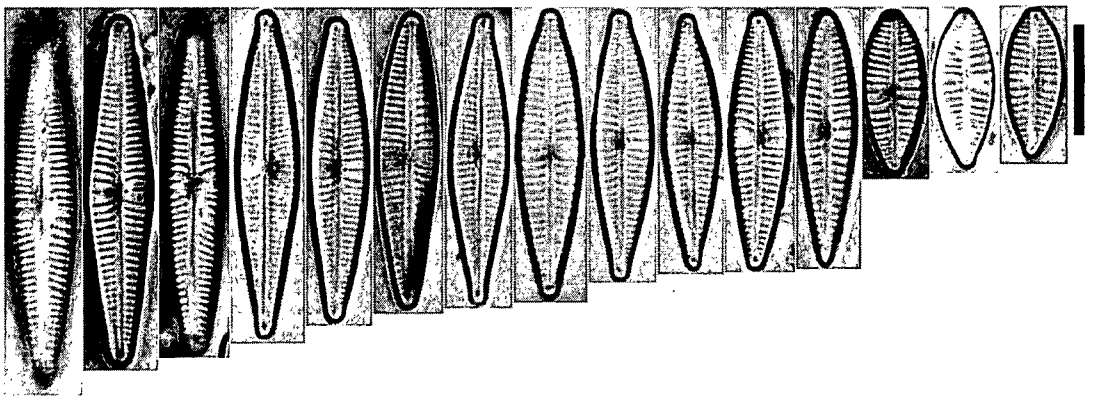
Figures 30-32. *Gomphonema parvulum* var. *parvulius*

Figures 33-36. *Gomphonema* sp. 1 ANS SAVANNAH EAM

Figure 37. *Gomphonema* aff. *angustatum* ANS SAVANNAH EAM

Figure 38. *Gomphonema* sp. 2 ANS SAVANNAH EAM

Scale bars : 10 μm



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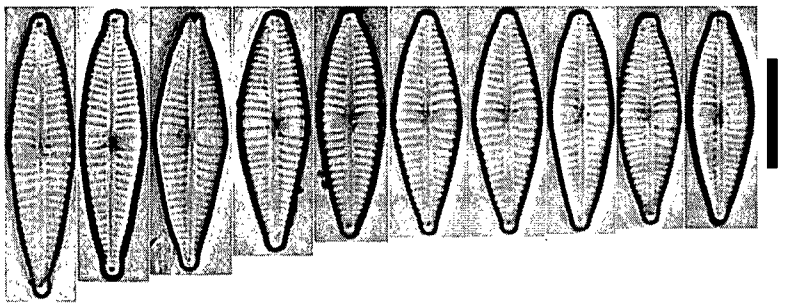

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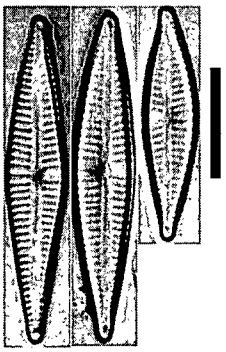

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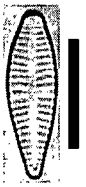

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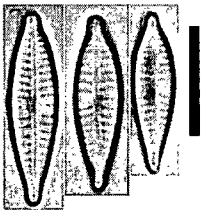

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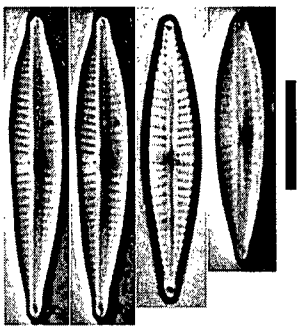

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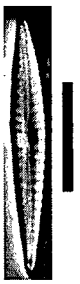

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Plate 6

Figures 1-6. *Gomphonema* sp. 14 SAVANNAH EAM

Scale bars: Figs. 1, 2, and 3: 5 μm; Figs. 3, 4, and 5: 2 μm.

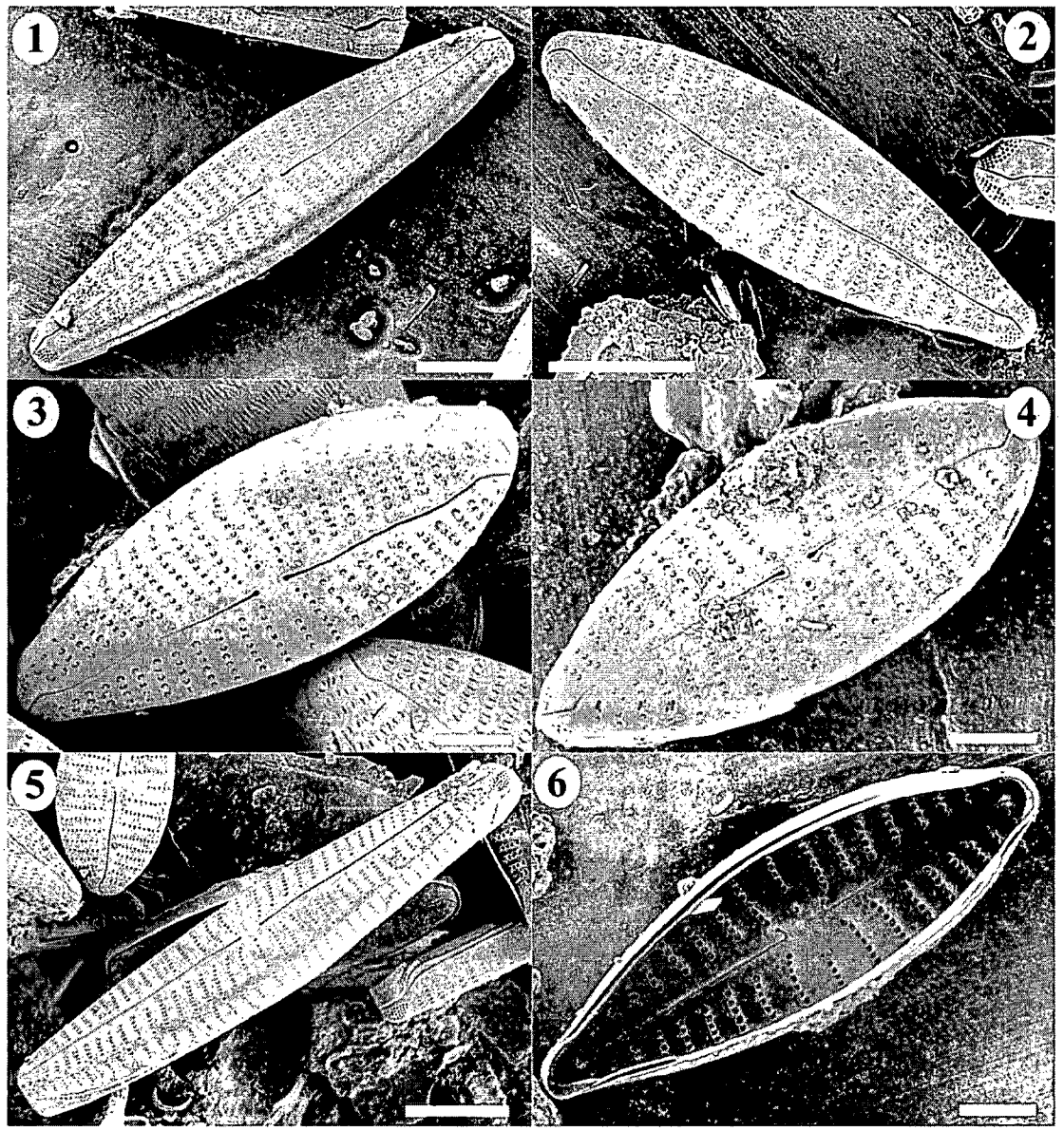
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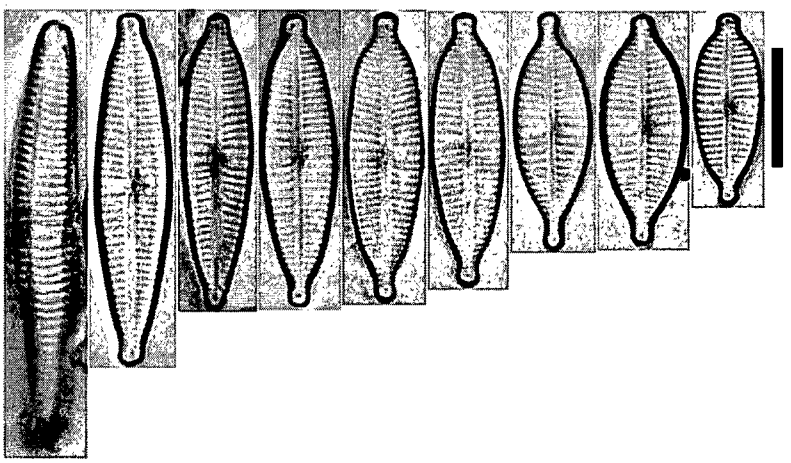
Plate 7

Figures 1-16. *Gomphonema lagenula*

Figures 17-43. *Gomphonema* sp. 17 SAVANNAH EAM

Scale bars: 10 μm



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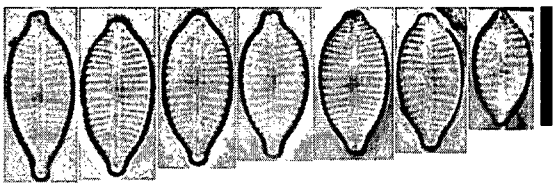

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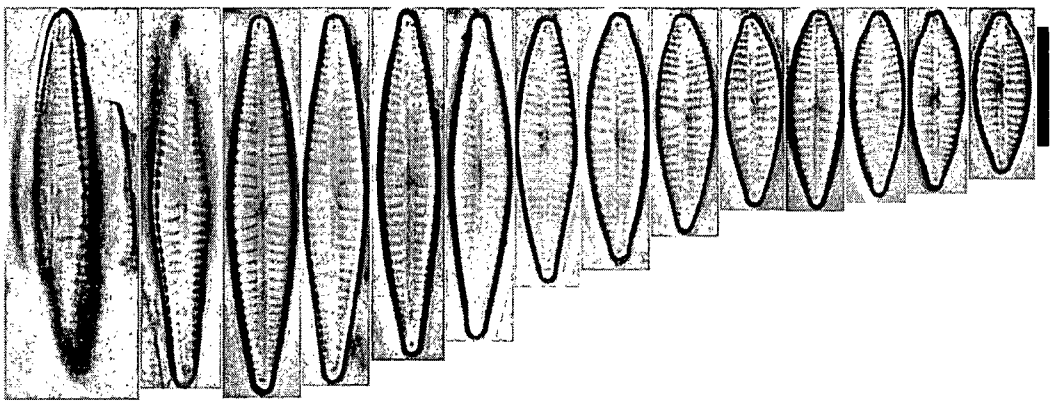

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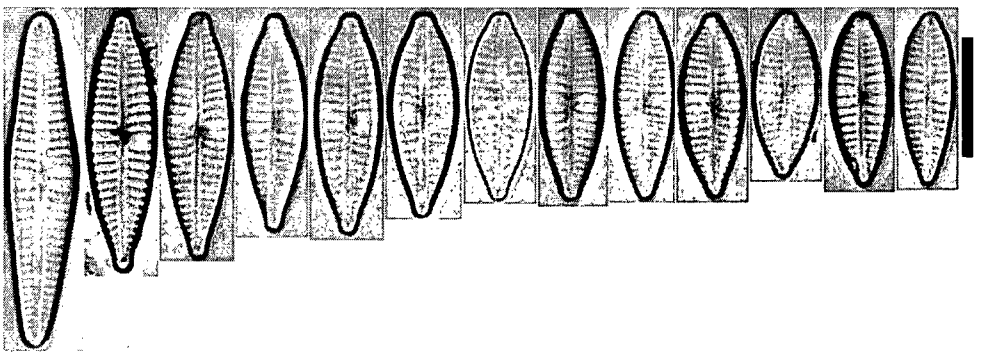

31-43

Plate 8

Figures 1-6. *Gomphonema lagenula*

Scale bars : Figs. 1, 2, 5, and 6 : 5 μm ; Figs. 3 and 4 : 2 μm.

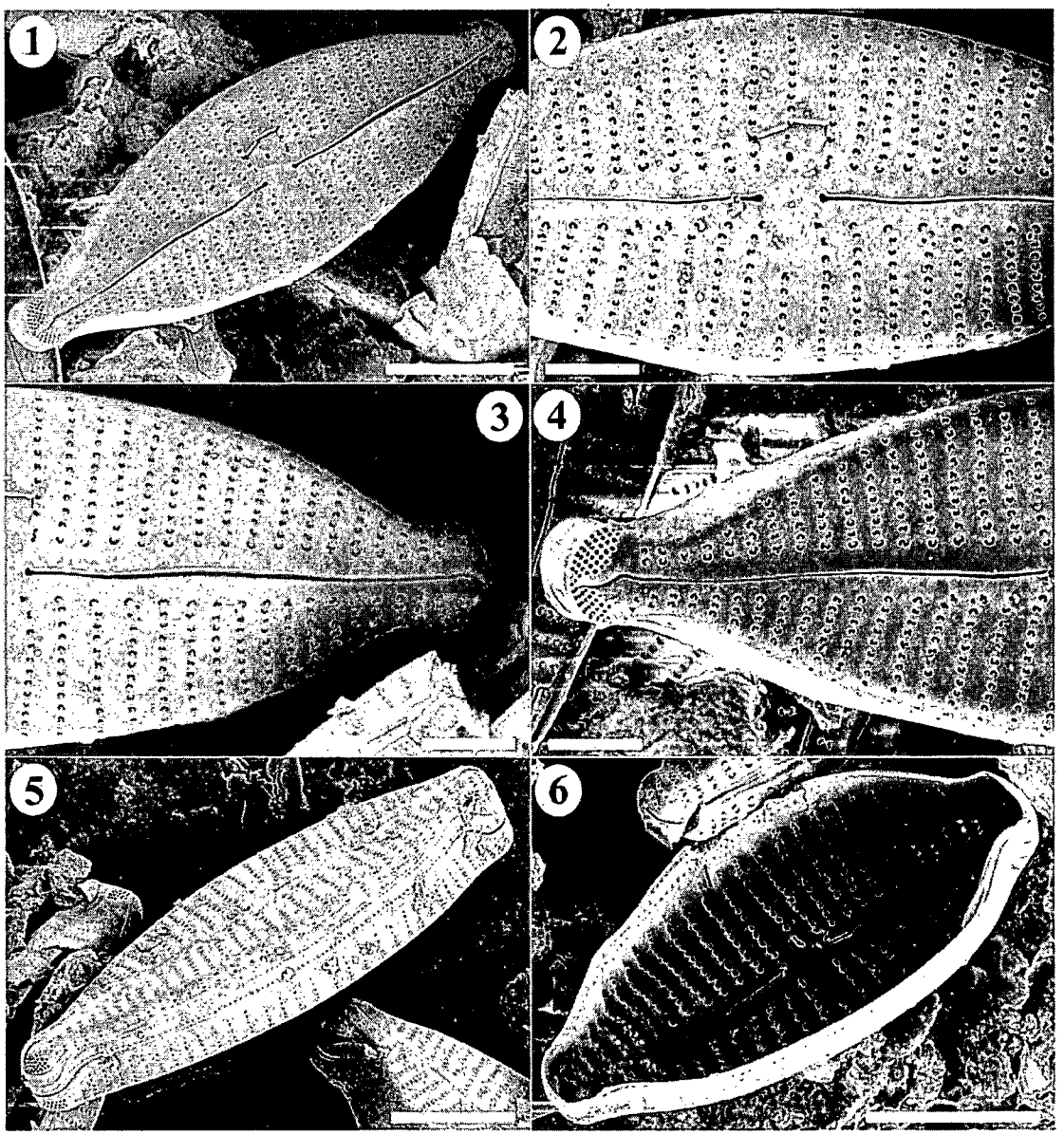
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Plate 9

Figures 1-6. *Gomphonema* sp. 17 SAVANNAH EAM

Scale bars: Figs. 1, 5, and 6: 5 μm; Figs 2-4: 2 μm.

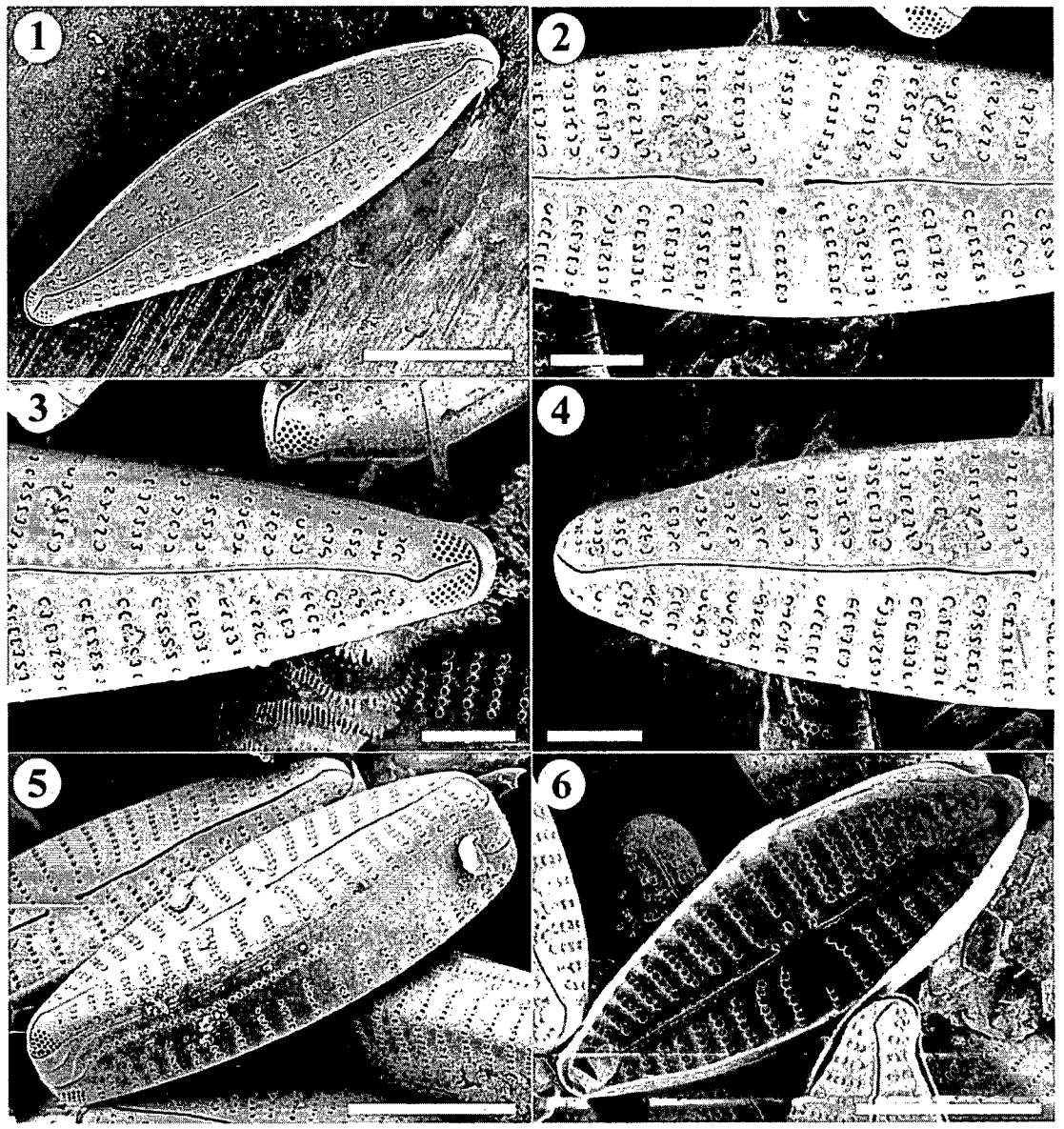
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Plate 10

Figures 1-8. *Gomphonema parvulum*

Figures 9-11. *Gomphonema* sp. 12 SAVANNAH EAM

Figure 12. *Gomphonema puggarianum* var. *aequatorialis*

Figures 13-23. *Gomphonema kobayasii*

Figures 24-37. *Gomphonema* sp. 13 SAVANNAH EAM

Figures 38-43. *Gomphonema* sp. 9 SAVANNAH EAM

Figures 44-45. *Gomphonema* sp. 13 SAVANNAH EAM (girdle views)

Scale bars: 10 μm.

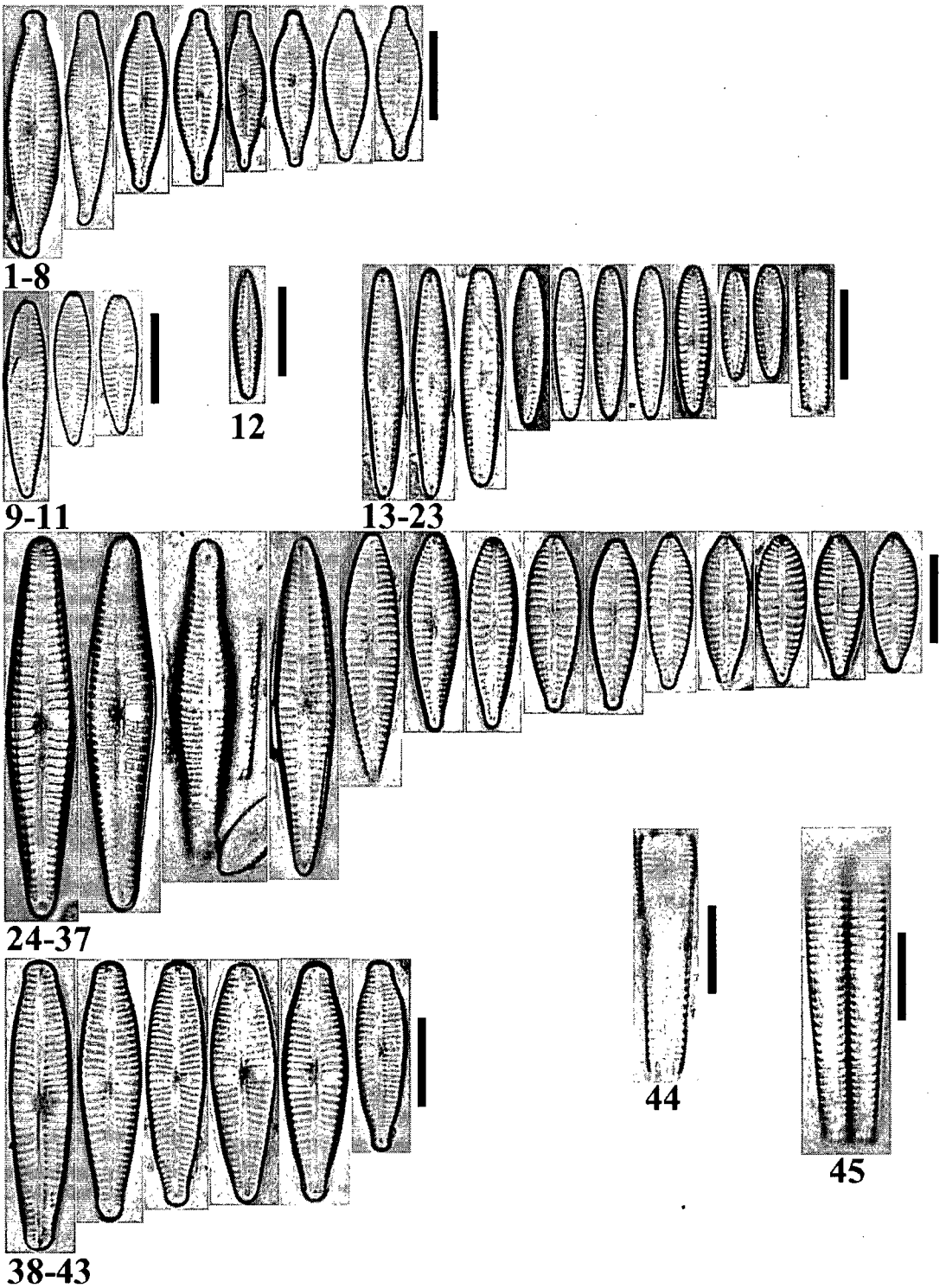
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Plate 11

Figures 1-6. *Gomphonema parvulum*

Scale bars: 5 μm.

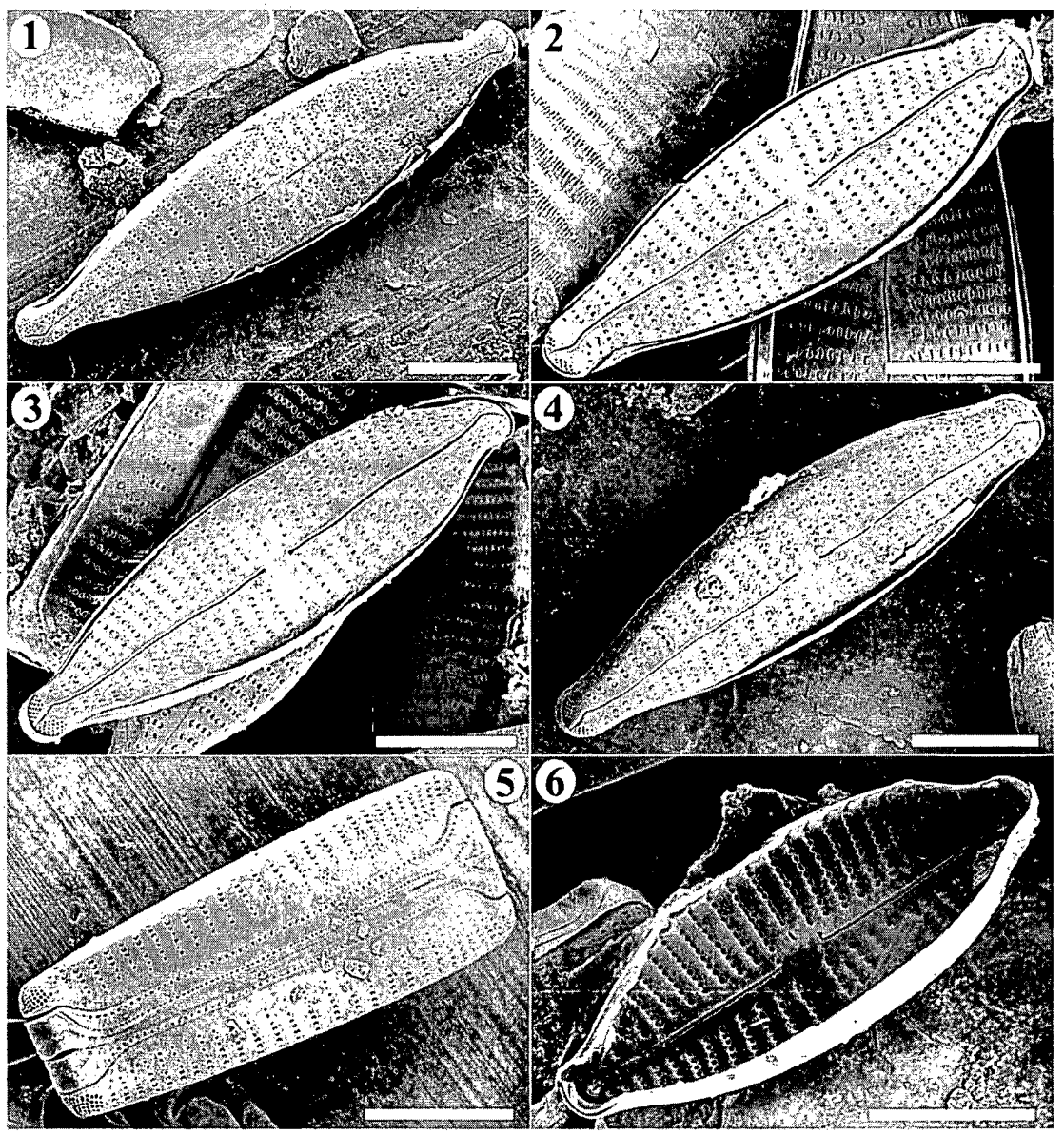
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Plate 12

Figures 1-6. *Gomphonema* sp. 13 SAVANNAH EAM

Scale bars: Figs. 1, 4, and 5: 10 μm. Fig. 2: 2 μm; Figs. 3 and 6: 5 μm.

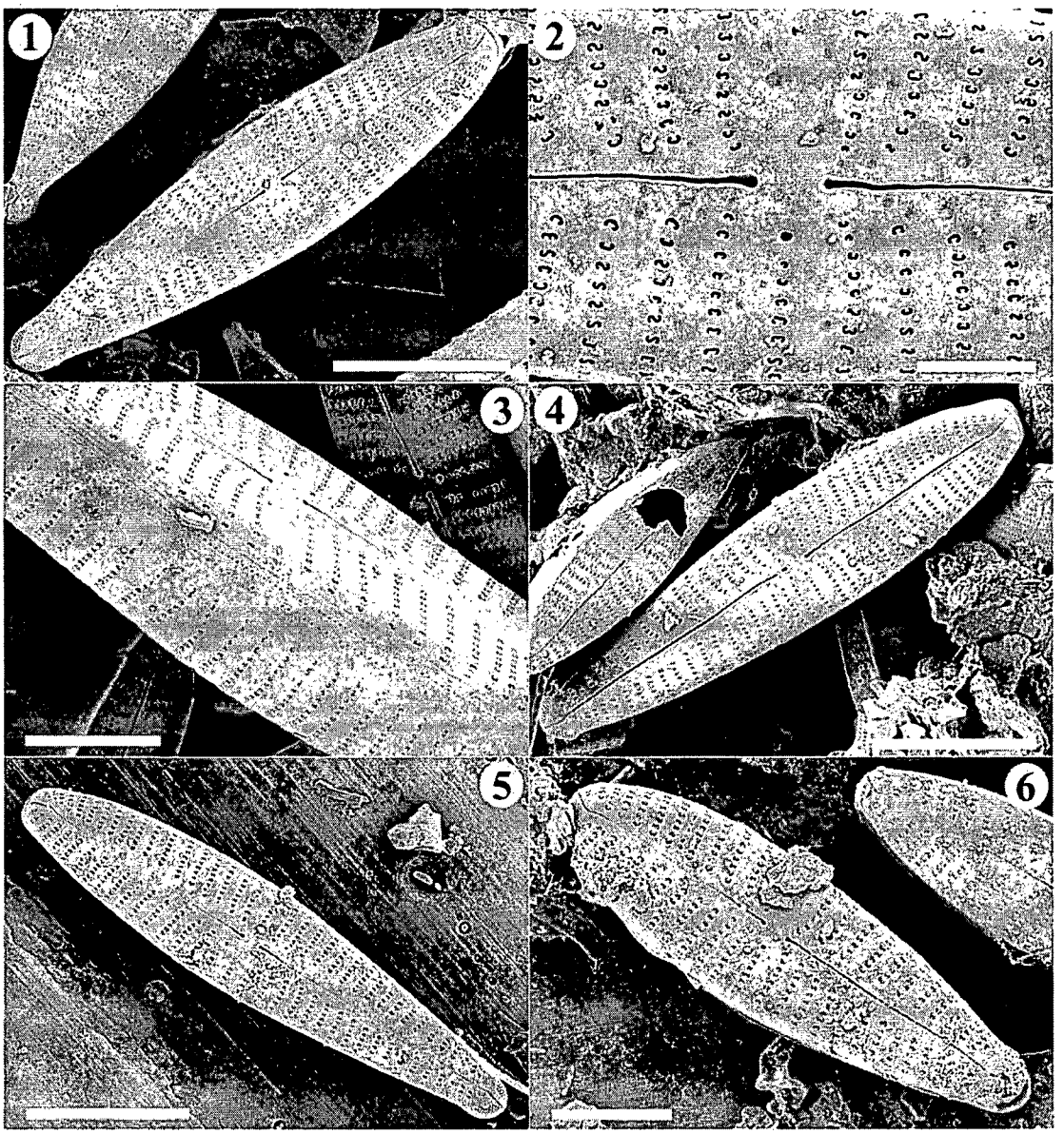
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Plate 13

Figure 1. *Gomphonema lagenula*

Figure 2. *Gomphonema parvulum*

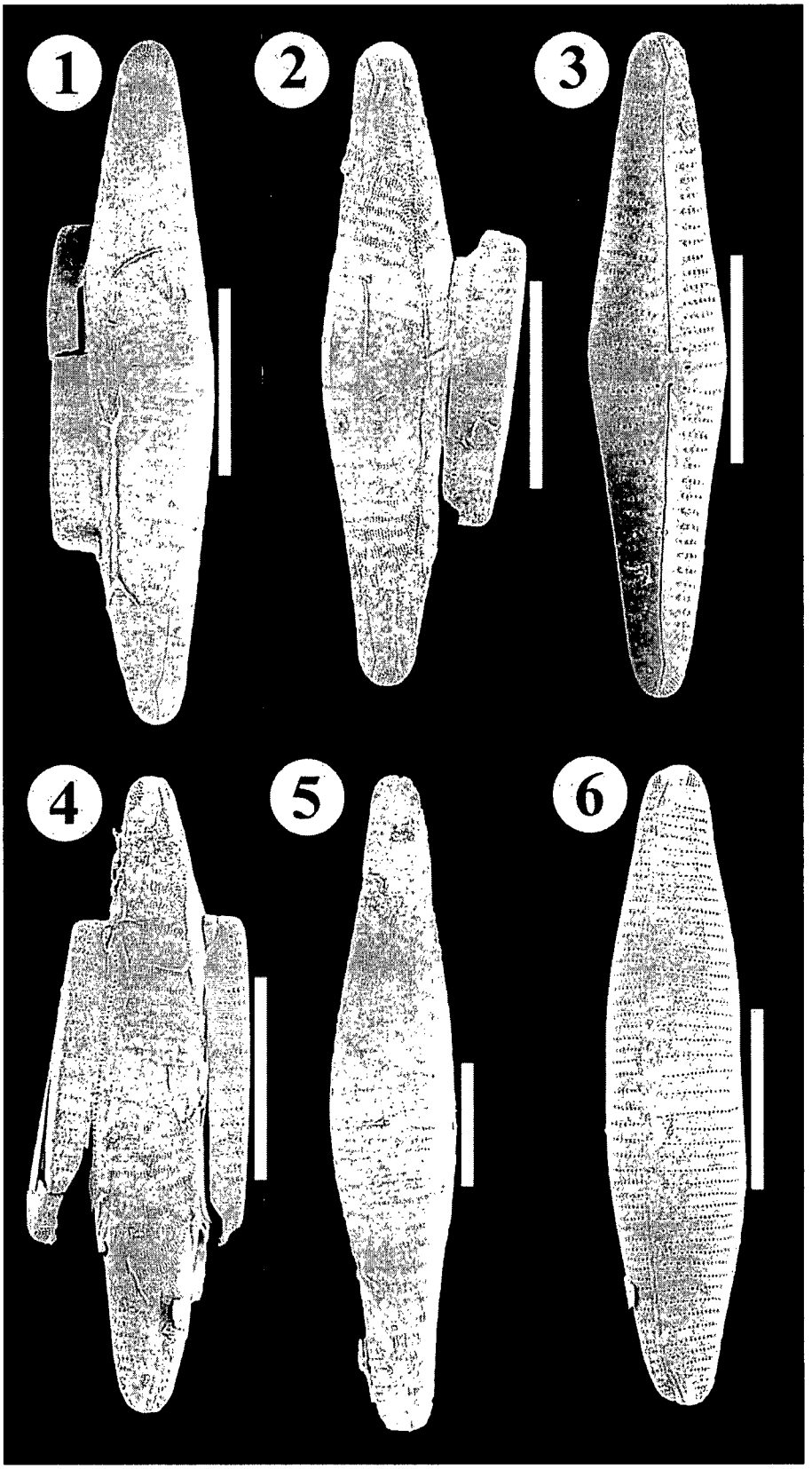
Figure 3. *Gomphonema* sp. 14 SAVANNAH EAM

Figure 4. *Gomphonema* sp. 17 SAVANNAH EAM

Figure 5. *Gomphonema* sp. 11 SAVANNAH EAM

Figure 6. *Gomphonema* sp. 13 SAVANNAH EAM

Scale bars: 10 μm.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B. NON-INSECT MACROINVERTEBRATES

Introduction

Non-insect macroinvertebrates are reliable indicators of water pollution because many species are sedentary and are sensitive to a wide range of ecological perturbations.

The Savannah River survey of non-insect macroinvertebrates was conducted on 24 to 27 August and 7 to 10 September 2001. The 24 to 27 August survey concentrated on mussel habitats to monitor the Savannah River populations of the most endangered invertebrate group in North America (Williams et al. 1993). These surveys were conducted in order to (1) compare an inventory of these organisms with earlier surveys for possible developing faunal trends, (2) relate the faunal characteristics and trends to such variables as habitat (e.g., relative aquatic vascular plant densities), river hydrodynamics and water quality changes as reflected by the sensitivities of the non-insect macroinvertebrates and (3) compare the faunas among stations upriver and downriver from the Savannah River Site. This report will also provide habitat and distribution information on the biota.

In 2001, non-insect macroinvertebrates were sampled at Stations 1, 2B, 5 and 6. However, with the exception of the mussels, only field data and specimens from Stations 1 and 6 were utilized for this report. The remaining samples and field notes are archived. This scope lies between the 2001 and 2003 non-insect macroinvertebrate programs. Comparisons with previous Savannah River surveys will be made in individual taxonomic sections, discussions in the section "Results," and via tables (B-1 and B-2). Individual taxonomic sections will include habitat comparisons for various taxa from Stations 1, 5 and 6 back to 1976 when less eutrophic conditions existed and Station 2B back to 1993. Eutrophic conditions prevailed in the Savannah River in 1972, and these data will be used for comparisons, where

Table B-1. Numbers of taxa collected by hand from the Savannah River at Stations 1 (1972 to 2001), 2B (1993 to 2000), 3 (1972 to 1989), 5 (1972 to 2000) and 6 (1972 to 2001) in August to October 1972, 1976, 1980, 1984, 1989, 1993, 1997, 1998, 1999, 2000 and 2001. Numbers for 1993 to 2001 (except Station 2B in 1993) include mussel studies.

	Stations				
Year	1	3/2B	5	6	Total
2001	27	-	-	22	34
2000	17	20	21	16	30
1999	29	25	23	29	37
1998	20	25	33	39	47
1997	32	37	38	37	49
1993	26	13	26	32	47
1989	21	16	14	17	27
1984	16	18	28	26	36
1980	16	9	20	23	33
1976	26	18	31	21	45
1972	37	30	34	47	60

Table B-2. Numbers of taxa in the dominant classes collected by hand from the Savannah River at Stations 1 (1972 to 2001), 2B (1993 to 2000), 5 (1972 to 2000) and 6 (1972 to 2001) in August to October. Species totals for 1993 to 2001 include mussel surveys. [Numbers in parenthesis (1989 to 1972) represent additional species from Station 3 [e.g., 6(1) =7 species at Stations 1, 3, 5 and 6 to permit four station comparisons 1972 to 2000].

			Clams/Mussels		
	Leeches	Snails	Bivalves	Crustaceans	Mites
2001	5	9	4/9	3	1
2000	4	5	4/8	4	1
1999	3	6	2/13	5	2
1998	4	7	7/13	7	1
1997	6	10	6/14	5	2
1993	4	8	5/13	6	2
1989	2(1)	7	4(1) /2	4	1
1984	2(1)	6(1)	3(1) /9	5	0
1980	2	7	5/9	5	1
1976	6	8	4/14	4(1)	2
1972	10	11	5/15	5	7

applicable. The tables will compare groups that historically have had the largest numbers of species and total taxa at each station. Four stations historically (1951 to 2000) have been examined along the study length of the Savannah River and are still retained herein (Tables B-1 and B-2) to compare with the two (most groups) to four (mussels) stations in 2001. These comparisons utilized Stations 1, 2B, 5 and 6 from 2000 through 1993 and Stations 1, 3, 5 and 6 from the

1989 through 1972 period. Data derived from the 1972 through 1993 surveys included only information from the late summer August or September months of these earlier bi-annual surveys. Contrasts of the mussel data will be across all Academy comprehensive Savannah River surveys (1951 through 2001) at all stations (1, 2B, 3, 5 and 6) and seasons (typically two in 1951 through 1993 and one in 1997 through 2001). Comparisons of data sets among years permits the best and most thorough understanding of the fauna, their distributions, and their habitats under various conditions, and it provides taxonomic consistency among the years.

Biological inventories are widely recognized as establishing necessary baseline data against which important comparisons with later investigations can be made to discern environmental changes. Traditionally, benthic non-insect macroinvertebrates have been chosen as reliable indicators of water pollution because many species exhibit sedentary habits, some taxa are long-lived with low reproductive rates, and others exhibit complex, easily interrupted reproductive life histories and different tolerances to stress. Together the group possesses phylogenetic, physiological, behavioral and ecological diversity with a sensitivity to a wide range of ecological perturbations. Alterations in community composition and population sizes reflect changes in the ecosystem. Consequently, studies of benthic macroinvertebrates are an important component of synoptic surveys that are designed for environmental impact assessment (e.g., Wilhm and Dorris 1968, Starrett 1971, Hynes 1972, 1974, Goodnight 1973, Hart and Fuller 1974, Whitton 1975, Taylor 1980, Downing and Rigler 1984, Krueger et al. 1988, Abel 1989, Root 1990, Rosenberg and Resh 1993, Loeb and Spacie 1994, Norris et al. 1995, Bournaud et al. 1996, Barbour et al. 1996, Karr and Chu 1998 and Rabeni et al. 1999, Brammer and MacDonald 2003).

Materials and Methods

The comprehensive non-insect macroinvertebrate study consisted of a survey of the mussel fauna on 24 to 27 August and the remaining groups on 7 to

10 September 2001. The non-insect macroinvertebrates were sampled at four stations (1, 2B, 5 and 6) on the Savannah River (see Location and Description of Stations). Approximately 5.5 to 6.5 hrs were spent at each station, including time to survey the area by foot or boat to identify accessible habitats that differ in substrate type, current velocity and water depth. Sampling was done in shallow water areas that could be accessed in waders. No attempt was made to sample any parasitic (e.g., leeches, crustaceans) or commensal (e.g., branchiobdellids, mite) species from their vertebrate or invertebrate hosts during the survey.

Because non-insect macroinvertebrates exhibit numerous morphologies and behaviors, they were sampled in a number of ways. Slow moving and sedentary forms usually were best collected by hand, with smaller species being more easily removed with small forceps from the substrate. In deeper water these animals were collected with a variety of dip nets. Soft-bottomed sandy, silty or muddy substrates were sampled with a Wildco bottom aquatic dip net (#425-A50) and a Wildco dip net (#484-D82) with a 3-mm (1/8-in) ace mesh. Harder, packed sand substrate areas in swifter currents were collected with the dip net placed perpendicular to the bottom and in front of the collector who disturbed the substrate with his feet while moving backwards upstream; any dislodged infauna were swept by the current into the dip net. More mobile animals were taken by dipnets which were swept through debris, leaf litter, aquatic vascular plants, flooded grasses and exposed root mats of riparian trees. Rip rap, woody deadfalls and debris trapped around pilings or in shallows along the shore were examined and organisms removed with forceps. The pilings themselves were also searched in the same manner for invertebrates.

The contents of the nets were rinsed in the river to remove sediment and then were placed in a shallow aluminum tray. In this manner even small animals were easily observed and removed. Common species were immediately identified, recorded and released. Some reference material and taxa which could not be identified with certainty in the field were preserved in 95% ethyl alcohol and taken to the Philadelphia laboratory for identification. Before storage in alcohol, highly contractile organisms such as planarians, leeches,

earthworms and tubificid worms were relaxed. They were passed through an intermediate step in 10% formalin solution and washed before storage in 80% alcohol. The habitat and relative abundance of all the taxa were noted and the macroinvertebrates later identified to the lowest practical taxon. Relative abundances were defined on the basis of the number of animals collected as rare (1 individual), uncommon (2 to 3), moderately common (4 to 15), common (16 to 30) and abundant (31 or more).

Mussels and their molluscan associates [Asian clams (*Corbicula fluminea*), sphaeriid clams and pointed campeloma snails (*Campeloma decisum*)] sharing the same habitat were collected quantitatively from areas delineated with a 1.0 m^2 quadrat. The perimeter of a sample area was delineated with flagged rebar at the 0.6 m depth. Study areas chosen in 2001 occurred immediately downriver from the downrivermost (=ultimate) set of pilings (Stations 2B and 6) and between the ultimate and penultimate sets of pilings(Stations 1 and 5). To encompass a variety of flows, substrates and depths, three transects were established roughly perpendicular to the shoreline. Along each transect, three quadrats were set at various depths (= nine quadrats). Based upon depth, substrate and flow, a tenth quadrat was selected in likely mussel habitat. This last quadrat was chosen to add more species and specimens to contribute mussel size distribution information. Sediments were scooped to a depth of approximately 19.5 cm (7.75 in) with a 2 L capacity polyethylene scoop and passed through a 30.5 OD X 8.89 D cm (12 X 3.5 in) sieve with a 2 mm (0.0787 in) mesh. The sediment within each quadrat was then searched by hand for animals that might occur deeper than the bite of the scoop. All bivalve molluscs pointed campeloma snails were counted and all mussels measured. Animals were returned to areas near where they were originally found. The common and scientific names of molluscs follows Turgeon, et al. (1998).

Results

In 2001, low water levels (mean river height of 1.5 and 1.4 ft on 24 to 27 August and 7 to 10 September 2001, respectively) were present during the mussel and comprehensive non-insect macroinvertebrate surveys. Water levels were so low that 2001 marked the second consecutive mussel survey in which the assistance of the U.S. Army Corps of Engineers was not needed to control water levels. The beds of submerged aquatic vascular plants absent from the study area since 1990 were still absent in 2001. Present, however, were scattered growths of alligator weed (*Alternanthera philoxeroides*) at Stations 1, 2B and 6, shade mudflower (*Micranthemum umbrosum*) at Stations 2B and 5, spikerush (*Eleocharis* species) and water pennywort (*Hydrocotyl ranunculoides*) at Station 6. The patches of aquatic vascular plants were more abundant than in previous post 1989 studies and provided habitat for a range of macroinvertebrates (see individual accounts below).

Sponges (Porifera)

An undetermined species of sponge was found to be moderately common on woody substrates and abundant on rip rap at Station 1 and moderately common on logs at Station 6. In the 2000 survey colonies of sponges were found at all stations. It was uncommon as Stations 5 (branch) and 6 (small log), moderately common [woody debris (e.g., logs and branches)] at Station 2B and common at Station 1 (woody debris). From the 1999 survey, colonies of this undetermined species of sponge were found to be moderately common on woody substrates at Stations 1 and 2B and rare at Station 6. In 1998, small colonies of sponge were abundant on rocky rip rap and a log and branch at Station 5, common on logs and roots at Station 6 and branches and logs at Station 1 and uncommon on a log at Station 2B. In 1997, large colonies of sponge were abundant on rocky rip rap and common on logs at Station 1. This taxon was found on roots and logs at the remaining stations where it was common at Station 2B and moderately common at Stations 5 and 6. In

1993, colonies of sponge were common on logs and were encrusting riparian roots at Station 1. Sponges were common at Station 2B as small colonies on logs and branches. This sponge was also found to be common on the left bank rip rap downriver from Wild Horse Slough (= Swift Gut) at Station 5. The observation of two large colonies on a small branch at Station 6 marks the first time this species had been sampled from this area [6UR (=upper reach) or 6LR (=lower reach)] (see Location and Description of Stations) since May 1972. In 1989, large colonies of sponge were common on rocks near shore along one of the pilings at Station 1 and this sponge was scattered on logs trapped by pilings at Station 5. Sponges were present in the 1980 (Station 1) and August 1976 (Station 1) studies. The Academy surveys reveal this sponge to generally be a widespread and common component of the Savannah River system in sheltered areas, and it is especially found wherever rocky substrata have been introduced.

Flatworms (Platyhelminthes)

The 2001 study found the flatworm *Girardia tigrina* to be uncommon both on willow roots and leaf litter at Station 1 and rare on water pennywort at Station 6. The 2000 survey found this same species of flatworm to be rare at Stations 1 (bark) and 6 (crawling on the outside of a plastic bottle)and moderately common at Station 5 (moderately common on woody debris). In 1999, this species was uncommon in muddy stick litter at Station 1 and on a log at Station 6. The 1998 survey found this same species of flatworm to be moderately common on a plastic cup at Station 1 and under the bark of a log at Station 5 and rare in water hyacinth, *Eichhornia crassipes*, roots and uncommon in willow roots at Station 6. In 1997, this planarian was found to be common on leaves and logs and among roots at Station 1, uncommon on leaf and stick liter at Station 2B, moderately common among roots and on loose bark and a branch at Station 5 and on alligator weed and willow roots at Station 6. Planarians were most often taken in 1993 from the surface of logs. On this habitat it was common at Station 2B, moderately common at Stations 1 and 6 and uncommon

at Station 5. The 1989 study found this species usually living among growths of aquatic vascular plants such as alligator weed, coon-tail (*Ceratophyllum demersum*) and waterweed (*Egeria densa*) at all stations. This flatworm was also collected at all stations during the 1984 survey, Stations 5 and 6 in 1980 and Stations 1, 5 and 6 in August 1976. This planarian has been and remains an uncommon to locally common part of the Savannah River fauna in the areas surveyed.

Roundworms (Nematoda)

As in recent surveys, no roundworms were taken in 2001. They occupy a wide range of habitats, and although they, along with ceratopogonid (biting midges) larvae, display a distinctive thrashing mode of locomotion in samples, they are often overlooked because of their small size. Roundworms were rare in collections of leaf litter at Station 1 in 1993. In 1989 these small worms were found in muddy to peaty sediments and among the root masses of aquatic vascular plants at Stations 1, 5 and 6. This group was collected from unnamed habitats in 1984 at Stations 5 and 6. No representatives of this group were recorded at Stations 1, 5 and 6 in 1980 or August 1976. Their poor representation in collections is probably a reflection of their small size.

Horsehair Worms (Nematomorpha)

No horsehair worms were found at Stations 1 and 6 in 2001, although field notes indicate an undetermined species was present in leaf litter at Station 5. An undetermined species of horsehair worm of the family Chordodidae was uncommon in 2000 at Station 2B in floating grasses. Horsehair worms were rare in 1999 at Stations 1 and 2B and uncommon at Station 5. The nematomorph at Station 2B was noted from open water, while those taken from Stations 1 and 5 were removed from root mats. Horsehair worms were rare in 1998 at Stations 1, 5 and 6. All

worms were taken from open water habitats either by dip net (Stations 1 and 5) or seine (Station 6 by the fisheries team). Single horsehair worms were collected from Stations 1 and 5 in 1997. The individual from Station 1 was collected by seine, while the horsehair worm at Station 5 was scooped up by hand while it was "swimming" in open water. A single animal was recorded in 1993 after it was found in a pile of small branches and leaf litter at Station 5. Not since May 1972, when a single horsehair worm was collected from undefined habitat at Station 1, had this group been represented in the Savannah River surveys. Nematomorphs are infrequently taken in aquatic surveys and less so in large rivers. The reason for their more widespread and/or rare to uncommon appearance in samples starting in the 1990s is unknown.

Moss Animals (Ectoprocta)

The branching ectoproct *Plumatella repens* occurs in the main stem of the river. A scant colony was found on rip rap at Station 1 and abundant colonies were noted on a log at Station 6. From a backwater at Station 5 in 2000, three small colonies of the gelatinous bryozoan *Plumatella magnifica* were observed on a section of old trot line. This is the first time this species has been noted from the Savannah River studies and is probably more a reflection of the quiet backwater habitat and low flows in 2000. Although no ectoprocts were observed in the 1999 investigation, in 1998 *P. repens* was moderately common on rocky rip rap and two sparse colonies were found on a branch at Station 5 and one meager colony was noted from a log at Station 1. *Plumatella repens* was uncommon on rocks at Station 5 and portions of a colony were found in a sample of riparian roots at Station 6 in 1997. In 1993, this species was found at only Station 5. Here two large colonies were noted from flat rocks at the rip rap bank downriver from Wild Horse Slough (= Swift Gut). This bryozoan was not found in 1989 but was taken from unspecified habitats at Stations 5 and 6 in 1984. A second bryozoan, *Pottsiella erecta* was recorded that same year from Station 6. In 1980, *P. repens* was tentatively identified from submerged wood at

Stations 1, 5 and 6. The bryozoan from the August 1976 investigation was tentatively identified as *P. emarginata*. It was found on "submerged vegetable trash" at all stations (ANSP 1977:40). *Plumatella repens* is generally rare to uncommon on hard substrates such as rip rap, finished board and logs in this portion of the Savannah River.

Segmented Worms (Annelida)

Annelids found free living in the Savannah River are represented by tubificids, earthworms and leeches. No tubificids were found at Stations 1 or 6 in 2001, although an undetermined tubificid was recorded from Station 5. In 1999, two species of tubificids were recorded. One was common in root mats and associated with logs at Station 1, while the second taxon was uncommon at Stations 2B and 5 and rare at Station 6. This latter species was found in muddy stick litter at Station 2B, root mats (rarely) and logs at Station 5 and from an undetermined habitat at Station 6. During the 1998 survey the tubificid *Branchiura sowerbyi* was moderately common in muddy detritus and fine muds at Station 5, while an undetermined species was common in detritus and fine muds at Station 5, common in muddy leaf litter and under the bark of logs at Station 2B and rare in root mats and muddy detritus at Stations 1 and 6, respectively. An undetermined species of tubificid was uncommon at Stations 2B, 5 and 6 and rare at Station 1 in 1997. Habitat at the various stations included root mats (Stations 2B and 6), leaf and stick litter (Station 2B), woody detritus (Station 1), a log (Station 5) and detritus (Station 5). They were poorly represented in the 1993 study. At this time they were rare under the bark of a floating tree trunk (Station 1) and in streamside root mats (Station 6). Tubificids were collected from 1989 to 1976 at the following stations: 1989 at Station 1, 1984 at Stations 5 and 6, 1980 at Station 1 and in August 1976 at Stations 1 and 5.

As in 2000, no aquatic earthworms were collected during the 2001 river survey. The earthworm, *Lumbriculus variegatus*, in 1999, was moderately common in root mats and associated with logs at Stations 1 and 6 and uncommon at Stations 2B (root mats and muddy stick litter) and 5 (root mats and

logs). In 1998, earthworms were moderately common under the bark of logs at Station 2B and rare in a sandy substrate, muddy detritus and muddy leaf litter at Stations 1, 5 and 6, respectively. This same species of earthworm was, in 1997, rare in a log and gallery within a branch at Stations 1 and 6, respectively, and in leaf and stick litter at Station 2B. This species was moderately common under the bark of a log at Station 5. In 1993, this taxon was poorly represented in terms of numbers and distribution. A single individual was found among a pile of branches at Station 5. No earthworms were found in 1989, and specimens were taken at Stations 1, 5 and 6 in 1984. Earthworms are widespread and generally uncommon in the study areas of the Savannah River.

During the low water survey of 2001 five species of leeches were (*Desserobdella phalera*, *Helobdella triserialis*, *Placobdella montifera*, *P. parasitica* and *Piscicolaria reducta*) were taken at Stations 1 and 6. *Desserobdella phalera*, a species found free living or parasitizing the bluegill, *Lepomis macrochirus* (Klemm 1985), was uncommon in willow roots at Station 1. *Helobdella triserialis* was uncommon (Station 1) to rare (Station 6) in leaf litter (Station 1) and on a log (Station 6). Two specimens of *Placobdella montifera* were collected at Station 6. During the mussel portion of the study, the smaller leech was found clamped between the valves of the eastern creekshell, *Villosa delumbis,* and the larger individual was found on the outside of the variable spike, *Elliptio icterina*. A single *P. parasitica,* typically a parasite of turtles (Klemm, 1985), was removed from a log at Station 6. This species was also found to be common on a large yellowbelly slider, *Trachemys scripta scripta,* captured at Station 5. A single *Piscicolaria reducta* was removed from leaf litter at Station 1.

In 2000, the leech fauna consisted of *D. phalera*, *H. triserialis*, *Placobdella papillifera* and an undetermined species of erpobdellid leech. A single *D. phalera* was collected from the shell of a living Savannah lilliput (*Toxolasma pullus*) taken at Station 6 during the mussel portion of the study. The leeches *Helobdella triserialis* and *P. papillifera* were rare at Stations 5 (paspalum grass) and 2B (seined by the fisheries team). The undetermined species of erpobdellid leech was found in flooded grasses at Station 5.

The 1999 leech fauna consisted of *H. triserialis*, *P. montifera* and *P. parasitica*. At Station 1 the leeches *H. triserialis* and *P. montifera* were rare. They were found in root mats and on a log, although the specific habitat for each species was not defined. *Helobdella triserialis* was also collected from root mats at Station 6. The leech *P. parasitica* was rare in a habitat consisting of root mats and leaf litter.

The leech fauna in 1998 consisted of *D. phalera*, *H. triserialis*, *P. papillifera* and *P. parasitica*. *Desserobdella phalera* was rare in leaf litter at Station 2B, while *H. triserialis* was rare in muddy leaf litter at Station 6. *Placobdella papillifera* and *P. parasitica* each occurred at two stations. *Placobdella papillifera* was uncommon on a branch and in leaf litter at Station 5 and rare in muddy leaf litter at Station 6. *Placobdella parasitica* was uncommon in leaf litter and on a log at Station 2B and one individual each was found in detritus and root mats at Station 5. In 1997, the leech fauna consisted of *D. phalera*, *H. triserialis*, *P. montifera, P. nuchalis, P. papillifera* and *P. parasitica*. *Desserobdella phalera* was rare on roots at Station 1, rare on the variable spike at Station 2B and uncommon in water pennywort and roots at Station 6. *Helobdella triserialis* was uncommon in an undetermined habitat at Station 1 and on the variable spike (*E. icterina*) and Carolina slabshell (*E. congaraea*) at Station 5 and rare on water pennywort at Station 6. *Placobdella montifera* was found on the variable spike and rayed pink fatmucket (*Lampsilis splendida*) at Station 2B and *P. nuchalis* in roots at Station 5. *Placobdella papillifera* was the most common species of leech in 1997. It was rare (log) at Station 1, moderately common at Station 2B (one on the eastern elliptio, *E. complanata*, and three in leaf and stick litter), rare at Station 5 (on the eastern creekshell) and rare on the Carolina slabshell at Station 6. *Placobdella parasitica* was present on undefined habitat at Station 2B and on a log at Station 5.

Leeches collected in September 1993 included *Mooreobdella melanostoma* (Station 6), *D. phalera* (Stations 2B and 6), *P. multilineata* (Station 6) and *P. parasitica* (Stations 5 and 6). Leeches were rare to uncommon in 1993. None of the species was represented by more than one or two individuals. The erpobdellid leech *M. melanostoma* was taken from root mats and the root tuft of a water hyacinth at Station 6. The

habitats for the remaining species included logs (*D. phalera*, *P. papillifera* and *P. parasitica*), root mats (*D. phalera*, *P. multilineata* and *P. parasitica*), mud (*P. papillifera*) and the surface of the Atlantic spike (*E. producta*).

Two species of leeches were found in September 1989 (*H. triserialis* and *P. parasitica*). Most specimens were collected from aquatic vascular plants, although one individual of *P. parasitica* was taken while swimming in open water. In 1984, two species of leeches were collected: *B. phalera* at Stations 5 and 6, and *P. parasitica* at Station 6. The 1980 survey produced two species of leeches: *B. phalera* at Stations 1 and 5 and *P. parasitica* at Station 5. In the August 1976 study six taxa of leeches were observed. *Desserobdella phalera* was found at the same stations as in the 1980 survey, *P. papillifera* at Station 5, *P. montifera* at Stations 5 and 6 and *Myzobdella lugubris*, an unidentified leech (sight record) and an unidentified erpobdellid leech at Station 1.

The five species of leeches in 2001 at only two stations is greater than all but the 1997 (6), 1976 (6) and 1972 (10) surveys. It is noteworthy that at least one other undetermined species of leech was present in unworked samples from Stations 2B and 5. The 6 species of leeches in 1997 and 1976 is decidedly lower than the 10 species collected in 1972. The differences among the surveys are due to water levels, extent and distribution of vegetation and collecting effort in other habitats during years when vegetation was less abundant. In general, the extent, density and distribution of submerged aquatic vascular vegetation has varied since 1972. These vegetated areas not only included stands in sheltered areas, but also patches of aquatic vasculars in the current. In 1972, when eutrophic conditions existed, dense stand of submerged aquatic vegetation existed in the Savannah River.

Molluscs (Mollusca)

Snails

In 2001, nine species of snails were noted at Stations 1 and 6 and included *Campeloma decisum* (pointed campeloma), *Amnicola limosus* (mud amnicola),

Pseudosuccinea columella (mimic lymnaea), *Physella heterostropha* (pewter physa), *Helisoma anceps* (two-ridge rams-horn), *Micromentetus dilatatus* (bugle sprite), *Ferrissia rivularis* (creeping ancylid), *Laevapex fuscus* (dusky ancylid) and *Novisuccinea ovalis* (oval ambersnail).

The pointed campeloma was abundant (Station 1) to moderately common (Station 6) in coarse to fine muddy sands. The mud amnicola was moderately common at Station 1 (moderately common in willow roots and uncommon in leal litter and spikerush). The mimic lymnaea was moderately common at Station 1, primarily on woody debris with two individuals taken from a leaf surface, and common on logs at Station 6. The pewter physa was found at both Stations 1 and 6, where it was common in leaf litter and willow roots and uncommon in spikerush at Station 1 and moderately common on logs and in flooded grasses at Station 6. At Station 1 was found a single two-ridge rams-horn in leaf litter and the bugle sprite, moderately common, in willow roots. Both ancylid snails found in the study area were collected only at Station 1. The creeping ancylid was uncommon in leaf litter while a single dusky ancylid was found on a stick. A single oval ambersnail was recorded from alligator weed at Station 1.

In 2000, five species of snails were taken and included the pointed campeloma, mimic lymnaea, pewter physa, creeping ancylid and oval ambersnail. The pointed campeloma was common in sand at Station 1 and moderately common at Stations 2B, 5 and 6 in sands and muds. The mimic lymnaea was common at Station 1, primarily on woody debris and pilings with an uncommon presence on alligator weed. This species was moderately common at Stations 2B, 5 and 6 in woody debris with an uncommon occurrence on a plastic bottle at Station 6. The pewter physa occurred in a range of abundances and habitats. It was moderately common at Stations 1 and 2B, common at Station 5 and abundant at Station 6. It occurred on woody debris, emergent and floating vascular plants (water hyacinth, shade mudflower and water pennywort), mud surfaces, undetermined flooded grasses and paspalum grass. The creeping ancylid was moderately common on plastic floats at Station 1 and uncommon on alligator weed stems at Station 2B. In the past, the amphibious

oval ambersnail has not been well represented in the Savannah River surveys. In past studies it has been rarely collected and only at Station 6 in 1997 and 1993. In 2000, a year of reduced flows and flooding events, this land snail was found at all stations where it was moderately common at Station 1 and uncommon at the remaining study sections of the river. It was collected from woody debris at Stations 1, 2B and 5, plastic bottles at Stations 5 and 6 and alligator weed at Station 6.

Six species of snails were collected in 1999. They included the pointed campeloma, mud amnicola, mimic lymnaea, pewter physa, creeping ancylid and dusky ancylid. The pointed campeloma was common at Station 1 (root mats and on logs), moderately common at Station 6 (muddy substrates, root mats and logs) and uncommon at Stations 2B (root mats and muddy stick liter) and 5 (root mats and logs). The mud amnicola was observed in root mats and logs where it was moderately common at Station 1 and uncommon at Station 6. The mimic lymnaea was moderately common in root mats and on logs at Stations 5 and 6 and uncommon at Station 1 on logs. The pewter physa was abundant at Stations 1 and 6 on logs and in root mats and moderately common at Stations 2B and 5 on logs and in root mats and muddy stick litter. The creeping ancylid was slightly less widespread than its ancylid relative the dusky ancylid. In the Savannah River, the creeping ancylid prefers firm to hard substrates in faster flowing waters. Here it was found to be uncommon on woody substrates at Stations 1 and 2B and rare at Station 5. The dusky ancylid prefers static or slow moving waters and was uncommon (Stations 1 and 2B) to rare (Stations 5 and 6) on logs and in leaf litter and root mats.

The seven species of snails represented in 1998 included the pointed campeloma, mud amnicola, mimic lymnaea, bugle sprite, marsh rams-horn (*Planorbella trivolvis*)), pewter physa and dusky ancylid. The pointed campeloma was abundant at all stations in a range of sand to muddy-sand and mud substrates with occasional individuals found on logs and in root mats at Station 1. The mud amnicola was moderately common at Stations 1 (root mats) and 6 (log with a single animal taken from muddy leaf litter) and uncommon at Sta-

tion 2B (leaf litter). The mimic lymnaea was moderately common on pilings at Stations 2B and 6 (one snail was collected from a patch of water pennywort at Station 6) and rare at Station 1 on a log. The bugle sprite was rare in root mats and on a log at Stations 5 and 6, respectively. The marsh rams-horn was uncommon at Stations 1 and 5 on logs and one marsh rams-horn was found crawling on wet sand onshore at Station 5. The pewter physa was common at Station 1 in root mats and on logs and moderately common at Stations 2B, 5 and 6. At Stations 2B and 5 the pewter physa occurred in the same root and log habitat as the population at Station 1, while at Station 6 it was found in both root mats and patches of water pennywort. The dusky ancylid was the only ancylid collected in 1998. It was moderately common on logs at Station 1.

The snail fauna in 1997 consisted of 10 species: pointed campeloma, mud amnicola, mimic lymnaea, two-ridge rams-horn, bugle sprite, marsh rams-horn, pewter physa, creeping ancylid, dusky ancylid and oval ambersnail. The pointed campeloma was abundant at all stations in sand and mud substrates with a single snail removed from a rotten log at Station 1. The mud amnicola was moderately common at Station 5 and abundant at the remaining stations. They were picked from branches (Stations 1 and 2B) and a log (Station 5), separated from leaf and stick litter (Station 2B) and found in samples of root mats (Stations 1, 2B and 6) and a patch of alligator weed (Station 6). The mimic lymnaea was moderately common at Station 6 (logs), uncommon at Stations 1 (piling) and 5 (piling and log) and rare at Station 2B (piling). An uncommon snail in the 1997 survey was the two-ridge rams-horn. Two snails were obtained from logs at Station 1. The bugle sprite was collected from logs and roots. It was moderately common at Stations 1 and 5 and rare at Station 6. At Station 1, this species was more common in roots than on logs. Similar to the two-ridge rams-horn, the marsh rams-horn was uncommon at Stations 1 and 6 and rare at Station 2B. At each of these stations the marsh rams-horn was found in a different habitat as follows: Station 1 on logs, Station 2B in leaf and stick litter and Station 6 in willow roots. The pewter physa was found in a variety of habitats that can be basically lumped into hard

surfaces such as logs, branches and sticks (Stations 1, 2B and 5) and fine roots (all stations). The pewter physa was abundant at Stations 1 and 6, moderately common at Station 5 and common at Station 2B. Of the two ancylid snails, the dusky ancylid was the more abundant and widespread. It was abundant at Station 2B, moderately common at Station 1 and rare at Station 5. At Station 1, single snails occurred on a log and among roots, while most individuals were collected from willow and sycamore leaf litter. The population at Station 2B was found on sticks, especially fresh, less seasoned, ones. The one dusky ancylid taken at Station 5 was found on a log. The less common creeping ancylid was rare on a log at Station 5 and on roots at Station 6. A single oval ambersnail was recorded from willow roots at Station 6.

Eight species of gastropods were obtained during the September 1993 survey at Stations 1, 5 and 6. The following snails were collected from the surfaces of logs: mud amnicola (Stations 1, 2B and 6), pewter physa (all stations), marsh rams-horn (Station 1), two-ridge rams-horn (Station 1), and dusky ancylid (Station 1). Two of the species mentioned above (dusky ancylid and pewter physa) occurred in other habitats. One dusky ancylid was found on a leaf and one was removed from an artificial insect substrate. Besides logs, the pewter physa grazed a wide range of habitats that included rocks, root mats and leaf litter. Of the two remaining species, one of them, the mimic lymnaea had a spotty distribution on pilings and logs. Where found, they were moderately to very common on from one to three pilings but lacking from other such structures. Besides the pilings, the mimic lymnaea was present on a branch. The pointed campeloma, was collected in mud, muddy sand and sand substrates, primarily in areas with at least some mud at all stations. Single individuals were also collected from a log and among a root mass.

Seven species of gastropods were obtained during the September 1989 survey. The following snails were collected from aquatic vascular plants in sheltered areas as follows: mud amnicola, pewter physa, marsh rams-horn and mimic lymnaea. Two of the species mentioned above occurred more (mimic lymnaea) or less (pewter physa) in other habitats. Most mimic lymnaea were found on the leeward side

of pilings. Pewter physa were also picked off logs trapped by pilings and swept from riparian grasses hanging into the water, while the pointed campeloma was collected in muddy, muddy sand and detrital substrates. The oval ambersnail was taken from riparian vegetation hanging into the water at Station 6. The dusky ancylid was removed from rocky substrates with one individual found on a decaying leaf.

In 1984, six species of snails were collected at Stations 1, 5 and 6. The dusky ancylid (*Laevapex fuscus* as *Lepyrium showalteri*) was found at Stations 1 and 5, the pointed campeloma (*C. decisum* as *Campeloma* sp.) at Stations 1, 5 and 6, the mud amnicola (*A. limosus* as *A. limosa*) at Stations 1, 5 and 6, the mimic lymnaea at Stations 1, 5 and 6, the bugle sprite (*P. dilatatus* as *Promenetes* sp.) at Station 1 and the pewter physa (*Physella heterostropha* as *Physa* sp.) at Stations 1, 5 and 6. The 1980 survey found the following seven species: pointed campeloma (*C. decisum* as *Campeloma* sp.) at Stations 5 and 6 in September, mud amnicola (*A. limosus* as *A. limosa*) at Stations 1 and 6, mimic lymnaea at Stations 1, 5 and 6, two-ridge rams-horn at Station 1, bugle sprite [*Promenetus dilatatus* as *Menetus* (*Micromenetus*) *dilatatus*] at Station 1, pewter physa (*Physella heterostropha* as *Physa* sp.) at Stations 1, 5 and 6 and three-ridge valvata (*Valvata tricarinata*) at Station 6.

The August 1976 survey collected eight taxa of snails which included the pointed campeloma (*C. decisum* as *Campeloma* sp.) at all stations, mud amnicola (*A. limosus* as *A. limosa*) at Stations 1 and 5, mimic lymnaea (*Pseudosuccinea columella* as *Lymnaea columella*) at Stations 1 and 5, marsh fossaria (*Fossaria humilis* as *Lymnaea humilis*) at Station 1, bugle sprite (*Promenetus dilatatus* as *Menetes dilatatus*) at Stations 1 and 6, pewter physa (*Physella heterostropha* as *Physa* sp.) at Stations 1, 5 and 6, an unidentified ancylid snail at Station 6 and an unidentified snail probably belonging to the family Valvatidae at Station 5.

The snail assemblage of the 2001 survey (nine species) at Stations 1 and 6 was only slightly less than the species numbers collected in 1997 (ten species)and September 1972 (11 species) (Table B-2). Snails occupy a wide range of habitats from hard substrates to vegetation, and many of the species

are more abundant in submerged aquatic vegetation in this portion of the Savannah River (e.g., mud amnicola, two-ridge rams-horn, bugle sprite, marsh rams-horn, pewter physa and creeping ancylid). Species that are more common on vegetation are still present in the river, although in smaller numbers. During the late summer to fall, it appears that a large number of the taxa present in the Savannah River can be collected irrespective of the amount of vegetation present [see discussion of leeches in the section Segmented Worms (Annelida)], although abundance for these species will be relative to the presence and extent of submerged aquatic vegetation. Field notes for 2001 indicated snails to be moderately common on submerged aquatic vascular plants at Stations 2B and 5.

Bivalves

Bivalve molluscs in this portion of the Savannah River consist of the Asian clam, fingernailclams, peaclams and mussels. Because of the importance of the mussel fauna, the following discussion of the bivalve fauna initially compares the distributions and habitats of the clams among surveys, with a separate discussion of the mussels. The bivalve fauna in 2001 consisted of 13 taxa divided between 4 species of clams and 9 mussel taxa.

Clams

The introduced Asian clam, *Corbicula fluminea,* in 2001, was abundant in a variety of substrates at all stations. These substrates ranged from silts and muds to fine through coarse grained sands, often containing leaf litter, leaf fragments and sticks. Three species of sphaeriids were collected and consisted of the mottled fingernailclam, *Eupera cubensis*, ridgebeak peaclam, *Pisidium compressum*, and greater eastern peaclam, *P. dubium*. At Station 1, the mottled fingernailclam and greater eastern peaclam were common in willow roots and uncommon in a muddy substrate containing abundant detritus, leaf fragments and sticks, respectively. The ridgebeak peaclam was rare in a muddy substrate with leaf fragments.

The clam fauna in 2000 consisted of the Asian clam, a fingernailclam and peaclams. The Asian clam, was abundant at all stations in the quantitative mussel survey. It occurred in a range of substrates that graded from silts and muds through sands and gravel with scattered small rocks. In areas consisting of finer particles, detritus was common and algae covered the substrate at some areas of Station 5. Most of the fingernailclams and peaclams were also primarily collected during the mussel survey. *Musculium securis*, swamp fingernailclam, ridgebeak peaclam and greater eastern peaclam. The swamp fingernailclam was moderately common at Station 5, where it was rare in willow roots and moderately common in muds sifted as part of the quantitative mussel survey. Except for one greater eastern peaclam taken from muds at Station 6 in the comprehensive survey, all other greater eastern and ridgebeak peaclams were obtained while sifting mud sediments during the mussel study. The ridgebeak peaclams were moderately common at Stations 2B and 5, while the greater eastern peaclam was rare at Station 1 and moderately common at Station 2B.

Of the clam species collected from the Savannah River in 1999, the Asian clam was collected at Stations 1, 5 and 6. At all three stations it was found in fast flowing sand and gravel substrates. It was common at Station 1, moderately common at Station 6 and uncommon at Station 5. The ubiquitous peaclam, *P. casertanum*, was the only species of fingernailclam collected in 1999. This species was uncommon in root mats and an unidentified habitat at Station 6.

The Asian clam, in 1998, was present at all stations. It was abundant in substrates ranging from sand (Stations 2B and 5) to muddy-sand (Station 2B). This species was common in sand substrates at Station 6 and moderately common in muddy leaf litter at Station 1. Three species of fingernailclams (*M. transversum*, long fingernailclam, swamp fingernailclam, and mottled fingernailclam) and two taxa of peaclams (ridgebeak peaclam, and greater eastern peaclam) were also noted. The long fingernailclam was uncommon at Station 5 in fine mud, while the numbers of the swamp fingernailclam ranged from abundant (Station 6 in mud), to common (Station 1 in muddy leaf litter), to moderately common (Station 5 in fine muds)and rare (Station 2B in

muddy leaf litter). In 1998, mottled fingernailclams were only noted from Station 6 in root mats where they were moderately common. The ridgebeak peaclam was abundant at Station 2B in mud and leaf litter, while the greater eastern peaclam was abundant in root mats and fine muds at Station 5 and rare in mud at Station 6.

In 1997, the clam species included the Asian clam at all stations in sand and mud substrates of slow to moderate currents. Three species of fingernailclams (long fingernailclam, swamp fingernailclam and mottled fingernailclam) and two taxa of peaclams (ridgebeak peaclam and greater eastern peaclam) were also noted. All the sphaeriids were sampled from root mats, with the ridgebeak peaclam and greater eastern peaclam found as well in leaf and stick litter at Station 2B. The long fingernailclam was rare at Station 5 and the swamp fingernailclam common at Stations 5 and 6 and moderately common at Station 1. The mottled fingernailclam abundant at Station 5, common at Station 2B, moderately common at Station 6 and rare at Station 1. The ridgebeak peaclam was abundant at Station 2B, uncommon at Station 1 and rare at Station 6. The greater eastern peaclam was moderately common at Station 2B and uncommon at Station 1.

The clams collected in September 1993 included the Asian clam at all stations. It occurred in sand and mud substrates as well as the roots of riparian trees. This species occurred in high densities and was the only bivalve in the packed sand areas with at least a moderate current. In the September comprehensive study and October mussel survey, an examination of oxbow areas found the substrate away from the mouth of the oxbows to consist of an especially fine, soupy mud. Bivalves in this substrate were rare with only occasional paper pondshells, *Utterbackia imbecillis*, and the Asian clam. The three genera of sphaeriids or fingernailclams and peaclams collected from the Savannah River in 1993 included the swamp fingernailclam, mottled fingernailclam and two taxa of peaclams (ubiquitous peaclam and greater eastern peaclam). All the sphaeriids were collected from root mats. The swamp fingernailclam was collected at Stations 1, 5 and 6, the mottled fingernailclam at Stations 5 and 6, ubiquitous peaclam at Station 6 and greater eastern peaclam at Station 1.

The sphaeriids and corbiculid in 1989 were represented by four species at Stations 1, 5 and 6. The four species included two species of *Pisidium* (greater European peaclam, *amnicum*, at Station 6 and ridgebeak peaclam at Station 1) as well as a single member of the genus *Musculium* (swamp fingernailclam, *securis* as *transversum*) at Station 1 and the Asian clam at Stations 1, 5 and 6. The clam fauna in 1984 included the ubiquitous peaclam only at Station 1, greater eastern peaclam at Stations 5 and 6 and the Asian clam at Stations 1, 5 and 6. Clams collected in 1980 included the ubiquitous peaclam and ridgebeak peaclam at Stations 1 and 6, greater eastern peaclam at Station 6, long fingernailclam at Station 1 and Asian clam at Stations 1, 5 and 6. In August 1976, the mottled fingernailclam (Station 5), long fingernailclam, *Musculium transversum* (as *Sphaerium transversum*, at Station 1), an unidentified species of peaclam (*Pisidium* at Station 1) and Asian clam *C. fluminea* (as *C. manilensis* at Stations 1, 5 and 6) were taken. From the September 1972 survey four species of sphaeriids were found at Stations 1, 5 and 6 as follows: ridgebeak peaclam, ubiquitous peaclam, long fingernailclam, *Musculium transversum* (as *Sphaerium transversum*) and mottled fingernailclam.

Mussels

Comparisons of the 2001 mussel survey results with those from previous years will include not only those stations (1, 2B, 5 and 6) surveyed in 2001, but also Station 3, which was part of the comprehensive (generally two times a year) river studies until 1993 (q.v., Tables B-3 and B-4).

In 2001, 122 mussels were recorded from a quantitative survey using 1.0-m^2 quadrats. This is the second consecutive year quadrats were used in the Savannah River surveys. Past surveys have included qualitative hand collections in shallow waters and diving in deeper areas. The addition of a quantitative aspect was initiated primarily to address the statement that there was an "almost uniform distribution" of mussels "from juveniles through old adults (over eight years of age)" in the 1960 survey (ANSP 1961: 48). With the exception of

Table B-3. Species of mussels collected during comprehensive surveys of the Savannah River, near the Savannah River Site, Georgia and South Carolina, from 1951 through 2001.('51 = 1951 & 1952, '55 = 1955 & 1956) (X = present, - = absent).

	'51	'55	'60	'65	'68	'72	'76	'80	'84	'89	'93	'97	'98	'99	'00	'01
Alasmidonta triangulata	—	–	X	–	–	X	X	–	–	–	–	X	X	X	–	X
A. couperiana	X	–	X	X	–	X	X	–	–	X	X	X	X	–	–	–
Elliptio complanata	X	X	X	X	X	X	X	X	X	–	X	X	X	X	X	X
E. congaraea	–	X	X	X	X	X	X	X	X	–	X	X	X	X	X	X
E. fraterna	–	–	–	–	–	X	–	–	–	–	–	–	–	–	–	–
E. icterina	–	–	–	X	X	X	X	X	X	X	X	X	X	X	X	X
E. producta	X	X	X	X	X	X	X	X	X	–	X	X	X	X	X	X
E. roanokensis	–	–	–	–	–	–	–	–	–	–	X	X	X	X	–	–
Lampsilis cariosa	X	X	X	X	X	X	X	X	X	–	X	X	X	X	–	–
L. splendida	X	–	X	X	X	X	X	X	X	–	X	X	X	X	X	X
Pyganodon cataracta	X	X	X	X	–	X	X	X	X	–	X	X	X	X	–	–
Strophitus undulatus	–	–	–	X	–	X	X	–	–	–	–	–	–	–	–	–
Toxolasma pullus	–	–	–	X	X	X	X	–	–	X	X	X	X	X	X	X
Uniomerus carolinianus	X	–	–	X	X	X	X	–	–	X	X	X	X	X	–	X
Utterbackia imbecillis	–	X	X	X	X	X	X	X	X	–	X	X	X	X	X	–
Villosa delumbis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table B-4. Species of mussels and stations collected during comprehensive surveys of the Savannah River, near the Savannah River Site, Georgia and South Carolina, from 1951 through 2001.

Station	1	2B	3	5	6
Alasmidonta triangulata	–	X	–	X	X
Anodonta couperiana	X	X	X	X	X
Elliptio complanata	X	X	X	X	X
E. congaraea	X	X	X	X	X
E. fraterna	–	–	–	–	X
E. icterina	X	X	X	X	X
E. producta	X	X	X	X	X
E. roanokensis	X	X	X	X	X
Lampsilis cariosa	X	X	X	X	X
L. splendida	X	X	X	X	X
Pyganodon cataracta	–	X	X	X	X
Strophitus undulatus	–	–	–	X	–
Toxolasma pullus	X	X	–	X	X
Uniomerus carolinianus	X	X	X	X	X
Utterbackia imbecillis	X	X	X	X	X
Villosa delumbis	X	X	X	X	X

the Savannah lilliput in 1998 and Savannah lilliput and paper pondshell in 1997 and 1993 there has been a scarcity of juveniles in qualitative collections. In addition, the quantitative collections would provide information on the population size of the introduced Asian clam, a competitor to the mussel fauna for habitat and food resources in the Savannah River. Also, the numbers of sphaeriids and pointed campelomas were also noted. Although employing quantitative measures by passing sediments through a sieve does a better job of collecting small individuals, the intensity of the labor involved results in a much smaller survey area. The smaller areal coverage tends to miss some taxa, especially rarer species (see overview of 2000 mussel survey below). The fauna at the four stations consisted of nine species as follows: *Elliptio icterina* (variable spike), *E. congaraea* (Carolina slabshell), *E. producta* (Atlantic spike), *E. complanata* (eastern elliptio), *Lampsilis splendida* (rayed pink fatmucket), *Villosa delumbis* (eastern creekshell), *Toxolasma pullus* (Savannah lilliput), *Alasmidonta triangulata* (southern elktoe) and *Uniomerus carolinianus* (Florida pondhorn). The *Uniomerus* in the Savannah River is assigned to the species *carolineanus* following Turgeon et al. (1998). Although Clarke (1981) synonymyzed *triangulata* with *A. undulata*, it is the opinion of Dr. Arthur Bogan (North Carolina State Museum of Natural Sciences) that, due to the continuing confusion concerning the taxonomic status of *triangulata*, it is tentatively recognized in spite of the conchological work of Clarke. Therefore, the name *triangulata* is applied herein to the *Alasmidonta* from the Savannah River.

The nine species collected in 2001 is similar to the numbers taken in 2000 (eight). Both years are characterized by the use of quadrats and the species numbers are lower than the numbers in most hand collections [1972 (15), 1976 (14), 1993 (13), 1997 (14) 1998 (13) and 1999 (13)], although similar to the species totals in 1980 and 1984 (9 species) and greater than 1989 (5 species). Three species were taken at three stations and included the eastern elliptio at Stations 2B, 5 and 6 and variable spike and eastern creekshell at Stations 1, 5 and 6. An equal number of species were taken at two stations. These three species consisted of the Carolina

slabshell and Atlantic spike at Stations 5 and 6 and the Savanna lilliput at Stations 1 and 6 (Savannah River populations of the Savannah lilliput, *T. pullus,* were originally described as a separate species, *Carunculina patrickae* Bates, 1966 (see Johnson 1967, 1970)). The rayed pink fatmucket and Florida pondhorn at Station 1 and southern elktoe at Station 6 were each collected at one station.

The Carolina slabshell constituted 28.7% (35 animals) of the mussels collected in 2001. Together with the variable spike (29, 25.8%) the two species constituted slightly over half 52.8% (64 animals) of the mussels collected in 2001. The numbers of mussels and percent abundance of the remaining seven species from highest to lowest are as follows: Savannah lilliput (18, 14.8%), Atlantic spike (16, 13.1%), eastern creekshell (14, 11.5%), eastern elliptio (6, 4.9%), rayed pink fatmucket (2, 1.6%)and southern elktoe and Florida pondhorn (1 each, 0.8% each).

The quadrat sampling was successful in collecting young mussels of the variable spike, Savannah lilliput and eastern creekshell. Asian clams, sphaeriids (peaclams)and pointed campelomas were also taken. The survey at 4 stations (40 quadrats) produced 1877 molluscs consisting of 3 sphaeriids (0.2%), 122 mussels (6.5%), 1597 Asian clams (85.1%) and 155 pointed campelomas (8.3%). Of the 40 quadrats sampled, 36 were placed along transects in a variety of habitats (e.g., river flow, substrate, depth, organic content) and 4 were chosen in likely mussel habitats to slightly increase the opportunities to add mussels to a small mussel database. The mean number of mussels in quadrats 1 to 9 was 3.1, while the mean number of mussels in quadrat 10 was 2.7. In 2001, unlike 2000, the average number of mussels collected in the 10th quadrat was lower than the numbers collected in quadrats 1 to 9. It is apparent that the introduced Asian clam numerically dominates the macrobenthic habitat of the Savannah River and because of its great numbers competes with the mussels for space and food resources.

Yearly ranking of abundance between 1993 and 1999 in hand collections deviate slightly, but the five most abundant (Carolina slabshell, Savannah lilliput, variable spike, Atlantic spike and eastern creekshell) taxa, five least abundant

[Florida pondhorn, eastern floater (*Pyganodon cataracta*), yellow lamp mussel (*L. cariosa*), barrel floater (*Anodonta couperiana*) and southern elktoe] and four moderately abundant [paper pondshell (*Utterbackia imbecillis*), eastern elliptio, rayed pink fatmucket and Roanoke slabshell (*E. roanokensis*)] species generally fall within the same three main categories each year. All five of the most abundant and two each of the moderately and least abundant taxa were represented in 2001. The use of quadrats in 2001 produced the expected results of doing a better job of collecting small mussels but performing less well at collecting larger numbers of species.

As in 2000, drought and low flows conditions prevailed in the Savannah River during 2001 (cf. Figure 2, mean daily gauge heights, in the Introduction and ANSP 2001)and the conditions in many mussel habitats that were left dry or with reduced water levels, especially at Station 5, continued in 2001. In 2000, mussel habitat downriver from the downrivermost (ultimate) set of #55 pilings at Station 5 was left dry and covered with a mix of terrestrial and emergent aquatic vegetation. An abundant population of mussels was collected here in 1997 and 1999. As with many such habitats downriver from the ultimate set of pilings, a ridge of sand separates a diagonally oriented shoreside trough of fine muds, leaves and sticks from the main channel. Most mussels collected here in 1997 and 1999 occurred in the trough. Unfortunately the physiognomy of this habitat traps mussels behind the ridge of sand when water levels are lowered, and its impact on the mussel population downriver from the ultimate set of #55 pilings was probably catastrophic. The most conspicuous changes at this site in 2001 was the increased size of the willow trees that dotted the newly created dry land. A series of muddy pools is present on the South Carolina side of the river opposite the mouth of Devils Elbow (Georgia). This area, for the most part, is separated from the river by a vegetated sand ridge and is connected with the river at its up- and downriver ends during periods of high water. This region was surveyed in 1993 and 1999 and supported a variety of mussels dominated by the Savannah lilliput. On 9/10/2000, the uprivermost pool at its maximum depth (following a 9/8/2000 precipitation) was 46 cm

maximum depth and was choked with emergent vegetation. The substrate was slightly compacted and 1 large adult male Savannah lilliput and several Asian clams were found. There was insufficient time to sample the entire site, but it seems apparent that the mussel population here was severely reduced. In 2001, the emergent vegetation, except for stubble, was lacking. The surface water area was approximately 51 m by 7 m with a 21 cm maximum depth. The area had a mix of grasses, including *Paspalum*, and knotweed (*Polygonum*) around the margins of the pool. The pool was seined and numerous tadpoles, a small largemouth bass (*Micropterus salmoides*), numerous small bluegills, a two-toed amphiuma (*Amphiuma means*), and two yellowbelly sliders (*Trachemys s. scripta*), the larger one especially bearing numerous leeches (*P. parasitica*), were captured. The whole area was searched by hand and no living mussels were located. Valves of the Savannah lilliput and eastern floater as well as shells of the pointed campeloma were present. Asian clams, approximately 2 cm or less in size, were still numerous in this habitat. A third locale outside Station 5 consisted of a perched, left bank (oriented downriver) shallow depression of muds and muddy sand upriver from the entrance to Little Hell Landing. In 1993 and 1997, this site supported a small variety of mussels dominated by the Savannah lilliput. In 2000, it consisted of an area approximately 3.7 by 5.5 m and 10 to 13 cm maximum depth. This small region was thoroughly surveyed and 1 Savannah lilliput, 8 Asian clams, 4 pointed campelomas and 2 bluegills were collected. The substrate in this pool had probably dried out and turned the bottom into a hard pan. The Savannah lilliput was lying on the surface of the hard bottom. In 2001, this area was dry with giant cutgrass (*Zizaniopsis miliacea*)dominating the former pool area and a mixture of sedge (*Cyperus*), bulrush (*Scirpus*) and rush (*Juncus*)at the crest of a slight berm, bisected by a muskrat runway, that separated the pool from the river during low water periods.

In 2000, 118 mussels were collected using 1.0 m^2 quadrats. The fauna at the four stations consisted of 8 species as follows: variable spike, Carolina slabshell, Atlantic spike, eastern elliptio, rayed pink fatmucket, eastern creekshell, Savannah lilliput and paper pondshell. In 2000, the Savan-

nah lilliput was found at all four stations. Three species were taken at three stations and included the Atlantic spike and eastern creekshell at Stations 1, 2B and 5 and the rayed pink fatmucket at Stations 1, 2B and 6UR. Only the eastern elliptio was collected at two stations (2B and 6UR), while the Carolina slabshell (Station 5) variable spike (Station 2B) and paper pondshell (Station 5) were collected at a single station.

The Savannah lilliput constituted 55.1% (65 animals) of the mussels collected in 2000. Together with the eastern creekshell (19, 16.1%) and variable spike (12, 10.2%) they represented 81.4% (96 animals) of the mussel fauna in 2000. The numbers of mussels and percent abundance of the remaining five species from highest to lowest are as follows:, Atlantic spike (8, 6.8%), eastern elliptio (6, 5.1%), rayed pink fatmucket (5, 4.2%), paper pondshell (2, 1.7%) and Carolina slabshell (1, 0.8%).

The quadrat sampling was successful in collecting young mussels of the eastern elliptio, rayed pink fatmucket, Savannah lilliput, paper pondshell and eastern creekshell. Asian clams and sphaeriids (fingernailclams and peaclams) were also taken. The survey at 4 stations (40 quadrats) produced 4073 bivalves consisting of 25 sphaeriids (0.61%), 118 mussels (2.9%) and 3930 Asian clams (96.5%). Of the 40 quadrats sampled, 36 were placed along transects in a variety of habitats (e.g., river flow, substrate, depth, organic content) and 4 were chosen in likely mussel habitats to slightly increase the opportunities to add to the small mussel database. The mean number of mussels in quadrats 1 to 9 was 2.1, while the mean number of mussels in quadrat 10 was 6.8.

Yearly ranking of abundance between 1993 and 1999 in hand collections deviate slightly, but the five most abundant (Carolina slabshell, Savannah lilliput, variable spike, Atlantic spike and eastern creekshell) taxa, five least abundant (Florida pondhorn, eastern floater, yellow lamp mussel, barrel floater and southern elktoe) and four moderately abundant (paper pondshell, eastern elliptio, rayed pink fatmucket and Roanoke slabshell) species generally fall within the same three main categories each year. Five of the most abundant and three of the moderately abundant taxa were represented

in 2000. Of note was the most abundant species in the long term hand collection data set, the Carolina slabshell, ranked eighth in 2000. One of the moderately abundant species and all five of the least abundant taxa were not collected in 2000.

In 1999, 2002 mussels were recorded from hand collections at all sites with 1645 of them collected at Stations 1, 2B, 5 and 6. The fauna at the four stations consisted of 13 species. Eight of the mussel species were found at all four stations and included the variable spike, Carolina slabshell, Atlantic spike, eastern elliptio, Roanoke slabshell, rayed pink fatmucket, Florida pondhorn (*U. carolinianus,* as *U. obesus*) and eastern creekshell. Three species were found at three stations and included the yellow lamp mussel and eastern floater at Stations 1, 2B and 5 and Savannah lilliput at Stations 2B, 5 and 6. Two taxa were found at two stations and consisted of paper pondshell at Stations 1 and 2B and southern elktoe at Stations 2B and 6. The remaining taxon collected in prior recent surveys, the barrel floater, was not represented in the 1999 study.

The Carolina slabshell, eastern creekshell, Atlantic spike, Savannah lilliput and variable spike were the most common species, while the southern elktoe, yellow lamp mussel, paper pondshell, eastern floater and eastern elliptio were the least common species. The numbers of mussels and percent abundance at these four stations in order from highest to lowest are as follows: Carolina slabshell (668, 40.6%), eastern creekshell (257, 15.6%), Atlantic spike (194, 11.8%), Savannah lilliput (185, 11.2%), variable spike (157, 9.5%), rayed pink fatmucket (85, 5.2%), Roanoke slabshell (30, 1.8%),Florida pondhorn (24, 1.5%), eastern elliptio (20, 1.2%), eastern floater (11, 0.7%), paper pondshell (6, 0.4%), yellow lamp mussel (5, 0.3%) and southern elktoe (3, 0.2%).

The 1916 mussels recorded from all hand and dive collections in 1998 were distributed among 14 species. The 802 animals tabulated from only hand collections at Stations 1, 2B, 5 and 6LR were divided among 13 species. In 1998, the Savannah lilliput, Carolina slabshell, variable spike, Atlantic spike and eastern creekshell were the most common species, while the yellow lamp mussel, rayed pink fatmucket, Florida

pondhorn (*U. carolinianus,* as *U. obesus*), eastern elliptio, eastern floater and southern elktoe were uncommon to rare. The numbers of mussels and percent abundance from hand collections at Stations 1, 2B, 5 and 6 in order from highest to lowest are as follows: Savannah lilliput (332, 41.4%), Carolina slabshell (129, 16.1%), variable spike (121, 15.8%), Atlantic spike (67, 8.3%), eastern creekshell (57, 7.1%), paper pondshell (28, 3.5%), Roanoke slabshell (20, 2.5%), rayed pink fatmucket (13, 1.6%), eastern floater (13, 1.6%), eastern elliptio (12, 1.5%),Florida pondhorn (8, 1.0%), yellow lamp mussel (1, 0.1%) and southern elktoe (1, 0.1%).

The 1648 mussels recorded in 1997 hand collections at Stations 1, 2B, 5, 6LR were distributed among 14 species. The numbers of mussels and percent abundance in order from highest to lowest were as follows: Carolina slabshell (710, 43.1%), variable spike (281, 17.0%), Savannah lilliput (180, 10.9% plus fresh shells from 31 individuals recently stranded by low water levels just upriver from the entrance to Little Hell Landing and one from Station 6), Atlantic spike (175, 10.6%), eastern creekshell (136, 8.3%), rayed pink fatmucket (48, 2.9%), Roanoke slabshell (41, 2.5%), eastern elliptio (34, 2.1%), paper pondshell (13, 0.8%), yellow lamp mussel (11, 0.7%), Florida pondhorn (*U. carolinianus,* as *U. obesus*)(9, 0.5%), eastern floater (5, 0.3%), barrel floater (4, 0.2%) and southern elktoe (1, 0.1%).

In 1997, the Carolina slabshell, variable spike, Savannah lilliput, Atlantic spike and eastern creekshell were the most common species, while the paper pondshell, yellow lamp mussel, Florida pondhorn, eastern floater, barrel floater and southern elktoe were uncommon to rare.

Like the 1998 survey, the 1993 mussel study included both shallow water hand collecting and sampling of deeper waters with divers. It should be noted that Station 3 was examined as part of the 1993 comprehensive program and not Station 2B (a mussel survey was not part of the Plant Vogtle program). This explains the low number of species at Station 2B in Table C-1. The 1483 mussels recorded from all sites were distributed among 13 species. The original report of

the 1993 study (ANSP 1994b) listed 14 species from Stations 1, 3, 5 and 6. Molecular comparisons of the Savannah River mussel fauna by Dr. Margaret Mulvey (formerly of the Savannah River Ecology Laboratory) revealed the pod lance, *E. folliculata*, collected at Station 3 in 1993 to be conspecific with the Atlantic spike. The only other times the pod lance morph has been recorded from the Academy surveys was in the summer and fall surveys of 1951 (as the delicate spike, *E. arctatus*) from Station 3.

From the two collecting methods in 1993 (i.e., shallow water hand collections and diving), eight species were taken in greater numbers in shallow waters. These included the eastern floater (8 vs 0 diving), barrel floater (7 vs 0), paper pondshell (79 vs 5), variable spike (123 vs 29), rayed pink fatmucket (19 vs 3), Savannah lilliput (266 vs 2),Florida pondhorn (*U. carolinianus,* as *U. obesus*)(7 vs 0) and eastern creekshell (27 vs 3). Only the Roanoke slabshell (13 vs 77) and the yellow lampmussel (1 vs 8) were much more common in the deeper water. The Atlantic spike (96 vs 59 diving) was approximately a third more common in the shallow water collections, while the eastern elliptio (46 vs 41 diving) and Carolina slabshell (267 vs 297) were roughly equally common in both shallow and deep water areas.

The four species that were the most common in the October 1993 shallow water hand collections by total and percent abundances were as follows: Carolina slabshell (247, 27.8%), Savannah lilliput (266, 27.7% plus fresh shells of 36 animals found in a drying muddy depression on the left bank of Station 6UR),variable spike (123, 12.8%) and Atlantic spike (96, 10.0%). The four least common species in hand collections included the eastern floater (8, 0.8%), Florida pondhorn (7, 0.7%), barrel floater (7, 0.7%) and yellow lamp mussel (3, 0.3%).

The collection of mussels in 1989, as part of the comprehensive non-insect macroinvertebrate surveys, was augmented by a late summer survey of this group downriver from Station 1 (17 August) and in a wide area from Johnson's Landing downriver almost to U.S. Highway 301 (18 August). This latter area encompasses both the upper (historic) and lower (present) reaches (UR and LR) of Station 6. The sur-

vey by Dr. Arthur Bogan concentrated solely on mussels and produced single specimens of the Florida pondhorn (*U. carolinianus,* as *U. obesus*) (near Station 1) and the variable spike (near Station 6). Both of these species had been collected during the June 1989 period. The mussel fauna in 1989 consisted of the barrel floater (Station 6LR in June), Savannah lilliput, (Station 6LR in June and September), Florida pondhorn (Station 3 in June and in the area of Station 6LR in August), variable spike (Station 3 in June and in the area of Station 1 in August), and the eastern creekshell (Station 1 in September). The barrel floater and Savannah lilliput were collected from a backwater mud substrate, while the Florida pondhorn and variable spikes taken in June were found in a muddy backwater vegetated with emergent aquatic vasculars and isolated from the main stream by low water levels. Shallow water substrates of sand, gravel and mixtures of the two were searched but produced no bivalves or only the introduced Asian clam. With the exception of the common presence of the Savannah lilliput and paper pondshell, the other species were rare.

In 1984, nine species of mussels were collected as follows: the paper pondshell, *Utterbackia imbecillis* (as *Anodonta imbecillis)* at Stations 5 and 6, eastern floater, *Pyganodon cataracta* (in part as *Anodonta catarata* (misspelling) and *A. gibbosa*) at Stations 5 and 6, Carolina slabshell at Stations 5 and 6, eastern elliptio, at Stations 5 and 6, variable spike at Station 5, Atlantic spike, *E. producta* (as *E. lanceolata)* at Stations 5 and 6, rayed pink fatmucket, *Lampsilis splendida* (as *L. radiata splendida* at Stations 5 and 6, yellow lampmussel at Station 5, and eastern creekshell at Stations 5 and 6. The mussel faunas between 1980 and 1984 are essentially the same.

The 10 species found to occur at the 4 stations in 1980 represented a return to the typical numbers of species found prior to the nutrient enrichment seen in 1972 (ANSP 1974a). However, in contrast to the mussel faunas of the early surveys, this group was rare at Stations 1 and 3 where only the variable spike (Station 1) and yellow lamp mussel (Station 3) were collected. The paper pondshell, *Utterbackia imbecillis* (as *Anodonta (U.) imbecillis*), Atlantic spike, *E. producta* (as *E. lanceolata)*, rayed pink fatmucket, *L. splendida* (as *L.*

radiata splendida) and eastern creekshell were collected at Stations 5 and 6. The Carolina slabshell and eastern elliptio were taken at Station 5, eastern floater, *Pyganodon cataracta* (as *Anodonta* (*P.*) *c. cataracta* and *A.* (*U.*) *gibbosa*) at Station 6, yellow lampmussel at Stations 3 and 6 and the variable spike at Stations 1, 5 and 6.

In 1980, the mussel fauna in the mouth of the oxbow at Devil's Elbow at Station 5 (right bank) had disappeared. A small variety of mussels, mostly *Elliptio*, persisted in a muddy backwater area along the left bank. In 1993, this muddy area had a shallow connection with the river [covered by grasses in 2000, reflecting an extended period(s) of low flow(s)] at its upper end and was divided into a series of pools that are contiguous only during high water. For the most part this series of pools is separated from the river by a vegetated sand ridge. At this site in 1993, the paper pondshell was the most common species, while in 1999 it was the Savannah lilliput. The only members of the genus *Elliptio* collected in recent surveys were *icterina* and *producta* in 1993 and 1999, respectively. In 1980, a reasonably diverse mussel fauna was encountered principally in the large backwater along the lower end of the right bank at the upper reach of Station 6. The population of the eastern floater, *Pyganodon cataracta* (as *Anodonta* (*P.*)*cataracta*) found at Station 6 was considered to be on the increase. Mussels were all but eliminated at Stations 1 and 3 (only the variable spike and rayed pink fatmucket were found), and greatly reduced at Stations 6 (upper reach) and 5 (to a lesser extent). Fuller attributes this decline in fauna to competition from the Asian clam. The Asian clam first appeared in collections in 1972 and by 1976 (present at all stations) it was apparent to Fuller that through competition it was damaging the native mussel fauna (Fuller and Richardson 1977).

The single August 1976 sampling period found only one less species (*E. fraterna*, brother spike) than the two surveys in 1972. The distributions of the 14 species include the Florida pondhorn, *U. carolinianus* (as *U. tetralasmus*) at Stations 3 and 5; Savannah lilliput, *Toxolasma pullus* (as *Carunculina pulla)* at Station 6; *Strophitus undulatus* (creeper) at Station 5; and *A. triangulata* (as *A. undulata*) at Stations 5 and 6. The Carolina slabshell and variable spike were collected at

all stations; rayed pink fatmucket, *Lampsilis splendida* (as *"Lampsilis" radiata splendida*), yellow lampmussel and eastern creekshell at Stations 3, 5 and 6; paper pondshell, *Utterbackia imbecillis* (as *Anodonta imbecillis*) and eastern elliptio at Stations 1, 5 and 6; *E. producta* (as *E. lanceolata*) at Stations 5 and 6; barrel floater at Station 5; and eastern floater, *Pyganodon cataracta* (as *Anodonta c. cataracta)* at Station 6. The Asian clam was identified as the chief threat to the survival of freshwater mussels in the study areas.

The 1972 studies were conducted in May-June and September. The highest number of mussel species (15) ever recorded during a comprehensive Academy survey was collected that year. All the species known to occur in the river at that time, including three of the rarest taxa in the study area, the brother spike and southern elktoe at Station 6 and creeper at Station 5, were part of the 1972 survey. The brother spike was found in 1972 for the first time since it was originally described in 1852 (ANSP 1974a:73). The taxonomic status of the Savannah River population of the brother spike is still uncertain at this time (q.v., Britton and Fuller, 1979:12). The other taxa and the stations from which they were recorded are as follows: Carolina slabshell at Stations 3, 5 and 6; eastern elliptio at Stations 1, 5 and 6; Atlantic spike, *E. producta* (as *E. lanceolata*) at Stations 1, 5 and 6; variable spike at all stations; *U. carolinianus* (as *U. tetralasmus*) at Station 6; eastern floater, *Pyganodon cataracta* (as *Anodonta c. cataracta*) at Stations 3, 5 and 6; paper pondshell, *Utterbackia imbecillis* (as *Anodonta imbecillis)* at Station 6; barrel floater at Station 5; eastern creekshell at all stations; yellow lampmussel at Stations 3, 5 and 6; rayed pink fatmucket, *L. splendida* (as *L. radiata splendida*) at all stations; and Savannah lilliput, *Toxolasma pullus* (as *Carunculina pulla)* at Station 6. The 15 species listed in the 1972 survey constitute more than half of the 25 taxa presently recognized from the whole drainage basin.

In 1972, the importance was noted of habitat at the mouth of the right bank backwater (substation 6B) at the lower end of the upper reach of Station 6 for the greater portion of the macroinvertebrates, probably also including the mussels. Fuller, in Britton and Fuller (1979:12), indicates the habitat of the 1972 specimens of the brother spike to be sand bars beneath one or two feet of water.

The five species that were the most common in the combined 1993 through 1999 shallow water hand collections (totals and percent abundances) were as follows: Carolina slabshell (1774, 35.1%), Savannah lilliput (963, 19.1%), variable spike (682, 13.5%), Atlantic spike (531, 10.5%) and eastern creekshell (477, 9.4%). The eastern creekshell, in 1993, is the only one of the five species that was not the most abundant in hand collection in each of the four surveys. The five least common species in hand collections during this period included the southern elktoe (5, 0.1%), barrel floater (11, 0.2%), yellow lamp mussel (20, 0.4%), eastern floater (37, 0.7%) and Florida pondhorn (48, 0.9%). The remaining species include the paper pondshell, eastern elliptio, rayed pink fatmucket and Roanoke slabshell. The five species that were the most common in the combined 1993 and 1998 deeper water dive collections were as follows: Carolina slabshell (447, 54.3%), Roanoke slabshell (101, 12.3%), Atlantic spike (87, 10.6%) variable spike (82, 10.0%) and eastern elliptio (55, 6.7%). The five least common species in dive collections during this period included the southern elktoe (0), eastern floater (0), barrel floater (1, 0.1%), Savannah lilliput (3, 0.4%) and Florida pondhorn (4, 0.5%). The remaining species in the dive collections include the paper pondshell, eastern creekshell, yellow lampmussel, and rayed pink fatmucket.

From the two collecting methods in 1998 and 1993 (i.e., shallow water hand collections and diving), six species were taken in greater numbers in shallow waters. These included the Savannah lilliput, southern elktoe, eastern floater, barrel floater, paper pondshell and eastern creekshell. Only the Roanoke slabshell and the yellow lampmussel were much more common in the deeper water. This distribution of the lampmussel is especially interesting considering its once prominence in earlier Academy investigations. The Atlantic spike, eastern elliptio, Carolina slabshell, variable spike, rayed pink fatmucket and Florida pondhorn were roughly as common in both shallow and deep water areas.

Any adverse impacts on the Savannah lilliput are especially important because of its limited range. This species is known only from four counties in North Carolina, a population in the Saluda River drainage in South Carolina (John Alder-

man, pers. com.) and as scattered populations in the Savannah River from RM 160.5 (#78 Pilings at Station 1) downriver to RM 118.9 (#38 Pilings, immediately upriver from the U.S. Highway 301 bridge). Only marginal populations have been found at the upriver sites at the #70 (Station 2A, last surveyed in 1998) and #69 (Station 2B at RM 149.8) pilings. To date the Savannah lilliput has been found to be common only at #78 Pilings at Station 1 and from River Mile 138.1 (#54 Pilings, upriver from Jack of Clubs Point, between Stations 3 and 5) downriver to River Mile 118.9. Of note is no populations of this species were located downriver from the U.S. Highway 301 bridge by John Alderman and Chris McGrath (Nongame and Endangered Wildlife Program, North Carolina Wildlife Resources Commission) in October 1993. This species was originally known only from Station 6. In view of the range extensions of this species to Station 5 in 1993, Station 2B in 1997, Station 2A and the U.S. Highway 301 bridge in 1998 and Station 1 in 2000, reexamining sites upriver from Station 1 and downriver from the U.S. Highway 301 bridge is warranted.

The mussel fauna in the Savannah River in the area of the Savannah River Site has changed in character since 1951 (ANSP 1953). The yellow lampmussel and eastern elliptio were the two most common species in the 1951/52 and 1955/56 studies. In the 1993 through 1999 period, 5056 specimens divided among 14 species were taken in hand collections at the study stations and the yellow lamp mussel ranked twelfth in abundance (20 specimens, 0.4%) and the eastern elliptio eighth (112 specimens, 2.2%). In 1960, these two species along with the Carolina slabshell and Atlantic spike were the dominant taxa. Surveys in the years from 1993 through 1999, the Carolina slabshell was the most common species in hand collections (1774 specimens, 35.1%), while the Atlantic spike ranked fourth (532 specimens, 10.5%).

The 1968 (ANSP 1970) study discusses the reduced mussel fauna from 1965 (ANSP 1966) with only the "hardier forms" having "persisted as widely as in recent years" (ANSP 1970:65). These "hardier forms" included the eastern elliptio and yellow lampmussel of earlier surveys and the variable spike and rayed pink fatmucket. The variable spike,

a species whose type locality lies in the Savannah River near Augusta, was not reported with certainty until 1965. This species may well have been considered a variant of the eastern elliptio in earlier surveys. The variable spike is presently one of the more common species in the Savannah River. It ranked third in abundance from 1993 through 1999 (682 specimens, 13.5%) and rayed pink fatmucket ranked sixth (165 specimens, 3.3%). In the 1980 study, mussels were considered all but eliminated at Stations 1 and 3, reduced at Station 5 (eliminated from the mouth of the oxbow at Devil's Elbow) and existing with a reasonably diverse fauna only at Station 6. Six species of mussels were collected from the mouth and along the downstream side of the oxbow at Devil's Elbow in 1993 and 1998. This area was not sampled in 1997 or 1999.

One noteworthy observation in the 1960 survey not addressed until the 2000 and 2001 studies was the "almost uniform distribution" of mussels "from juveniles through old adults (over eight years of age)" in 1960 (ANSP 1961: 48). One conspicuous observation concerning the mussel surveys was the scarcity of juveniles. The Savannah lilliput in 1998 and Savannah lilliput and paper pondshell in 1997 and 1993 were the only taxa represented by a uniform distribution of age classes. In the 2000 and 2001 surveys, young mussels of the Savannah lilliput (2000 and 2001) and paper pondshell (2000) were again collected as well as individuals of the eastern elliptio (2000), variable spike (2001), rayed pink fatmucket (2000) and eastern creekshell (2000 and 2001). From the 1993 through 1999 period, it appears that the yellow lampmussel and rayed pink fatmucket have been reduced in numbers, while the Savannah lilliput appears to be more common, although the impact of extended low water levels on the Savannah lilliput in 2000 and 2001 has not been completely determined.

The greater abundance of the Savannah lilliput, a species that was only discovered in the river in 1962, and first appeared in the comprehensive surveys in 1965, may well be related to the regulated flows of the Savannah River. The species prefers shallow waters, and many of these habitats until the recent drought were less subject to drying with certain base flows being maintained in the river. However, ex-

tended periods of extremely low water levels in the Savannah River in 2000 and 2001 have had an impact on this species by stranding populations in shallow linear depressions separated from the main channel by sand bars or shallow perched basins above the main channel. The impact of the extended period of low water levels in 2000 and 2001 has been to severely reduce or extirpate some populations of the Savannah lilliput. With the return of normal water levels, monitoring the temporal scale of this species' population structure, growth rates and ability to repopulate areas in which it was formerly abundant will contribute to the knowledge of the biology of the Savannah lilliput.

Besides the brother spike, creeper and southern elktoe, which have always been rare in the Savannah River, recent mussel surveys reveal that the barrel floater, eastern floater and Florida pondhorn are also rare to uncommon but their abundance in previous studies is unknown. The record for the creeper at Station 5 between 1965 and 1976 was based upon a single individual which was recollected during this period (Samuel L. H. Fuller, pers. com.). Most of the mussels in backwater areas seem to be confined to deep troughs downriver from the last set of pilings and can only be hand collected if water conditions are low. Specimens are rarer in shallow shoreline areas around the troughs and along the shorelines among the pilings. The construction of dykes, upriver dams and removal of meanders has resulted in changes in flow characteristics of the river and the slow development of mussel beds outside the original river banks, overflow channels, backwaters and shelves and has resulted in a change in the mussel fauna. It is expected that without wet collecting by hand during low water conditions, reduced numbers of mussels will mark the comprehensive surveys and close monitoring of the most endangered group of animals (Williams, et al. 1993) in North America is warranted.

Crustaceans (Crustacea)

In 2001 three species of crustaceans were collected from the Savannah River: the crayfish *Procambarus enoplosternum,* the riverine grass shrimp, *Palaemonetes paludosus*, and the amphipod (scud or sideswimmer)

Hyalella azteca. *Procambarus enoplosternum* was moderately common at Stations 1 (under logs and in root mats) and 6 (root mats and flooded grasses). The riverine grass shrimp occurred in a range of habitats that included alligator weed (abundant at Station 1), leaf litter (rare at Station 1), root mats (moderately common at Station 6) and flooded grasses (rare at Station 6). The amphipod *H. azteca* was moderately common at Station 1 (root mats, including willow roots, and alligator weed) and abundant at Station 6 (roots of water pennywort).

Four species of crustaceans were collected in 2000 and included the crayfish *P. enoplosternum,* the riverine grass shrimp, the amphipods *H. azteca* and an undetermined species of *Gammarus*. *Procambarus enoplosternum* was uncommon at Stations 1 and 6 in flooded grasses, root mats of the water hyacinth, a log gallery and one specimen was shocked into the water column by a walk-along electrofishing unit being employed by the fisheries team. At Station 2B, this species was moderately common in flooded grasses and alligator weed, while at Station 5 it was moderately common in willow roots. The riverine grass shrimp was rare at Stations 1 in flooded grasses and moderately common at the remaining stations in flooded grasses, alligator weed, willow roots, paspalum grass and root mats of the water hyacinth. The amphipod *H. azteca* was abundant at Stations 1 (flooded grasses, water-milfoil (*Myriophyllum* species), alligator weed and woody branches) and 6 (paspalum grass, shade mudflower and water pennywort) and common at Stations 2B (flooded grasses and alligator weed) and 5 (root tufts of flooded grasses, paspalum grass and woody branches). The gammarid amphipod was uncommon at Station 5 and rare at Station 6 in root mats, woody debris and shade mudflower.

In 1999, the recorded crustaceans included the crayfishes *P. enoplosternum* and white river crayfish, *P. acutus,* the riverine grass shrimp, the amphipod *H. azteca* and the isopod (water slater) *Caecidotea communis*. *Procambarus enoplosternum* was found in root mats and leaf litter at Stations 1, 2B (moderately common) and 6 (uncommon), while the abundance of the white river crayfish ranged from moderately common (Station 1) to uncommon (Station 6) and rare (Station 5) in seine samples collected by the fisheries

team. The riverine grass shrimp was moderately common at Stations 2B and 6 in root mats and leaf litter and was uncommon at Station 5 in the same habitat. The amphipod *H. azteca* was predominantly found in root mats where is was common at Station 6, moderately common at Stations 1 and 2B, and uncommon at Station 5. The only other habitat noted for this species was its rare occurrence in muddy stick litter at Station 2B. The remaining species collected in 1999 was the isopod, *C. communis*, which was rare at Station 6 in root mats.

Crustaceans collected in the 1998 survey included the crayfishes *P. enoplosternum* and white river crayfish, the riverine grass shrimp, the amphipods *H. azteca,* an undetermined species of *Crangonyx* and an undescribed species of *Gammarus* and the isopod *C. communis*. The crayfish *P. enoplosternum* was found in root mats and leaf litter at Stations 1 and 2B (moderately common), root mats at Station 5 (abundant) and willow roots, detritus and leaf litter at Station 6 (common). The white river crayfish was moderately common in muddy leaf litter at Station 5, uncommon in willow roots at Station 6 and one crayfish was captured from an isolated pool at Station 1. The riverine grass shrimp was common at Station 6 in willow roots and moderately common at the remaining three stations in root mats as well as leaf litter at Stations 1 and 2B. The amphipod *H. azteca* was abundant at Stations 5 and 6 and moderately common at Station 2B. At Station 5 it was collected from root mats, under the bark of logs and in leaf litter, while at Station 6 it was abundant in water pennywort and moderately common in water hyacinth roots. At Station 2B it was picked from the fissures of rough bark and a clump of Spanish moss (*Tillandsia usneoides*) that had fallen into the river. The crangonyctid amphipod was uncommon at Station 6 in the same habitat as the other amphipods and rare at Stations 1 (root mats) and 2B (Spanish moss). The undescribed *Gammarus* was abundant at Station 6 in willow roots, detritus and from undercut banks and moderately common at Station 5 in the same habitat as the hyalellid amphipod. The isopod, *C. communis*, was common at Station 6 in root mats and detritus, moderately common in leaf liter and on logs at Station 2B and rare in muddy leaves at Station 5.

Five species crustaceans were noted in the 1997 survey consisting of the crayfish *P. enoplosternum*, the riverine grass shrimp, the amphipods *H. azteca* and an undescribed species of *Gammarus* and the isopod *C. communis*. *Procambarus enoplosternum* was common in the roots of riparian trees at all stations and water pennywort and leaf and stick litter at Station 6. The riverine grass shrimp was common in root mats at all four stations. The amphipod *H. azteca* was abundant at Stations 1 and 6 and moderately common at Station 5 and uncommon at Station 2B. At Station 1 it was more common in moss and less so in root mats, while at Station 6 it was equally abundant in root mats and water pennywort. At Stations 2B and 5 it was found only in root mats. The undescribed *Gammarus* was also collected from root mats, where it was abundant at Station 6 and moderately common at Station 5. The isopod, *C. communis*, was moderately common at Station 6 in root mats.

Crustaceans were especially well represented in the 1993 survey with six species that included the crayfish *P. enoplosternum*, the riverine grass shrimp, the isopod, *C. communis*; and the amphipods, *H. azteca,* an undescribed species of *Gammarus* and an undetermined species of *Crangonyx*. *Procambarus enoplosternum* was uncommon to common in the fine roots of riparian trees and leaf litter at Stations 1, 5 and 6 and uncommon at Station 2B where it was associated with brush piles and dense concentrations of root mats. The riverine grass shrimp was rare to very common at Stations 1, 5 and 6 and moderately common in riparian roots at Station 2B. The isopod was uncommon to very common at all study areas except Station 1 where it did not appear in samples. It was primarily found in the roots of riparian trees at all stations and the furrows of rugose logs at Station 5. The talitrid (*Hyalella*) and gammarid amphipods were collected at all stations, while the crangonyctid was found only at Station 6. All three amphipods were taken primarily from the same root mat and log habitats as the water slater. The gammarid was also recorded from leaf litter at Station 1. This is the first time that the crangonyctid had been collected from the main stem of the Savannah River since 1965 (ANSP 1966).

Four species of crustaceans were collected in September 1989 and included the crayfish *P. enoplosternum* (as *P. pubescens*), the riverine grass shrimp and the amphipods *H. azteca* and an undescribed species of *Gammarus*. *Procambarus enoplosternum* was common along both banks in beds of submerged aquatic vascular plants, leaf litter, brush piles as well as the fine roots of riparian trees at Stations 1, 5 and 6. The riverine grass shrimp was very abundant in submerged weed beds in both backwater areas and in the current at Stations 1, 5 and 6. The talitrid amphipod *H. azteca* and an undescribed species of gammarid in the genus *Gammarus,* were collected at Stations 5 and 6. *Hyalella azteca* was taken from submerged beds of aquatic vascular plants in backwater areas and among the stems of riparian grasses hanging in the water along the shore. The undescribed species of *Gammarus* was collected from weed beds in moderate current.

Five species of crustaceans were found in September 1984 at Stations 1, 5 and 6 and consisted of *Caecidotea communis* (as *Asellus communis*), *H. azteca*, a *Gammarus* species, the riverine grass shrimp and *P. enoplosternum* (as *P. pubescens*). The 1980 and 1976 surveys produced five and four species of crustaceans, respectively, as follows: the water slater at Station 5 (September 1980 and August 1976), talitrid amphipod at Stations 1, 5 and 6 in September 1980 and Stations 1 and 5 in August 1976, the gammarid amphipod (as *G. fasciatus* in 1976 and an undetermined species of gammarid in 1980) at Stations 5 and 6 (September 1980 and August 1976), the riverine grass shrimp *P. paludosus* (as *P. kadiakensis* in 1976) at Stations 5 and 6 in September 1980 and Stations 1, 5 and 6 in August 1976 and the crayfish *P. enoplosternum* (as *P. pubescens*) at Stations 1, 5 and 6 in 1980.

Mites (Arachnida)

Mites have generally been uncommon in Academy surveys dating back through the 1976 study. An undetermined species of *Lebertia* was uncommon at Station 1 and rare at Station 6. This taxon was a part of the fauna in habitats consisting of willow roots (Station 1) and the roots of water pennywort (Station 6).

A single species (*Lebertia*) of mite was discovered in 2000, where it was common at Station 1 in flooded grasses at the river margin. In 1999, an undetermined species of *Lebertia* was represented in root mat habitat where it was moderately common at Station 1 and rare at Station 6. An undetermined species of aquatic mite was rare in the same root mat habitat at Station 6. In 1998, an undetermined species of *Lebertia* was rare in leaf litter at Station 2B and root mats at Station 6. In 1997, an undetermined species of mite was moderately common in roots at Station 2B, while the undetermined *Lebertia* species was moderately common at Stations 1 and 2B in roots and uncommon at Station 6 in roots and water pennywort. A single undetermined species of mite occurred in litter samples from Station 6 in September 1993 and an undetermined species of *Hydrachna* was removed from a log at Station 2B. The undetermined species of *Lebertia* was moderately common at Stations 1 and 6 in 1989. No aquatic mites were collected in 1984 and the 1980 survey found only the *Lebertia* species at Station 6. The August 1976 study collected the *Lebertia* (?) species at Stations 1 and 5 and a mite of the genus *Arrenurus* at Station 1. During the 1972 survey six of seven species of mites (individuals of *Unionicola* are parasitic or commensal in the gills or mantle cavities of mussels) were collected from the luxuriant weed beds which were so prevalent at that time. With the decline in extent of these beds of aquatic vascular plants has been a decrease in the mite fauna that inhabits them. This group is most abundant in vegetated areas and is another of several taxa whose presence and/or abundance reflect the areal extent of submerged aquatic vascular plants.

Conclusions

Dominant Macroinvertebrate Groups

The results of the 2001 survey indicate that the principal groups of non-insect macroinvertebrates in the Savannah River in the vicinity of the Savannah

River Site are broadly similar to studies in the 1976 to 2000 period (ANSP 1977, 1981a, 1985b, 1991b, 1994a, 1994b, 1998, 1999 and 2001) with four major assemblages dominating. The most notable difference among recent studies is the lower numbers of mussels collected in 2000 and 2001. These numbers reflect the use of quadrat sampling versus the comprehensive qualitative hand collections of earlier surveys. In 2001, these dominant 4 macroinvertebrate groups collected at Stations 1 and 6 consisted of the bivalves [13 species: mussels (9) and clams (4)], snails (9), leeches (5), and crustaceans (3). These same four groups dominated the non-insect macroinvertebrate fauna of the previous nine studies (2000, 1999, 1998, 1997, 1993, 1989, 1984, 1980 and 1976) (Table B-2). Only in 1972 did an additional group, the mites, exhibit a diversity that made them a significant part of the fauna (loc. cit.). The remaining, less well-represented, taxonomic groups have been historically either widely collected (e.g., the planarian, *Girardia tigrina*; the earthworm, *Lumbriculus variegatus*; and an undetermined species of sponge), spotty in distribution (e.g., the ectoprocts and a nematomorph), usually rarely collected (e.g., the nemertean, *Prostoma rubrum*) or are not given the collecting and/or taxonomic effort of larger forms (e.g., nematodes and tubificids).

The number of snail taxa collected during the 1972 through 2000 surveys varies from 5 to 11 with an average of 7.6 species. The species totals from 1972 (11) and 2000 (5) represent the high and low ends of the range of species collected between these years. The 2001 total (9), although only from Stations 1 and 6, is above the modal (7) and mean (7.6) values for this period and second only to 1997 (10) and 1972 (11). The greatest number of species collected in 1972 was during a period when eutrophic conditions created large areas of habitat in the form of submerged vascular plants. A review of vegetation levels in the 1972 through 2001 period and other factors affecting species totals is discussed below in the section Species Diversity Among Years.

The five species of leeches taken at Stations 1 and 6 in 2001 compare well with the numbers taken during the years 1972 through 2000 (range 2 to 10, mean 4.5, mode 3 to 4 species). The number of species collected in 2001 is only

slightly lower than the 6 taxa found in 1997 and 1976 but half the number of species recorded in 1972 when large beds of submerged aquatic vascular plants were present. It should be noted that at least one other unidentified leech was collected at Station 5 in 2001. The addition of this species would raise the number of leech species collected in 2001 to at least six taxa, matching the highest number of taxa seen during the post eutrophic period since 1972.

The number of clam species collected has varied from 2 to 7 (mean 4.7, mode 4 to 5). Most of the sphaeriid clams taken at Stations 1 and 6 in 2001 were mottled fingernailclams (92.9%, 39 of 42 specimens). This species is more commonly found in riparian root mats. Other species of sphaeriids were not as well represented in the quadrat mussel survey, where sediments are sieved through a fine screen, as they were in 2000 (92.6%, 25 of 27 specimens).

The number of mussel species recorded from hand collections in the Savannah River surveys during the August to October, 1972 through 2000 period has ranged from 2 to 15 species with an average of 11.0 taxa. The most salient trend in the mussel data can be seen in the decrease of species from 1972 to 1989 (q.v., Table C-2). Prior to 1993, comprehensive studies were conducted twice a year and comparisons within and among years were made using both seasonal and combined data sets. The combined June and September 1989 total of five mussel species continued the trend of decreasing mussel diversity [15 (1972) to 14 (1976), 9 (1980 and 1984) to 5 (1989)]. In addition, a Savannah River mussel survey undertaken by Dr. Arthur Bogan (formerly of the Academy's Malacology Department) in August 1989 produced only single specimens of two of the five species collected in the June and September studies. The 1972 through 1989 trend prompted a more thorough mussel survey in 1993. Part of the 1993 effort included a review of the long-term data set of Academy studies and discussions with present and former personnel associated with the earlier Academy Savannah surveys. It was surmised that sampling the macroinvertebrate fauna to a depth that could be thoroughly searched in waders and spreading the field effort across all taxonomic groups had resulted in the collection of a more diverse non-mussel macroinvertebrate fauna but

fewer mussels [q.v., Tables B-1 (dominant taxa) and B-2 (total numbers of taxa)]. Between 1972 and 1984, samples were collected in waters up to neck deep. The effort in deeper water resulted in access to more permanently watered substrates and the collection of more mussel species (9 to 15). However, fewer non-mussel taxa were collected during this period. Studies from 1993 through 2001 have included both deeper water sampling at low water levels for mussels and a comprehensive sampling of the other macroinvertebrates. The two sampling efforts typically result in a more thorough assessment of the complete macroinvertebrate fauna [i.e., more species (see 1993 through 1998) including mussels (see 1972 to 1976 and 1993 through 1999)]. The conclusions of the mussel survey are discussed in a separate section below.

The number of crustacean taxa in 2001 (3 species) is slightly below the mean (5.1) and modal (5) values of crustaceans collected at four Savannah River stations. This number is at the lower end of the 4 to 7 range of previous studies. Other species of crustaceans that have been collected in past surveys and not at Stations 1 and 6 in 2001 include several species of crayfishes, an isopod and gammarid and crangonyctid amphipods. They have all been taken in small numbers, and their presence in the surveys has been spotty, although one or more are typically collected. However, their absence from a survey would not be unexpected. It should be noted that at least one other unidentified amphipod species was collected at Station 5 in 2001. The addition of this species would raise the number of crustaceans collected in 2001 to at least four taxa, a number closer to the species diversity seen in previous studies.

Additional details on habitat, abundance, frequency of occurrence and range of the dominant groups (leeches, snails, bivalves and crustaceans), as well as the once diverse mite fauna (q.v., Table B-2), can be found in the section Results, for each group.

Mussel Fauna

The nature of the mussel fauna in the Savannah River in the area of the Savannah River Site has changed since the early 1951 to 1968 studies when the yellow lamp mussel, eastern elliptio, Carolina slabshell, Atlantic spike, variable spike and rayed pink fatmucket were all listed as the most abundant species. Only the Carolina slabshell, variable spike and Atlantic spike were among the dominant taxa in hand collections in 1993 through 1999. The eastern elliptio and rayed pink fatmucket were moderately common and the yellow lamp mussel uncommon in the recent surveys. The "almost uniform distribution" of mussels "from juveniles through old adults (over eight years of age)" reported in 1960 was only observed in the paper pondshell in 1993 and 1997 and the Savannah lilliput in 1993, 1997 and 1998. This species is known only from four counties in North Carolina, a population in the Saluda River drainage in South Carolina (John Alderman, pers. com.) and as scattered populations in the Savannah River, Georgia and South Carolina. Near the Savannah River Site, most mussels are found in backwater areas near pilings and can only be studied by hand collecting at low water levels. Reasons for the decline in some species is unknown at this time.

The reduced numbers of juvenile mussels in hand collections since 1960 prompted the use of a quantitative method in 2000 and 2001 that would pass sediments through a sieve to recover small mussels. This method would provide abundance measures of mussels, Asian clams, sphaeriids (fingernailclams and peaclams) and the pointed campeloma snail. In 2000, the quadrat sampling was successful in collecting young mussels of the eastern elliptio, rayed pink fatmucket, Savannah lilliput, paper pondshell and eastern creekshell, while in 2001, young of the variable spike, Savannah lilliput and eastern creekshell were taken. The survey at four stations in 2001 (40 quadrats) produced 1877 molluscs consisting of 3 sphaeriids (0.2%), 122 mussels (6.5%), 1597 Asian clams (85.1%) and 155 pointed campelomas (8.3%). It is apparent that the introduced Asian clam numerically dominates the macrobenthic habitat of the Savannah River and because of its great numbers competes with the mussels for space and food resources.

The impact of low flows severely reduced or extirpated mussel populations, especially the Savannah lilliput at and near Station 5 (see Results, Mussels).

Species Diversity Among Years

The total number of species collected during the 1972 through 2001 surveys has varied from a low of 27 (1989) to a high of 60 (1972). The 2001 total (34 species) is less than average (mean 41.1, 1972 through 2000) and significantly lower than the recent 1993 through 1998 studies (47 to 49 species). To view at least recent trends, comparisons of the 2001 study with recent surveys (2000 to 1993) is complicated by the analysis of only the Stations 1 and 6 samples from the 2001 collections, except for the mussel fauna at all stations (1, 2B, 5 and 6). Comparisons of these recent surveys, except the 2000 study, is further complicated by using a quantitative analysis of the mussel fauna via quadrats. Quadrats survey much smaller areas of substrate, and fewer numbers of species are usually collected. Although the specimens from Stations 2B and 5 were not sorted and identified, it is clear from the field notes that undetermined species not found at Stations 1 and 6 were present in the 2001 samples.

Despite the uneven comparisons, the total number of taxa for 2001 is still similar to the results of 2000 (30), 1999 (37), 1984 (36) and 1980 (33). Compared to the 2000 study, in which the same technique was utilized to sample the mussel fauna, slightly more species were collected in the 2001 study (34). Like 2001, the 2000 study was conducted in a year with low flows. However, the lower numbers of species in 2000 were, in part, the result of limited access to habitats because of, ironically, higher water levels during the survey. Continued low flows during the summer months of 2000 lowered the base water level of the river. A new shoreline was established, root mat habitat was left high and dry and many populations of sessile and less vagile macroinvertebrate species were extirpated. Elevated water levels during the study, although still low in an historical context, limited access to species that occurred below the newly established base level. The greater number of snail

taxa in 2001 especially contributed to the larger number of species in 2001 (q.v., Table B-2). Compared to the higher species total in 1999 (37 species) and 1984 (36 species), the lower numbers in 2001 (34 species) are a result of less diversity in the mussel community due to the quantitative sampling (9 species) in 2001 vs the qualitative study in 1999 (13 species) as well as only analyzing the Station 1 and 6 samples in 2001. The fewer number of stations in 2001 is also the reason for the lower numbers in 2001 than 1984.

The higher numbers of species in some groups, as well as the total number of taxa in 1972, correlates with the dense stands of submerged aquatic plants. With the exception of the mussels, most members of the dominant five groups in Coastal Plain regions are typically abundant in areas associated with these dense stands, and their species richness and/or abundance reflects the areal extent of these growths. Since 1990 (ANSP 1991a, 1991b), the weed beds have been absent from the study areas, and population densities of many species have declined (e.g., snails sphaeriid clams, crustaceans and mites). The differences between the 1989 to 1976 and 1972 surveys reflect variation in effort, water levels and density of vegetation. In 1976, relative to 1972, there was a near disappearance of submerged vascular vegetation at Station 1 (ANSP 1977:37), vegetation among the pilings at Station 3 disappeared (op. cit: 38), the weed beds at Station 5 all but disappeared (loc. cit.), and Station 6 was expanded downriver into the present day lower section of Ring Jaw Point to reach aquatic vascular plant beds (op. cit: 39). Almost no beds were present in the upper portion of Station 6 (loc. cit.) in 1976. In 1980 there was a loss of vegetation at Station 1 (ANSP 1981:78), no beds at Stations 3 and 5 (op. cit:80) and smaller beds at Station 6 (op. cit:81). In 1984, submerged aquatic vascular plants varied from scarce at Stations 1 and 3 (ANSP 1985b:107) to lush and dense at Stations 5 and 6 (op. cit:107, 108). In 1989 (ANSP 1991b), patches of aquatic vascular plants were common, but by 1990 the submerged aquatic flora was either lacking, reduced to an occasional patch or represented by a few plants carried into the station by the river's current and ensnared by branches or logs. In 2001, patches of aquatic vascular plants were more abundant than in the recent (1999

to 2000) studies and provided habitat for a range of macroinvertebrates. The greater species richness in 1972 reflects an abundance of this habitat (=dense growths of submerged aquatic vascular plants). Submerged macrophytes provide one of the most important habitats in Coastal Plain streams, since this region generally lacks the well-indurated substrates of rock and cobble typical of lotic habitats above the Fall Line zone. The higher numbers of species in 1993 and 1997, when the submerged flora was reduced, are due to a greater collecting effort in other habitats (see individual species accounts). Two areas of strongest differences since the 1972 survey can be found in a comparison of the leech and mite species richness. A slightly higher total number of snail taxa was also collected in 1972. The decline in total numbers of taxa and dominance and abundance of some groups (leeches, snails, fingernailclams, peaclams, crustaceans and mites) is probably a reflection of the areal extent of the vegetation. The bagging of bottom debris and sorting of samples in a field laboratory in 1972 likely contributed some taxa to the species list.

Species Diversity Among Stations

A comparison of the species numbers of non-insect macroinvertebrates collected between 1972 and 2001 at Stations 1 and 6 reveals a generally higher average number of species collected at Station 6 (28.1) than at Station 1 (24.3). The 2001 and 1989 studies are the only surveys in which more species have been collected at Station 1 than any other station (q.v., Table B-1). Species totals at Station 1 in 1989 were higher as a result of storm events and an impending hurricane during the September survey. Stations 3 and 5 were collected the same day under rising water levels and Station 6 was surveyed under high water conditions. The higher number at Station 1 in 2001 may also reflect that more species may be present in the unsorted Station 5 samples. The long-term database for the August to October period indicates that, in a given survey, slightly more species are typically collected at Stations 5 (26.8) and 6 (28.1) than at either Stations 1 (24.3) or 2B/3 (21.1), and since 1972 more species have been collected at either Stations 5 and 6,

four years each, than at Station 1. The highest number of species collected in 1999 (29 species) was from both Stations 1 and 6. The high number of species at Station 1 in 1999 reflects a greater effort over a two-day period.

Summary

The most salient aspects of the 2001 study are the slightly lower numbers of species in the dominant groups (Table B-2) and lower total number of species (Table B-1). These lower numbers are a continuation of a trend that began in 1999 and primarily reflect drought conditions in the basin and lower flows in the Savannah River during these years. Water levels in the Savannah River have been low since June 1998. Low summer flows are normal, but these conditions have persisted with only a few occasional spikes in water levels into 1999, 2000 and 2001 (cf., ANSP 1994, 1998, 1999, 2000, 2001 and Figure 2 herein). The 2001 study was conducted in a year with the lowest flows to date. Compared to 1998 and earlier surveys, the low numbers of species in 2001 were probably, in part, also the result of the examination of only the Station 1 and 6 samples from the 2001 collections, except for the mussel fauna at all stations (1, 2B, 5 and 6). Comparisons of these recent surveys, except the 2000 study, is further complicated by using a quantitative analysis of the mussel fauna via quadrats. Quadrat sampling for mussels, although collecting a wider range of size classes, produces fewer species. This is usually especially true for the more rare taxa due to the smaller area surveyed, although in 2001 two of the five least abundant species of mussels, the Florida pondhorn and southern elktoe, were part of the 2001 species list, while none of these rarer taxa was taken in the 2000 quantitative study. More species were collected in 2001 than in 2000; the difference would have been even greater if specimens from Stations 2B and 5 had been examined. Although the results of the 2001 study produced fewer taxa than other recent studies (1993, 1997, 1998 and 1999), the numbers fall within the long-term trends (1972 to 2000) (Table B-1). The 2001 results reflect the drought conditions in the Savannah River

and are part of a faunal trend that was first apparent in the 1999 study. With a large number of less vagile species, non-insect macroinvertebrates appear to have been impacted by this extended period of low flows, including the loss of some mussel populations. The 2001 results do not indicate an impact on the non-insect macroinvertebrate biota of the Savannah River by the Savannah River Site.

Appendix B. List of taxa of non-insect macroinvertebrates collected 24 to 27 August and 7 to 10 September 2001 at Stations 1 and 6 (Stations 1, 2B, 5 and 6 for mussels) on the Savannah River, Georgia and South Carolina (X = present; - = not present; NA = not analyzed).

	Station			
Taxa	1	2B	5	6
Phylum Porifera				
Class Demospongiae				
Order Haplosclerina				
Family Spongillidae				
Undet. Sp.	X	*NA*	*NA*	X
Phylum Platyhelminthes				
Class Turbellaria				
Order Tricladida				
Family Dugesiidae				
Girardia tigrina (Girard)	X	*NA*	*NA*	X
Phylum Ectoprocta				
Class Phylactolaemata				
Family Plumatellidae				
Plumatella repens (Linnaeus)	X	*NA*	*NA*	X
Phylum Annelida				
Class Oligochaeta				
Class Hirudinea				
Order Rhynchobdellida				
Family Glossiphoniidae				
Desserobdella phalera (Graf)	X	*NA*	*NA*	–
Helobdella triserialis (Blanchard)	X	*NA*	*NA*	X
Placobdella montifera Moore	–	*NA*	*NA*	X
P. parasitica (Say)	–	*NA*	*NA*	X
Family Piscicolidae				
Piscicolaria reducta Meyer	X	*NA*	*NA*	–
Phylum Mollusca				
Class Gastropoda				
Order Mesogastropoda				
Family Viviparidae				
Campeloma decisum (Say)	X			X
Family Hydrobiidae				
Amnicola limosus (Say)	X	*NA*	*NA*	–
Order Basommatophora				
Family Lymnaeidae				
Pseudosuccinea columella (Say)	X	*NA*	*NA*	X

Appendix B (continued). List of taxa of non-insect macroinvertebrates collected 24 to 27 August and 7 to 10 September 2001 at Stations 1 and 6 (Stations 1, 2B, 5 and 6 for mussels) on the Savannah River, Georgia and South Carolina (X = present; - = not present; NA = not analyzed).)

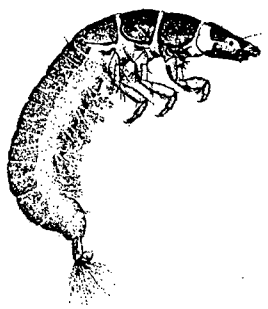
	Station			
Taxa	1	2B	5	6
Family *Planorbidae*				
Micromenetus dilatatus (Gould)	X	*NA*	*NA*	–
Helisoma anceps (Menke)	X	*NA*	*NA*	–
Family *Physidae*				
Physella heterostropha (Say)	X	*NA*	*NA*	X
Family *Ancylidae*				
Ferrissia rivularis (Say)	X	*NA*	*NA*	–
Laevapex fuscus (Adams)	X	*NA*	*NA*	–
Order Stylommatophora				
Family *Succineidae*				
Novisuccinea ovalis (Say)	X	*NA*	*NA*	–
Class Bivalvia				
Order Unionida				
Family Unionidae				
Alasmidonta triangulata (Lea)	–	--	--	X
Elliptio icterina (Conrad)	X	–	X	X
E. complanata (Lightfoot)	–	X	X	X
E. congaraea (Lea)	–	–	X	X
E. producta (Conrad)	–	–	X	X
Lampsilis splendida (Lea)	X	–	–	–
Villosa delumbis (Conrad)	X	–	X	X
Toxolasma pullus (Conrad)	X	–	–	X
Uniomerus carolineanus (Bosc)	X	–	–	–
Order Veneroida				
Family *Sphaeriidae*				
Euperba cubensis (Prime)	X	–	--	–
Pisidium casertanum (Poli)	X	–	--	–
P. compressum Prime	–	–	–	X
Family Corbiculidae				
Corbicula fluminea (Muller)	X	–	–	X

Appendix B (continued). List of taxa of non-insect macroinvertebrates collected 24 to 27 August and 7 to 10 September 2001 at Stations 1 and 6 (Stations 1, 2B, 5 and 6 for mussels) on the Savannah River, Georgia and South Carolina (X = present; - = not present; NA = not analyzed).)

	Station			
Taxa	**1**	**2B**	**5**	**6**
Phylum Arthropoda				
Class Crustacea				
Order Amphipoda				
Family Hyalellidae				
Hyalella azteca (Saussure)	X	NA	NA	X
Order Decapoda				
Family Cambaridae				
Procambarus enoplosternum Hobbs	X	NA	NA	X
Family Palaemonidae				
Palaemonetes paludosus (Gibbes)	X	NA	NA	X
Class Arachnoidea				
Lebertia sp.	X	NA	NA	X
Total	**27**			**22**

C. AQUATIC INSECTS

Introduction



Caddisfly

(*Hydropsyche orris*)

Aquatic organisms have provided water quality assessment programs with valuable insight for more than 100 years (Cairns and Pratt 1993), and benthic (i.e., bottom-dwelling) macroinvertebrates (especially aquatic insects, but also crustaceans, worms, mollusks, and other non-insects) are the most common group of aquatic organisms included in these programs (Hellawell 1986). Aquatic insects are included in water quality assessment programs because: (1) they provide an extended temporal perspective (relative to traditional water samples that are collected periodically) as a result of their limited mobility and relatively long life spans (e.g., a few months for some chironomid midges to a year or more for some beetles and dragonflies); (2) they are an important link in the aquatic food web, converting plant and microbial matter into animal tissue that is then available to fish; (3) the group has measurable responses to a wide variety of environmental changes and stresses; and (4) they are abundant and their responses can be easily analyzed statistically (Weber 1973). Thus, the presence or conspicuous absence of certain aquatic insect species at a site is a meaningful record of environmental conditions during the recent past, including ephemeral events that might be missed by assessment programs that rely only on periodic sampling of water chemistry.

The structure and function of the aquatic assemblage in the Savannah River can be affected by a diverse group of environmental factors, including direct and indirect interactions with depth, temperature, current velocity, volume of water input and release, nutrient levels, dissolved oxygen concentration, substrate type, sedimentation, erosion, metals, pesti-

cides, herbicides, food availability, intra- and interspecific competitors, and predators. These factors can vary temporally and spatially in response to natural processes (e.g., river topography, riparian vegetation, seasonal and annual changes in temperature or precipitation), as well as human influences (e.g., local fisheries management practices or urban, agricultural, forestry, mining, and/or industrial developments that result in non-point sources and discharges from numerous point sources within the watershed).

The aquatic insect component of the Savannah River monitoring program uses long-term and recent data to address the following goals: (1) to use spatial variation in the aquatic insect assemblage to assess current habitat and water quality in the Savannah River near the Savannah River Site (SRS), (2) to evaluate these current conditions with regard to conditions observed at these stations in previous surveys, and (3) to identify the effect (if any) of upstream factors (i.e., above Station 1) that may be affecting habitat and water quality in the Savannah River near SRS, and (4) to understand mechanisms that determine the distribution and abundance of aquatic insect populations within the Savannah River. These goals are addressed in the 2001 report by describing the aquatic insect assemblage at Stations 1 and 6 in September 2001, and by comparing the 2001 aquatic insect assemblage at these stations with the assemblages observed in recent surveys.

Materials and Methods

Location and Habitat Characteristics of the Study Area

In 2001, qualitative and quantitative aquatic insect collections were made at four stations (Stations 1, 2B, 5 and 6, numbered from upstream to downstream) in April (25-28) and September (6-8) (Table C-1). Although samples were taken at four stations and two seasons in 2001, only results for September samples from Stations 1 and 6 will be analyzed in this report. Stations 1 and 6 have typi-

Table C-1. Information concerning the placement, retrieval, and processing of Conservation Webbing traps from two stations (on the Savannah River in the vicinity of the SRS) in 2001. Qualitative collections were made on the same dates as traps were retrieved.

Station	Placement Date	Retrieval Date	Number Placed	Number Retrieved	Number Processed
1	*August* 8, 2001	*September* 8, 2001	4	4	4
6	*August* 8, 2001	*September* 6, 2001	4	3	3

cally been sampled as part of the Academy's Savannah Cursory and Comprehensive surveys. Fall sampling during all recent surveys (1998-2001) has been completed during the same general time period (September 6-20) due to consistently low flows.

All effluent and runoff from the SRS enter the Savannah River downstream of Station 1. Thus, river conditions observed at Station 1 are unaffected by SRS, and the station was designated *a priori* as a reference site for this study. The aquatic insect sampling area at Station 1 included all available habitats among the pilings near marker 78 on the left bank (facing downstream) and along the right bank opposite the pilings. In addition, any unique habitats observed within approximately 75 m upstream or downstream of these areas (on either bank) were also sampled.

Station 6 is the downstream most site on the Savannah River, below the confluence with Lower Three Runs. Aquatic insects were collected in the lower reach of this station, between RM 122.35 and 122.85. Aquatic insects at this station are exposed to discharge from the Vogtle Nuclear Power Plant and any discharge/runoff from the entire SRS, including what in carried in Lower Three Runs. Station 6 was designated *a priori* as a potential impacted site, integrating the effects of Vogtle Power Plant and the SRS. The aquatic insect sampling area at Station 6 included all available habitats among the pilings near marker 42 on the left bank (facing downstream) and along the right bank opposite the pilings. In addition, any unique habitats observed within approximately 75 m upstream or downstream of these areas (on either bank) were also sampled.

Qualitative Sampling

The strategy for the qualitative sampling program was to collect the insect fauna from all possible microhabitats within each station that could be safely sampled. This includes root masses (primarily willow); submerged and floating woody debris; floating and submerged vegetation; river pilings; rock, sand, and silt sediments; and edge habitat (very shallow areas along the shoreline). Collecting was generally along the margin of the river where the water was not as deep. We attempted to locate the same microhabitats at each station so that the collections were comparable. Overall, any recognizable microhabitat was examined intensively and the fauna present collected. Two people collected at each station, and the duration of collecting ranged from 8-10 person hours per station. In general, if no new recognizable species were found after collecting at a site for a few hours, it was assumed that the majority of species from the station had been collected. This method was the standard protocol used during previous surveys by The Academy of Natural Sciences (ANSP SOP S-04-01), although the overall collecting effort in 2001 (and also 1998-2000) may exceed recent efforts (e.g., 1990-1997) at these same sites.

Aquatic insects were collected from each station by sweeping a D-net through roots and submerged detritus; by removing medium-sized rocks and woody debris from the river, placing them in a bucket, and scrubbing them with a brush; by scrubbing submerged substrates (e.g., pilings in the river) with a net held downstream to collect dislodged specimens; by hand-picking specimens from natural substrates (leaves, wood, etc.); and by sieving smaller sediments through 4.76-mm, 1.47-mm, and 125-μm mesh sieves. Collected material was examined in enamel pans, insects were separated into larger taxonomic groups (e.g., orders), and all specimens were preserved in 90% ETOH immediately. Observations concerning important ecological characteristics such as depth, velocity, siltation, algal and weed growth, and physical disturbance were noted in the field. Additional notes were made concerning the distribution, relative abundance, and habitat preference of particular species.

All specimens were brought to the Stroud Water Research Center (SWRC), Avondale, PA. In the laboratory, the contents of each sample jar were transferred to petri dishes, and specimens identified to the lowest practical level (usually species), depending on size and condition of the individual specimens, and the availability of taxonomic keys. Identifications were done with the aid of a dissecting microscope (4-50X magnification) or compound microscope (40-1000X magnification). Chironomids were not subsampled in 2001, and all collected specimens were identified to genus or species. Selected specimens collected in 2001 have been incorporated into the permanent collections at the SWRC. Various terms including uncommon, rare, moderately abundant, abundant, and dominant are used in discussing the results of qualitative sampling and refer only to the relative size of populations in the opinion of the collectors.

Hypotheses concerning potential effects of effluent/runoff from the SRS were defined *a priori*. For aquatic insects, a negative impact resulting from SRS effluent was defined as a meaningful decrease in Total Richness, a decrease in richness of a pollution-sensitive group such as mayflies, or a decrease in relative abundance of a pollution-sensitive group such as mayflies (Weiderholm 1984). These decreases would be apparent at Station 6, downstream of SRS, if the SRS was negatively affecting water quality. Declines in richness would reflect the rareness or absence of species (or species groups), especially those known to be pollution sensitive (Hilsenhoff 1987, Lenat 1993). Concurrently, the relative abundance of pollution-tolerant species (or species groups) may increase (Weiderholm 1984). Employing personal judgment based on >40 years of field and laboratory experience (i.e., for J.K. Jackson, Ph.D., D.A. Lieb, D.H. Funk), the 2001 data and the historical data from the Savannah River near SRS were used to evaluate the conditions at each station and the significance of differences between stations.

These data were summarized in tables and figures that listed all taxa found at the separate stations, total numbers of species in each major order for each station and across stations. Long-term qualitative data for late summer/fall were available for Stations 1 and 6 (1955-2001). The long-term data

for the Savannah River near SRS presented in this report were from ANSP (1974a, 1977, 1980b, 1981a, 1985b, 1990a, 1991b, 1992b, 1993b, 1994b, 1996a,b, 1999, 2000 and 2001). Additional data may be available from other surveys, and will provide further perspective in future assessments as these data are incorporated into the comparisons.

Quantitative Sampling

Floating artificial substrates (insect "traps") were used to provide quantitative samples of insect abundance, even if high flow conditions made qualitative collections difficult. Traps were constructed of 0.64-cm (0.25-in) mesh hardware cloth in the form of a box, with dimensions of 15.2 cm x 20.3 cm x 30.5 cm (6 x 8 x 12 in). Each trap was filled with 9-10 rectangular sheets (approximately 20.3 x 30.5 cm) of Conservation Webbing (3M Company) to provide an interior substrate for aquatic insects. One rectangular piece of Styrofoam was added to the top of each trap for buoyancy because traps that sink tend to fill with silt, contain fewer insects, and can be difficult to retrieve in the field. The traps were tied to tree branches or pilings and left floating in the water. Four traps were placed in the field at the beginning of the colonization period. After colonization, the traps that remained (3-4 of the 4 placed in the field) were removed from the river and placed separately in large plastic tubs. Upon retrieval, current velocities varied among traps (i.e. some traps were retrieved from slow current while others were retrieved from fast current). On shore, the insects were removed from the traps by placing the traps in a water-filled basin (20-gal) and rinsing each piece of Conservation Webbing with clean river water from a battery powered pump. Slapping the webbing against the side of the basin also helped dislodge some specimens. Then, each piece of Webbing was scrubbed with a large plastic brush and clean river water was sprayed onto the webbing to remove the last of the attached detritus/insects. Finally, the contents of the holding tub and wash basin were poured through a pair of sieves which included a home-made sieve with 1.8 x 1.4-mm rectangular mesh (used in 1997 and earlier and referred to as the coarse sieve) followed by a standard 0.5 x 0.5-mm mesh

sieve (used in 1998 and 1999 and referred to as the fine sieve). All material (both insects and detritus) retained by the coarse sieve was transferred into a jar containing 10% buffered formalin. All material retained by the fine sieve was transferred into a separate jar which also contained 10% buffered formalin. Material retained by the coarse sieve was kept separate from that retained by the fine sieve in order to examine the potential impact of a reduction in mesh size (from 1.8 x 1.4-mm to 0.5 x 0.5-mm; done at the request of SRS) on the quantitative data and allow samples collected in 2001 to be compared to those collected prior to 1998. Each sample was labeled (with permanent black ink) on the lid and outside of the jar with information concerning river, station, date, and trap number. Notes pertaining to trap placement, conditions, and any other pertinent information were recorded in the field notebook. Samples were transported to the SWRC and stored until processing.

In the laboratory, 3-4 trap samples from each site and sampling date were processed. Each trap sample was split into four subsamples (each = 1/4th of a sample unit), one of these subsamples was split again into four subsamples (each = 1/16th of a sample unit), and finally one of these subsamples was split into four subsamples (each = 1/64th of a sample unit). Subsamples were then processed (sorted and identified) until 100-200 individuals were examined. Since macroin- vertebrate densities varied across sites and seasons, some samples required more processing than others (i.e. some samples were processed in their entirety while for other samples a 1/64th produced the required number of insects). Sample processing involved separating the aquatic insects from the detritus under a dissecting microscope and, as with the qualitative samples, specimens were identified to the lowest practical level (usually species). The level of identification depended on the size and condition of the individual specimens and the availability of taxonomic keys. Identifications were done with the aid of a dissecting microscope (4-50X magnification) or compound microscope (40-1000X magnification). All chironomids (as opposed to a subset as in years prior to 1998) in a subsample were identified to genus. Individuals of each taxon from a given sample were enumerated and most taxa were placed in separate

vials and preserved in 80% ETOH for future reference. Selected specimens collected in 2001 have been incorporated into the permanent collections at the SWRC. Our ability to separate insects from detritus and other material (i.e., our removal efficiency) was tested by resorting 15% of the samples we processed. Results of resorting indicated that our removal efficiency averaged 95%.

There is no single descriptor of aquatic insect assemblages that is generally accepted as better than all others (i.e., most accurate, most sensitive, most reliable, etc). Thus, the quantitative data were summarized as estimates of density for individual species or groups of species. Nine metrics, which are commonly used in water quality monitoring programs, were also calculated. Each of the variables described below is calculated from the same data set, which results in a certain degree of redundancy among the descriptors. Thus, when meaningful changes in aquatic insect assemblages occur, we would expect that those changes would affect more than one descriptor.

Density

Densities of selected genera/species (i.e., usually those that averaged > 100 individuals/trap at any station in at least one season) were examined. This included pollution-sensitive taxa [e.g., many Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)] and pollution-tolerant taxa [e.g., many Diptera (true flies), Odonata (dragonflies, damselflies), and Coleoptera (beetles)]. In response to moderate exposure to pollution, a decrease in the density of pollution-sensitive taxa accompanied by an increase in density of pollution-tolerant species would be predicted. In some cases, species densities were pooled together (i.e., to estimate densities of genera, families, orders, etc.) because densities were low and/or pooled groups provided a statistical resolution that was not available otherwise. Densities of Ephemeroptera, Plecoptera, and Trichoptera are commonly pooled together and analyzed as a group (EPT density) to assess changes in water/habitat quality in streams and rivers. Species in this group are generally more pollution-sensitive than other taxa; thus, a decrease in

EPT density would be predicted in response to moderate exposure to pollution. All density data were ln transformed, a standard procedure to correct for the clumped spatial dispersion of invertebrate populations in rivers (Elliott 1977).

Total Richness

Total Richness summarizes species responses (as presence/absence but not abundance) of all taxa, including pollution-sensitive and pollution-tolerant taxa. It is reported as the mean number of aquatic insect taxa found in each subsample. Total Richness generally decreases in response to moderate to severe pollution. Total Richness is often split into EPT Richness and Chironomid Richness.

EPT Richness

EPT Richness is reported as the mean number of Ephemeroptera, Plecoptera, and Trichoptera species found in each subsample. These three insect orders contain many pollution-sensitive taxa; thus, this metric summarizes responses of mostly pollution-sensitive taxa. EPT Richness generally decreases in response to moderate to severe pollution, and can be somewhat more responsive to environmental change than Total Richness.

Chironomid Richness

Chironomid Richness is reported as the mean number of chironomid midge genera/species found in each subsample. In terms of richness and abundance, the family Chironomidae is generally the most dominant family of aquatic insects in streams and rivers. In the Savannah River, chironomid midges represent about 30% of Total Richness and about 50% of density. Pollution tolerances among the species range from sensitive (e.g., similar to many Ephemeroptera, Plecoptera, or Trichoptera) to very tolerant, and are similar to the range generally observed across all non-chironomid species of aquatic insect species. Chironomid Richness generally decreases in response to

moderate to severe pollution, as more sensitive species are no longer able to survive at a site. Because some species are very tolerant, Chironomid Richness often represents most of Total Species Richness in cases of severe pollution.

Species Diversity

Species diversity (Shannon-Wiener Index) integrates both Total Richness and evenness (i.e., how individuals are apportioned across taxa); all taxa are included. Species diversity is estimated with data from each sample, and summarized as a mean. Species diversity generally decreases in response to moderate to severe pollution.

% Chironomidae

Chironomids are an important part of the aquatic insect assemblage in the Savannah River, often representing 50% of total insect abundance in the traps. While some chironomid species are sensitive to pollution (see Chironomid Richness above), other chironomid species are very tolerant of pollution (more than any Ephemeroptera, Plecoptera, or Trichoptera) and actually increase in abundance in response to moderate to severe pollution. Thus, while Chironomid Richness may decrease as more sensitive species are lost, % Chironomidae (i.e., % of total insect density) often increases in response to moderate to severe pollution. As with other percentage based metrics (see % Dominance-1, and % Dominance-5 below), percent Chironomid data were arc sine square root transformed before statistical analyses, a standard procedure for percentage data (Elliott 1977).

% Dominance-1

Percent Dominance-1 is the percent contribution (% of total density) of the taxon with the greatest abundance in a given sample. Percent Dominance often increases in response to moderate to severe pollution, similar to % Chironomidae.

% Dominance-5

Percent Dominance-5 is the percent contribution (% of total density) of the five taxa (rather than a single taxon, see above) with the greatest abundance in a given sample. Percent Dominance-5 often increases in response to moderate to severe pollution, similar to % Chironomidae. This metric was recently found to be more informative than % Dominance-1 using data from over 450 sites in Maryland, Pennsylvania, Virginia and West Virginia (Smith and Voshell 1997).

Hilsenhoff Biotic Index

Analyses involving abundance (i.e., density) or presence/absence (richness) are only able to incorporate pollution tolerance information indirectly, through the interpretation of results for individual taxa or groups of taxa. Biotic indices combine abundance data and pollution tolerance values for each taxon to form a weighted average for the aquatic insects at that site. A biotic index is estimated with data from each sample, and summarized as a mean per sample. Tolerance values (values range from 0 to 10, with 10 being most tolerant and 0 being least tolerant of pollution) for the Hilsenhoff Biotic Index (HBI) were obtained from Hilsenhoff (1987) and Plafkin et al. (1989). These tolerance values generally address only genera; thus, family values were derived from generic identifications.

NC Biotic Index

Similar to the Hilsenhoff Biotic Index, the North Carolina Biotic Index (NCBI) combines abundance data and pollution tolerance values for each taxon to form a weighted average for the aquatic insects at that site. Tolerance values for this analysis were obtained during intensive studies by David Lenat and his colleagues (Lenat 1993, personal communication) in numerous streams and rivers throughout North Carolina. Thus, the data may be more applicable to the Savannah River than tolerance values derived by Hilsenhoff (1987) or Plafkin et al. (1989). Toler-

ance values are estimated for species when possible (values range from 0 to 10, with 10 being most tolerant and 0 being least tolerant to pollution). The variation among species within some genera illustrate the value of species identifications, and contribute to the differences often observed between HBI and NCBI.

Statistical Analysis of Abundance and Community Structure Data

The primary objective of our analysis of the 2001 quantitative data was to examine the aquatic insect assemblages (as described by abundance of certain species or groups of species, or summary indices) at Station 1 (i.e., the reference site) compared to Station 6 (i.e., the potentially impacted site). Our approach to addressing this question involved using analysis of variance (ANOVA) to examine if densities of common taxa varied between the two stations. The null hypothesis was that the aquatic insect assemblages did not differ significantly between the stations. All analyses employed the General Linear Models procedure of the SAS (1985) Statistical Analysis System. If differences between stations were observed for any variable, we attempted to determine whether these differences could be attributed to an effect of effluent or runoff from the SRS by comparing the differences with responses predicted *a priori* for that variable, and with responses observed for other variables. Differences that did not conform or appeared to be contradictions (e.g., Total Richness increases while EPT Richness decreases) with respect to *a priori* predictions were considered inconsistent with a SRS effect. Means and standard errors presented in this report were calculated with untransformed data.

Our second objective was to use September quantitative data collected from 1998 through 2001 to examine if Stations 1 and 6 had similar patterns each year. The analysis was limited to these four years of data because all samples had been processed using a fine-mesh sieve. Earlier samples had been processed using a coarse-mesh sieve. To determine if insect groups differed between stations and among years, we used

a two-way analysis of variance (ANOVA: station, year, station-year interaction), with a Tukey's multiple range test to determine the significance of station differences.

Our third objective was to determine how the reduction in the size of the mesh used during 2001 field processing (see quantitative sampling method section for details of this change) affected density estimates for common orders and families and estimates of selected community structure indices (Species Richness, EPT Richness, Chironomidae Richness, HBI, NCBI, Shannon-Wiener Diversity, % Dominance-1 taxon, % Dominance-5 taxa, and % Chironomidae). For each station in 2001, a multivariate analysis of variance (MANOVA, 3 orders, 2 mesh-sizes) was used to determine if the relative abundances for the three most common orders (Ephemeroptera, Trichoptera and Diptera) differed between the mesh-sizes.

Results

Conditions at Station 1 Based on Qualitative Collections

A total of 93 taxa including 24 EPT taxa were collected in September 2001 from Station 1 (Tables C-2 and C-3). Three mayfly taxa (*Baetis intercalaris*, *Caenis punctata* and *Tricorythodes* spp.), three caddisfly taxa (*Cheumatopsyche* spp., *Nectopsyche* spp. and *Chimarra* spp.), one gerrid (*Trepobates*), and four beetle taxa (*Dineutus discolor*, *Stenelmis hungerfordi*, *Neoporus hybridus* and *Coptotomus* nr. *loticus*) were abundant at Station 1. The dytiscids (*Neoporus hybridus* and *Coptotomus* nr. *loticus*) were found in the backwater. *Baetis intercalaris*, *Cheumatopsyche* spp., *Nectopsyche* spp. and *Chimarra* spp. were found in moderate to fast current, especially in willow root snags. Another taxon (*Tricorythodes* spp.) was abundant in slow current root masses. Chironomid abundance and richness (32 taxa collected) were high and 4 taxa were abundant. These taxa (*Dicrotendipes* nr. *modestus*, *Polypedilum illinoensi* grp., *Polypedilum halterale* grp., and *Ablabesmyia ramphe* grp.) constituted 55% of the chironomids collected.

Table C-2. List of aquatic insects collected from the Savannah River at Stations 1 and 6 in the vicinity of the Savannah River Site in September 2001. Qualitative columns represent hand collections from all available habitats at each station. Quantitative columns are data from traps suspended on the river's surface. X indicates presence of a taxon; — indicates none were collected at that station.

	Qualitative		*Quantitative*	
	1	6	1	6
Phylum Arthropoda				
Class Insecta				
Order Odonata				
Suborder Anisoptera	—	—	x	—
Family Corduliidae				
Subfamily Corduliinae				
Epitheca (=Epicordulia) princeps	x	—	—	—
Neurocordulia sp.	—	—	x	x
Neurocordulia alabamensis	x	x	—	x
Neurocordulia molesta	—	x	—	—
Subfamily Macromiinae				
Macromia spp.	x	x	x	—
Macromia illinoiensis georgina	x	x	—	—
Family Gomphidae				
Dromogomphus spinosus	x	—	—	—
Gomphus sp.	—	x	—	—
Family Libellulidae				
Libellula sp.	x	x	—	—
Suborder Zygoptera	—	—	—	x
Family Calopterygidae				
Hetaerina americana	—	x	—	x
Hetaerina titia	—	x	—	x
Family Coenagrionidae	—	—	x	x
Argia spp.	—	x	—	—
Argia apicalis/tibialis	x	—	—	—
Argia nr. moesta	x	—	—	—
Argia sedula	x	x	—	—
Argia translata	—	x	—	—
Enallagma spp.	x	—	x	—
Enallagma divagans	—	x	—	—
Enallagma signatum	x	—	—	—
Order Ephemeroptera	—	—	x	x
Family Baetidae	—	—	x	x
Baetis spp.	—	—	x	x
Baetis intercalaris	x	x	x	x
Callibaetis sp.	x	—	—	—
Heterocloeon sp.	—	—	x	—
Pseudocloeon propinquum grp.	x	x	—	x
Plauditus spp.	x	—	—	—
Centroptilum/Procloeon spp.	x	—	—	—
Centroptilum sp.	—	x	—	—
Family Caenidae	—	x	—	x
Caenis spp.	x	—	x	x
Caenis punctata	x	—	—	—
Caenis amica	x	—	—	—

Table C-2(continued). List of aquatic insects collected from the Savannah River at Stations 1 and 6 in the vicinity of the Savannah River Site in September 2001. Qualitative columns represent hand collections from all available habitats at each station. Quantitative columns are data from traps suspended on the river's surface. X indicates presence of a

	Qualitative		*Quantitative*	
	1	6	1	6
Family Heptageniidae	—	—	X	X
Heptagenia spp.	—	X	—	—
Heptagenia flavescens	—	X	—	—
Macdunnoa sp.	X	X	—	—
*Stenonema spp.***	—	—	X	X
Stenonema exiguum	X	X	X	—
Stenonema mexicanum integrum	X	X	X	X
Stenonema modestum	X	X	X	X
Stenonema nr. terminatum	—	—	—	X
Stenonema terminatum	X	X	—	—
Family Isonychiidae				
Isonychia spp.	—	X	X	X
Family Leptohyphidae	—	—	X	X
Tricorythodes spp.	X	X	X	X
Order Plecoptera				
Family *Perlidae*				
Paragnetina kansensis	—	X	—	—
Family *Pteronarcyidae*				
Pteronarcys dorsata	X	X	—	—
Order Heteroptera				
Family Belostomatidae				
Belostoma spp. (larva)	—	X	—	—
Belostoma flumineum	X	—	—	—
Family *Corixidae*	X	—	—	—
Palmacorixa sp.	X	—	—	—
Trichocorixa spp.	—	X	—	—
Trichocorixa calva	X	—	—	—
Family Gerridae				
Rheumatobates spp.	X	—	—	—
Rheumatobates tenuipes	X	—	—	—
Rheumatobates trulliger	X	—	—	—
Trepobates spp.	X	—	—	—
Order Megaloptera				
Family *Corydalidae*	—	—	—	X
Corydalus cornutus	X	X	X	X
Order Lepidoptera				
Family *Pyralidae*	—	X	—	—
Parapoynx spp.	X	X	—	X
Order Trichoptera	—	—	X	X
Family Brachycentridae				
Brachycentrus numerosus	—	X	—	—
Family Hydropsychidae	—	—	X	X
Cheumatopsyche spp.	X	X	X	X
Hydropsyche spp.	—	—	X	—
Hydropsyche mississippiensis [1]	X	X	—	X
Hydropsyche rossi [2]	X	—	X	X
Macrostemum spp.	—	—	—	X
Macrostemum carolina	—	X	—	X

Table C-2(continued). List of aquatic insects collected from the Savannah River at Stations 1 and 6 in the vicinity of the Savannah River Site in September 2001. Qualitative columns represent hand collections from all available habitats at each station. Quantitative columns are data from traps suspended on the river's surface. X indicates presence of a

	Qualitative		*Quantitative*	
	1	6	1	6
Family Hydroptilidae	—	—	x	x
Hydroptila spp.	—	—	x	—
Family Leptoceridae	x	—	x	x
Ceraclea spp.	—	—	x	x
Ceraclea maculata	x	—	—	—
Ceraclea mentiea	—	x	—	—
*Oecetis spp.****	x	x	x	x
Nectopsyche spp.	x	x	x	x
Nectopsyche candida	—	—	x	—
Triaenodes spp.	—	—	x	—
Triaenodes tardus	x	—	—	—
Triaenodes injustus	x	x	—	—
Family Philopotamidae	—	—	x	x
Chimarra spp.	x	x	x	x
Family Polycentropodidae	—	—	x	—
Neureclipsis crepuscularis	x	—	x	x
Order Coleoptera				
Family Dytiscidae				
Coptotomus nr. loticus	x	x	—	—
Laccophilus fasciatus rufus	—	x	—	—
Neoporus (=Hydroporus) spp.	x	—	—	—
Neoporus clypealis	—	x	—	—
Neoporus venustus	x	—	—	—
Neoporus hybridus	x	—	—	—
Family Elmidae				
Ancyronyx variegata	x	x	—	—
Dubiraphia vittata	x	x	x	—
Macronychus glabratus	x	x	x	—
Optioservus sp.	x	—	—	—
Stenelmis spp.	—	x	—	x
Stenelmis hungerfordi	x	x	x	x
Stenelmis antennalis	x	x	—	—
Family Gyrinidae				
Dineutus spp.	x	x	—	x
Dineutus assimilis	x	—	—	—
Dineutus discolor	x	x	—	—
Gyrinus analis/lugens	—	x	—	—
Gyrinus analis	x	—	—	—
Family Haliplidae				
Haliplus fasciatus	—	x	—	—
Peltodytes spp.	x	x	—	—
Peltodytes bradleyi	x	x	—	—
Peltodytes dunavani	—	x	—	—
Peltodytes sexmaculatus	x	x	—	—

Table C-2(continued). List of aquatic insects collected from the Savannah River at Stations 1 and 6 in the vicinity of the Savannah River Site in September 2001. Qualitative columns represent hand collections from all available habitats at each station. Quantitative columns are data from traps suspended on the river's surface. X indicates presence of a

	Qualitative		*Quantitative*	
	1	6	1	6
Hydrophilidae				
Berosus sp.	X	X	—	—
Berosus aculeatus	—	X	—	—
Derallus altus	—	X	—	—
Enochrus ochraceus	—	X	—	—
Hydrochus sp.	—	X	—	—
Sperchopsis tessellata	—	—	—	X
Tropisternus sp.	—	X	—	—
Tropisternus blatchleyi blatchleyi	—	X	—	—
Tropisternus collaris striolatus	—	X	—	—
Tropisternus lateralis nimbatus	—	X	—	—
Scirtidae				
Cyphon sp.	—	X	—	—
Order Diptera				
Family *Ceratopogonidae*	—	—	—	X
Palpomyia/Bezzia spp. complex	X	X	X	X
Family *Empididae*	—	—	X	—
Hemerodromia spp.	X	—	X	X
Family *Simuliidae*	—	—	X	X
Simulium spp.	X	X	X	X
Family *Tipulidae*	—	X	—	—
Limonia sp.	X	—	—	—
Tipula sp.	—	X	—	—
Family: *Chironomidae*	—	—	X	—
Subfamily: *Tanypodinae*	—	—	X	X
Ablabesmyia spp.	—	—	X	—
Ablabesmyia ramphe grp. sp.	X	X	—	—
Ablabesmyia mallochi	X	X	—	—
Clinotanypus sp.	X	—	—	—
Coelotanypus sp.	—	X	—	—
Conchapelopia sp.	—	—	X	—
Labrundinia sp.	—	—	—	X
Nilotanypus spp.	—	—	X	X
Pentaneura nr. inconspicua	—	—	—	X
Procladius (Holotanypus) sp.	X	X	—	—
Rheopelopia sp.	X	X	X	—
Thienemannimyia spp.	—	—	X	—
Tanypus punctipennis	X	X	—	—
Subfamily: *Orthocladiinae*	X	—	—	X
Corynoneura spp.	—	—	X	X
Cricotopus cf. patens	X	X	—	—
Cricotopus nr. politus	X	X	—	—
Cricotopus bicinctus grp. sp.	X	X	—	—
Cricotopus/Orthocladius spp.	X	X	X	X
Thienemanniella spp.	—	—	X	X
Tvetenia discoloripes grp. spp.	X	—	X	X

Table C-2(continued). List of aquatic insects collected from the Savannah River at Stations 1 and 6 in the vicinity of the Savannah River Site in September 2001. Qualitative columns represent hand collections from all available habitats at each station. Quantitative columns are data from traps suspended on the river's surface. X indicates presence of a

	Qualitative		*Quantitative*	
	1	6	1	6
Subfamily: Chironominae				
Tribe: Chironomini	—	X	X	—
Chironomus sp.	X	X	X	—
Cladopelma sp.	X	X	—	—
Cryptochironomus spp.	X	X	—	—
Cryptotendipes sp.	X	—	—	X
Dicrotendipes sp.	X	X	—	—
Dicrotendipes neomodestus	X	X	—	—
Dicrotendipes sp. nr. modestus	X	X	—	—
Harnischia sp.	—	—	X	—
Parachironomus nr. carinatus	X	—	X	—
Phaenopsectra obedians grp. sp.	X	—	—	—
Polypedilum spp.	X	X	X	X
Polypedilum sp. illinoensi grp.	X	X	—	—
Polypedilum convictum grp.	X	X	—	—
Polypedilum fallax	X	—	—	—
Polypedilum scalaenum grp.	X	—	—	—
Polypedilum halterale grp.	X	X	—	—
Stenochironomus spp.	X	X	X	—
Tribelos fuscicorne	X	—	—	—
Xenochironomus xenolabis	X	—	—	—
Tribe: Tanytarsini	—	—	X	—
Cladotanytarsus sp.	X	X	X	—
Paratanytarsus sp.	X	—	—	—
Rheotanytarsus spp.	X	X	X	X
Tanytarsus spp.	X	X	X	X
Tanytarsus sp. 2 Funk	X	X	—	—
Tanytarsus sp. 4 Funk	—	X	—	—
Tanytarsus sp. E Epler	X	X	—	—
Tanytarsus sp. O Epler	X	—	—	—

1 *H. simulans* according to Schuster

2based on Academy vouchers verified by Boris, Schuster couldn't confirm it- never seen rossi larva

Table C-3. Total number of insect taxa, number of EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa, and number of insect taxa by order collected from the Savannah River in the vicinity of the Savannah River Site in September 2001, qualitative collections only.

Order	Station		
	1	6	Both Stations
Odonata	10	10	15
Ephemeroptera	13	13	16
Plecoptera	1	2	2
Hemiptera	6	2	6
Megaloptera	1	1	1
Lepidoptera	1	1	1
Trichoptera	10	9	13
Coleoptera	15	22	26
Diptera	36	26	39
EPT	24	24	31
Total	93	86	119

Some EPT groups were rare or missing from September collections. The most obvious group was the stoneflies; only a single individual (*Pteronarcys dorsata*) was collected. The mayfly *Isonychia* and the caddisfly *Macrostemum* were also absent.

Conditions at Station 6 Based on Qualitative Collections

A total of 86 taxa including 24 EPT taxa were collected from Station 6 in September 2001 (Tables C-2 and C-3). A number of taxa including the damselfly *Hetaerina americana*, the mayflies *Baetis intercalaris*, *Tricorythodes* spp. and *Isonychia* spp., the stonefly *Paragnetina kansensis*, the caddisflies *Cheumatopsyche* spp., *Nectopsyche* spp. and *Chimarra* spp., the beetles *Peltodytes dunavani*, *Gyrinus analis/lugens*, *Dineutus discolor*, *Stenelmis hungerfordi* and *Stenelmis antennalis*, and the dipterans *Coelotanypus* spp.,

Chironomus spp., *Tanytarsus* sp. 2 Funk and *Tanytarsus* sp.E Epler were abundant at Station 6 in September. Of the taxa listed above, the baetid mayfly *Baetis intercalaris* and the stonefly *Paragnetina kansensis* were collected primarily from pilings and associated woody debris in moderate to fast current while the beetles *Stenelmis hungerfordi* and *S. antennalis* were mainly collected from willow roots in moderate to fast current. Other abundant taxa including *Isonychia*, *Nectopsyche* spp. and *Chimarra* were found among both willow roots and woody debris in moderate to fast current. The four most abundant chironomid taxa (*Tanytarsus* sp. 2 Funk, *Tanytarsus* sp.E Epler, *Coelotanypus* spp. and *Chironomus* spp.) constituted 65% of the chironomids collected. Except for the collection of one belostomatid taxon and one corixid taxon, hemipterans were absent from Station 6 collections in September.

Comparison of Station 1 with Station 6 for September 2001 Based on Qualitative Collections

Total richness was slightly lower at Station 6 (86 vs. 93 at Station 1) and EPT Richness was identical (24 at both stations). The difference in total richness was due primarily to a greater number of dipteran (mostly chironomid) species at Station 1 (36 vs. 26 at Station 6).

Despite the somewhat lower total richness, several important indicator species were present at Station 6 that were missing at Station 1. For example, the mayfly *Isonychia* spp. and the stonefly *Paragnetina kansensis* were both abundant at Station 6, but missing altogether from Station 1. Similarly, the caddisfly *Macrostemum carolina* was common at Station 6, but missing from Station 1. This pattern has been observed consistently in recent surveys (1998-2001). These three taxa are relatively intolerant of pollution (NCBI values of 3.8, 2.0 and 3.6, respectively).

The damselflies *Hetaerina americana* and *H. titia* were both found at Station 6 in fall 2000 and 2001 (*H. americana* was abundant in 2001), but neither species has been found at Sta-

tion 1 in recent surveys. The elmid beetles *Stenelmis hungerfordi* and *S. antennalis* were both abundant at Station 6, but much less common at Station 1, a pattern that has been evident in all recent surveys.

Although chironomid midge richness was higher at Station 1 (32 vs. 23 at Station 6), the 4 numerically dominant taxa, composing 55% of the chironomids collected, are relatively tolerant (*Dicrotendipes* nr. *modestus,* NCBI=9.2; *Polypedilum illinoensi* grp., 9.2; *Polypedilum halterale* grp., 7.2; and *Ablabesmyia ramphe* grp., unknown tolerance value). Tolerance values for the four most abundant chironomid taxa at Station 6, composing 65% of the chironomids collected, are generally lower (*Tanytarsus* sp. 2 Funk, NCBI=6.7; *Tanytarsus* sp.E Epler, 6.7; *Coelotanypus* spp., 6.2; and *Chironomus* spp., 9.8).

Differences Among Stations Based on Recent Qualitative Collections

Some differences among stations have been observed repeatedly during recent (1998-2001) qualitative surveys. These include the scarcity of stoneflies at Station 1 compared to Station 6. Stoneflies have been absent from Station 1 during all recent fall surveys except for a single *Pteronarcys dorsata* individual collected in 1998 and another in 2001. The caddisfly *Macrostemum* has been absent from Station 1 during most recent surveys (the exception was the collection of one individual from Station 1 in May 1999), but has been collected from Station 6 during all recent surveys. Other taxa, including the ephemerellid mayflies and *Heptagenia*, were much less abundant at Station 1 than at the downstream Station 6 during most recent spring surveys. Additionally, the damselfly *Argia sedula* was always absent from Station 1 (except for a single individual found in fall 2001), but was always collected from Station 6 during recent surveys. Similarly, the mayfly *Isonychia* was always absent from Station 1 in the fall (although a few individuals were collected in Spring 1998 and one in Spring 2001), but was abundant at Station 6 during most spring and fall surveys.

Long-term Trends in Taxa Richness Based on Qualitative Collections

The results of late summer-fall surveys indicate that total richness and richness within most major orders of aquatic insects have generally increased since the late 1980s/early 1990s (Figs. C-1 to C-8). Total richness at Stations 1 and 6 (Fig. C-1) appears to follow the same pattern over the long term, with neither station consistently higher or lower. The long-term pattern at both sites suggests that overall water quality has improved since the mid-1980s. River flow conditions more favorable for collecting and/or greater sampling effort during recent surveys could have also contributed to this long-term pattern. The absence of a consistent difference in total richness between Stations 1 and 6 suggests there is no negative effect of the SRS.

EPT richness at Station 1 has been lower than at Station 6 for 15 of the 17 fall sampling periods for which we have data (Fig. C-2), suggesting water quality below the SRS is higher than that above the SRS. The difference in EPT richness appears to be due primarily to Ephemeroptera (Fig. C-3) and Plecoptera (Fig. C-4); Trichoptera richness (Fig. C-5) appears to be quite similar on average. Odonata and Coleoptera richness (Figs. C-6 and C-7) have shown no consistent difference. The same is true for Diptera richness (Fig. C-8), although for the last three years (1999-2001) richness at Station 1 appears to be higher. Because Ephemeroptera and Plecoptera are generally pollution sensitive, the above patterns are consistent with the observation based on total richness that aquatic insects exhibit no negative response to the SRS.

September 2001 Quantitative Collections

Total insect densities averaged from 8,758 to 10,053 individuals/trap in September 2001 (Table C-4).

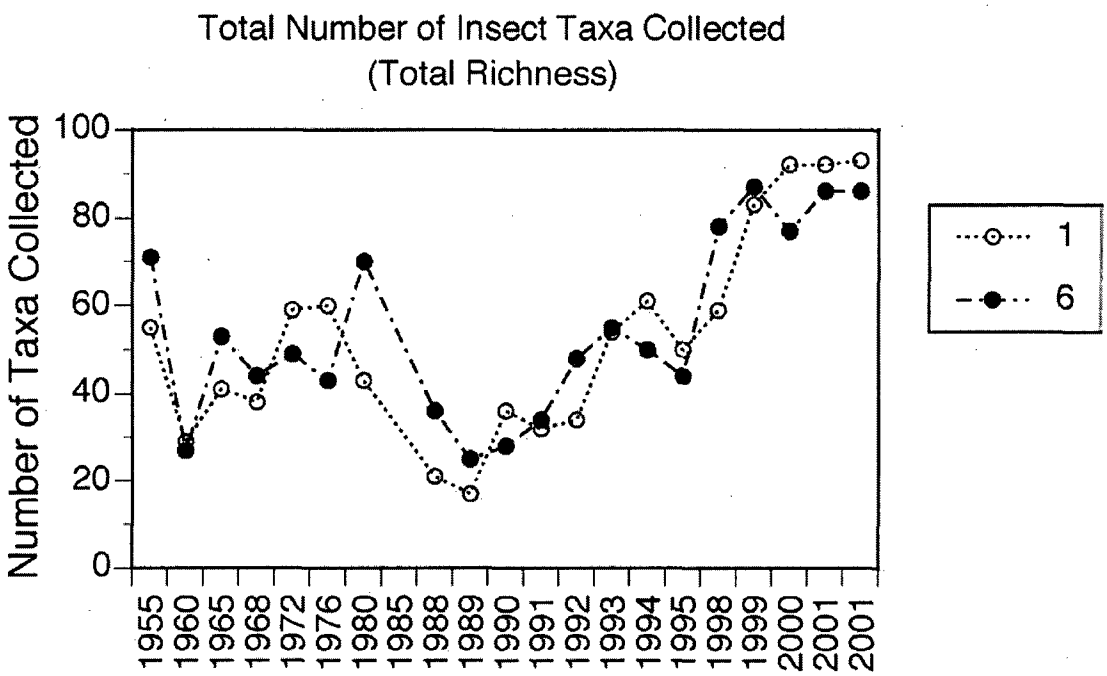


Figure C-1. Total number of insect taxa qualitatively collected (total richness) at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1955-2001).

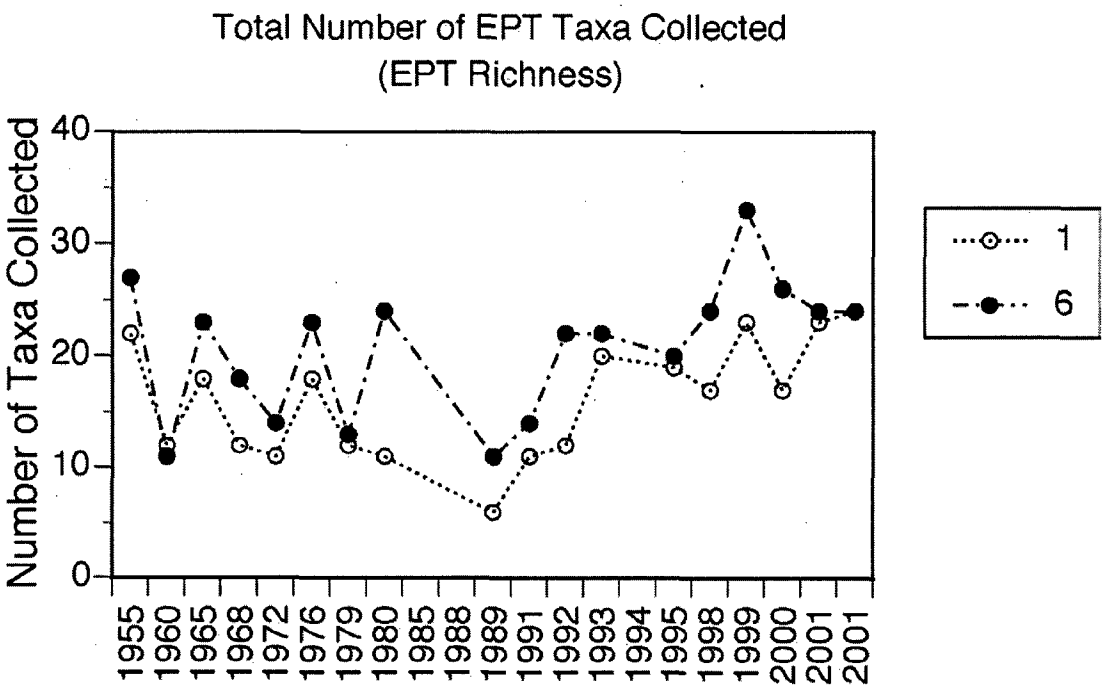


Figure C-2. Total number of EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa (EPT richness) qualitatively collected at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1955-2001).

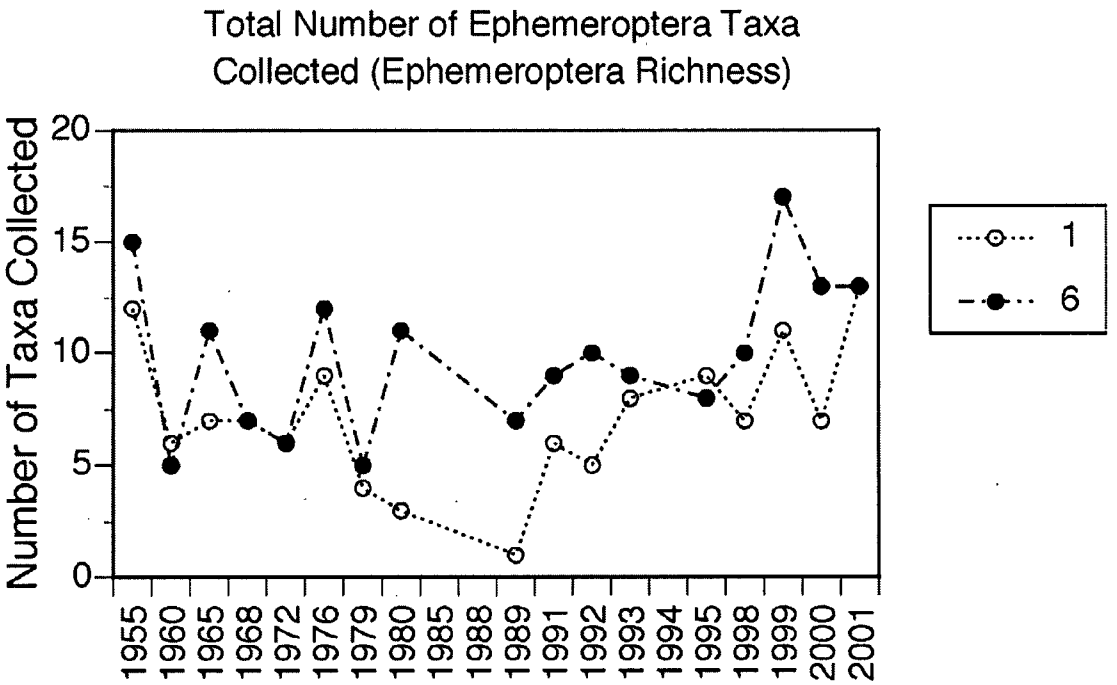


Figure D-3. Total number of Ephemeroptera taxa (Ephemeroptera richness) qualitatively collected at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1955-2001).

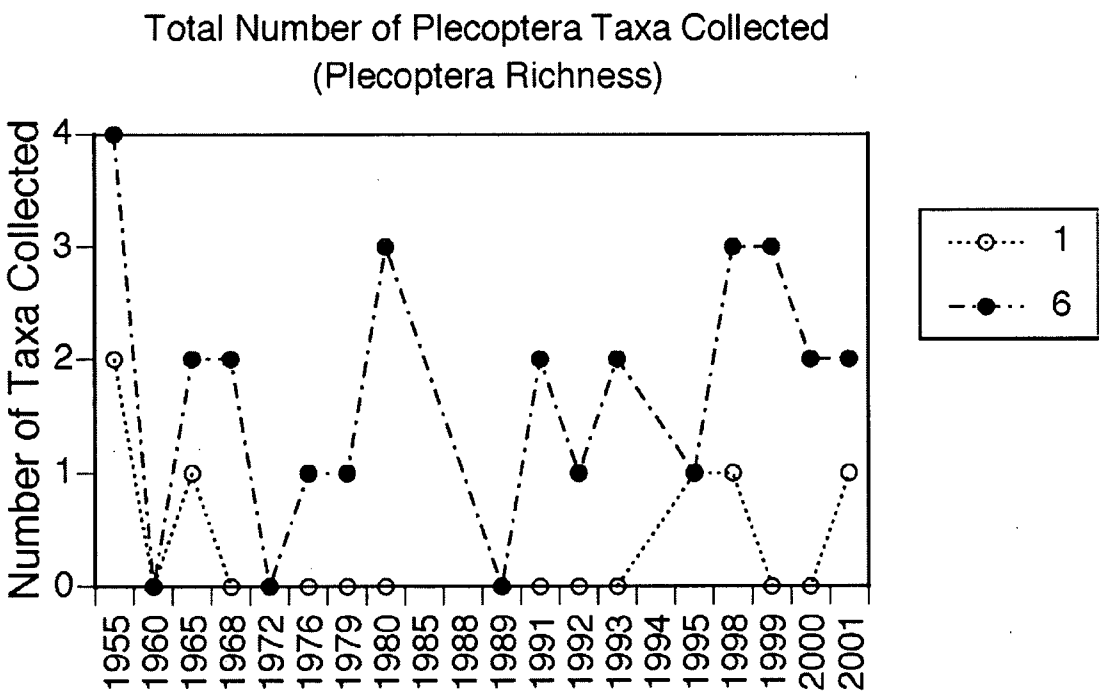


Figure C-4. Total number of Plecoptera taxa (Plecoptera richness) qualitatively collected at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1955-2001).

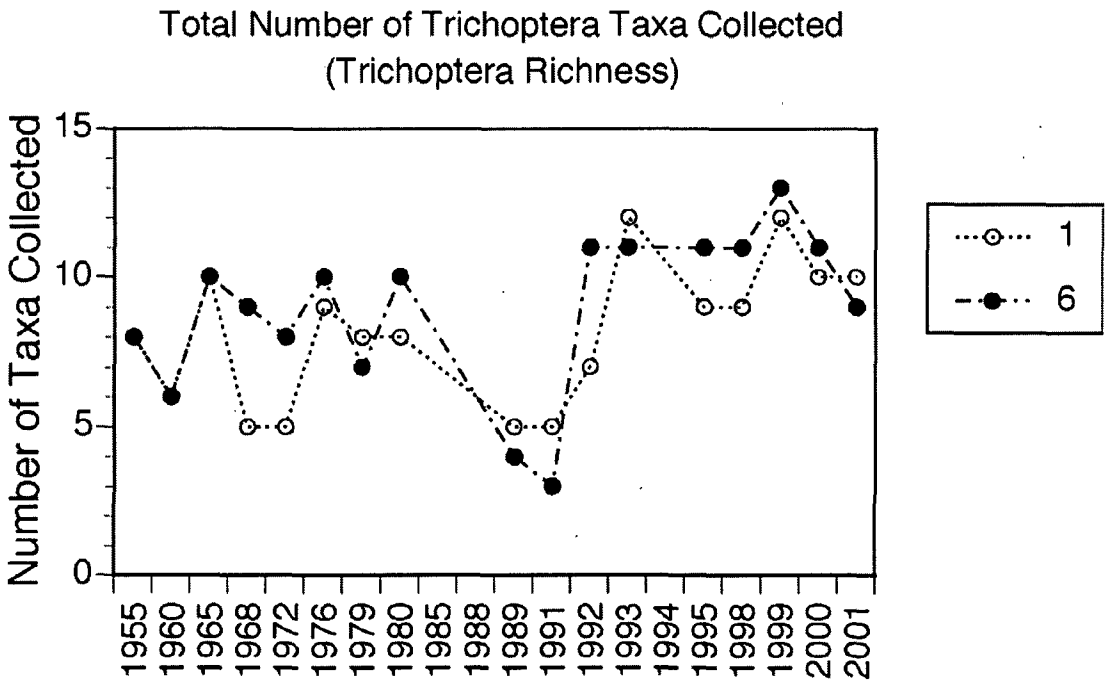


Figure C-5. Total number of Trichoptera taxa (Trichoptera richness) qualitatively collected at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1955-2001).

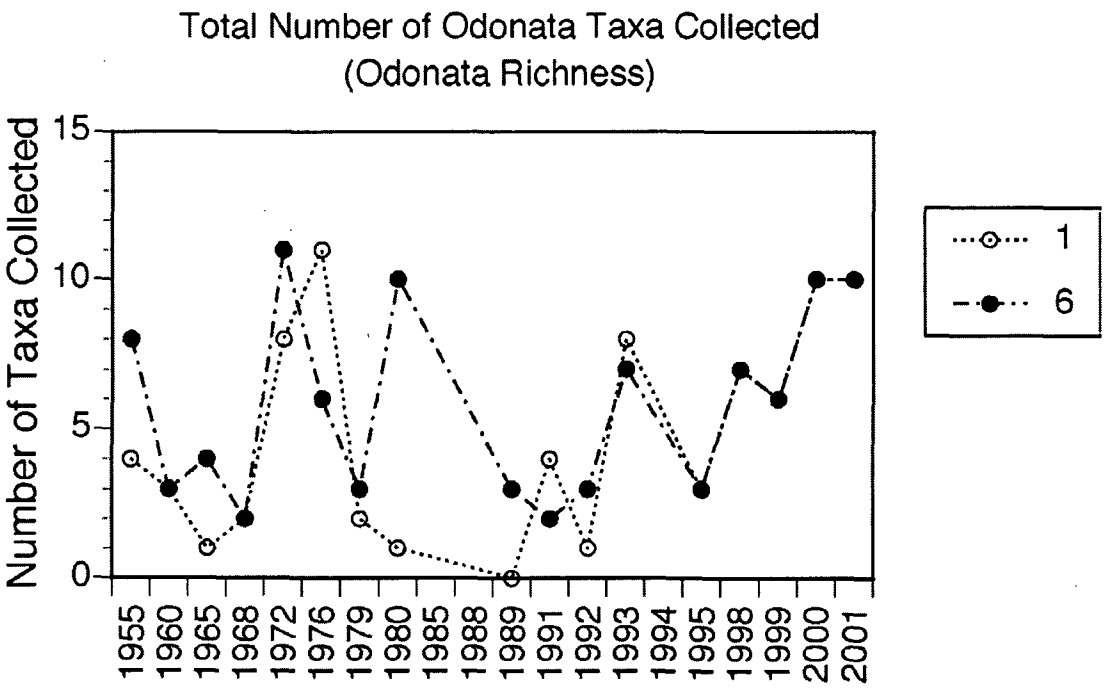


Figure C-6. Total number of Odonate taxa qualitatively collected (Odonate richness) at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1955-2001).

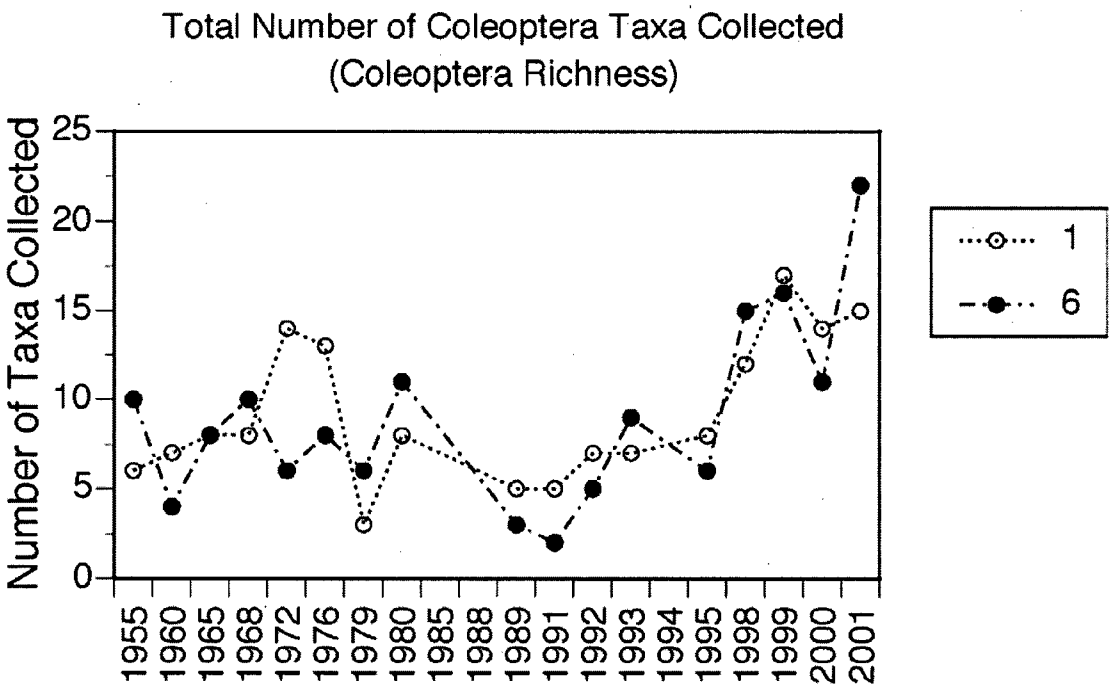


Figure C-7. Total number of Coleoptera taxa qualitatively collected (Coleoptera richness) at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1965-2001).

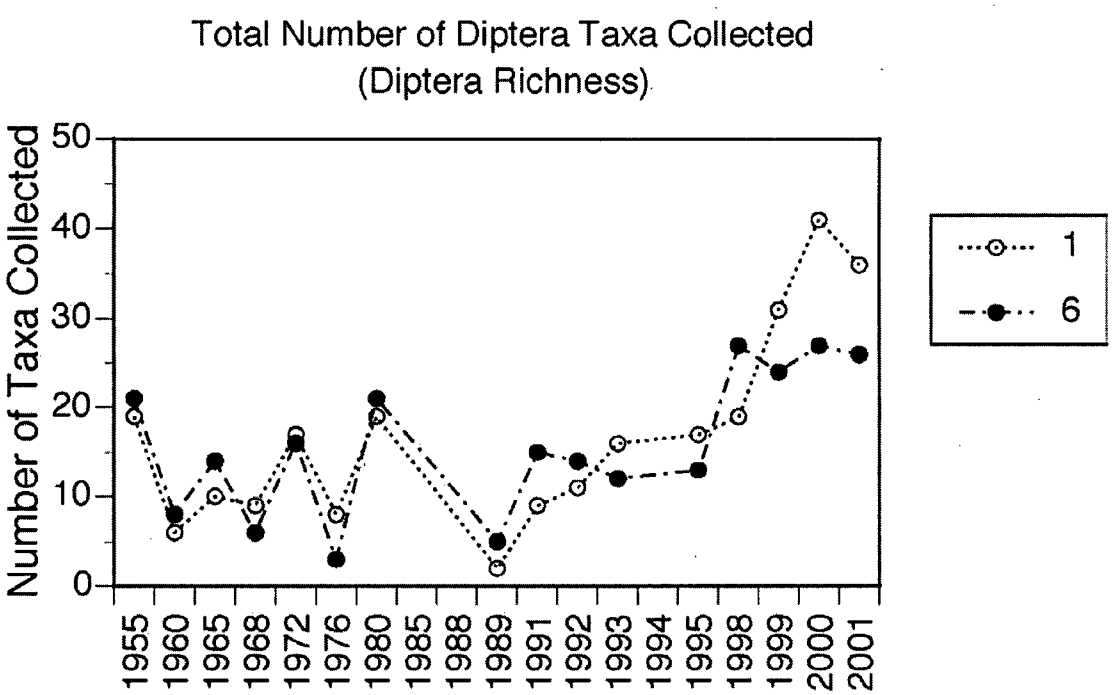


Figure C-8. Total number of Diptera taxa (Diptera richness) qualitatively collected at each station during late spring-summer surveys of the Savannah River in the vicinity of the Savannah River Site (1965-2001).

Table C-4. Abundance (mean individuals per trap ± 1 standard error) of common aquatic insects found at Stations 1 and 6 in September 2001. Families, genera, or species listed had >90 individuals per trap at one station (> 1% of total insect density).

Taxa	Station 1	Station 6	St 1 vs St 6
Total Insects	8757.5 ± 2340.7	10053.3 ± 1875.3	$P = 0.593$
Ephemeroptera	1917.5 ± 303	3312.0 ± 1113.2	$P = 0.194$
Baetidae	396.5 ± 177.7	645.3 ± 321.4	$P = 0.462$
Baetis spp	110.5 ± 36.1	272.0 ± 216	$P = 0.697$
Baetis intercalaris	32.5 ± 14.4	122.7 ± 99.6	$P = 0.807$
Unidentified *Baetis*	78.0 ± 43.9	149.3 ± 118.8	$P = 0.736$
Caenidae (*Caenis*)	16.0 ± 16.0	938.7 ± 309.5	$P = 0.007$**
Heptageniidae	463.0 ± 110.8	272.0 ± 84.7	$P = 0.341$
Stenonema spp.	146.5 ± 40.6	112.0 ± 80.5	$P = 0.349$
Leptohyphidae	990.5 ± 204.1	336.0 ± 88.1	$P = 0.016$*
Tricorythodes	440.5 ± 124.6	181.3 ± 32.4	$P = 0.066$+
Isonychiidae (*Isonychia*)	4.0 ± 4.0	901.3 ± 347.6	$P = 0.002$**
Trichoptera	4479.5 ± 1793.2	4176.0 ± 1106.8	$P = 0.764$
Hydropsychidae	3356.5 ± 1521.5	1685.3 ± 603.1	$P = 0.775$
Cheumatopsyche	2210.0 ± 815.6	1013.3 ± 391.6	$P = 0.614$
Macrostemum	0.0 ± 0.0	170.7 ± 93.0	$P = 0.063$+
Leptoceridae	127.0 ± 38.3	117.3 ± 19.2	$P = 0.863$
Philopotamidae (*Chimarra*)	852.0 ± 334.1	2256.0 ± 644.6	$P = 0.222$
Diptera	2204.0 ± 424.1	2245.3 ± 259.5	$P = 0.796$
Chironomidae	2072.0 ± 394.1	1957.3 ± 219.8	$P = 0.974$
Polypedilum	1012.5 ± 254.6	949.3 ± 123	$P = 0.877$
Rheotanytarsus	676.0 ± 135.6	778.7 ± 54.1	$P = 0.515$
Tanytarsus	16.0 ± 9.2	90.7 ± 59.4	$P = 0.151$
Simuliidae	59.5 ± 8.7	256.0 ± 60.6	$P = 0.003$**
Simulium	44.0 ± 17.7	138.7 ± 70.6	$P = 0.279$
Odonata	112.0 ± 17.3	181.3 ± 62.9	$P = 0.299$
Megaloptera (Corydalidae)	24.0 ± 15.3	69.3 ± 29.7	$P = 0.173$
Lepidoptera	0.0 ± 0.0	5.3 ± 5.3	$P = 0.286$
Coleoptera	20.5 ± 12.9	64.0 ± 42.3	$P = 0.692$

\+ Comparison nearly significant ($0.10 > P > 0.05$)
* Comparison significant ($P \leq 0.05$)
** Comparison significant ($P \leq 0.01$)

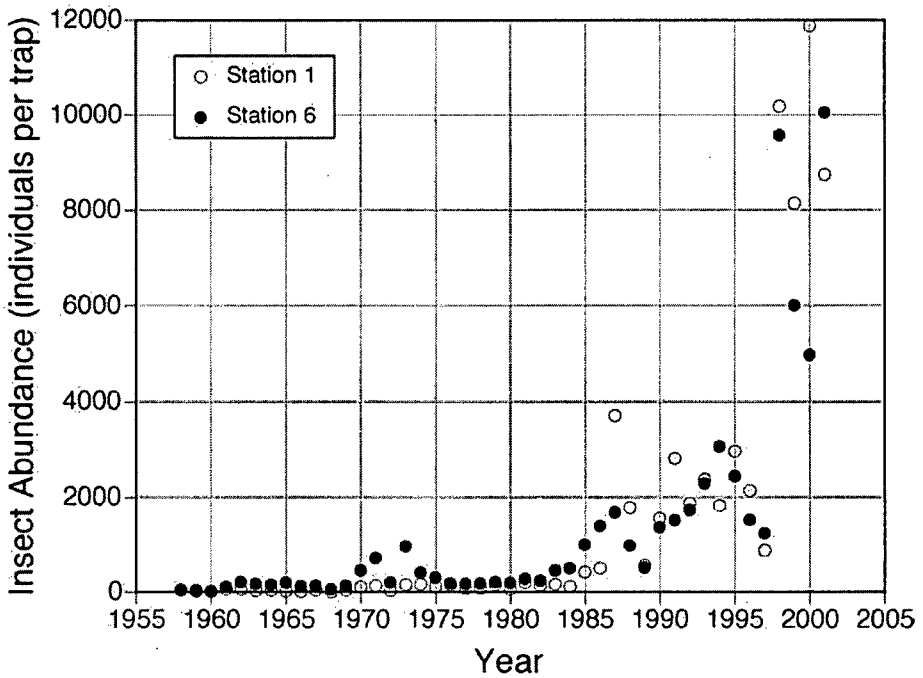


Figure C-9. Total insect abundance (annual mean number of individuals per trap) at Savannah River Stations 1 and 6. Annual means summarize four sampling seasons for 1958-1995, two sampling seasons for 1996-2000, and one sample season for 2001. Samples from 1998 - 2001 were washed through a 0.5-mm mesh sieve (a modern standard) rather than the 1.8- x 1.4-mm mesh screen that was used earlier. This change presumably contributed to the high densities observed in 1998-2001.

These densities are comparable to observations from 1998-2000, but greater than earlier observations (Fig. C-9). Differences relative to earlier observations are confounded by the change in mesh size that occurred in 1998; nevertheless, abundances in 2001 were relatively high. Ephemeroptera, Trichoptera and Diptera composed over 96% of the individuals collected in 2001. Ephemeroptera constituted 22-33% of total insect density. Trichopterans were the most abundant taxa composing approximately 40-50% of the total numbers; the majority of caddisflies were from the family Hydro- psychidae. Diptera were predominantly chironomid midge larvae. Odonata, Megaloptera, Lepidoptera and Coleoptera were present, but not common (>1% of the total abundance; Table C-4). Plecoptera and Hemiptera were absent from all traps, presumably because they are not common at these sites (see qualitative collections above), the traps do not sample all microhabitats, and subsampling reduces the number of taxa found.

The September 2001 samples comprised 57 taxa (Table C-2). Taxa diversity was greatest among the orders Diptera, Trichoptera, Ephemeroptera, Coleoptera, and Odonata. Diptera accounted for 23 taxa while Trichoptera, Ephemeroptera, Coleoptera, and Odonata had 11, 10, 5 and 5 taxa, respectively (Table C-2). A total of 17 taxa was collected in the quantitative traps that were not collected in the qualitative samples. Ten of these taxa were midges and none was very common.

Reference Conditions Upstream of SRS

Station 1 is designated as the reference site because it is upstream of SRS and therefore not exposed to effluent or runoff from SRS. Insect density at Station 1 averaged 8,758 individuals/trap in September. Trichoptera composed 50% of the total numbers with an average of 4,480 individuals/trap (Table C-4). The Hydropsychidae caddisfly, *Cheumatopsyche* was the dominant species with 2,210 individuals/trap. Leptoceridae and Philopotamidae were also common caddisflies at Station 1. Diptera comprised over 25% of the total abundance, with *Polypedilium* and *Rheotanytarsus* being the dominant species. Ephemeroptera made up 22% of the total numbers, with the families of Baetidae, Heptageniidae and Leptohyphidae being most common. Odonata, Megaloptera and Coleoptera were also present, but together they made up <2% of the total abundance (Table C-4).

A total of 44 taxa was identified at Station 1 (Table C-2). Species richness averaged 16 taxa/100 individuals (Table C-5). Ephemeroptera, Plecoptera, and Trichoptera (EPT) Richness averaged 8 taxa/100 individuals, accounting for 50% of the total richness. Chironomid Richness averaged 5 taxa/100 individuals, making up 30% of the total richness. HBI score was 4.9 and NCBI score was 5.3, indicating good water quality (Table C-5; Hilsenhoff 1987, Lenat 1993). Shannon-Wiener Diversity indicated relatively good diversity as well as evenness (i.e., distribution of individuals across taxa). This was also apparent in measures of dominance.

Table C-5. Commonly used biometrics (mean ± 1 standard error) based on aquatic insects found at Stations 1 and 6 in September 2001. Estimates per sample based on 100 individuals.

Index	Station 1	Station 6	St 1 vs St 6
Species Richness	15 ± 2	17 ± 0	$P = 0.544$
EPT Richness	8 ± 1	9 ± 0	$P = 0.071$ +
Chironomid Richness	5 ± 0	4 ± 0	$P = 0.119$
HBI	4.9 ± 0.1	4.4 ± 0.2	$P = 0.041$ *
NCBI	5.3 ± 0.0	4.7 ± 0.2	$P = 0.020$ *
Shannon Diversity	2.44 ± 0.15	2.58 ± 0.04	$P = 0.506$
% Dominance – 1 taxon	27 ± 5	21 ± 1	$P = 0.389$
% Dominance – 5 taxa	69 ± 4	65 ± 2	$P = 0.453$
% Chironomidae	28 ± 2	24 ± 3	$P = 0.293$

\+ Comparison nearly significant ($0.10 > P > 0.05$)
* Comparison significant ($P \leq 0.05$)
** Comparison significant ($P \leq 0.01$)

The most dominant taxon (% Dominance-1 taxon) represented a third of the total abundance while the five most common taxa (% Dominance - 5 taxa) comprised 69% of the total abundance. Chironomids averaged 28% of the total numbers (Table C-5).

Comparison of Reference and Downstream Conditions

To assess if the water quality of the Savannah River changed while passing by the SRS, aquatic insects from Station 1 (i.e., the reference site upstream of SRS) were compared to Station 6 (i.e., the downstream site that could have been potentially exposed to effluent or runoff from the SRS). A negative impact was defined *a priori* as lower densities of pollution-sensitive taxa (e.g., mayflies), potentially accompanied by higher densities of pollution-tol-

erant taxa (e.g., some chironomid species). Lower total richness, the richness of pollution-sensitive groups (i.e., EPT Richness), and the richness of large groups containing sensitive and tolerant species (i.e., Chironomidae) were also designated a priori as evidence of a negative impact. Meaningful differences in relative abundance and richness (as described above) would be expected to result in lower species diversity and higher values of % Chironomidae, % Dominance-1, % Dominance-5, HBI, or NCBI.

Comparison of Station 1 to Station 6 indicates no difference for total insect abundance (Table C-4; $P>0.05$). Abundances for the seven most common orders also did not differ. However there were differences between stations for some families (Table C-4). The mayflies Caenidae and Isonychiidae, and the black fly larvae Simuliidae were more abundant at Station 6 than Station 1. Mean density of Caenidae (mainly *Caenis*) and Isonychiidae (mainly *Isonychia*) was <20 individuals/trap at Station 1, but >900 individuals/trap at Station 6. Simuliidae larvae had nearly 5-fold higher numbers at Station 6 relative to Station 1. The caddisfly *Macrostemum* was not found at Station 1, but had a mean abundance of 170 individuals/trap at Station 6 ($P=0.063$). The only taxon exhibiting higher densities at Station 1 relative to Station 6 was the mayfly Leptohyphidae, which had a 3-fold difference in abundance (Table C-4).

Of the nine biometrics examined (Species Richness, EPT Richness, Chironomid Richness, HBI, NCBI, Shannon-Wiener Diversity, % Dominance -1 taxon, % Dominance- 5 taxa, and % Chironomids), only HBI and NCBI differed significantly between the two stations (Table C-5). HBI was 4.9 at Station 1 and was 4.4 at Station 6, indicating good and very good water quality, respectively (Hilsenhoff 1987). NCBI was also higher at Station 6. NCBI rated water quality at Station 1 as good and at Station 6 as excellent (Lenat 1993). Although these biotic indices were statistically different they do not necessarily indicate very different insect assemblages. The insects indicate that both sites have relatively good water quality and exhibit little or no impairment due to pollution. It is important to note that both biotic indices were designed primarily for streams much smaller than the Savannah River and to include insect and non-insect

macroinvertebrates (Hilsenhoff 1987, Lenat 1993). Therefore, our application involving only insects from a large river may have influenced the values, although probably not dramatically. Differences between Stations 1 and 6 were nearly significant for EPT Richness (P=0.074), with Station 6 averaging a few more mayfly or caddisfly species. Results for HBI, NCBI and EPT Richness indicate that conditions at the potential impact site, Station 6, downstream of SRS inputs are generally superior to those at the upstream reference station. Thus, there was no evidence that suggests a general negative response by aquatic insects in the Savannah River near the SRS. Rather, differences that we observed between stations in 2001 could reflect the differences that occur naturally between spatially separate sites (i.e., natural spatial variation) or they could indicate that water quality improved over the 38 miles between Stations 1 and 6.

Comparison of Reference and Downstream Conditions from 1998 to 2001

A two-way ANOVA was used to examine if there were consistent differences between the two stations for 1998 through 2001 September samples (Table C-6). Data for these years were collected using the same methods (see Materials and Methods). Annual variation in insect abundances is expected to confound the results, but consistency across time is an important factor in evaluating conditions at a site. The interest in this analysis was not to analyze yearly variation but to determine if there were consistent annual differences in the upstream and downstream stations. The most notable difference was the greater abundance of Ephemeroptera at Station 6 compared to Station 1 (Table C-6). Ephemeroptera had higher densities all four study years at Station 6 versus Station 1 (Fig. C-10). Four of the five mayfly families had higher abundances at Station 6 than 1. Figure C-11 illustrates the tendency for higher numbers of Baetidae, Caenidae, Heptageniidae and Isonychiidae at the downstream station. Only Leptohyphidae had a higher density at the reference site, Station 1 and this

Table C-6. Summary of the results of statistical tests [2-way ANOVA with station x year interaction (inter.)] used to evaluate station (1 and 6) and year (1998, 1999, 2000 and 2001) differences ($p < 0.05$) for specific aquatic insects in September. Analysis completed on the most common aquatic insects found at Station 1 and 6 (> 1% of total insect density). Tukey's pairwise comparison was used to examine differences between stations.

		P	Station
All Insects	Station	0.819	
	Year	0.161	
	Inter.	0.175	
Ephemeroptera	Station	0.006	6>1
	Year	0.014	
	Inter.	0.602	
Baetidae	Station	0.003	6>1
	Year	0.195	
	Inter.	0.038	
Caenidae	Station	<0.001	6>1
	Year	0.002	
	Inter.	0.024	
Heptageniidae	Station	0.001	6>1
	Year	0.002	
	Inter.	0.013	
Leptohyphidae	Station	<0.001	1>6
	Year	0.077	
	Inter.	0.557	
Isonychiidae	Station	<0.001	6>1
	Year	0.074	
	Inter.	0.509	
Trichoptera	Station	0.844	
	Year	0.134	
	Inter.	0.620	
Hydropsychidae	Station	0.060	
	Year	0.016	
	Inter.	0.704	
Leptoceridae	Station	0.279	
	Year	0.005	
	Inter.	0.669	
Philopotamidae	Station	0.186	
	Year	0.533	
	Inter.	0.063	

Table C-6(continued). Summary of the results of statistical tests [2-way ANOVA with station x year interaction (inter.)] used to evaluate station (1 and 6) and year (1998, 1999, 2000 and 2001) differences ($p < 0.05$) for specific aquatic insects in September. Analysis completed on the most common aquatic insects found at Station 1 and 6 (> 1% of total insect density). Tukey's pairwise comparison was used to examine differences between

		P	Station
Species Richness	Station	0.184	
	Year	0.044[a]	
	Inter.	0.885	
EPT Richness	Station	<0.001	6>1
	Year	0.013	
	Inter.	0.404	
Chironomid Richness	Station	0.032	1>6
	Year	<0.001	
	Inter.	0.886	
HBI	Station	<0.001	1>6
	Year	<0.001	
	Inter.	0.614	
NCBI	Station	<0.001	1>6
	Year	0.649	
	Inter.	0.136	
Shannon Diversity	Station	0.006[a]	
	Year	0.175	
	Inter.	0.710	
% Dominance - 1 taxon	Station	0.016[a]	
	Year	0.288	
	Inter.	0.909	
% Dominance - 5 taxa	Station	<0.001	1>6
	Year	0.109	
	Inter.	0.368	
% Chironomidae	Station	<0.001	1>6
	Year	<0.001	
	Inter.	0.008	

[a]primary model not significant (p>0.05)

consistently occurred for all four years. Diptera also had different densities between stations with more chironomids at Station 1 versus Station 6. This difference was not consistent across all years (Fig. C-12). Overall, Simuliidae occurred at lower densities than Chironomidae (Table C-4), but it had higher abundances downstream at Station 6 than upstream during 1999 and 2001. This analysis indicates that Ephemeroptera are more common at Station 6, while chironomids are often more common at Station 1.

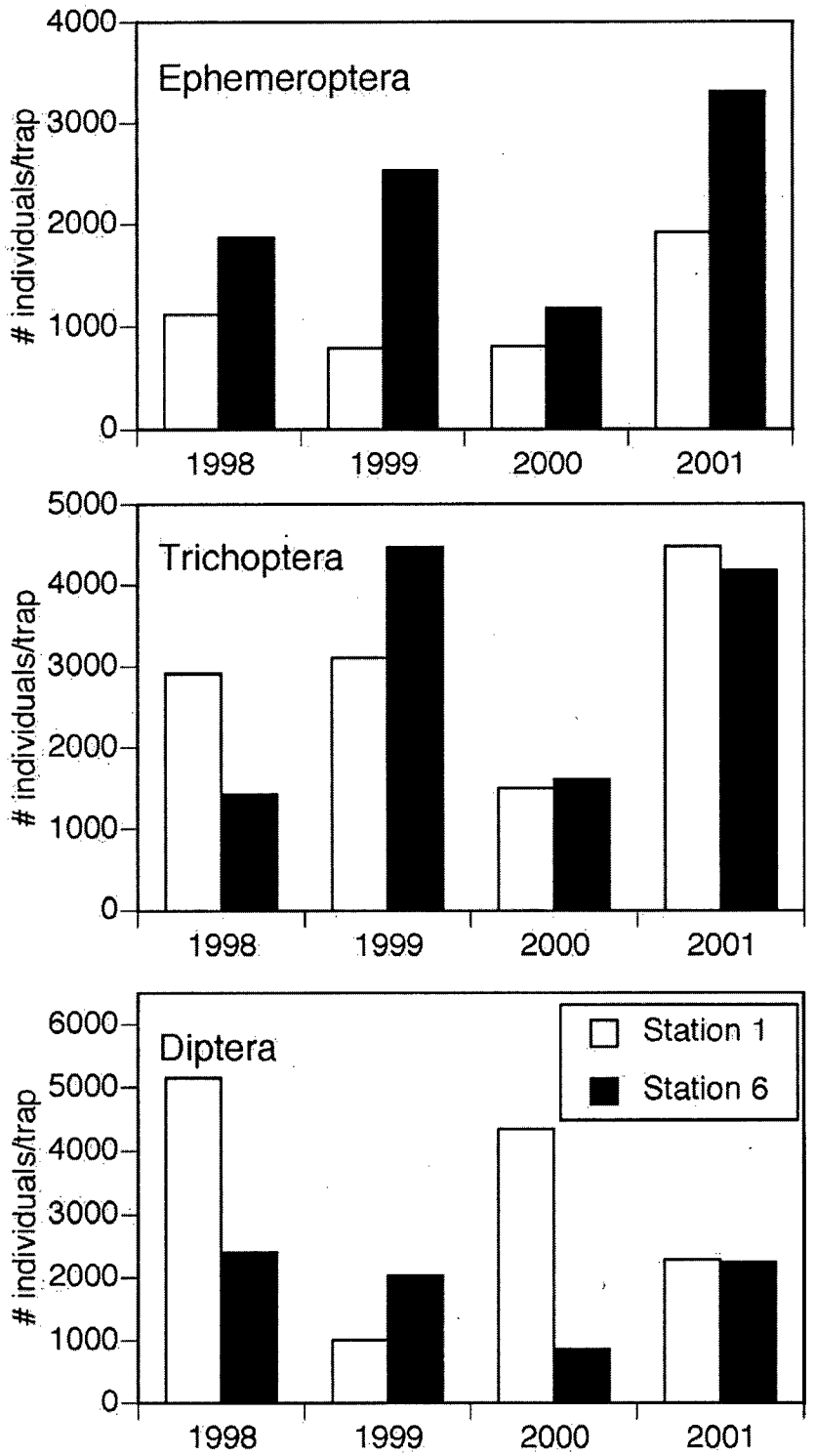


Figure C-10. Abundances of Ephemeroptera, Trichoptera and Diptera in traps at Stations 1 and 6 from September 1998 to 2001.

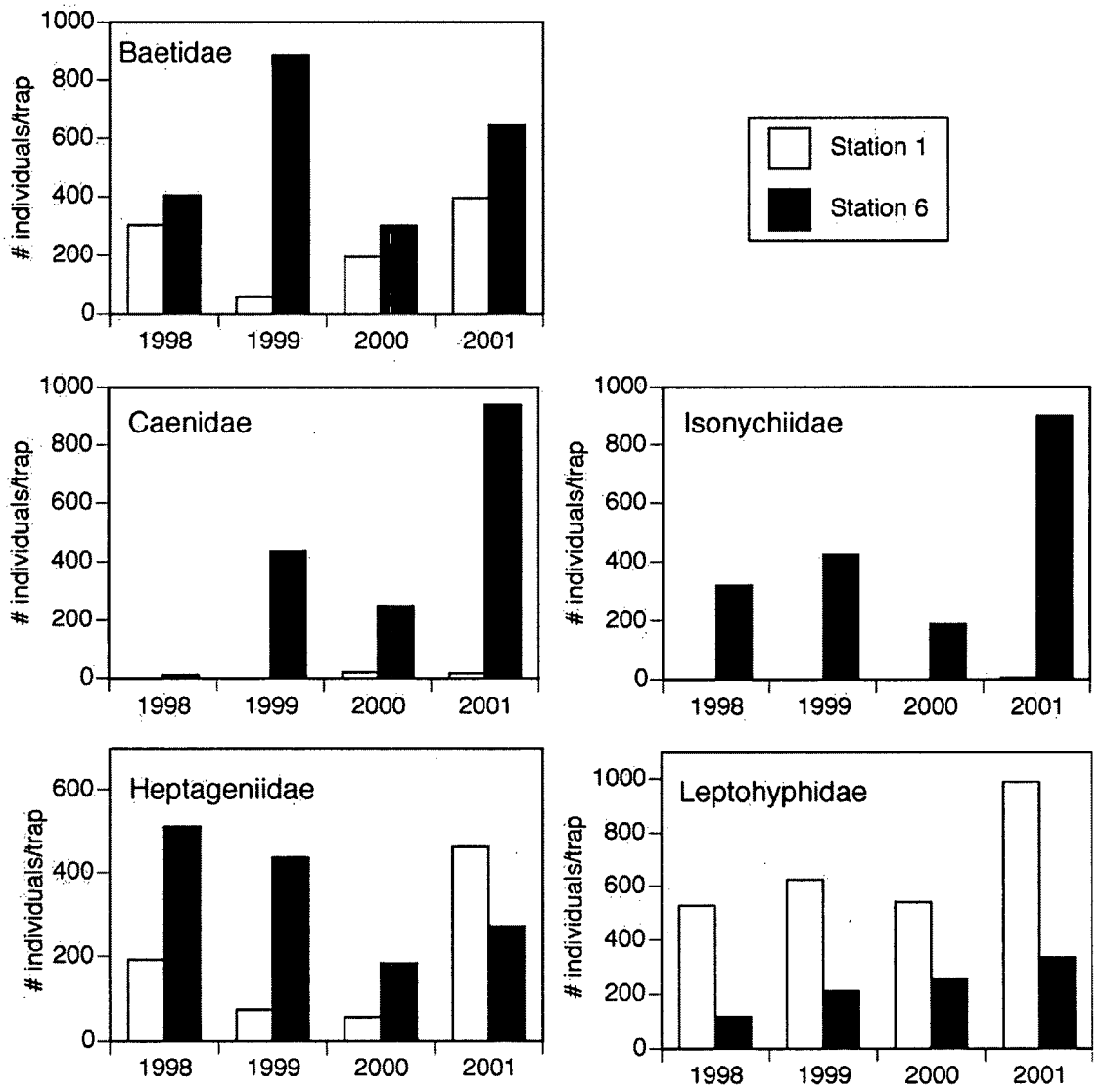


Figure C-11. Abundances of mayfly families in traps at Stations 1 and 6 from September 1998 to 2001.

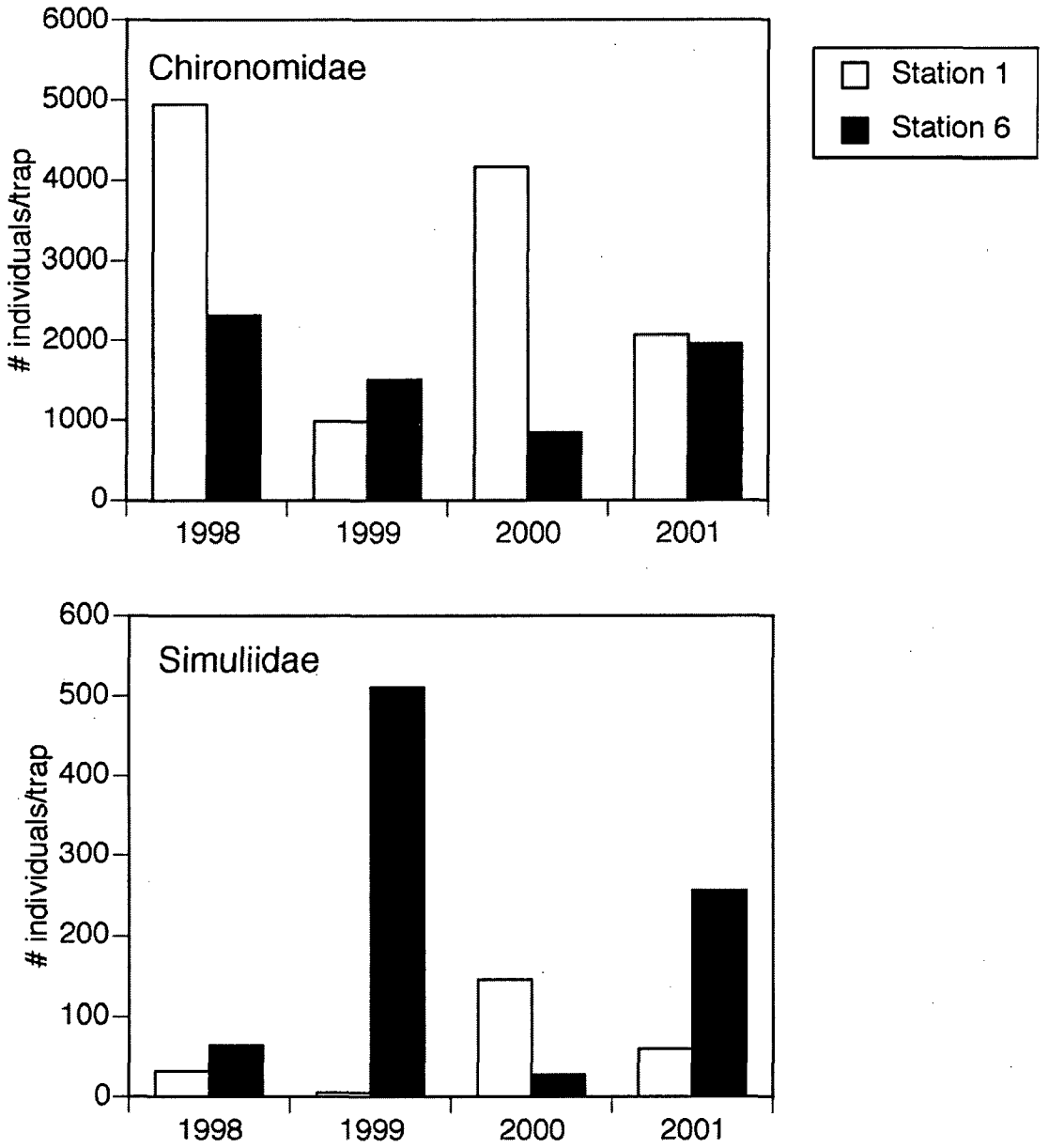


Figure C-12. Abundances of Diptera families in traps at Stations 1 and 6 from September 1998 to 2001.

Table C-7. Summary of the results of statistical tests [2-way ANOVA with station x year interaction (inter.)] used to evaluate station (Stations 1 and 6) and year (1998, 1999, 2000 and 2001) differences ($p < 0.05$) for the biometrics. Tukey's pairwise comparison was used to examine differences between stations.

		P	Station	
Species Richness	Station	0.184		
	Year	0.044[a]		
	Inter.	0.885		
EPT Richness	Station	<0.001	6>1	
	Year	0.013		
	Inter.	0.404		
Chironomid Richness	Station	0.032	1>6	
	Year	<0.001		
	Inter.	0.886		
HBI		Station	<0.001	1>6
	Year	<0.001		
	Inter.	0.614		
NCBI	Station	<0.001	1>6	
	Year	0.649		
	Inter.	0.136		
Shannon Diversity	Station	0.006[a]		
	Year	0.175		
	Inter.	0.710		
% Dominance – 1 taxon	Station	0.016[a]		
	Year	0.288		
	Inter.	0.909		
% Dominance – 5 taxa	Station	<0.001	1>6	
	Year	0.109		
	Inter.	0.368		
% Chironomidae	Station	<0.001	1>6	
	Year	<0.001		
	Inter.	0.008		

[a]primary model not significant ($p > 0.05$)

Combining the four years in a single analysis comparing standard pollution monitoring metrics showed that the above differences in insect abundances translated into differences in overall aquatic insect assemblages (Table C-7). Of the nine biometrics examined (Species Richness, EPT Richness, Chironomid Richness, HBI, NCBI, Shannon-Wiener Diversity, % Dominance -1 taxon, % Dominance- 5 taxa, and % Chironomids), Species Richness, % Dominance -1 taxon, and Shannon-Wiener Diversity did not differ significantly between stations. EPT Richness was significantly greater at Station 6 while HBI, NCBI, % Dominance- 5 taxa, and % Chironomids were greater at Station 1 (Table C-7). These patterns suggest, as did the analysis with 2001 data alone, that conditions at Station 6 (downstream of the SRS inputs) were generally superior to those at the upstream reference station. The year by station interaction was not significant for these comparisons, indicating that this pattern is consistent across the four years. Thus, there was no evidence that suggests a general negative response by aquatic insects in the Savannah River near the SRS.

Effects of a Reduction in Mesh Size on Quantitative Collections

Prior to 1998, samples were cleaned in the field by passing them through a coarse sieve with 1.8 x 1.4-mm mesh. Starting in 1998, the coarse sieve was replaced by a fine sieve (0.5 x 0.5-mm), which is the mesh-size most commonly used in benthic macroinvertebrate monitoring (Carter and Resh 2001). Although the switch to a more standard mesh size facilitates comparisons between the SRS data and data collected elsewhere, direct comparisons between long-term SRS data (that collected prior to 1998) and more recent data (that collected from 1998-2001) must be done cautiously because the reduction in mesh size appears to capture significantly more insects. One of the objectives of the 2001 sampling program was to determine if switching to a smaller mesh size affected quantitative collections, and whether this affected the conclusions from the site comparisons. This was accomplished by separating each sample into a coarse-mesh fraction (material retained by the

coarse sieve) and a fine-mesh fraction (material that passed through the coarse sieve but was retained by the fine sieve). Using Stations 1 and 6 from 2001, the coarse-mesh data were compared to the fine-mesh data to provided estimates of insect retention by mesh-size.

The use of a smaller mesh generally resulted in density estimates that were much higher than those provided by the coarse-mesh. For example, total insect densities in 2001 averaged 2,834 - 3,221 individuals/trap using the coarse-mesh. These abundances are comparable to the highest estimates obtained in the 1990s, and greater than most observations since the 1950s (Fig. C-9). However, the combination of the coarse- and fine-meshes for 2001 totaled 8,758-10,053 individuals/trap (Tables C-4 and C-8). Thus, many of the individuals collected in the traps passed through the coarse-mesh but were retained by the fine-mesh. In the 2001 samples, over 67% of the total insect abundance passed through the coarse-mesh but was retained by the fine-mesh sieve (Table C-8). The proportion of individuals passing through the coarse mesh varied among taxa - 82-90% of Ephemeroptera, >60% of the Trichoptera, and 45-57% of the Diptera passed through the coarse mesh but were retained by the fine-mesh. Similar patterns were observed for the lower taxonomic groups.

It appears that the additional individuals captured by the fine-mesh are not a random subset of the individuals captured in the coarse-mesh. The MANOVA analysis indicates that insect relative abundances differed between the coarse-mesh and fine-mesh (Table C-9). More Ephemeroptera passed through the coarse-mesh and were retained by the fine-mesh relative to Diptera and Trichoptera. Surprisingly, the coarse-mesh sieve retained a higher proportion of midge and other fly larvae, so that the relative abundance of Diptera was lower in the finer-mesh sieve. Caddisfly numbers were at equal proportions in both sieves (Table C-9). This translated into some differences in measures of community structure (Table C-10). Insects retained in the fine-mesh had lower HBI and NCBI values (indicating better water quality). For both stations, the HBI rated the coarse-mesh insect assemblage as good and the fine-mesh assemblage as very good. NCBI rated water quality at Station

Table C-8. Abundance (mean individuals per trap ± 1 standard error) of common aquatic insects found at Stations 1 and 6 in September 2001. Families, genera, or species listed had >90 individuals per trap at one station (> 1% of total insect density).

	Station 1		Station 6	
Index	**Coarse-mesh**	**Fine-mesh**	**Coarse-mesh**	**Fine-mesh**
Total Insects	2833.5 ± 1138.2	5924.0 ± 1518.1	3221.3 ± 685.5	6832.0 ± 1987.2
Ephemeroptera	185.5 ± 41.3	1732.0 ± 304.0	597.3 ± 108.3	2714.7 ± 1075.9
Baetidae	16.5 ± 6.1	380.0 ± 176.5	0.0 ± 0.0	645.3 ± 321.4
Baetis spp.	6.5 ± 3.6	104.0 ± 33.0	0.0 ± 0.0	272.0 ± 216.0
Baetis intercalaris	0.5 ± 0.5	32.0 ± 14.6	0.0 ± 0.0	122.7 ± 99.6
Unidentified *Baetis*	6.0 ± 3.8	72.0 ± 40.5	0.0 ± 0.0	149.3 ± 118.8
Caenidae (*Caenis*)	0.0 ± 0.0	16.0 ± 16.0	101.3 ± 71.8	837.3 ± 298.5
Heptageniidae	75.0 ± 18.6	388.0 ± 100.0	48.0 ± 18.5	224.0 ± 102.9
Stenonema spp.	50.5 ± 12.9	96.0 ± 47.1	37.3 ± 10.7	74.7 ± 74.7
Leptohyphidae	70.5 ± 20.4	920.0 ± 207.5	42.7 ± 21.3	293.3 ± 78.6
Tricorythodes	60.5 ± 22.9	380.0 ± 132.0	37.3 ± 19.2	144.0 ± 51.4
Isonychiidae (*Isonychia*)	0.0 ± 0.0	4.0 ± 4.0	389.3 ± 203.7	512.0 ± 199.8
Trichoptera	1683.5 ± 799.5	2796.0 ± 1122.4	1328.0 ± 586.9	2848.0 ± 889.3
Hydropsychidae	1372.5 ± 666.7	1984.0 ± 932.7	576.0 ± 319.6	1109.3 ± 300.9
Cheumatopsyche	1250.0 ± 598.7	960.0 ± 329.2	373.3 ± 225.8	640.0 ± 192.0
Macrostemum	0.0 ± 0.0	0.0 ± 0.0	117.3 ± 59.4	53.3 ± 38.5
Leptoceridae	39.0 ± 8.7	88.0 ± 41.6	37.3 ± 23.2	80.0 ± 24.4
Philopotamidae (*Chimarra*)	256.0 ± 140.5	596.0 ± 249.4	693.3 ± 256.7	1562.7 ± 690.7
Diptera	940.0 ± 332.9	1264.0 ± 219.3	1216.0 ± 259.1	1029.3 ± 5.3
Chironomidae	900.0 ± 318.1	1172.0 ± 191.3	1130.7 ± 219.8	826.7 ± 69.3
Polypedilum	440.5 ± 179.3	572.0 ± 118.0	512.0 ± 97.8	437.3 ± 64.9
Rheotanytarsus	356.0 ± 105.8	320.0 ± 65.3	517.3 ± 83.8	261.3 ± 37.3
Tanytarsus	0.0 ± 0.0	16.0 ± 9.2	74.7 ± 50.9	16.0 ± 9.2
Simuliidae	15.5 ± 7.5	44.0 ± 7.7	64.0 ± 40.3	192.0 ± 80.5
Simulium	8.0 ± 8.0	36.0 ± 13.7	37.3 ± 23.2	101.3 ± 85.8
Odonata	12.0 ± 7.7	100.0 ± 16.5	48.0 ± 16.0	133.3 ± 47.4
Megaloptera (Corydalidae)	8.0 ± 8.0	16.0 ± 16.0	16.0 ± 9.2	53.3 ± 38.5
Lepidoptera	0.0 ± 0.0	0.0 ± 0.0	5.3 ± 5.3	0.0 ± 0.0
Coleoptera	4.5 ± 2.6	16.0 ± 11.3	10.7 ± 5.3	53.3 ± 38.5

Table C-9. Relative abundances for the three most common insects orders at Stations 1 and 6. Significant differences between mesh sizes across stations indicated for each order. Station by mesh size interaction was not significant for any comparison.

	Station 1		Station 6	
Index	**Coarse-mesh**	**Fine-mesh**	**Coarse-mesh**	**Fine-mesh**
Ephemeroptera **	12.3 ± 5.6	32.4 ± 4.9	21.3 ± 6.5	37.7 ± 4.0
Trichoptera	49.0 ± 8.9	40.6 ± 9.4	37.9 ± 10.3	41.1 ± 2.8
Diptera **	35.9 ± 3.3	23.9 ± 3.7	38.3 ± 6.0	17.5 ± 4.3

** Comparison of mesh sizes significant ($P \leq 0.01$)

Table C-10. Commonly used biometrics (mean ± 1 standard error) based on aquatic insects found at Stations 1 and 6 in September 2001. Estimates per sample based on 100 individuals. Comparison of Stations 1 and 6 were made for coarse-mesh data only, which mirrors pre-1998 comparisons.

	Station 1		Station 6	
Index	**Coarse-mesh**	**Fine-mesh**	**Coarse-mesh**	**Fine-mesh**
Species Richness	14±1	15±2	14±0	17±0
EPT Richness	7±1	7±1	7±0	9±0
Chironomid Richness	4±0	5±1	3±0	4±0
HBI	5.1±0.1	4.7±0.1	4.5±0.1**	4.4±0.2
NCBI	5.6±0.1	5.1±0.1	4.7±0.2**	4.7±0.3
Shannon Diversity	2.07±0.19	2.55±0.12	2.15±0.14	2.69±0.03
% Dominance – 1 taxon	36±7	24±4	25±2	20±2
% Dominance – 5 taxa	80±5	64±3	81±4	57±2
% Chironomidae	34±3	22±4	36±6	14±3

** Comparison of Stations 1 and 6 significant for the coarse-mesh ($P \leq 0.01$)

1 as good and at Station 6 as excellent for the insects retained by the coarse-mesh, while the rating for the fine-mesh was excellent at both stations. Additionally, Shannon-Wiener Diversity was higher for the insects retained in the fine-mesh compared to the coarse-mesh assemblage (Table C-10).

Combining the coarse- and fine-mesh data had a limited effect on the comparison of Stations 1 and 6 in 2001. Comparison of Stations 1 and 6 using only the coarse-mesh data still indicate a difference between stations for HBI and NCBI (Tables C-5 and C-9). The nearly significant difference in EPT richness observed with the combined data was not apparent using only the coarse-mesh data.

Discussion

The primary objective of the 2001 study was to describe qualitatively and quantitatively the assemblage of aquatic insects inhabiting the Savannah River upstream (Station 1) and downstream (Station 6) of the SRS. Observed similarities and differences between the upstream and downstream sites were used to evaluate the effect of the SRS on the Savannah River ecosystem in 2001. For the qualitative analysis, lower species richness at Station 6 relative to Station 1 would suggest a loss of species in response to exposure from effluent and runoff from the SRS. This decrease in richness would reflect the absence of species (or species groups), especially those known to be pollution sensitive (Hilsenhoff 1987, Lenat 1993). Concurrently, the relative abundance of pollution-tolerant species (or species groups) may increase. Personal judgment was used to evaluate the significance of differences in richness or relative abundance observed in the qualitative data.

A parallel approach was used in the quantitative analysis of the aquatic insects at the two stations. Lower species richness, species diversity, densities of pollution-sensitive species (or species groups) and/or increases in densities or relative abundance (dominance) of pollution-tolerant species (or species groups) at Station 6 relative to Station 1 would suggest that differences between stations were attributable to effluent or runoff from the SRS. The significance of these differences was determined statistically; the probability of erroneously identifying a difference was $\leq$ 5%.

Environmental Conditions in 2001 as Indicated by Aquatic Insect Collections

A wide variety of species, many of which were abundant, were found in both qualitative and quantitative aquatic insect collections from both sampling stations in 2001. The qualitative and quantitative assessments of the aquatic insect assemblages did not indicate that inputs from the SRS had a negative effect on aquatic insects in the Savannah River. Conditions (as indicated by aquatic insect communities) at the potential impact station (downstream of SRS inputs) were as good or better than those at the upstream reference station. Likewise, species composition at both stations in 2001 was generally similar to observations from previous surveys.

The qualitative collections provide a thorough description of the overall composition of the insect fauna at each of the two stations because all habitats are sampled. Seventy-six taxa were unique to the qualitative collections (not found in trap samples), whereas only 17 taxa were unique to the trap samples. This difference primarily represents the greater number of habitats included in the qualitative samples relative to the trap samples. The insect faunas in the qualitative collections from September 2001 were generally similar to those found in earlier studies; a total of 131 taxa was collected at the 2 stations in 2001. This includes 15 dragonfly and damselfly taxa, 17 mayfly taxa, 14 caddisfly taxa, 6 true bug taxa, 2 stonefly taxa, 28 beetle taxa, and 47 Diptera (primarily Chironomidae) taxa. Total Richness estimated in September 2001 was similar to previous surveys. There were some differences in the insect faunas of the two stations, but these differences did not confirm to our *a priori* hypotheses regarding negative responses from exposure to effluent and runoff from the SRS (i.e., conditions were generally better downstream of the SRS inputs than at an upstream site). Therefore, the qualitative aquatic insect data do not appear to indicate significant environmental degradation in the Savannah River in the vicinity of the SRS. When 2001 qualita-

tive data were combined with data collected in previous surveys, we found no evidence that long-term exposure to effluent or runoff from the SRS had an adverse effect on the taxonomic composition of the insect assemblages downstream of the SRS in 2001.

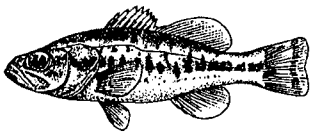
The trap samples are quantitative examinations of the many species that inhabit snag and debris habitats. Most of these species are also in the qualitative samples (only 17 species were unique to the quantitative samples, and all were rare), but the quantitative data can be examined using rigorous statistical techniques that cannot be applied to the qualitative data. Quantitative examination of the aquatic insects (i.e., as measures of population density of individual species, and overall community structure) found no evidence that effluent or runoff from the SRS resulted in changes in the aquatic insect assemblages downstream of the SRS. Some differences were observed between stations, but these differences do not appear indicative of environmental degradation downstream of the SRS. Rather, these results indicate that conditions at the potentially impacted station (downstream of SRS inputs) are generally superior to those at the upstream reference station. This pattern has been observed consistently over the last four years. The available data suggest that the differences between sites reflect the differences that occur naturally among spatially separate sites (i.e., natural spatial variation) or they could indicate that water quality improved over the 38 miles between Stations 1 and 6.

A significant change in the field sampling protocol involved a reduction of the sieve mesh size beginning in 1998. Analysis of the 2001 data found that insect material that passes through the coarse-mesh sieve that was historically used is not identical to the material captured in the fine-mesh sieve. However, it does not appear that this has resulted in an erroneous interpretation of conditions at Stations 1 or 6, or an erroneous interpretation of the differences between Stations 1 and 6. Because year-to-year fluctuations in density and community structure are common for riverine insect assemblages, efforts will be made to repeat these mesh size analyses in subsequent years.

In summary, Stations 1 and 6 supported aquatic assemblages in 2001 that contained diverse species, many of which were quite numerous and pollution sensitive. Differences were observed between stations upstream and downstream. However, aquatic insect composition and abundance at the downstream station was generally similar to the upstream (reference) station. Thus, exposure to effluent and runoff from the SRS did not appear to have a measurable effect on the aquatic insect assemblage.

D. FISH

Introduction



The Academy has studied the fish of the Savannah River for almost 50 years, and this information is useful in determining the long-term effects of the Savannah River Site operations, on the health of the river.

The structure and dynamics of fish assemblages are commonly used to assess the health of aquatic systems. Fishes are good indicators of overall system integrity because assemblages include a diversity of species that occupy a variety of trophic levels whose presence or absence can be indicative of local conditions. The presence or absence of fishes intolerant to pollution or tolerant to physical and chemical habitat degradation, and the presence of introduced species and various life stages of fishes and their population dynamics have also been used to measure the health of aquatic systems. The study of fish assemblages and the changes in these assemblages over time are important elements in the monitoring and evaluation of human impacts upon aquatic ecosystems.] Monitoring the structure of fish assemblages in Savannah River has been an integral part of environmental assessments of the Savannah River Site by The Academy of Natural Sciences of Philadelphia (ANSP) since 1951.

Until 1997 these assessments included comprehensive studies, cursory studies and independent monitoring of locations near Plant Vogtle. Comprehensive studies included a twice per year assessment every 4-5 years at four stations. The cursory studies were annual assessments at three of the four stations. The Vogtle study was an annual assessment of two stations, upstream and downstream of Plant Vogtle, both upstream from the SRS. The last cursory and Vogtle studies were conducted in 1996 and the last comprehensive study was conducted in 1993.

The current study design is an annual, early fall assessment, which has been conducted in 1997-2000. This report docu-

ments the 2001 study. Sampling is done in representative river and backwater habitats at four stations, using walkalong electroshocking in shallow backwater areas, boat electroshocking in channels and deeper backwaters, and seining along shores of the main channel. Three of the stations, Stations 1, 5 and 6, have been sampled in previous years in both cursory and comprehensive surveys. The fourth station, 2B, was sampled prior to 1997 as the downstream Vogtle station (V-2) and reported as part of the Plant Vogtle studies. There are historical data from each of these four stations that can be used to examine changes in occurrence of fish species over time. The examination of temporal variation in fish assemblage structure is necessary for the detection of any perturbations that may be related to SRS because there are few reliable data from Savannah River that document fish assemblage dynamics prior to plant construction. Although field samples were collected at all four stations during the 2001 study, the analysis of the field collections will only incorporate the results from samples which were obtained from Stations 1 and 6, the upstream and downstream most stations. The samples collected from Stations 2B and 5 have been archived for future reference.

The main objectives of the 2001 survey were to: 1) evaluate possible effects of the SRS through comparison of fish species richness, abundance, and occurrence at stations upstream and downstream of the plant; and 2) compare results with those of the 1997-2000 surveys and previous comprehensive surveys to identify temporal variation in fish assemblage structure related to SRS.

Methods

Fishes were sampled at four stations in the Savannah River on 7-12 September 2001. Stations 1, 2B, and 5 are on the river adjacent to the SRS and Station 6 is immediately downstream from the site. Station 1 is located upstream from all tributaries that pass through or originate within the SRS and therefore serves as a reference station. Stations 2B, 5 and 6 are located downstream from two or more SRS tributaries and are therefore exposed to SRS influ-

ence. All stations have been sampled in previous Academy surveys. Seining, walk-along electrofishing in backwaters, and boat electrofishing in the main channel were the primary collection techniques used in the 2001 survey. Additional fish specimens were collected with dip nets and from traps during macroinvertebrate and insect sampling and were incorporated into the fisheries results. Individually, each of the primary methods was more efficient for the assessment of specific habitats and the collection of particular species than other methods. Together, the techniques were complementary and resulted in an adequate assessment of species occurrences and distributions throughout the river reach.

Changes in sampling methods among surveys must be considered in any comparisons of these data among years. Sampling methods used in the 1997-2001 are most comparable to those used in previous comprehensive surveys (at Stations 1, 5 and 6) and previous Vogtle surveys (at Station 2B; ANSP 1990a, 1994a). The comprehensive surveys were conducted twice each year, while the current program includes only one survey per year. More seine samples were taken in the 1997-2001 surveys than in previous cursory surveys (no seining was done in most cursory surveys), but fewer compared to comprehensive surveys. In 1995, walk-along electrofishing sampling replaced rotenone sampling in backwater areas in all surveys. Boat electrofishing was initially employed in 1995 to collect fishes from the main channel at Station 1 during a cursory study, in 1996 for Vogtle stations and used extensively in the 1997-2001 studies at all stations. The boat electroshocking sampling provides valuable data on fish populations inhabiting the main river channels, replacing gill netting and trapping, which were used in previous comprehensive surveys.

Seine Samples

Seine samples were taken along both river banks using a 6.1-m x 1.2-m (20- x 4-ft) bag seine with 0.318-cm (1/8-in) mesh and extra weight on the lead line. Seine hauls were typically taken in the direction of river flow (usually downstream), in varying lengths depending on available habitat. Counter- current flow areas (occasionally

encountered between pilings) were sampled in the direction of the dominant flow. In samples where the seine was not opened to its full extent, the area of the sample was adjusted accordingly. The area seined was calculated for each haul for standardization of fish densities. Habitat variables were measured within the area seined, and these data were used in statistical analyses to investigate differences among stations. Fishes from each seine sample were preserved separately for subsequent identification and processing in the laboratory.

Seine Habitat Variables

Within each seine sampling area, water depth (m), water current velocity (m/s), and most prevalent substrate material were measured at three points, the upstream outer corner, the midpoint and the downstream outer corner, within each seine sampling area. Notes were taken on presence of aquatic vegetation or woody debris. Water depth was measured with a metal meter stick. Velocity was measured with a Swoffer model 201 digital current meter according to Patrick Center Standard Operating Procedure No. P-13-14. Current velocity was measured at 0.6 of depth in water less than 1-m deep and at 0.2 and 0.8 of depth in water deeper than 1 m. Dissolved oxygen, conductivity and water temperature were measured at one location with the sample area. Dissolved oxygen (mg/L) and water temperature (°C) were measured with a YSI (Yellow Springs Instrument Co., Model 58E) meter. Conductivity (μmhos) was measured with a YSI model 33 SCT meter or a TDS Tester Conductivity Pen.

Dominant substrate types in the area (i.e., in a 15-cm diameter circle) around each measurement point in seine sample areas were recorded as gravel, sand, silt, or organic detritus. Substrates were categorized by referring to a scale of particle sizes. Where a mix of substrate sizes was present, two types were noted in order of decreasing dominance. Substrate composition was coded for use in statistical analyses by assigning a value of seven to gravel, nine to sand, and ten to silt, and eleven to organic detritus. In areas where two substrates occurred together, a weighted average of the two numbers was taken with the dominant substrate weighted at 75%.

The average of the three point measurements in each station was used as an index of habitat conditions. Since the sampling points are on the middle and outside of the sampling area, these averages are indices of habitat condition, but are not unbiased estimates of averages over the entire sampling area. In particular, average depth over the site will usually be less than the average over the three measurement points.

Walk-Along Shocking

Depletion sampling was done using a walk-along electroshocker at one location within Stations 1 and 6. No backwater areas were available for this technique at the other two stations because of low water levels. Locations sampled were backwater areas along the South Carolina bank. Prior to 1995, these sites had been sampled using rotenone. The electroshocking used a Honda EG5000X generator and a Coffelt VVP-15 controller that generated 250-400 volts and output current of 3-6 amps. Positive electrodes were hoops covered with 0.32-cm mesh netting and mounted on fiberglass poles carried by two collectors. The negative electrode was a single stainless steel cable that was submerged into the sampling area. Block seines with mesh size of 0.32-cm were installed around the sampling area, providing an obstructed perimeter from which fish presumably could not escape. Operators wading with anodes and 0.32-cm mesh dip nets shocked the blocked area and collected effected fishes along with two additional netters. The stunned fishes were held in river water during each pass until they were identified, measured, weighed and released, or preserved. Each pass sample was preserved and recorded as a separate distinct sample. Three successive electrofishing passes were made in each blocked area, until depletion of the fish population residing within that area was apparent. Additional fishes were removed from the block nets only at the end of sampling. The catches in the block nets were mathematically apportioned to the catch from each of the passes for analysis of catch rates (see below). Each area was mapped and distances between various boundary points were measured using a Opti-Logic laser rangefinder. The sample area was calculated using a Placom

Dig i tal Planimeter, which was used on a scale map drawn of the collection site. The number of fishes in each successive electrofishing pass was used to calculate a depletion estimate (see below) of the total number and density of those species pres ent in the sam ples. Wa ter tem per a ture, dis solved ox y gen and con duc tiv ity were also mea sured in the sam pling area.

Walkalong shock ing is done at con sis tent sites within each sta tion. These sites are given in di vid ual num bers con sis tent over dif fer ent sur veys. De pending on wa ter level, sam pling may only be pos si ble at some sites dur ing each sur vey. Several types of back water hab i tats are pres ent and sam pled at the different stations. Differences in the topography and hydrology of these sites may affect fish use. Major types include:

- Small pools off the main channel, connected to the main channel by inlets and outlets which may be shallow or dry at low water levels. These sites fill during high water levels and shrink in area and volume as water levels fall. These area and volume changes create a potential for concentration of fish, although fish may be able to leave the sites when inlets and outlets are open. These pools are typically lentic, with little current velocity even at high water levels. Examples of this type occur at Station 1 (site 2) and Station 5 (the "levee" sites, 2 and 3). These particular pools may be partly artificial in origin, created by deposition below pilings or shore dumping of dredge spoils.
- Small inlets between the shoreline and bar deposits, e.g., behind sand/mud bars which build up below pilings. The bars are typically covered at high water levels, so that the sites are part of the main channel at high flows. At low flows, they are broadly connected to the main channel at the bottom, and may have input flows at the top. Thus, these sites have less potential for concentration of fish at low water levels. The sites may have some current, so may provide habitat for fish preferring lotic habitats as well as more lentic species. Examples of this type occur at Station 1 (site 1, sampled in 2001) and Station 6 (site 1).

- Portions of side channels. These channels divert a portion of the channel's flow at high water levels, but may dry up at lower levels. These areas have a potential for concentration of fish. They may be lotic at high flows, although they become more lentic as the lower portions dry up. As a result, they may be favorable to riverine and backwater species at different times. An example of this type is the top of Wild Horse Slough at Station 5 (site 1).
- Coves. These are the lower part of current or historical side channels, abandoned meander bends, etc. These sites may have inflow from the top at high flows, but these typically dry up at low flows. They remain broadly connected to the main channel at the lower end. Because of this downstream connection, these sites probably have less potential for concentration of fish as water levels fall. They probably also contain water for longer periods than some of the other types. These sites tend to be lentic, with little current velocity and soft substrates. Ring Jaw Cove at Station 6 is an example of this type of habitat. Portions of this cove (site 2, at the upper part of the cove, sampled in 2001) are routinely sampled. In 1999, an additional area (site 3) in the middle of Ring Jaw Cove was also sampled.

Boat Electrofishing Samples

Boat electroshocking was done using an 17-ft Coffelt electroshocking boat with the same generator and VVP unit used for walk-along shocking. Shocking was done us ing a 40-in Wis con sin ring with drop pers as the positive elec trode. The volt age ranged from 180-280 volts to main tain a cur rent of 5-7 amps. Sam ples were taken fol low-ing Patrick Center Standard Operating Procedure No. P-14-02. One crew mem ber op er ated the boat while two technicians used long han dled dip nets with 0.32-cm square mesh to col lect fishes. Sam pling was done in a va ri ety of bank habitats, including debris dams and areas with downed trees, swift cur rents and un der cut banks along the fringes of the main river channel. Sampling was also done in the deeper, lower parts of backwaters (e.g., Ring Jaw Cove at

Station 6 and Devil's Elbow at Station 5), as well as along the main channel. The distance traversed along the shoreline during the sample was measured to the nearest meter using a Opti-Logic laser rangefinder, using piling sets or overhanging trees as target marks. The distance around piling sets (if in area sampled) was not included in the overall length of the sample. Four 15-min samples were taken at each station. Sample lengths ranged from 70-367 m (depending on habitat and numbers of fish effected, with higher capture of fish resulting in shorter distances covered). Habitat variables (see below) were measured within the area shocked (except for sample 6BS4). Most fishes from each sample were measured, weighed and released back to the river. Some smaller fish (mainly minnow species) were preserved for subsequent identification and processing in the laboratory.

Boat Electroshocker Habitat Assessment

An evaluation of habitat was performed at boatshock sample locations along the Savannah River and adjacent coves in the 2001 study year. Both qualitative and quantitative measures were recorded after fish from boatshock samples were identified and measured. The entire length of individual samples was examined for nine major habitat characteristics. These habitat characteristics included: flow, # of snag piles/instream woody cover (≥ 1 root wad or > 2 submerged tree logs), % riparian bank coverage, substrate, bank stability, sample area morphology, sinuosity, amount of submerged/emergent aquatic vegetation, presence of instream structure. Ordinal scales were arranged for seven categories (# of sang piles/instream woody cover and % riparian bank coverage were recorded by discrete and continuous measurements respectively) and one overall measurement for each of the nine habitat characteristics was recorded for the entire sample. Depths were also recorded for each boatshock sample using either a Hummingbird depth finder (feet) or a ruled pole (meters). Three depth measurements were taken at five transects perpendicular to the bank for each boatshock sample (15 total depth measure-

ments per boatshock sample). Five transects were determined at each sample by 0.1, 0.3, 0.5, 0.7, and 0.9 of total length of shoreline sampled. Three measurements at each transect were taken at 0.167, 0.5, and 0.83 of the width of shoreline sampled (ca. 5.25 m for each sample). Dissolved oxygen, conductivity, and water temperature was measured at one location with the sample area. Resulting data was used to determine if significant relationships existed between selected species and habitat characteristics in boatshock samples.

Hand Collections

Small fish specimens (particularly catfishes, including *Noturus insignis*, and mosquitofish, *Gambusia* sp.) were supplied to fisheries personnel by the Academy macroinvertebrate and Stroud Water Research Center insect crews for subsequent laboratory identification. The fish were collected either by fine mesh dip nets or removed from floating aquatic insect traps, where they were residing.

Specimens

Most of the medium to large sized fish were identified, measured, weighed and released in the field. The smaller and some medium sized fishes (mainly young-of-year sunfish and minnows) collected were preserved in the field with 10% buffered formalin for subsequent laboratory identification and processing. In the lab, fishes were transferred to 50% ethanol after a two-day water rinse and, subsequently to 70% ethanol for long-term storage and curation. A selected number of specimens representing five species (*Cyprinella leedsi, Notropis hudsonius, Lepomis macrochirus, Lepomis auritus, Lepomis marginatus*) were measured and weighed in the laboratory for comparison of fish condition between Stations 1 and 6. A number of young-of-year (YOY) minnows were not identifiable to genus and are listed as *Cyprinidae* species; many or all of these are probably *Cyprinella*, (either *Cyprinella nivea* or *C. leedsi*, both of which are common in the river during the study). Fishes were identified to the species level using stan-

dard references, including Blair et al. (1968), Miller and Robinson (1973), Bennett and McFarlane (1983), Menhinick (1991) and Jenkins and Burkhead (1994). We used nomenclature from Robins et al. (1991). Selected fish specimens will be accessioned into the permanent fish Ichthyology fish collection at the Academy.

Analyses

Diversity Measures

Species richness (the number of species present) was determined for all individual samples taken by each technique. Shannon-Wiener Diversity index values were calculated for each quantitative seine sample. The Shannon-Wiener Diversity index incorporates the number of taxa present and the evenness of the distribution of taxa in a sample to provide an assessment of the structure of the assemblage. Thus, if a sample has a large number of taxa and the taxa are evenly proportionate across the sample, the diversity index value for the sample will be high.

Depletion Estimates

Total populations and densities of fish species in backwater sample sites were estimated. These estimates are comparable to the rotenone sample densities, since rotenone sampling was considered to collect virtually all fish in the sample area. The total population sizes of each species in the electrofishing samples were calculated using MicroFish 3.0 (Van Deventer and Platts 1989; 1983), which provides maximum likelihood estimates (MLE) of density from successive removal data. This technique is analogous to the linear regression method based on Seber (1973) which was used for the 1996 and 1997 analyses. MicroFish also provides confidence intervals of population estimates. Both methods are based on the following assumptions of the removal-depletion method: the population is closed, all organisms within each group (each species in this case) have the same probability of being captured and that probability is constant for each pass, and sampling effort is constant. The

accuracy of the estimate is dependent upon how strictly these assumptions are met. Reliable MLEs cannot be calculated in several cases: 1) All fish of a species are caught on the first pass; 2) Only one individual of a taxon is caught over all passes; 3) The pattern of catches on successive passes does not form a decreasing trend. For the first two cases, the total number of fish caught was used as the population estimate, which is reasonable given the conditions when these cases occur. The third condition is analogous to the requirement of a negative slope for the regression method. Non-decreasing trends can arise from violation of the assumptions, or from sampling error (for rare species). In these cases, MicroFish arbitrarily assigns an estimate of 1.5 times the total catch. In past years, groups of similar species were grouped together in order to provide reliable estimates of population sizes. Fishes identified as *Gambusia spp*. were grouped together with *Gambusia holbrooki* for depletion estimates from both backwater sites.

For both backwater sites, fish were recovered from the block nets at the end of sampling (i.e., block nets were kept in place throughout sampling to avoid escape of fish). These fish could have been chased into the nets during any of the passes. These fish were apportioned among the sample passes in the proportion that each species occurred in the passes. For example, if 60% of the specimens caught in 4 passes were caught in the first pass, 25% in the second pass, 15% in the third pass, and none in the fourth pass, then 60% of the net fish would be added to the first pass results, etc. Apportioning net fish among samples results in fractional numbers of fish caught, which were rounded to integers as required by the depletion estimation procedure. Because of the rounding, the total number of fish after apportionment for net fish can sometimes be one more or less than the total number actually caught. In these cases, the population estimates and confidence bounds are increased (where the adjusted number was less than the actual number caught) or decreased by one. Population estimates were adjusted by adding or subtracting by the difference between actual total number of fish caught (all passes plus net) and total number of fish in all passes after apportioning net fish. Occasionally, the only specimens of a species may be recovered from the

net (this occurred for one species in one sample in 2000). In these cases, it is assumed that these were the only fish of those species in the sample site, i.e., the total number caught is used as the total population estimate.

Densities of fish in the backwater sampling areas were estimated from the total population estimates for each species and the calculated sample areas. Fish densities from seine samples were standardized to number of fish per 100 m^2 as a measure of catch-per-unit-effort (CPUE).

Statistical Analysis of Seine Data

Fish densities from seine samples were standardized to number of fish per 100 m^2 as a measure of catch-per-unit-effort (CPUE). Analysis of variance/analysis of covariance (ANOVA/ANCOVA) was used to test differences in abundances of species among stations. Fish densities were transformed to ln(CPUE + 1) for statistical analyses. Stat-Soft Statistica software was used for all analyses. Catch-per-unit-effort of fishes present in at least 50% of the samples, species richness, and mean diversity of fishes at each station were compared using the general linear model option in Statistica. Species richness was transformed to square root of richness for analyses. Both ANOVAs/ ANCOVAs and resulting least squares means were used to identify differences among stations. An ANCOVA was the most appropriate analysis because it adjusts for differences in microhabitat among stations and focuses on differences among densities of species. The habitat covariables used were average depth, average current velocity, average substrate composition, maximum depth, and maximum current velocity. Habitat variables were also compared among stations in an ANOVA. Probability values for all statistical tests were considered significant at a level determined by a Bonferroni correction (0.05/number of tests run) which reduces the likelihood of erroneously rejecting a true hypothesis.

Statistical Analysis of Historical Backwater Samples

Individual backwater samples from study years 1995 to 2001 were analyzed by the detrended correspondence analysis (DCA) option in Canoco 4.5 software (ter Braak and Smilauer, 2002). DCA is an indirect gradient analysis ordination method, which falls under the broader category of multivariate analysis, that produces a biplot of sample and species scores based on species relative abundances in each sample. DCA is based on reciprocal averaging in which sample scores are calculated from averages of species scores and vice versa. Relative abundances of species caught in each walkalong samples were arcsine transformed ($x' = \text{arcsine } \sqrt{x}$) before DCA analysis. Species only occurring in one sample from the entire sample set were not used in the analysis. Rare species were downweighted according to Canoco 4.5 software procedures.

It is again important to note that all backwater habitats are not sampled at both Station 1 and 6 for each study year analyzed because of annual differences in water levels and/or available habitat. River-connected samples (referred to as small inlets above) occur at both Stations 1 and 6. Backwater/disconnected samples (referred to as small pools above) only occur at Station 1 (adjacent to Piling set #78), while cove samples only occur at Station 6 (Ring Jaw Cove). Grouping of samples scores into discrete groups on a DCA biplot results from differences in fish community structure. The objective of this analysis does not attempt to explain differences in samples relative to Savannah River Site effects, but to examine overall trends in fish communities in backwater samples from 1995-2001. Resulting sample biplot scores were examined for grouping of samples based on year (1995-2001), station (1 and 6), and habitat (river-connected, backwater/disconnected, or cove).

Site and Sampling Descriptions and Conditions

Although ANSP collections on the Savannah River have been made at the same stations over time, the precise sampling locations and volume of areas sampled have varied with changes in water level and floodplain morphology. In 2001, the water levels during the sampling period (early September) were decreasing from a low level to a very low level. The presence of grasses, wild rice and other terrestrial macrophytes along river banks and sand bars was evidence that summer water levels were relatively low allowing these grasses good growth to the rivers edge. The water levels affected formation of side channels and pools typically sampled by backwater sampling. The water levels were typical of the levels experienced in the previous surveys but much lower than the higher levels experienced during the 1995-96 surveys.

Station 1

Seine samples at this station were collected along a long firm sand-gravel beach on the right bank (facing downstream) and between pilings in a silt-sand area with high organic detritus and some woody debris along the left bank. One walk-along electrofishing sample site, last sampled in 2000, was a river connected side pool area, downstream of piling set #78. The site was bordered by a sand spit island on the river side and a moderate sloping terrestrial grass covered mud bank with a small submerged log pile and a group of willow trees along the shoreline. The substrate consisted of mainly silt in the middle of the sample area and sand along the shorelines. The maximum depth of this area was 0.8-m.. No submerged aquatic vegetation was present at this site. Boat electrofishing samples were taken along both banks. One location sampled along the left bank

included the shoreline downstream of piling set #78, which contained submerged tree/brush snags and moderate flow with sand bottom.. Two locations between the pilings along the left bank were also sampled. The area contained little flow, some backeddy currents with debris dams along pilings and a gently sloping sand/silt shoreline. The right bank was sampled by boat shocking from the area of a intermittent creek at the lower end of the station to the upper sand beach across the river from the piling sets. Some rock rip-rap was present at the lower end of the station, forming the upstream mouth of the creek. The areas sampled contained moderately swift water with deeply cut banks, snag piles and submerged trees.

Station 6

One soft silt depositional, no flow area with a patch of flooded saw grass was seined at the pilings along the left bank. The large open beach area along the right bank at the upstream end of the station was also sampled. The substrate consisted of firm sand with small piles of woody debris (sticks). An additional beach along the left bank 200 meters upstream of Ring Jaw Cove was also seined. This area was an open firm sand beach with a sand/silt substrate and a small patch of submerged aquatic vegetation. One walk-along electroshocking sites was sampled in Ring Jaw Cove at Station 6. The historically sampled inner area was sampled (site 2). This area contained recently flooded shoreline grasses and patches of saw grass with submerged logs and a large downed tree. A moderately sized open area was contained within the sampled area. The maximum depth of the sample site was 0.8-m. The area contained moderate to soft silt substrate, with no aquatic vegetation. Few brush piles were present in the sampling area. Boat shocking samples were taken along both banks after water levels had dropped 0.5 m from time of walk-along shock sample, four days prior. The piling area on the left bank was sampled. The area contained pilings with brush piles, overhanging trees, a moderate amount of aquatic vegetation and open shore areas with woody debris. Additionally, the area just downstream and into the mouth of

Ring Jaw Cove was also shocked. This area contained steep to gradual sloping banks with snag piles, exposed root masses and stumps and open shoreline areas with no cover or flow. The large cove area along the right bank downstream of the upper sand beach was also boat shocked. The area contained submerged trees/logs and brush piles with mud covered shorelines.

Results

A total of 3951 specimens of 48 species were collected or observed at Stations 1 and 6 in the 2001 fish survey (see Table D-1 for totals and common and scientific names). The most common species were spottail shiner (both stations) and taillight shiner (Station 6 only). Large numbers of young-of-year minnows (some too small for specific identification) were collected at both stations. Notable records include a single Southern flounder (about 20 cm total length) observed at Station 6 and several margined madtoms (both Stations 1 and 6).

Two species of mosquitofish are currently recognized, the Eastern mosquitofish *Gambusia holbrooki* and the Western mosquitofish *G. affinis* (these were formerly considered subspecies of *G. affinis*). The Eastern mosquitofish is native to the Savannah River drainage. The Western mosquitofish is not considered native, although it has been reported from the upper drainage (Lydeard and Wooten 1991), where it apparently hybridizes with the Western species (based on molecular analyses). The two species are morphologically distinguished on the basis of dorsal rays counts (7 in the Eastern, and 6 in the Western), anal ray counts of males (10 in the Eastern and 9 in the Western), and strength of hooks on the posterior of the third gonopodial ray and the claw on the fourth gonopodial ray of males. Fin ray counts of specimens from the 2001 collections show counts typical of both species. The gonopodial character was examined in fish from the Savannah River collection, as well as fish from other areas (e.g., Texas and Florida, within the presumed ranges of the Western and Eastern species). It is possible that both species (and possibly hybrids) are present in the

Table D-1. Total number of fish caught by all techniques at Stations 1 and 6 in the 2001 ANSP Savannah River survey.

Family	Scientific	Common Name	Station 1	Station 6	Total	%
Lepisosteidae	*Lepisosteus osseus*	longnose gar	1	0	1	0.03
Lepisosteidae	*Lepisosteus platyrhincus*	Florida gar	0	1	1	0.03
Amiidae	*Amia calva*	bowfin	4	2	6	0.15
Anguillidae	*Anguilla rostrata*	American eel	13	15	28	0.71
Clupeidae	*Alosa aestivalis*	blueback herring	0	5	5	0.13
Clupeidae	*Dorosoma cepedianum*	gizzard shad	5	27	32	0.81
Clupeidae	*Dorosoma petenense*	threadfin shad	0	12	12	0.30
Cyprinidae	*Cyprinella leedsi*	bannerfin shiner	103	96	199	5.04
Cyprinidae	*Cyprinella nivea*	whitefin shiner	134	28	162	4.10
Cyprinidae	Cyprinidae species	minnow	175	490	665	16.83
Cyprinidae	*Hybognathus regius*	eastern silvery minnow	0	1	1	0.03
Cyprinidae	*Notemigonus crysoleucas*	golden shiner	2	0	2	0.05
Cyprinidae	*Notropis cummingsae*	dusky shiner	12	0	12	0.30
Cyprinidae	*Notropis hudsonius*	spottail shiner	342	624	966	24.45
Cyprinidae	*Notropis lutipinnis*	yellowfin shiner	0	2	2	0.05
Cyprinidae	*Notropis maculatus*	taillight shiner	0	772	772	19.54
Cyprinidae	*Notropis petersoni*	coastal shiner	18	58	76	1.92
Cyprinidae	*Notropis rubescens*	rosyface chub	99	0	99	2.51
Cyprinidae	*Opsopoeodus emiliae*	pugnose shiner	3	29	32	0.81
Catostomidae	*Minytrema melanops*	spotted sucker	5	29	34	0.86
Ictaluridae	*Ameiurus catus*	white catfish	0	4	4	0.10
Ictaluridae	*Ameiurus nebulosus*	brown bullhead	0	1	1	0.03
Ictaluridae	*Ameiurus platycephalus*	flat bullhead	4	0	4	0.10
Ictaluridae	*Ictalurus punctatus*	channel catfish	4	1	5	0.13
Ictaluridae	*Noturus gyrinus*	tadpole madtom	3	0	3	0.08
Ictaluridae	*Noturus insignis*	margined madtom	1	5	6	0.15
Ictaluridae	*Noturus leptacanthus*	speckled madtom	13	14	27	0.68
Esocidae	*Esox americanus*	redfin pickerel	4	0	4	0.10
Esocidae	*Esox niger*	chain pickerel	2	2	4	0.10
Aphredoderidae	*Aphredoderus sayanus*	pirate perch	29	2	31	0.78
Cyprinodontidae	*Fundulus lineolatus*	lineated topminnow	13	1	14	0.35
Poeciliidae	*Gambusia holbrooki*	eastern mosquitofish	14	11	25	0.63
Poeciliidae	*Gambusia* species	mosquitofish species	13	4	17	0.43
Atherinidae	*Labidesthes sicculus*	brook silverside	27	57	84	2.13
Centrarchidae	*Centrarchus macropterus*	flier	2	1	3	0.08
Centrarchidae	*Enneacanthus gloriosus*	bluespotted sunfish	8	0	8	0.20
Centrarchidae	*Lepomis auritus*	redbreast sunfish	47	68	115	2.91
Centrarchidae	*Lepomis gibbosus*	pumpkinseed	17	1	18	0.46
Centrarchidae	*Lepomis gulosus*	warmouth	7	7	14	0.35
Centrarchidae	*Lepomis macrochirus*	bluegill	82	120	202	5.11
Centrarchidae	*Lepomis marginatus*	dollar sunfish	32	62	94	2.38
Centrarchidae	*Lepomis microlophus*	redear sunfish	7	7	14	0.35
Centrarchidae	*Lepomis punctatus*	spotted sunfish	4	9	13	0.33
Centrarchidae	*Micropterus salmoides*	largemouth bass	12	37	49	1.24
Centrarchidae	*Pomoxis nigromaculatus*	black crappie	4	20	24	0.61
Percidae	*Etheostoma fusiforme*	swamp darter	1	0	1	0.03
Percidae	*Etheostoma olmstedi*	tesselated darter	5	23	28	0.71
Percidae	*Perca flavescens*	yellow perch	0	1	1	0.03
Percidae	*Percina nigrofasciata*	blackbanded darter	3	0	3	0.08
Mugilidae	*Mugil cephalus*	striped mullet	0	2	2	0.05
Bothidae	*Paralichthys lethostigma*	southern flounder	0	1	1	0.03
Soleidae	*Trinectes maculatus*	hogchoker	14	11	25	0.63
		Total	**1288**	**2663**	**3951**	**100**
		Number of Species	**39**	**40**	**48**	

middle Savannah River. If so, these could have come from the documented upstream occurrence or could result from stocking of Western mosquitofish elsewhere in the drainage. However, it is also possible that the characters are more variable than recognized within each species. In the report, individuals with fin ray counts typical of the Western mosquitofish are listed as *Gambusia* sp. For depletion analyses and historical comparisons, all *Gambusia* are grouped together.

Backwater Samples

A single backwater site was sampled at Station 1 and at Station 6 using walkalong (tow-barge) electroshocking (Table D-2). Three passes were taken in each site. For most species (excepting rare species), a decreasing pattern of catches was seen, and good depletion estimates of total abundance were feasible (Table D-3); confidence intervals were typically around 5-30% of the estimated population size. As typical of past years, mosquitofish and silversides showed a poor pattern of depletion. A relatively high proportion of the hogchokers caught were recovered from block nets at the end of sampling. The taillight shiner was abundant in the Station 6 catch, where it comprised 45% of the total catch. Some of the YOY cyprinids caught may have been taillight shiners as well, though most were probably spottail, bannerfin or whitefin shiners. Total density was about twice as high in the Station 6 sample as in the Station 1 sample (Table D-4). However, excepting the taillight shiner, densities were relatively similar at the two sites (185 fish/100 m^2 at Station 1 vs. 257 at Station 6). Spottail shiner, bluegill, dollar sunfish and brook silverside were common in the samples from both stations. Species common in one station only were bannerfin shiner (Station 6), rosyface chub (Station 1), and pirate perch (Station 1), pumpkinseed (Station 1). In general, the Station 1 site had higher densities of several species typically associated with backwater cover (e.g., pirate perch, redfin pickerel, chain pickerel, bluespotted sunfish, swamp darter), although the taillight shiner (abundant at Station 6) is typical of this habitat as well. Station 1 also had higher densities of rosyface chub, which is typically a channel species.

Table D-2. Total number of fish caught in walkalong samples in the 2001 ANSP Savannah River survey.

Species	Sample 1WS1	Sample 6WS1
Lepisosteus osseus	1	0
Anguilla rostrata	1	2
Dorosoma cepedianum	2	1
Dorosoma petenense	0	12
Cyprinella leedsi	0	35
Cyprinella nivea	1	0
Cyprinidae species	0	342
Hybognathus regius	0	1
Notropis hudsonius	156	324
Notropis maculatus	0	764
Notropis rubescens	53	0
Opsopoeodus emiliae	0	17
Minytrema melanops	1	10
Ameiurus catus	0	1
Ameiurus nebulosus	0	1
Ameiurus platycephalus	2	0
Esox americanus	4	0
Esox niger	1	0
Aphredoderus sayanus	28	0
Fundulus lineolatus	13	0
Gambusia holbrooki	8	3
Gambusia species	4	4
Labidesthes sicculus	15	29
Centrarchus macropterus	2	1
Enneacanthus gloriosus	8	0
Lepomis auritus	14	16
Lepomis gibbosus	17	0
Lepomis gulosus	7	3
Lepomis macrochirus	72	57
Lepomis marginatus	30	48
Lepomis microlophus	7	3
Lepomis punctatus	4	0
Micropterus salmoides	6	13
Pomoxis nigromaculatus	4	15
Etheostoma fusiforme	1	0
Etheostoma olmstedi	3	0
Trinectes maculatus	11	4
Total	476	1706
Sample Area (m^2)	278.4	408.8
Min Total Density (per 100 m^2)	170.98	417.32
Number of Passes	3	3
Number of Species	28	22

Table D-3. Number of fish caught in walkalong samples, confidence intervals (CI) and population estimates (PE) by Microfish (*Gambusia* species combined with GAHOL for depletion estimates).

Scientific Name	Site	Common Name	Pass-1	Pass-2	Pass-3	Net	Total	PE	CI	Method	Warning	Est. % Caught	Capture Probability
Lepisosteus osseus	1WS1	*longnose gar*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Anguilla rostrata	1WS1	*American eel*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Dorosoma cepedianum	1WS1	*gizzard shad*	2	0	0	0	2	2	2-2	*Total*	2	100.00	
Cyprinella nivea	1WS1	*whitefin shiner*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Notropis hudsonius	1WS1	*spottail shiner*	81	47	14	14	156	171	157-185	MLE	0	91.23	0.5512
Notropis rubescens	1WS1	*rosyface chub*	22	10	6	15	53	59	53-69	MLE	0	89.83	0.5248
Minytrema melanops	1WS1	*spotted sucker*	0	1	0	0	1	1	1-1	*Total*	1	100.00	
Ameiurus platycephalus	1WS1	*flat bullhead*	1	1	0	0	2	2	2-7	MLE	0	100.00	0.6667
Esox americanus	1WS1	*redfin pickerel*	2	1	1	0	4	4	4-7	MLE	0	100.00	0.5714
Esox niger	1WS1	*chain pickerel*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Aphredoderus sayanus	1WS1	*pirate perch*	18	10	0	0	28	28	28-30	MLE	0	100.00	0.7368
Fundulus lineolatus	1WS1	*lineated topminnow*	8	4	1	0	13	13	13-15	MLE	0	100.00	0.6842
Gambusia holbrooki	1WS1	*mosquitofish*	10	1	1	0	12	12	12-13	MLE	0	100.00	0.8
Labidesthes sicculus	1WS1	*brook silverside*	12	2	1	0	15	15	15-16	MLE	0	100.00	0.7895
Centrarchus macropterus	1WS1	*flier*	2	0	0	0	2	2	2-2	*Total*	2	100.00	
Enneacanthus gloriosus	1WS1	*bluespotted sunfish*	5	1	2	0	8	8	8-10	MLE	0	100.00	0.6154
Lepomis auritus	1WS1	*redbreast sunfish*	12	0	2	0	14	14	14-15	MLE	0	100.00	0.7778
Lepomis gibbosus	1WS1	*pumpkinseed*	9	7	1	0	17	17	17-20	MLE	0	100.00	0.6538
Lepomis gulosus	1WS1	*warmouth*	5	2	0	0	7	7	7-8	MLE	0	100.00	0.7778
Lepomis macrochirus	1WS1	*bluegill*	46	20	6	0	72	75	72-81	MLE	0	96.00	0.6372
Lepomis marginatus	1WS1	*dollar sunfish*	19	11	0	0	30	30	30-32	MLE	0	100.00	0.7317
Lepomis microlophus	1WS1	*redear sunfish*	3	3	1	0	7	7	7-10	MLE	0	100.00	0.5833
Lepomis punctatus	1WS1	*spotted sunfish*	3	0	0	1	4	4	4-4	*Total*	2	100.00	
Micropterus salmoides	1WS1	*largemouth bass*	2	3	1	0	6	6	6-10	MLE	0	100.00	0.5455
Pomoxis nigromaculatus	1WS1	*black crappie*	2	0	2	0	4	4	4-9	MLE	0	100.00	0.5
Etheostoma fusiforme	1WS1	*swamp darter*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Etheostoma olmstedi	1WS1	*tesselated darter*	1	0	0	2	3	3	3-3	*Total*	2	100.00	
Trinectes maculatus	1WS1	*hogchoker*	1	0	1	9	11	26	12-105	MLE	0	42.31	0.1739

Table D-3 (continued). Number of fish caught in walkalong samples, confidence intervals (CI) and population estimates (PE) by Microfish (*Gambusia* species combined with GAHOL for depletion estimates).

Scientific Name	Site	Common Name	Pass-1	Pass-2	Pass-3	Net	Total	PE	CI	Method	Warning	Est. % Caught	Capture Probability
Anguilla rostrata	6WS1	*American eel*	2	0	0	0	2	2	2-2	*Total*	2	100.00	
Dorosoma cepedianum	6WS1	*gizzard shad*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Dorosoma petenense	6WS1	*threadfin shad*	5	5	1	1	12	12	11-14	MLE	0	100.00	0.6111
Cyprinella leedsi	6WS1	*bannerfin shiner*	34	1	0	0	35	35	35-35	MLE	0	100.00	0.9722
Cyprinidae species	6WS1	*minnow*	181	131	18	12	342	375	355-393	MLE	0	91.20	0.5623
Hybognathus regius	6WS1	*eastern silvery minnow*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Notropis hudsonius	6WS1	*spottail shiner*	208	72	23	21	324	336	326-346	MLE	0	96.43	0.6653
Notropis maculatus	6WS1	*taillight shiner*	422	211	91	40	764	853	817-889	MLE	0	89.57	0.5284
Opsopoeodus emiliae	6WS1	*pugnose minnow*	11	3	0	3	17	17	17-18	MLE	0	100.00	0.8095
Minytrema melanops	6WS1	*spotted sucker*	7	0	2	1	10	10	10-11	MLE	0	100.00	0.7143
Ameiurus catus	6WS1	*white catfish*	1	0	0	0	1	1	1-1	*Total*	2	100.00	
Ameiurus nebulosus	6WS1	*brown bullhead*	0	1	0	0	1	1	1-1	*Total*	1	100.00	
Gambusia holbrooki	6WS1	*mosquitofish*	0	3	4	0	7	11	0	1.5 x *total*	3	63.64	
Labidesthes sicculus	6WS1	*brook silverside*	5	15	8	1	29	44	0	1.5 x *total*	3	65.91	
Centrarchus macropterus	6WS1	*flier*	0	1	0	0	1	1	1-1	*Total*	1	100.00	
Lepomis auritus	6WS1	*redbreast sunfish*	8	8	0	0	16	16	16-18	MLE	0	100.00	0.6667
Lepomis gulosus	6WS1	*warmouth*	0	1	2	0	3	5	0	1.5 x *total*	3	60.00	
Lepomis macrochirus	6WS1	*bluegill*	33	8	13	3	57	67	57-82	MLE	0	85.07	0.4634
Lepomis marginatus	6WS1	*dollar sunfish*	19	16	12	1	48	84	47-155	MLE	0	57.14	0.241
Lepomis microlophus	6WS1	*redear sunfish*	2	1	0	0	3	3	3-4	MLE	0	100.00	0.75
Micropterus salmoides	6WS1	*largemouth bass*	9	0	3	1	13	13	13-15	MLE	0	100.00	0.6842
Pomoxis nigromaculatus	6WS1	*black crappie*	9	2	3	1	15	15	15-17	MLE	0	100.00	0.6522
Trinectes maculatus	6WS1	*hogchoker*	2	0	0	2	4	4	4-4	*Total*	2	100.00	

Table D-4. Estimated densities (number per 100 m^2 from depletion estimates) of fish caught in walkalong samples (*Gambusia* species combined with GAHOL for depletion estimates) from the 2001 ANSP Savannah River survey.

Scientific Name	Common Name	1WS1	6WS1
Lepisosteus osseus	longnose gar	0.36	0.00
Anguilla rostrata	American eel	0.36	0.49
Dorosoma cepedianum	gizzard shad	0.72	0.24
Dorosoma petenense	threadfin shad	0.00	2.69
Cyprinella leedsi	bannerfin shiner	0.00	8.56
Cyprinella nivea	whitefin shiner	0.36	0.00
Cyprinidae species	minnow	0.00	91.49
Hybognathus regius	eastern silvery minnow	0.00	0.24
Notropis hudsonius	spottail shiner	61.42	82.19
Notropis maculatus	taillight shiner	0.00	208.66
Notropis rubescens	rosyface chub	21.19	0.00
Opsopoeodus emiliae	pugnose shiner	0.00	4.16
Minytrema melanops	spotted sucker	0.36	2.45
Ameiurus catus	white catfish	0.00	0.24
Ameiurus nebulosus	brown bullhead	0.00	0.24
Ameiurus platycephalus	flat bullhead	0.72	0.00
Esox americanus	redfin pickerel	1.44	0.00
Esox niger	chain pickerel	0.36	0.00
Aphredoderus sayanus	pirate perch	10.06	0.00
Fundulus lineolatus	lineated topminnow	4.67	0.00
Gambusia holbrooki	eastern mosquitofish	4.31	2.69
Labidesthes sicculus	brook silverside	5.39	10.76
Centrarchus macropterus	flier	0.72	0.24
Enneacanthus gloriosus	bluespotted sunfish	2.87	0.00
Lepomis auritus	redbreast sunfish	5.03	3.91
Lepomis gibbosus	pumpkinseed	6.11	0.00
Lepomis gulosus	warmouth	2.51	1.22
Lepomis macrochirus	bluegill	26.94	16.39
Lepomis marginatus	dollar sunfish	10.78	20.30
Lepomis microlophus	redear sunfish	2.51	0.73
Lepomis punctatus	spotted sunfish	1.44	0.00
Micropterus salmoides	largemouth bass	2.16	3.18
Pomoxis nigromaculatus	black crappie	1.44	3.67
Etheostoma fusiforme	swamp darter	0.36	0.00
Etheostoma olmstedi	tesselated darter	1.08	0.00
Trinectes maculatus	hogchoker	9.70	0.98
Total (Sum of spp. Estimates)		185.34	465.75
Sample Area		278.40	408.80
Location		Pilings	Upper Ring Jaw Cove
Relation to River		Edge/River connected	Cove/River connected

Seine Samples

Three seine samples were taken at each of the stations. Seining sites included open sand or sand/gravel beaches, sand-silt areas along the shoreline, and shorelines between pilings. These shoreline areas between pilings are mainly fine sediments (silts and detritus), but some areas had firm sand, as well. While there was a gradation in microhabitat conditions in the seine sites, they were divisible into two types: areas with fine sediments (silts and detritus) and low current velocity, versus sites with higher current velocities and more coarse-grained sediments (Table D-5). Relationships between fish occurrence and microhabitat for the 2001 samples were assessed in two ways: 1) using averages of microhabitat variables (depth, velocity, substrate) measured within each sample site as a continuous measure of microhabitat (used as covariates in analysis of covariance), and 2) using the two main habitat types as discrete habitat types (used as treatment effects in analysis of variance).

Table D-5. Habitat characteristics of seine samples from the 2001 ANSP Savannah River survey.

	Stations	
Habitat Characteristic	**1**	**6**
Average Depth(m)	0.89	0.64
Minimum of Depth (m)	0.86	0.59
Maximum of Depth (m)	0.94	0.72
Average of Velocity (m/s)	0.21	0.19
Minimum of Velocity (m/s)	-0.06	0.00
Maximum of Velocity (m/s)	0.37	0.30
Average of Substrate	3.97	4.47
Minimum of Substrate	3.58	4.17
Maximum of Substrate	4.58	5.00

Spottail shiner (both stations), whitefin shiner (Station 1), and rosyface chub (Station 1) were the most common species (Table D-6). A large number of small, unidentifiable YOY minnows were caught at both stations; these could be any of several species of *Notropis* and *Cyprinella*. Several species of sunfish, the tessellated darter, speckled madtom, bannerfin shiner, mosquitofish and hogchoker were fairly

Table D-6. Average CPUE (per 100 m^2) of fish caught in seine samples from the 2001 ANSP Savannah River survey.

Scientific Name	Common Name	Station 1	Station 6
Cyprinella leedsi	bannerfin shiner	0.90	3.03
Cyprinella nivea	whitefin shiner	27.84	4.89
Cyprinidae species	minnow	40.40	32.67
Notropis hudsonius	spottail shiner	18.28	32.75
Notropis petersoni	coastal shiner	0.00	0.22
Notropis rubescens	rosyface chub	5.96	0.00
Opsopoeodus emiliae	pugnose shiner	0.00	0.36
Ameiurus catus	white catfish	0.00	0.18
Noturus insignis	margined madtom	0.00	0.22
Noturus leptacanthus	speckled madtom	0.24	1.78
Fundulus lineolatus	lineated topminnow	0.00	0.18
Gambusia holbrooki	eastern mosquitofish	0.00	1.48
Labidesthes sicculus	brook silverside	2.14	0.22
Lepomis auritus	redbreast sunfish	0.70	3.06
Lepomis macrochirus	bluegill	0.00	2.34
Lepomis marginatus	dollar sunfish	0.00	0.72
Lepomis punctatus	spotted sunfish	0.00	0.58
Micropterus salmoides	largemouth bass	0.35	0.72
Etheostoma olmstedi	tesselated darter	0.70	3.83
Percina nigrofasciata	blackbanded darter	0.22	0.00
Trinectes maculatus	hogchoker	0.22	1.29
TOTAL		97.97	90.53
	Avg. No. Species	5.33	9.33
	Avg. SWDI	0.78	1.34

common at Station 6 as well. Statistical analyses (with and without microhabitat factors) found no significant differences in abundances of common species between the two stations. Several species showed significant relationships with microhabitat: hogchoker (negative relationship with maximum depth; $p<0.035$), tessellated darter (negative relationship with mean velocity; $p<0.036$); and spottail shiner (negative relationship with substrate coarseness; $p<0.024$). Species richness (square-root transformed) was significantly higher at Station 6 ($p<0.006$) and decreased with depth ($p<0.022$). Shannon-Wiener diversity also decreased with depth ($p<0.051$), but there was no significant station differ-

ence. Mean depth differed in samples at the two stations, with deeper water at Station 1. As a result, it is hard to separate station and depth effects on diversity. With the low sample size, the statistical power of comparisons is low.

Statistical comparisons of among-year and between-station differences were performed for common species collected in the 1997-2001 seine samples. Various models were investigated, with different combinations of microhabitat variables (depth, velocity, and substrate), year, station and year-station interactions. Significant explanatory models were developed for several species, with pairwise comparisons indicated. In many cases, several microhabitat variables showed significant effects singly reflecting covariation in microhabitat conditions (e.g., slower currents and finer substrates). The best models were selected:

1) Bannerfin shiner; significant model ($r^2 = 0.56$) with mean velocity ($p < 0.0005$), station ($p < 0.048$) and year ($p < 0.0073$); higher abundance at Station 6; higher abundance in 1999 than 1997.
2) Whitefin shiner; significant model ($r^2 = 0.73$) with mean substrate ($p < 0.000001$), year ($p < 0.0055$) and station-year interaction ($p < 0.037$); higher abundance in 1999 than in the other years.
3) Eastern mosquitofish; significant model ($r^2 = 0.21$) with mean substrate ($p < 0.0026$); higher abundance in fine substrates.
4) Eastern silvery minnow; significant model ($r^2 = 0.30$) with year ($p < 0.011$); higher abundance in 1998 and 1997 than in the other years.
5) Brook silverside; significant model ($r^2 = 0.10$) with mean velocity ($p < 0.043$); higher abundance in slower currents.
6) Redbreast sunfish; significant model ($r^2 = 0.40$) with mean substrate ($p < 0.000011$); higher abundance in fine substrates.
7) Bluegill; significant model ($r^2 = 0.43$) with mean velocity ($p < 0.00023$) and year ($p < 0.031$); higher abundance in 1998 and 2000 than in 1997.
8) Largemouth bass; significant model ($r^2 = 0.27$) with mean velocity ($p < 0.00050$); higher abundance in slower currents.

9) Spottail shiner; significant model ($r^2=0.29$) with year ($p<0.014$); higher abundance in 2001 than in 1998.

In general, these indicate strong microhabitat relationships, with several species (mosquitofish, brook silverside, sunfish and largemouth bass) more common in slower areas with finer currents (e.g., between pilings), and a few species (bannerfin shiner and whitefin shiner) more common in faster areas of coarser substrates. Several species (bannerfin shiner, whitefin shiner, spottail shiner, Eastern silvery minnow, and bluegill) showed significant differences between years, though most of these indicated one or a few years with high or low abundance. The spottail shiner and Eastern silvery minnow showed opposing trends (Fig. D-1). Spottail shiner was moderately common in 1997, uncommon in 1998 and has increased subsequently. In contrast, the Eastern silvery minnow showed high abundance in 1998 and has decreased subsequently. Bannerfin shiner was the only species to show significant station differences.

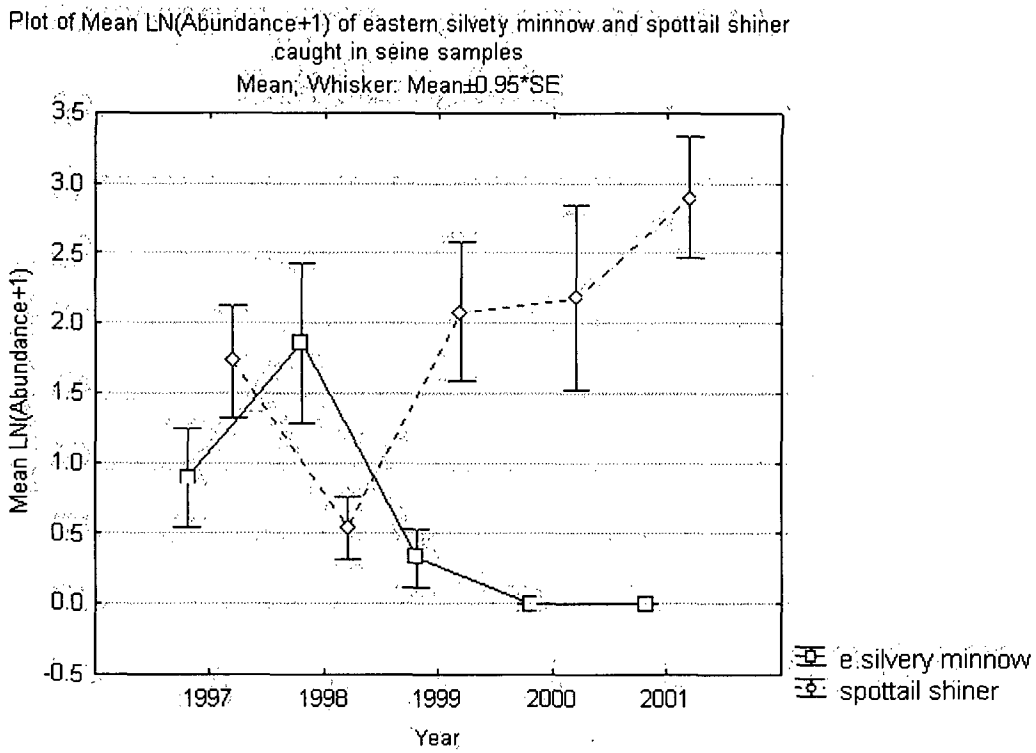


Figure D-1. Catch rate (number of fish per 100 m of shoreline seined) for spottail shiner (*Notropis hudsonbius*) and eastern silvery minnow (*Hybognathus regalis*) in seine samples from stations 1 and 6 in recent ANSP Savannah River surveys.

Boat Electroshocking Samples

Four boat-shocking samples were taken at each station. At Station 6, three of the four were in backwater habitats, while there were no backwater habitats at Station 1. Average species richness and total abundance tended to be higher at the Station 6 sites, although there was overlap in both variables in the samples from the two stations (Table D-7). Abundance of individual species was variable within stations and within habitats. The most common species was spottail shiner, which was abundant in some samples from both stations and habitats. Several species were most common in some channel sites, including rosyface chub (found in all channel samples from Station 1, though not at Station 6), whitefin shiner (found in four of the five channel samples), bannerfin shiner (abundant in three channel samples), hogchoker (present only in two samples, both from channel), blackbanded darter and channel catfish (both found in only two samples, both in channels). Other species were most common in some backwater sites, such as gizzard shad, coastal shiner, taillight shiner, spotted sucker, brook silversides, and redbreast sunfish (all most common at site 6BS3 or 6BS4), and bluegill, largemouth bass and black crappie (all most common at sites 6BS3 and 6BS4). These two sites (6BS3 and 6BS4), were located in the larger backwater coves on the SC side (Ring Jaw Cove) and GA side (unnamed cove). Spotted sunfish was found in all four Station 6 samples, but in none of the Station 1 samples. At Station 1, the lowest abundance was at the first site, located along the river bank away from pilings, while the other three samples were taken between pilings. In 2001, a habitat assessment was tested to help distinguish habitat differences in and between stations. Relationships between fish assemblages and habitat characteristics were investigated using canonical correspondence analysis (CANOCO), which calculates and selects correlated assemblage and environmental axes. The analyses showed differences between the backwater and channel samples, but did not indicate other habitat variables explaining assemblage variation.

Table D-7. Number of fish per 100m shoreline in boatshock samples from the 2001 ANSP Savannah River survey.

Scientific Name	Common Name	1BS1 Channel	1BS2 Channel	1BS3 Channel	1BS4 Channel	1 Mean	6BS1 Backwater	6BS2 Channel	6BS3 Backwater	6BS4 Backwater	6 Mean	# of Occ.	Backwater	Channel
Lepisosteus platyrhincus	Florida gar	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.19	1	0.26	0.00
Amia calva	bowfin	0.54	0.77	0.00	0.63	0.48	0.00	0.45	0.00	0.71	0.29	5	0.26	0.97
Anguilla rostrata	American eel	1.09	1.54	1.50	1.88	1.50	0.77	1.36	2.86	4.29	2.32	8	2.37	2.91
Alosa aestivalis	blueback herring	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.57	0.89	1	1.32	0.00
Dorosoma cepedianum	gizzard shad	0.00	0.77	0.00	1.25	0.50	0.00	0.45	0.00	17.86	4.58	4	6.58	0.78
Cyprinella leedsi	bannerfin shiner	0.54	30.77	28.00	0.63	14.98	5.38	17.73	1.43	0.00	6.14	7	2.11	26.74
Cyprinella nivea	whitefin shiner	0.27	4.62	3.00	0.00	1.97	0.00	2.73	0.00	0.00	0.68	4	0.00	3.68
Notemigonus crysoleucas	golden shiner	0.00	1.54	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	1	0.00	0.39
Notropis cummingsae	dusky shiner	0.00	0.00	6.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	1	0.00	2.33
Notropis hudsonius	spottail shiner	1.63	40.00	31.50	5.63	19.69	23.08	19.55	54.29	20.00	29.23	8	25.26	33.53
Notropis lutipinnis	yellowfin shiner	0.00	0.00	0.00	0.00	0.00	0.00	0.45	1.43	0.00	0.47	2	0.26	0.19
Notropis maculatus	taillight shiner	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.71	1.43	1	2.11	0.00
Notropis petersoni	coastal shiner	0.00	3.85	6.00	0.63	2.62	4.62	3.18	57.14	2.86	16.95	7	13.16	4.84
Notropis rubescens	rosyface chub	0.54	16.92	1.50	1.25	5.05	0.00	0.00	0.00	0.00	0.00	4	0.00	5.62
Opsopoeodus emiliae	pugnose shiner	0.00	2.31	0.00	0.00	0.58	0.77	2.73	1.43	1.43	1.59	5	1.05	1.74
Minytrema melanops	spotted sucker	0.00	3.08	0.00	0.00	0.77	3.85	0.00	17.14	1.43	5.60	4	5.00	0.78
Ameiurus platycephalus	flat bullhead	0.00	0.00	1.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	1	0.00	0.39
Ictalurus punctatus	channel catfish	0.27	0.00	1.00	0.00	0.32	0.00	0.45	0.00	0.00	0.11	3	0.00	0.78
Esox niger	chain pickerel	0.00	0.77	0.00	0.00	0.19	0.00	0.45	0.00	0.71	0.29	3	0.26	0.39
Aphredoderus sayanus	pirate perch	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.71	0.37	2	0.53	0.00
Labidesthes sicculus	brook silverside	0.00	1.54	0.50	0.00	0.51	1.54	0.45	4.29	15.00	5.32	6	6.84	0.78
Lepomis auritus	redbreast sunfish	0.82	11.54	3.00	4.38	4.93	7.69	4.09	20.00	1.43	8.30	8	6.84	7.75
Lepomis gibbosus	pumpkinseed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	0.00	0.36	1	0.26	0.00
Lepomis gulosus	warmouth	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	2.14	0.73	2	1.05	0.00
Lepomis macrochirus	bluegill	0.27	5.38	0.50	0.63	1.70	4.62	0.91	11.43	24.29	10.31	8	12.63	2.33
Lepomis marginatus	dollar sunfish	0.00	0.00	0.00	1.25	0.31	0.00	0.00	2.86	5.71	2.14	3	2.63	0.39
Lepomis microlophus	redear sunfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.86	0.71	1	1.05	0.00
Lepomis punctatus	spotted sunfish	0.00	0.00	0.00	0.00	0.00	0.77	0.45	4.29	0.71	1.56	4	1.32	0.19
Micropterus salmoides	largemouth bass	0.00	2.31	0.00	1.25	0.89	2.31	0.91	7.14	7.14	4.38	6	4.74	1.36
Pomoxis nigromaculatus	black crappie	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	2.86	1.07	3	1.32	0.00
Etheostoma olmstedi	tesselated darter	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.11	1	0.00	0.19
Perca flavescens	yellow perch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.71	0.18	1	0.26	0.00
Percina nigrofasciata	blackbanded darter	0.00	0.77	0.50	0.00	0.32	0.00	0.00	0.00	0.00	0.00	2	0.00	0.39
Mugil cephalus	striped mullet	0.00	0.00	0.00	0.00	0.00	1.54	0.00	0.00	0.00	0.38	1	0.53	0.00
Paralichthys lethostigma	southern flounder	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.11	1	0.00	0.19
Trinectes maculatus	hogchoker	0.27	0.00	0.00	0.63	0.22	0.00	0.00	0.00	0.00	0.00	2	0.00	0.39
All Fish		6.27	128.46	84.00	20.00	59.68	59.23	57.27	188.57	122.14	106.80		380	516
Sample Length		367	130	200	160	214.25	130	220	70	140	140.00			
Number of Species	single sample or mean	10	17	13	12	13.00	15	18	15	21	17.25		17	14
Station Total					22					30			26	26

Hand Samples

A few specimens were collected by dip nets during macroinvertebrate sampling (Table D-8). As in past years, these samples show the widespread occurrence of small catfishes which are less frequently collected by other techniques. The speckled madtom (*Noturus leptacanthus*) was the most common catfish, but white catfish (*Ameiurus catus*), channel catfish (*Ictalurus punctatus*) and margined madtom (*N. insignis*) were also caught. The margined madtom was caught at both stations. Its occurrence is notable; it was last recorded in ANSP Savannah River surveys in 1981 (about 50 miles below Station 6), and last recorded from the SRS stations (1, 3, 5 and 6) in 1977.

Table D-8. Fish collected in hand samples for the 2001 ANSP Savannah River survey.

Scientific Name	Common Name	Station 1	Station 6
Anguilla rostrata	American eel		1
Cyprinidae species	Minnow species		1
Ameiurus catus	White catfish		2
Ictalurus punctatus	Channel catfish	1	
Noturus gyrinus	Tadpole madtom	3	
Noturus insignis	Margined madtom	1	4
Noturus leptacanthus	Speckled madtom	12	6
Aphredoderus sayanus	Pirate perch	1	
Gambusia holbrooki	Eastern mosquitofish	6	
Gambusia species	Mosquitofish sp.	9	
Etheostoma olmstedi	Tesselated darter		1
Trinectes maculatus	Hogchoker		1

Overall Proportions

An index of relative abundance at each station was calculated (Table D-9), based on relative abundance within each collecting type. Since different techniques are used in different habitats and are have different efficiencies on different species, the overall proportions of different species (e.g., Table D-2) are sensitive to the rela-

Table D-9. Average relative abundances of species caught by major collection techniques (boatshock, walkalong shock, seine) in the 2001 ANSP Savannah River survey. Proportions are the averages of the proportions of each species in collections by each technique (first three columns) and averages over all specimens (next three columns).

		Mean of Technique Proportions			Proportion among all Specimens		
Scientific Name	Common Name	1	6	All	1	6	All
Lepisosteus osseus	longnose gar	0.06	0.00	0.01	0.08	0.00	0.03
Lepisosteus platyrhincus	Florida gar	0.00	0.07	0.04	0.00	0.04	0.03
Amia calva	bowfin	0.34	0.13	0.22	0.32	0.08	0.15
Anguilla rostrata	American eel	1.09	0.83	0.93	1.04	0.53	0.69
Alosa aestivalis	blueback herring	0.00	0.33	0.19	0.00	0.19	0.13
Dorosoma cepedianum	gizzard shad	0.39	1.73	1.12	0.40	1.02	0.82
Dorosoma petenense	threadfin shad	0.00	0.19	0.15	0.00	0.45	0.31
Cyprinella leedsi	bannerfin shiner	8.80	4.78	6.64	8.21	3.63	5.10
Cyprinella nivea	whitefin shiner	11.46	2.08	6.46	10.68	1.06	4.15
Cyprinidae species	minnow	15.00	17.79	18.16	13.94	18.47	17.02
Hybognathus regius	eastern silvery minnow	0.00	0.02	0.01	0.00	0.04	0.03
Notemigonus crysoleucas	golden shiner	0.17	0.00	0.07	0.16	0.00	0.05
Notropis cummingsae	dusky shiner	1.03	0.00	0.45	0.96	0.00	0.31
Notropis hudsonius	spottail shiner	26.96	27.35	25.76	27.25	23.57	24.76
Notropis lutipinnis	yellowfin shiner	0.00	0.13	0.07	0.00	0.08	0.05
Notropis maculatus	taillight shiner	0.00	15.46	12.05	0.00	29.17	19.78
Notropis petersoni	coastal shiner	1.54	3.83	2.83	1.43	2.19	1.95
Notropis rubescens	rosyface chub	7.75	0.00	2.58	7.89	0.00	2.54
Opsopoeodus emiliae	pugnose shiner	0.26	1.11	0.80	0.24	1.10	0.82
Minytrema melanops	spotted sucker	0.41	1.43	1.01	0.40	1.10	0.87
Ameiurus catus	white catfish	0.00	0.17	0.09	0.00	0.08	0.05
Ameiurus nebulosus	brown bullhead	0.00	0.02	0.01	0.00	0.04	0.03
Ameiurus platycephalus	flat bullhead	0.30	0.00	0.10	0.32	0.00	0.10
Ictalurus punctatus	channel catfish	0.26	0.07	0.15	0.24	0.04	0.10
Noturus gyrinus	tadpole madtom	0.00	0.00	0.00	0.00	0.00	0.00
Noturus insignis	margined madtom	0.00	0.08	0.04	0.00	0.04	0.03
Noturus leptacanthus	speckled madtom	0.09	0.61	0.36	0.08	0.30	0.23
Esox americanus	redfin pickerel	0.26	0.00	0.06	0.32	0.00	0.10
Esox niger	chain pickerel	0.15	0.13	0.13	0.16	0.08	0.10
Aphredoderus sayanus	pirate perch	1.81	0.13	0.46	2.23	0.08	0.77
Fundulus lineolatus	lineated topminnow	0.84	0.08	0.22	1.04	0.04	0.36
*Gambusia holbrooki**	eastern mosquitofish	0.78	0.80	0.64	0.96	0.57	0.69
Labidesthes sicculus	brook silverside	2.00	2.63	2.33	2.15	2.15	2.15
Centrarchus macropterus	flier	0.13	0.02	0.04	0.16	0.04	0.08
Enneacanthus gloriosus	bluespotted sunfish	0.52	0.00	0.11	0.64	0.00	0.21
Lepomis auritus	redbreast sunfish	3.73	3.89	3.64	3.75	2.57	2.95
Lepomis gibbosus	pumpkinseed	1.10	0.07	0.27	1.35	0.04	0.46
Lepomis gulosus	warmouth	0.45	0.35	0.31	0.56	0.26	0.36
Lepomis macrochirus	bluegill	5.70	5.46	4.71	6.53	4.53	5.18
Lepomis marginatus	dollar sunfish	2.11	2.42	2.16	2.55	2.34	2.41
Lepomis microlophus	redear sunfish	0.45	0.32	0.29	0.56	0.26	0.36
Lepomis punctatus	spotted sunfish	0.26	0.62	0.40	0.32	0.34	0.33
Micropterus salmoides	largemouth bass	0.90	1.85	1.39	0.96	1.40	1.26
Pomoxis nigromaculatus	black crappie	0.26	0.59	0.45	0.32	0.76	0.62
Etheostoma fusiforme	swamp darter	0.06	0.00	0.01	0.08	0.00	0.03
Etheostoma olmstedi	tesselated darter	0.37	1.67	1.01	0.40	0.83	0.69
Perca flavescens	yellow perch	0.00	0.07	0.04	0.00	0.04	0.03
Percina nigrofasciata	blackbanded darter	0.26	0.00	0.11	0.24	0.00	0.08
Mugil cephalus	striped mullet	0.00	0.13	0.07	0.00	0.08	0.05
Paralichthys lethostigma	southern flounder	0.00	0.07	0.04	0.00	0.04	0.03
Trinectes maculatus	hogchoker	2.00	0.53	0.78	1.12	0.38	0.62
Total		100.00	100.00	100.00	100.00	100.00	100.00

tive effort by each technique. To reduce the dependence on relative effort, the overall index averages the relative proportion of species by each major collecting technique (seining, boat electroshocking, and walkalong electroshocking), giving equal weight to each collecting technique. As expected, the relative abundance index (Table D-9) results in lower proportions of species found in high abundance in only one technique (e.g., taillight shiner)

The resultant frequencies of occurrence show differences in occurrence across the stations. The proportions are generally similar for many species, with some differences in proportions of minnows and other species. The taillight shiner was a large proportion of the catch at Station 6 (especially in the backwater site, but also in boat-shocking channel collections), but was not caught at Station 1. Conversely, the whitefin shiner and rosyface chub were more common at Station 1.

Condition Analysis

Condition (length-weight relationships) was analyzed for five species (Table D-10; Figs. D-2 to D-6). There were no differences in condition between the stations for bannerfin shiner, bluegill or redbreast sunfish. There was a weak difference in slopes between the stations for spottail shiner, leading to a higher least squares mean weight at Station 6. There were highly significant differences in intercept and slope between the stations for dollar sunfish. However, there was no difference in least-squares mean weight between the stations, i.e., the two weight-length regressions cross around the mean length of fish.

Discussion

Temporal Trends in River Fish Communities

The relative abundance of fishes among the last three survey years (Tables D-11 and D-12) provides general information on temporal trends. These propor-

Table D-10. Condition analysis of fish from the 2001 ANSP Savannah River survey. Columns labeled Station Differences and Separate Slopes show p values for tests of the null hypothesis that the intercepts and slopes (respectively) of length-weight regression lines are equal for Stations 1 and 6. Letters for the column labeled Pairwise Differences indicate whether the two stations differed significantly ($p<0.05$) with respect to least-squares mean (LSM) length; stations that did not differ significantly have the same letter.

Species and Station	p values		n	Mean Length (cm) and LSMs	Pairwise Differences
	Station Differences	Separate Slopes			
Bannerfin shiner (*Cyprinella leedsi*)					
	0.716	0.563	100	5.19	
1			50	0.96	A
6			50	0.93	A
Spottail shiner (*Notropis hudsonius*)					
	0.077	0.025	100	6.58	
1			50	1.79	A
6			50	1.91	B
Bluegill (*Lepomis macrochirus*)					
	0.862	0.962	86	5.89	
1			38	2.83	A
6			48	2.69	A
Redbreast sunfish (*Lepomis auritus*)					
	0.670	0.945	50	4.56	
1			12	1.32	A
6			38	1.42	B
Dollar sunfish (*Lepois marginatus*)					
	0.000245	0.000113	71	4.69	
1			20	1.67	A
6			51	1.67	A

tions are the total over all specimens and are thus sensitive to the sampling effort by each technique. The 1999 study consisted of two backwater samples, five seine hauls and three boatshock samples at each station, while the 2000 and 2001 studies consisted of one backwater sample, three seine hauls and four boatshock samples at each station (hand collections were done for all three studies).

The most striking difference was the high abundance of tail-

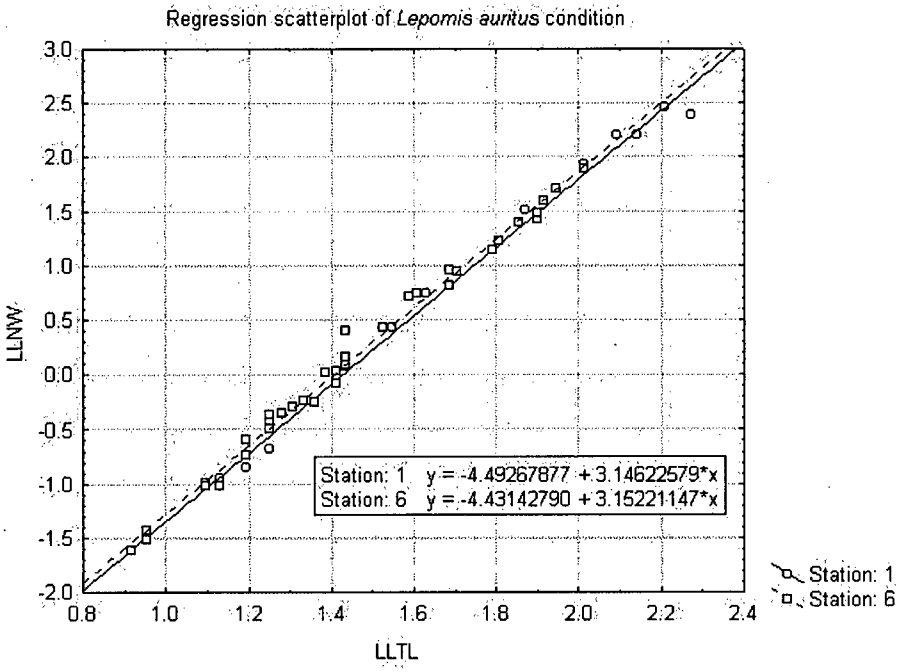


Figure D-2. Length-weight relationships of red breast sunfish (*Lepomis auritus*) in the 2001 ANSP Savannah River surveys. See text for information on significance of difference among slopes and intercepts of regressions.

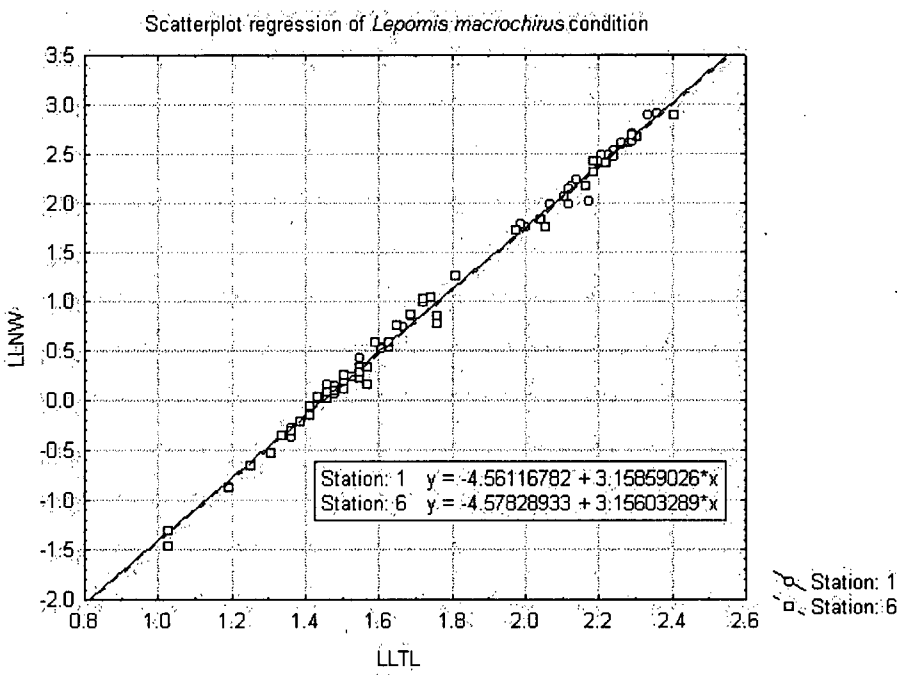


Figure D-3. Length-weight relationships of bluegill (*Lepomis macrochirus*) in the 2001 ANSP Savannah River surveys. See text for information on significance of difference among slopes and intercepts of regressions.

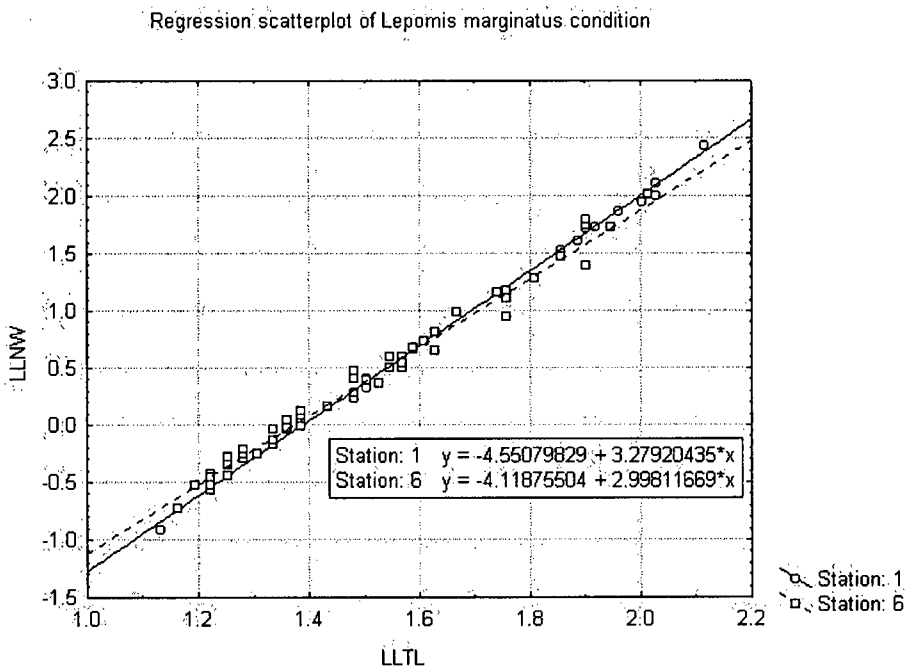


Figure D-4. Length-weight relationships of dollar sunfish (*Lepomis marginatus*) in the 2001 ANSP Savannah River surveys. See text for information on significance of difference among slopes and intercepts of regressions.

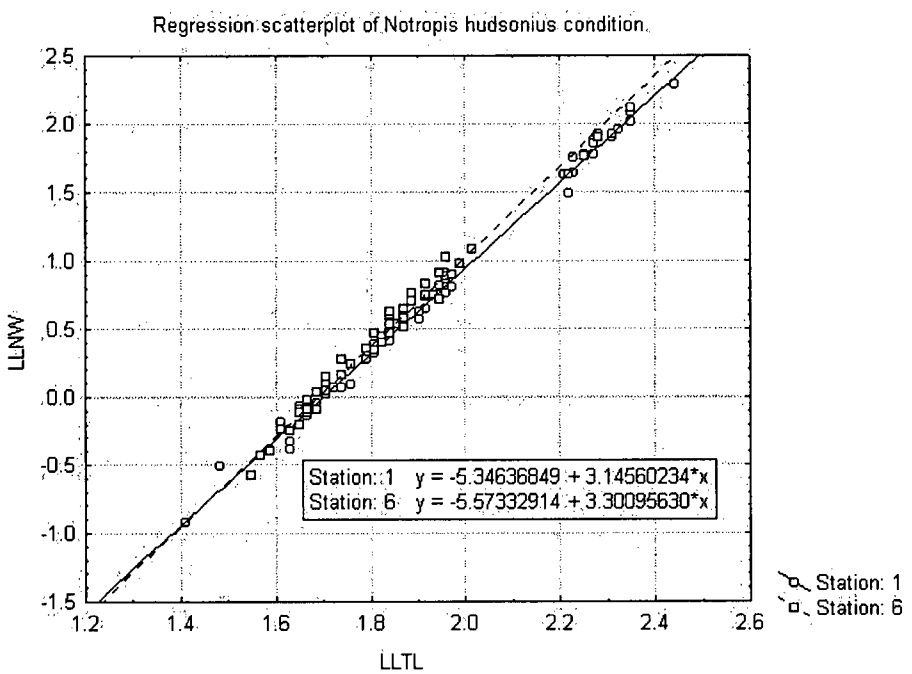


Figure D-5. Length-weight relationships of spottail shiner (*Notropis hudonius*) in the 2001 ANSP Savannah River surveys. See text for information on significance of difference among slopes and intercepts of regressions.

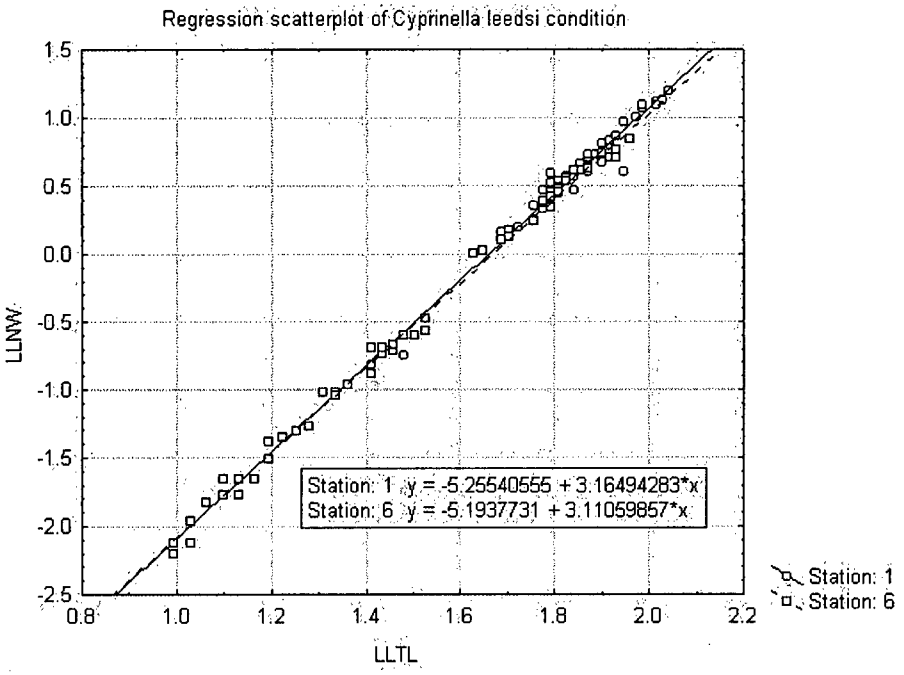


Figure D-6. Length-weight relationships of bannerfin shiner (*Cyprinella leedsi*) in the 2001 ANSP Savannah River surveys. See text for information on significance of difference among slopes and intercepts of regressions.

more common in 2001 samples than in earlier samples. Small numbers of a few infrequently caught species, such as margined madtom, Southern flounder, flat bullhead, and yellowfin shiner, were also caught in 2001. A few species, such as Eastern silvery minnow, bluegill, spotted sucker and blackbanded darter have decreased in relative abundance in samples over the last three years.

The statistical analyses of species abundance in seine samples showed several temporal patterns. A few of these, such as the increase in spottail shiner and decrease in Eastern silvery minnow, formed consistent multi-year trends. However, for most species, temporal patterns are mainly evident as occasional years of high or low abundance.

The 2001 sample period followed a period of relatively low flow in the Savannah River. Effects of flow patterns on Savannah River fish may be complex, with effects related to timing of flow relative to fish reproduction (e.g., spring versus summer spawners), microhabitat preferences of channel fishes (e.g., related to reduction in current velocities), and changes in amount and habitat conditions of swamp and backwater habitats. Catch rates of fish will be related to pop-

Table D-11. Percentages of species (based on all techniques combined) in 1999-2001 ANSP Savannah River surveys.

			Year						
			1999		2000		2001		Average
Family	Species		Total	%	Total	%	Total	%	%
Cyprinidae	*Notropis hudsonius*	spottail shiner	549	18.94	595	27.58	966	24.45	23.66
Centrarchidae	*Lepomis macrochirus*	bluegill	456	15.73	235	10.89	202	5.11	10.58
Cyprinidae	*Cyprinella nivea*	whitefin shiner	334	11.52	179	8.30	162	4.10	7.97
Cyprinidae	*Cyprinella leedsi*	bannerfin shiner	89	3.07	289	13.40	199	5.04	7.17
Cyprinidae	*Cyprinidae* species	minnow species	0	0.00	96	4.45	665	16.83	7.09
Cyprinidae	*Notropis maculatus*	taillight shiner	7	0.24	11	0.51	772	19.54	6.76
Atherinidae	*Labidesthes sicculus*	brook silverside	222	7.66	197	9.13	84	2.13	6.31
Cyprinidae	*Cyprinella* species	*Cyprinella* species	447	15.42	62	2.87	0	0.00	6.10
Centrarchidae	*Lepomis auritus*	redbreast sunfish	93	3.21	77	3.57	115	2.91	3.23
Catostomidae	*Minytrema melanops*	spotted sucker	106	3.66	55	2.55	34	0.86	2.36
Centrarchidae	*Lepomis marginatus*	dollar sunfish	74	2.55	38	1.76	94	2.38	2.23
Cyprinidae	*Notropis petersoni*	coastal shiner	37	1.28	35	1.62	76	1.92	1.61
Cyprinidae	*Notropis rubescens*	rosyface chub	38	1.31	21	0.97	99	2.51	1.60
Poeciliidae	*Gambusia holbrooki*	eastern mosquitofish	79	2.73	22	1.02	25	0.63	1.46
Centrarchidae	*Micropterus salmoides*	largemouth bass	41	1.41	36	1.67	49	1.24	1.44
Cyprinidae	*Opsopoeodus emiliae*	pugnose shiner	20	0.69	34	1.58	32	0.81	1.03
Centrarchidae	*Pomoxis nigromaculatus*	black crappie	22	0.76	25	1.16	24	0.61	0.84
Anguillidae	*Anguilla rostrata*	American eel	11	0.38	18	0.83	28	0.71	0.64
Centrarchidae	*Lepomis gulosus*	warmouth	27	0.93	13	0.60	14	0.35	0.63
Centrarchidae	*Lepomis microlophus*	redear sunfish	27	0.93	11	0.51	14	0.35	0.60
Centrarchidae	*Lepomis gibbosus*	pumpkinseed	25	0.86	9	0.42	18	0.46	0.58
Soleidae	*Trinectes maculatus*	hogchoker	16	0.55	11	0.51	25	0.63	0.56
Clupeidae	*Dorosoma cepedianum*	gizzard shad	2	0.07	16	0.74	32	0.81	0.54
Percidae	*Percina nigrofasciata*	blackbanded darter	32	1.10	5	0.23	3	0.08	0.47
Centrarchidae	*Lepomis punctatus*	spotted sunfish	27	0.93	2	0.09	13	0.33	0.45
Ictaluridae	*Noturus leptacanthus*	speckled madtom	10	0.34	5	0.23	27	0.68	0.42
Cyprinodontidae	*Fundulus lineolatus*	lineated topminnow	10	0.34	12	0.56	14	0.35	0.42
Percidae	*Etheostoma olmstedi*	tesselated darter	6	0.21	4	0.19	28	0.71	0.37
Cyprinidae	*Hybognathus regius*	eastern silvery minnow	24	0.83	4	0.19	1	0.03	0.35
Aphredoderidae	*Aphredoderus sayanus*	pirate perch	3	0.10	1	0.05	31	0.78	0.31
Amiidae	*Amia calva*	bowfin	10	0.34	6	0.28	6	0.15	0.26

Table D-11 (continued). Percentages of species (based on all techniques combined) in 1999-2001 ANSP Savannah River surveys.

			Year						
			1999		2000		2001		Average
Family	Species		Total	%	Total	%	Total	%	%
Cyprinidae	*Notemigonus crysoleucas*	golden shiner	15	0.31	3	0.07	2	0.03	0.14
Cyprinidae	*Notropis cummingsae*	dusky shiner	0	0.00	5	0.12	12	0.20	0.11
Poeciliidae	*Gambusia* species	mosquitofish species	0	0.00	0	0.00	17	0.29	0.10
Centrarchidae	*Enneacanthus gloriosus*	bluespotted sunfish	2	0.04	3	0.07	8	0.13	0.08
Ictaluridae	*Ameiurus catus*	white catfish	4	0.08	3	0.07	4	0.07	0.07
Esocidae	*Esox niger*	chain pickerel	2	0.04	4	0.10	4	0.07	0.07
Mugilidae	*Mugil cephalus*	striped mullet	7	0.14	1	0.02	2	0.03	0.07
Clupeidae	*Dorosoma petenense*	threadfin shad	0	0.00	0	0.00	12	0.20	0.07
Esocidae	*Esox americanus*	redfin pickerel	3	0.06	2	0.05	4	0.07	0.06
Centrarchidae	*Centrarchus macropterus*	flier	5	0.10	0	0.00	3	0.05	0.05
Ictaluridae	*Ictalurus punctatus*	channel catfish	2	0.04	1	0.02	5	0.08	0.05
Lepisosteidae	*Lepisosteus osseus*	longnose gar	3	0.06	2	0.05	1	0.02	0.04
Clupeidae	*Alosa aestivalis*	blueback herring	0	0.00	2	0.05	5	0.08	0.04
Ictaluridae	*Noturus insignis*	margined madtom	0	0.00	0	0.00	6	0.10	0.03
Percidae	*Perca flavescens*	yellow perch	0	0.00	2	0.05	1	0.02	0.02
Lepisosteidae	*Lepisosteus platyrhincus*	Florida gar	1	0.02	1	0.02	1	0.02	0.02
Percidae	*Etheostoma fusiforme*	swamp darter	1	0.02	1	0.02	1	0.02	0.02
Catostomidae	*Erimyzon sucetta*	lake chubsucker	3	0.06	0	0.00	0	0.00	0.02
Ictaluridae	*Ameiurus platycephalus*	flat bullhead	0	0.00	0	0.00	4	0.07	0.02
Cyprinidae	*Notropis chalybaeus*	ironcolor shiner	0	0.00	2	0.05	0	0.00	0.02
Ictaluridae	*Noturus gyrinus*	tadpole madtom	0	0.00	0	0.00	3	0.05	0.02
Clupeidae	*Alosa sapidissima*	American shad	2	0.04	0	0.00	0	0.00	0.01
Catostomidae	*Moxostoma anisurum*	silver redhorse	2	0.04	0	0.00	0	0.00	0.01
Cyprinidae	*Notropis lutipinnis*	yellowfin shiner	0	0.00	0	0.00	2	0.03	0.01
Centrarchidae	*Lepomis* species	sunfish species	0	0.00	1	0.02	0	0.00	0.01
Cyprinidae	*Nocomis leptocephalus*	bluehead chub	1	0.02	0	0.00	0	0.00	0.01
Belonidae	*Strongylura marina*	Atlantic needlefish	1	0.02	0	0.00	0	0.00	0.01
Cyprinodontidae	*Fundulus chrysotus*	golden topminnow	1	0.02	0	0.00	0	0.00	0.01
Ictaluridae	*Ameiurus nebulosus*	brown bullhead	0	0.00	0	0.00	1	0.02	0.01
Bothidae	*Paralichthys lethostigma*	southern flounder	0	0.00	0	0.00	1	0.02	0.01
	Total:		4898	59.19	4157	51.89	5952	66.38	59.15
	Number of Species		46		43		48		57

Table D-12. Relative abundance of fishes caught during study years 1999-2001 at Stations 1 and 6 on the Savannah River during ANSP surveys.

	Year-Station					
Species	1999-1	2000-1	2001-1	1999-6	2000-6	2001-6
Lepisosteus osseus	0.00	0.33	0.08	0.18	0.00	0.00
Lepisosteus platyrhincus	0.00	0.00	0.00	0.06	0.06	0.04
Amia calva	0.72	0.66	0.31	0.06	0.13	0.08
Anguilla rostrata	0.08	0.66	1.01	0.60	0.90	0.56
Alosa aestivalis	0.00	0.00	0.00	0.00	0.13	0.19
Alosa sapidissima	0.16	0.00	0.00	0.00	0.00	0.00
Dorosoma cepedianum	0.00	0.82	0.39	0.12	0.71	1.01
Dorosoma petenense	0.00	0.00	0.00	0.00	0.00	0.45
Cyprinella leedsi	2.33	13.79	8.00	3.62	13.24	3.60
Cyprinella nivea	18.26	22.33	10.40	6.46	2.78	1.05
Cyprinella species	28.80	0.16	0.00	5.37	3.94	0.00
Cyprinidae species	0.00	0.00	13.59	0.00	6.20	18.40
Hybognathus regius	1.85	0.00	0.00	0.06	0.26	0.04
Nocomis leptocephalus	0.08	0.00	0.00	0.00	0.00	0.00
Notemigonus crysoleucas	0.00	0.16	0.16	0.91	0.13	0.00
Notropis chalybaeus	0.00	0.16	0.00	0.00	0.06	0.00
Notropis cummingsae	0.00	0.00	0.93	0.00	0.32	0.00
Notropis hudsonius	19.07	25.29	26.55	18.84	28.49	23.43
Notropis lutipinnis	0.00	0.00	0.00	0.00	0.00	0.08
Notropis maculatus	0.00	0.00	0.00	0.42	0.71	28.99
Notropis petersoni	1.77	0.66	1.40	0.91	2.00	2.18
Notropis rubescens	2.98	3.28	7.69	0.06	0.06	0.00
Opsopoeodus emiliae	0.08	1.64	0.23	1.15	1.55	1.09
Erimyzon sucetta	0.00	0.00	0.00	0.18	0.00	0.00
Minytrema melanops	1.61	0.99	0.39	5.19	3.17	1.09
Moxostoma anisurum	0.16	0.00	0.00	0.00	0.00	0.00
Ameiurus catus	0.32	0.33	0.00	0.00	0.06	0.15
Ameiurus nebulosus	0.00	0.00	0.00	0.00	0.00	0.04
Ameiurus platycephalus	0.00	0.00	0.31	0.00	0.00	0.00
Ictalurus punctatus	0.16	0.16	0.31	0.00	0.00	0.04
Noturus gyrinus	0.00	0.00	0.23	0.00	0.00	0.00
Noturus insignis	0.00	0.00	0.08	0.00	0.00	0.19
Noturus leptacanthus	0.16	0.00	1.01	0.48	0.32	0.53
Esox americanus	0.24	0.33	0.31	0.00	0.00	0.00
Esox niger	0.00	0.49	0.16	0.12	0.06	0.08
Aphredoderus sayanus	0.08	0.16	2.25	0.12	0.00	0.08
Strongylura marina	0.00	0.00	0.00	0.06	0.00	0.00
Fundulus chrysotus	0.00	0.00	0.00	0.06	0.00	0.00
Fundulus lineolatus	0.16	1.31	1.01	0.48	0.26	0.04
Gambusia holbrooki	2.74	2.63	1.09	2.72	0.39	0.41
Gambusia species	0.00	0.00	1.01	0.00	0.00	0.15
Labidesthes sicculus	0.80	1.31	2.10	12.80	12.21	2.14
Centrarchus macropterus	0.08	0.00	0.16	0.24	0.00	0.04
Enneacanthus gloriosus	0.00	0.49	0.62	0.12	0.00	0.00
Lepomis auritus	3.94	6.24	3.65	2.66	2.52	2.55
Lepomis gibbosus	1.53	0.66	1.32	0.36	0.32	0.04
Lepomis gulosus	0.08	0.99	0.54	1.57	0.45	0.26
Lepomis macrochirus	3.78	8.87	6.37	24.70	11.69	4.51
Lepomis marginatus	2.25	0.82	2.48	2.78	2.13	2.33
Lepomis microlophus	0.48	0.16	0.54	1.27	0.65	0.26
Lepomis punctatus	0.32	0.33	0.31	1.39	0.00	0.34
Lepomis species	0.00	0.00	0.00	0.00	0.06	0.00
Micropterus salmoides	1.53	2.46	0.93	1.33	1.36	1.39
Pomoxis nigromaculatus	0.00	0.16	0.31	1.33	1.55	0.75
Etheostoma fusiforme	0.08	0.00	0.08	0.00	0.06	0.00
Etheostoma olmstedi	0.48	0.16	0.39	0.00	0.19	0.86
Perca flavescens	0.00	0.16	0.00	0.00	0.06	0.04
Percina nigrofasciata	2.41	0.66	0.23	0.12	0.06	0.00
Mugil cephalus	0.16	0.00	0.00	0.30	0.06	0.08
Paralichthys lethostigma	0.00	0.00	0.00	0.00	0.00	0.04
Trinectes maculatus	0.24	0.16	1.09	0.79	0.65	0.41
Total	100.00	100.00	100.00	100.00	100.00	100.00
Number of Species	35	35	39	38	37	40

ulation trends (e.g., reproductive success and adult survival), as well as behavioral responses to flow (e.g., movement of fish from swamp habitats into river backwater and edge habitats). For example, the taillight shiner typically occurs in slow pools with high amounts of detritus. The high abundance of taillight shiner in 2001 could be explained by increase in this habitat type at low flows (e.g., with reduced flushing and shallower water in backwater and swamp habitats) and/or by movement of fish from swamp habitats into the sampling sites with very low water.

Differences among Stations

Differences in occurrence and abundance of species between the two stations were seen, but these may represent differences in habitat availability between the stations or habitat characteristics of sample sites, or other station differences (e.g., related to anthropogenic impacts). The statistical analyses of the seine data showed few station differences in abundance of species. Differences in boat electroshocking samples mainly reflected differences between channel and backwater habitats. The occurrence of extensive backwaters at Station 6 led to greater abundance of several species at that station. The backwater walkalong shocking samples showed higher abundance of several cover-associated species in the Station 1 sample, which may reflect specific conditions of the sampling sites. This parallels results of past studies, which tend to show consistent differences between the stations related to the amount of backwater habitat, along with considerable between-sample differences related to microhabitat differences. In general, the past and current studies show greater temporal variation in fish assemblages than spatial variation within the study sites.

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