Acid mine drainage and its effects on salamander assemblages in Cumberland Plateau streams of the North Chickamauga Creek Watershed, Tennessee

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ACID MINE DRAINAGE AND ITS EFFECTS ON SALAMANDER ASSEMBLAGES IN CUMBERLAND PLATEAU STREAMS OF THE NORTH CHICKAMAUGA CREEK WATERSHED, TENNESSEE.

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ABSTRACT

In Appalachia's coal mining regions, acid mine drainage (AMD) has contributed to the widespread degradation of stream ecosystems. Salamanders are common inhabitants of healthy headwater streams and because of their permeable skins are excellent indicators of ecosystem intergrity. Hence, we investigated the potential effects of AMD on the species richness and relative abundance of aquatic salamanders in selected stream reaches (sites) of the North Chickamauga Creek (NCC) system, Tennessee. Specimens were collected by kick-net sampling with a 500υm mesh dip net and/or electroshocking at four AMD-impacted sites (pH < 5.6) and two reference sites pH > 6.2), May-July 1996. Species richness was similarly low at reference sites, 2 -3 species, and AMD-impacted sites 1 - 2 species. No salamanders were observed at sites with pH values < 4 and aluminium concentrations > 2500 υg/L. Dusky salamander *Desmognathus fuscus* (present at all sites and toal salamander (all species) abundances were greater (P< 0.05) at reference sites versus AMD-impacted sites, regardless of the sampling method. Findings from this ongoing study underscore the negative effects of coal mining on stream-dwelling salamanders and provide baseline data for AMD-mitigation projects.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

LIST OF APPENDICES

Appendix Page

Appendix Page

INTRODUCTION

Acid mine drainage (AMD) is a major contributor to acid pollution in North American streams (National Research Council 1992). Streams polluted by AMD exhibit low pH, high concentrations of sulfates and dissolved metals (e.g. , iron, manganese and aluminum), and heavy sediment loads (National Research Council 1992; Robb and Robinson 1994). Acid and metal pollution can have direct negative effects on aquatic plants and animals including fish, amphibians, and invertebrates (Mayer et al. 1986). Consequently AMD can be detrimental to the biodiversity and functional integrity of stream ecosystems (Starnes and Gasper 1995).

Salamanders, an integral part of stream ecosystems, are important as both prey and predators. The permeable skin of amphibians (and their eggs) that allows them to live in both aquatic and terrestrial habitats makes them very sensitive to toxins in both the water and the air (Milstein 1990). Salamanders are very sensitive to chemical changes in their environment and thus are good indicators of the health of aquatic ecosystems. Although the effects of low pH on salamanders are species specific, generally acidity can impair their chemosensory systems, reproductive success, and survival (Mayer et al. 1986; Dodd 1997). Increased concentrations of dissolved metals can be toxic to aquatic amphibians, especially when coupled with low pH (Dodd 1997). In addition to the direct physiological effects of AMD on salamanders, acid and/or metal pollution may impact their trophic base (mostly aquatic invertebrates and plants) and habitat (Havas et al. 1995)

Coal mining activities, responsible for the majority of AMD pollution in lotic ecosystems (Kleinmann and Hedin 1990), have polluted approximately 18 miles of streams of North Chickamauga Creek (NCC) watershed, Chattanooga, Tennessee (USOSMRE 1987). Most AMD-impacted streams in the NCC system have a limited buffering capacity to ameliorate the effects of high acidity (Starnes and Gasper 1995). Eighteen salamander species have been identified in the NCC watershed (USOSMRE 1987); however, the potential effects of AMD on stream-dwelling salamanders have not been documented in this system.

The purpose of this study was to investigate the potential effects of AMD on salamander assemblages in mountain stream ecosystems. Specific objectives of my study were to examine water quality conditions, instream and riparian habitat features, and salamander assemblages in AMD-impacted and reference streams in the NCC system.

MATERIALS AND METHODS

Study Area

NCC watershed drains approximately 121 square miles of land located within the Walden Ridge section of the Cumberland Plateau, in Hamilton and Sequatchie counties, Tennessee. The vegetation of the area is dominated by mixed pine-hardwood forests. Although much of the NCC watershed is forested, many of the tributary streams flow through residential areas and near highways. Land use in the watershed is about 92% rural, 6% agricultural, and 2% urban (USOSMRE 1987).

Seven sites were established in AMD-impacted (N=5) and reference stream sites (N=2) in the Cumberland Plateau region of the NCC watershed (Figure 1). A sampling site was defined as a 200-m stream reach marked off in 20-m sections. Water quality, habitat conditions, and salamanders were sampled at each of the seven sites.

Water Quality Assessment

Surface water temperature (ºC), dissolved oxygen (mg/L), conductivity (µmhos/cm), and pH were assessed monthly at all seven sites using a Hydrolab meter, January-December 1996 (Figure 1). Additional water samples were collected from six sites (not including NCC2) each month in May-July 1996, and analyzed in the laboratory (Tennessee Valley Authority) to assess for concentrations of dissolved aluminum (µg/L), manganese (µg/L), and iron (µg/L). These three metals were chosen because they are common in AMD waters resulting from coal mining activities similar to those in this area (Robb and Robinson 1994). In addition all three have been recorded in past studies as being particularly toxic to stream life (Havas et. al. 1995).

Instream and Riparian Habitat Assessments

Habitat conditions were assessed once at all seven sites, May-July 1996. Instream assessments were based on stream-width and longitudinal (upstream-downstream) transects at each site. Ten transects were made across the channel to assess stream width (m) and stream depth (m); channel substrate composition (% area: sediments, gravel, cobble, boulder, bedrock);

detritus (%), algae (%), vascular plants (%), embeddedness (% gravel/cobble surrounded or covered by sediments), and sediment depth (cm) were assessed using quadrats (0.3 x 0.3-m plastic grid) at 3-4 equally spaced intervals along each transect. Discharge (m^3/s) was calculated using a digital flowmeter at three transects (upper, middle, lower) according to Orth (1983). Assessments of pools, riffles, and runs were made along 200-m longitudinal transects. Canopy shading (% cover) was assessed using a densiometer at 3 equally spaced intervals along each stream width transect.

Salamander Sampling

Kick-net sampling was conducted once each month in riffle habitats (3 replications) at four AMD-impacted and 2 reference sites, May -June 1996 (Figure 1). On each sampling date salamanders were collected within three randomly selected 20-m stream sections at a site. Kick-net sampling was conducted for 2 minutes with a rectangular-frame net (500-μm mesh) along longitudinal transects.

Electroshocking was used to sample salamanders once each month in riffle-run habitats (3 replications) at three AMD-impacted and one reference site, May- July 1996 (Figure 1). On each sampling date, salamanders were collected within three randomly selected 20-m stream sections at a site. Using two gasoline powered backpack electroshockers, stunned salamanders were collected by dip-netting between two block-off nets (1.8-m x 6.1-m seines with 0.5-cm mesh) positioned upstream and downstream of the sampling area.

Salamander specimens were immediately fixed in a 10% formalin solution and later identified in the laboratory and transferred to 70% ethanol. All specimens were archived in the University of Tennessee at Chattanooga Natural History Museum.

Statistical Analyses

Data analyses were performed using the Statistical Analysis System (SAS 1985) and ecological analysis software (Brower et al. 1990). Statistical comparisons were made between samples collected from AMD-impacted and reference sites. Water quality and habitat data were analyzed using analysis of variance; however, because salamander abundance data did not meet the assumptions of parametric statistical testing, these data were analyzed with

Kruskal-Wallis tests. Statistical significance was declared at a group-wise level of α =0.10, and a sequential Bonferroni-adjustment procedure (Rice 1989) was applied within groups of related variables (water quality, habitat conditions, salamander abundance).

Salamander data collected by electroshocking and kick-net sampling methods were analyzed separately. Moreover, kick-net sampling data from first-order and second- and third-order streams were analyzed separately.

RESULTS

Water Quality

Water quality conditions exhibited similar patterns at small (first-order) and large (second- and third-order) stream sites (Figures 2 -5). Significant seasonal variation was observed for all four water quality parameters ($P< 0.1$), but intersite variation was observed only for pH and conductivity ($P< 0.1$). In both stream types the pH averaged lower at AMD-impacted sites (4.70) than at reference sites (7.05). In small streams conductivity averaged higher at AMD-impacted sites (0.11 μmhos/cm) than at reference sites (0.04 μmhos/cm). In large streams conductivity was not significantly different at any of the sites.

Concentrations of dissolved metals (Table 1) exhibited significant intersite variation ($P < 0.1$) in both large and small streams. Aluminum averaged higher at AMD-impacted sites (716.7 μg/L) than at the reference sites (106.7 μg/L) in the large streams. In the small streams aluminum varied across sites with the highest concentrations at the AMD- impacted sites (SC1=3700 μg/L, SC2=1400 μg/L, BC2=180 μg/L). Manganese varied across sites with the highest concentrations at the AMD- impacted sites in both the small (SC1= 1833.3 μg/L, SC2= 716.7 μg/L, BC2=19.3 μg/L) and large streams (NCC1=393.3 μg/L, NCC3= 196.7 μg/L, FWC= 18.3 μg/L). Iron varied only in the small streams where it averaged highest at the most impacted site (SC1= 1470 μg/L) compared to the other two sites (146.5 μg/L).

Habitat Conditions

In small streams significant intersite variation ($P < 0.1$) was observed for certain instream and riparian habitat conditions (Table 2).

Embeddedness varied across all sites (SC1=78.5%, SC2=36.1%, BC2=12.6%). Sediment depth averaged higher at the most impacted site (SC1=6.0 cm) than at the other sites (1.4 cm). Riparian plant cover averaged lower at the most impacted site (SC1=11.5%) than at the other sites (31.15%). Algae averaged higher at the moderately impacted site (SC2=19.5%) than at the other two sites (0%).

In large streams significant intersite variation ($P < 0.1$) was also observed for certain instream and riparian habitat conditions (Table 2). Sediment depth averaged higher at the reference site (FWC=9.5 cm) than at the other sites (2.6 cm). Detritus averaged higher at the most impacted site (NCC1=42.8%) than at other sites (18.85%). Algae averaged highest at one AMD-impacted site (NCC3=30.8%), followed by the other two impacted sites (0.1-0.3%), and the reference site (FWC=0.6%). Instream vascular plants averaged higher at the reference site (FWC=16.6%) than at the other sites (1.95 %).

Other habitat differences among sites were inconsequential or revealed no contrasts between AMD-impacted and reference sites.

Salamander Assemblages

Kick-net sampling survey - A total of 51 salamanders were captured during kick-sampling surveys. Two different species were identified: dusky salamander (*Desmognathus fuscus*) and two-line salamander (*Eurycea bislineata*). Dusky salamanders compromised approximately 90% of the total number of individuals (Table 3).

The mean salamander abundance (number of individuals/100m^2) from the small and large streams showed similar trends (Figure 6-7). In both stream types dusky and total salamander abundances were significantly greater ($P< 0.1$) at the reference sites than at the AMD-impacted sites.

Electroshocking survey - A total of 67 salamanders were captured during electroshocking surveys. Four different species were identified: dusky salamander, two-line salamander, spring salamander (*Gyrinophilus porphyriticus*), and red salamander (*Psuedotriton ruber*). Dusky salamanders comprised approximately 88% of the total number of individuals (Table 3).

Mean salamander abundance (number of individuals/100m^2) showed varying trends across months (Figure 8). In May and June total and dusky salamander abundance was significantly greater ($P< 0.1$) at the reference site than at two of the three AMD-impacted sites. In July, total and dusky salamander abundances were greater at the reference site than at two of the three AMD-impacted sites.

DISCUSSION

In this study AMD-impacted stream reaches with low pH and high metal concentrations were found to have significantly smaller populations of salamanders than in similar stream reaches that were not affected by AMD. On average, the smaller AMD-impacted sites had the lowest pH (4.0), highest metal content (e.g., Al= 2208 µg/L) and fewest salamanders (e.g., no salamanders were found at SC1, the site immediately downstream from several mine seeps). In the AMD-impacted sites, further downstream from the mine seeps, water quality problems were less severe; however, low salamander densities were observed in these sites.

All of the salamanders found in this study are included in the family *Plethodontidae,* lungless salamanders, that breath primarily through their skin. This necessitates a level of permeability of the skin which renders the animal extremely sensitive to chemical changes in its environment. In addition the life cycle of these salamanders consists of the eggs and larval stages being generally restricted to the aquatic environment, whereas the adults live on the stream banks and riparian zones. Sampling techniques used in this study were selective mainly for the larval forms that stay in the stream. These stages have been reported to be the most sensitive to low pH and high metal concentrations (Dodd 1997). Because of these features, aquatic salamanders populations, especially the larval forms sampled in this study are extremely vulnerable to the effects of AMD.

High concentrations of metals in AMD can also be detrimental to stream ecosystems. In this study most of the AMD-impacted reaches had high dissolved metal concentrations. Havas et. al. (1995) showed that aluminum levels can be a very important factor in acidified waters. Aluminum concentrations can intensify the detrimental effects of low pH. In amphibians the main problem associated with low pH (H+ toxicity) is thought to be ionoregulatory failure. When low pH is combined with high levels of aluminum, respiratory and circulatory distress also become problems (Havas et al. 1995). Moreover, during episodes of high water flow, which happen annually in the NCC system, the pH can increase resulting in the immediate precipitation of aluminum which can be detrimental to aquatic organisms (Havas et al. 1995).

Sedimentation impacts on stream biota may be attributable to eroded land associated with abandoned mines. Increased sediment loads can smother salamander eggs in the stream (Havas et al. 1995). In the small streams, sedimentation and embeddedness were most pronounced in the AMD-impacted sites near the mine seeps. In the large streams, further downstream from the mine seeps, sedimentation and embeddedness were substantially reduced. In contrast, FWC, the reference site, had a substantially greater sediment depth than the other sites. This may be related to a highway that crosses the stream; it has been reported that increased siltation due to these "transportation corridors" can have detrimental effects on salamander breeding habits (Dodd 1997). This site, however, appears to have the healthiest salamander population of all of the sites sampled in the study.

The amount of algae was significantly higher in the moderately impacted sites, NCC3 and SC2, than in the other sites. Hermann et al. (1993) showed that increase in filamentous green algae may be explained by decreased grazing pressure by invertebrates. This decrease in grazer populations could be a result of the detrimental effects of AMD. Also, higher percentages of detritus at NCC1 may be related to impairment of microbial decomposition (Hildrew et al 1984).

Findings from this study illustrate the sensitivity of stream-dwelling salamanders to acid pollution and thus underscore their potential as biological indicators. Gibbons (1988) stated that "a new attitude is needed toward the recognition of the importance of amphibians to ecosystem functioning." In the past, amphibians have been perceived as inconsequential in wildlife and land management. Gibbons (1988) points out that these animals should be focused on because threats to their populations may be symptomatic of serious environmental problems. In light of the capacity of amphibians to indicate environmental health, monitoring salamander populations in the NCC watershed would be beneficial in investigating the progress of the rehabilitation of the system. In future studies an additional aspect of monitoring should be to study the salamander populations in the streambank and riparian zones to investigate potential effects on the adults of the populations.

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Table 1. Dissolved Metals in six stream reaches in the North Chickamauga Creek watershed, Chattanooga, TN, May-July 1996.

Parameter	SC1	SC2	BC2	NCC1	NCC3	FWC
Al (ug/L)	3700	1400	180	717	153	60
Mn (ug/L)	1833	717	19	393	197	18
Fe (ug/L)	1470	203	89	-	-	-

Table 2. Habitat conditions for seven stream reaches in the North Chickamauga Creek watershed, Chattanooga, Tennessee 1996.

	First-Order Streams			Second- and Third-Order Streams			
Parameter	SC1 (AMD)	SC2 (AMD)	BC2 (REF)	NCC1 (AMD)	NCC2 (AMD)	NCC3 (AMD)	FWC (REF)
Stream width(m)	3.2 (0.3)	5.2 (0.6)	4.6 (0.6)	10.0 (1.1)	13.5 (1.4)	10.7 (1.6)	10.8 (0.8)
Stream depth (m)	0.10 (0.02)	0.07 (0.01)	0.10 (0.02)	0.19 (0.05)	0.35 (0.23)	0.14 (0.03)	0.16 (0.04)
Sediments (%)	1.5 (9.2)	18.1 (1.0)	0.6 (0.3)	0.3 (0.2)	2.4 (1.1)	0.7 (0.4)	9.9 (5.1)
Gravel (%)	5.0	31.8 (1.5)	11.8 (2.9)	17.4 (4.7)	14.7 (3.3)	19.7 (5.9)	11.1 (3.8)
Cobble (%)	14.1 (5.1)	22.0 (3.3)	18.1 (5.6)	21.6 (7.1)	35.3 (4.4)	16.3 (4.9)	19.5 (4.5)
Boulder (%)	10.3 (3.5)	18.2 (5.3)	44.4 (6.8)	29.0 (7.5)	47.7 (5.8)	41.4 (6.7)	43.4 (6.6)
Bedrock (%)	10.6 (6.2)	62.0 (8.6)	24.6 (9.5)	32.8 (12.6)	0.0 (0.0)	17.5 (9.9)	13.8 (8.2)

Table 2-continued..

Parameter	First-Order Streams SC1 (AMD)	SC2 (AMD)	BC2 (REF)	Second- and Third-Order Streams NCC1 (AMD)	NCC2 (AMD)	NCC3 (AMD)	FWC (REF)
Detritus (%)	20.4 (9.3)	10.1 (1.9)	7.3 (2.2)	42.8 (7.8)	14.0 (3.1)	19.4 (4.5)	23.7 (5.2)
Algae (%)	0.0 (0.0)	19.5 (5.1)	0.0 (0.0)	15.8 (4.6)	16.0 (2.4)	30.8 (8.6)	0.6 (0.6)
Vas.Plants (%)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.7 (1.7)	3.6 (3.5)	0.3 (0.3)	16.6 (6.9)
Embeddedness (%)	78.5 (5.2)	36.1 (9.4)	12.6 (4.5)	65.1 (7.9)	45.1 (7.2)	37.0 (7.7)	46.3 (7.9)
Sed. depth (cm)	2.2 (0.4)	0.6 (0.1)	0.5 (0.2)	0.8 (0.1)	1.2 (0.2)	0.7 (0.1)	3.4 (1.2)
Discharge (m^3/s)	0.04 (0.002)	0.02 (0.003)	0.02 (0.003)	0.04 (0.001)	0.14 (0.014)	0.14 (0.044)	0.02 (0.006)
Pool:Riffle	1.2	1.39	1.65	4.1	1.56	1.7	0.48
Canopy Cover (%)	99.7 (0.1)	98.1 (0.5)	98.3 (0.7)	94.5 (2.1)	90.4 (1.4)	56.8 (6.5)	90.0 (2.6)

Table 3. Total Salamanders (%) caught in seven stream reaches in the North Chickamauga Creek watershed , Tennessee, May- July 1996

	First-Order Streams			Second- and Third-Order Streams				
Salamanders	SC1	SC2	BC2	NCC1	NCC2	NCC3	FWC	Total
			Kick-net sampling					
Dusky salamander *Desmognathus fuscus*		1(100)	20(83.3)		--		25 (100)	46
Two-lined salamander *Eurycea bislineata*			4(16.6)		--	1(100)		5
			Electroshocking					
Dusky salamander *Desmognathus fuscus*	--	--	--	6(85.7)	10 (100)	19(90.5)	24(82.8)	59
Two-lined salamander *Eurycea bislineata*	--	--	--				3(10.3)	3
Red salamander *Psuedotriton ruber*	--	--	--				2(6.8)	2
Spring salamander *Gyrinophilus porphyriticus*	--	--	--	1(14.3)		2(9.5)		3

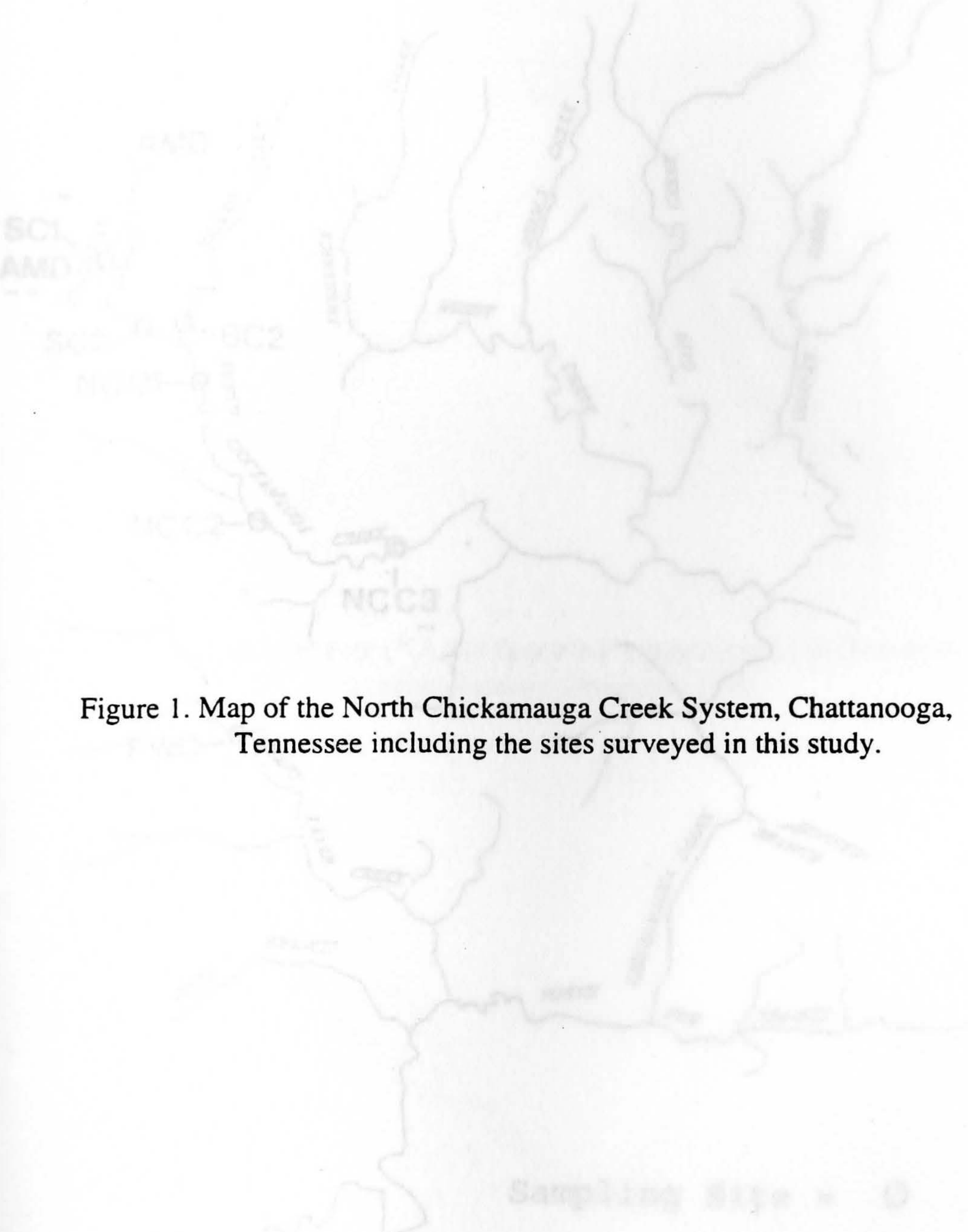


Figure 1. Map of the North Chickamauga Creek System, Chattanooga, Tennessee including the sites surveyed in this study.

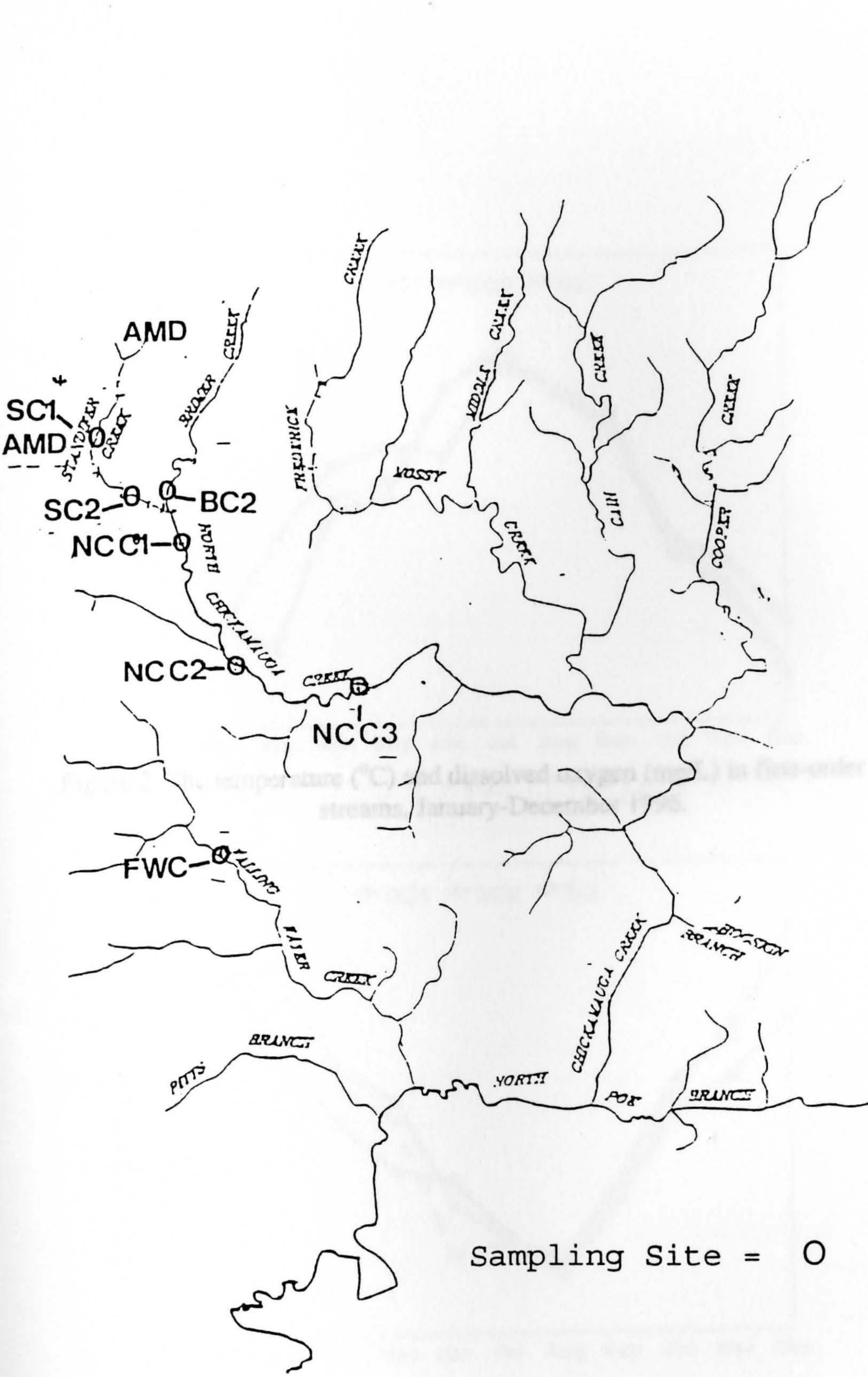
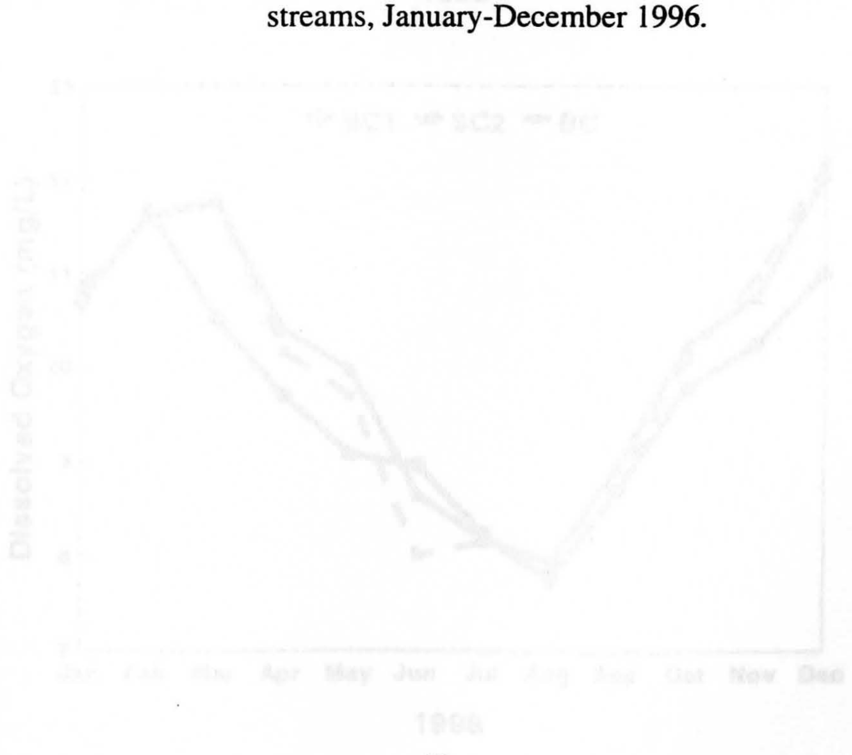
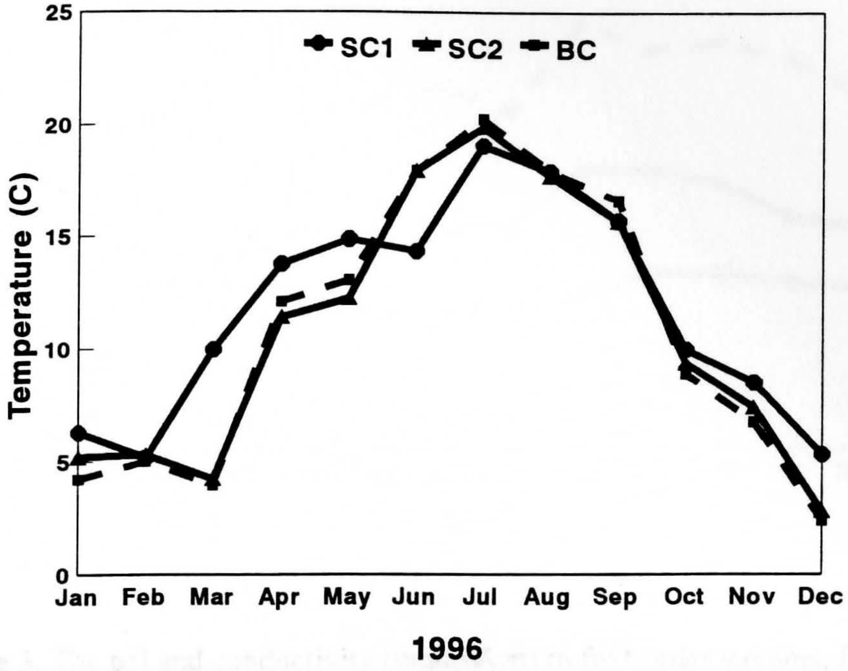
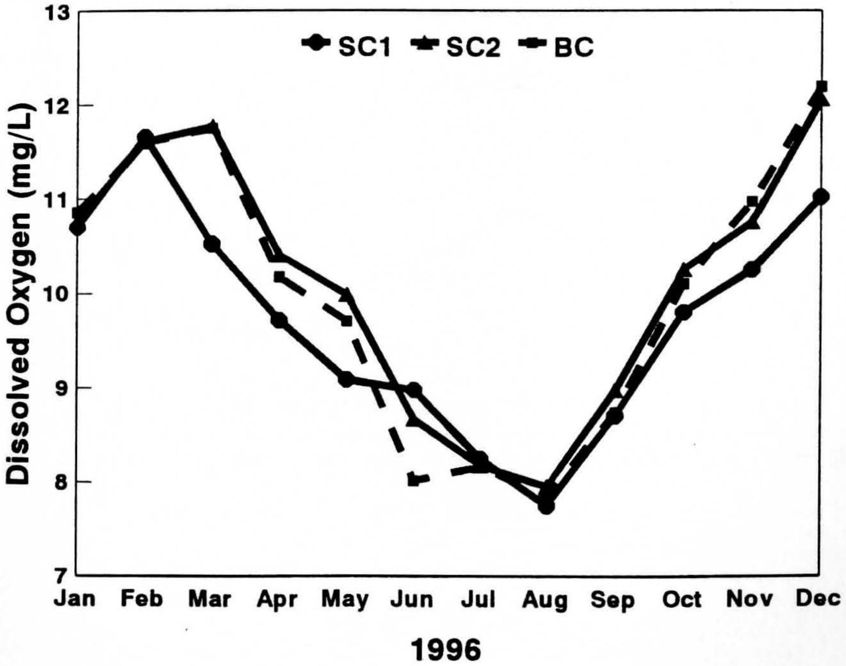

AMD
SC1
AMD
SC2
BC2
NCC1
NCC2
NCC3
FWC
Sampling Site = O

Figure 2. The temperature (^{o}C) and dissolved oxygen (mg/L) in first-order streams, January-December 1996.



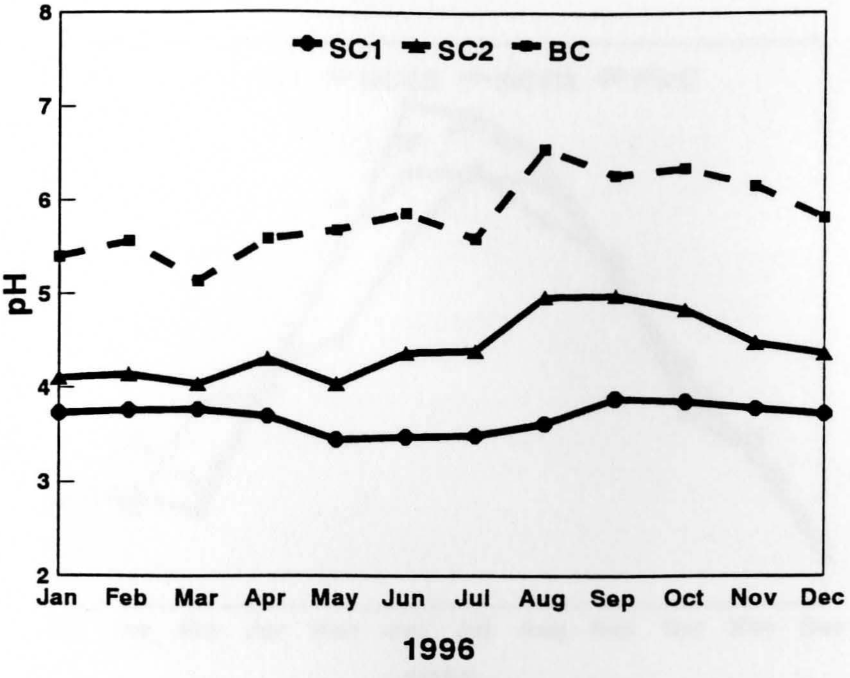


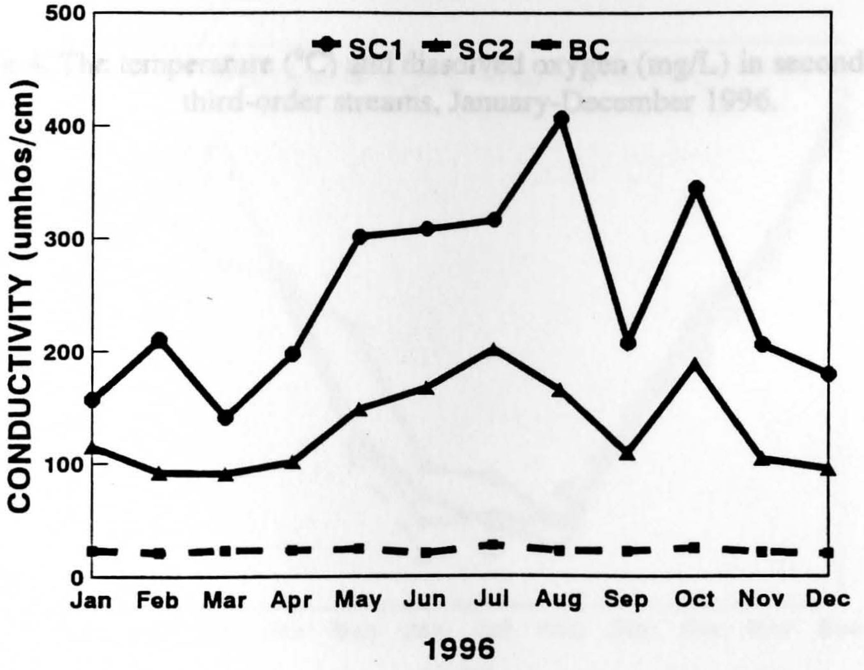
SC1
SC2
BC
Temperature (C)
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996



SC1
SC2
BC
Dissolved Oxygen (mg/L)
13
12
11
10
9
8
7
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

Figure 3. The pH and conductivity (umhos/cm) in first-order streams, January-December 1996.


SC1
SC2
BC
pH
8
7
6
5
4
3
2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996


SC1
SC2
BC
CONDUCTIVITY (umhos/cm)
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

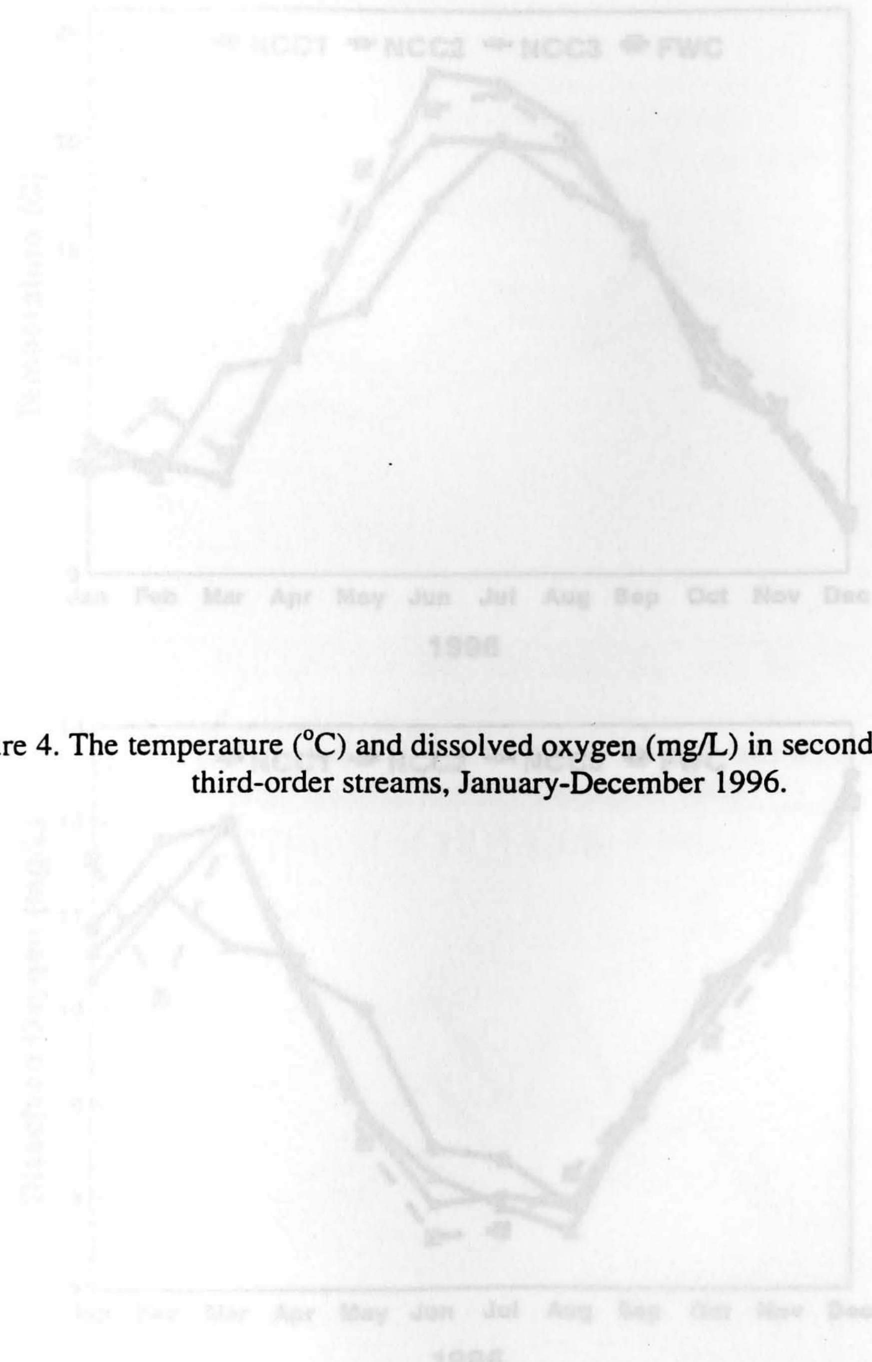
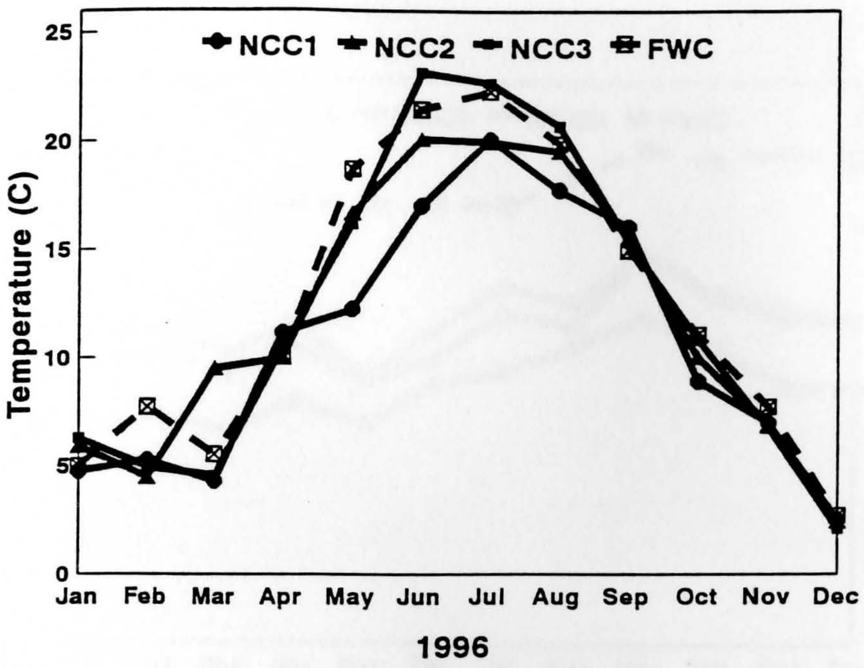


Figure 4. The temperature (°C) and dissolved oxygen (mg/L) in second- and third-order streams, January-December 1996.


NCC1
NCC2
NCC3
FWC
Temperature (C)
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

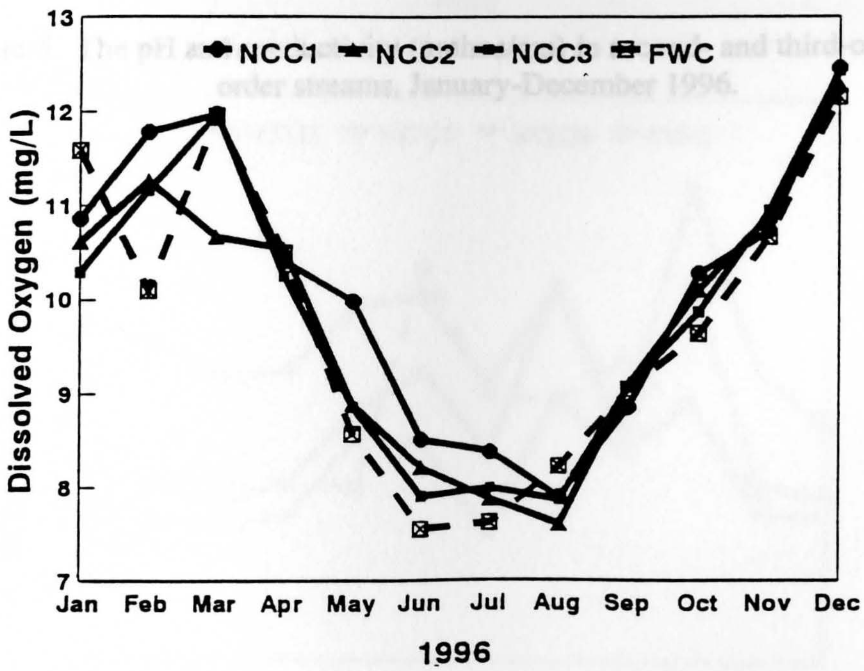
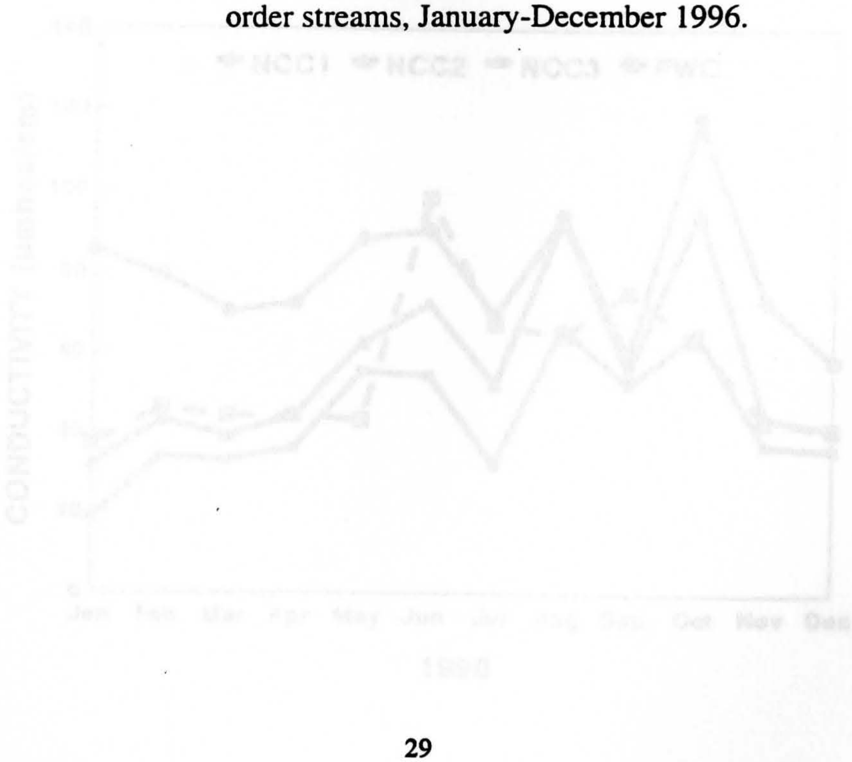
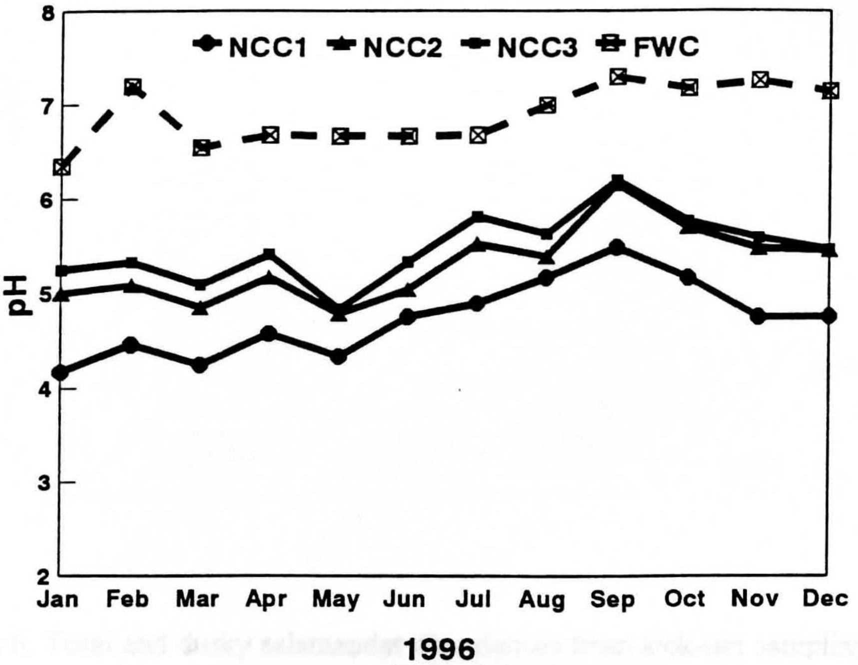

NCC1
NCC2
NCC3
FWC
Dissolved Oxygen (mg/L)
13
12
11
10
9
8
7
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1996

Figure 5. The pH and conductivity (umhos/cm) in second- and third-order
order streams, January-December 1996.




NCC1 NCC2 NCC3 FWC
pH
8
7
6
5
4
3
2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1996

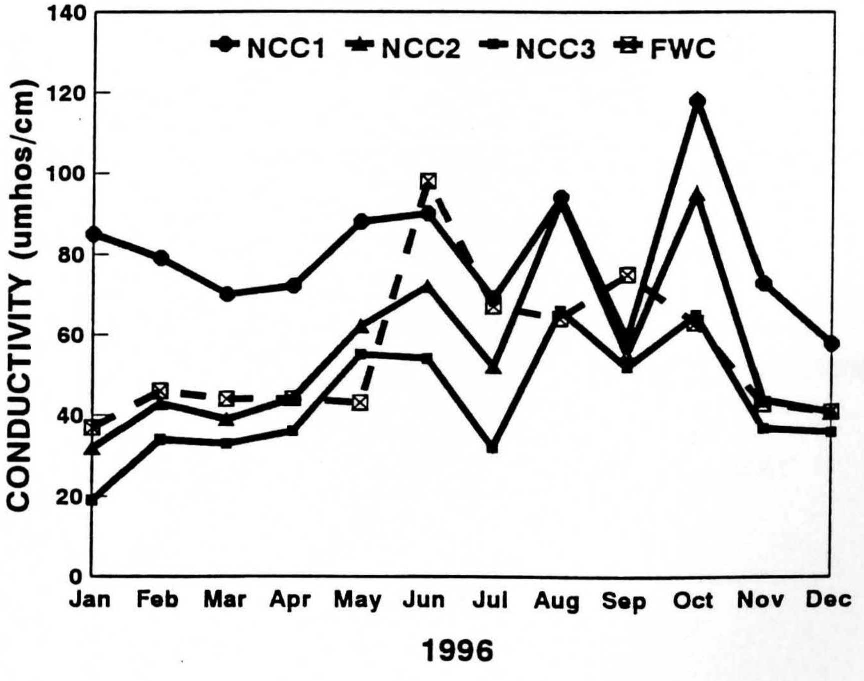
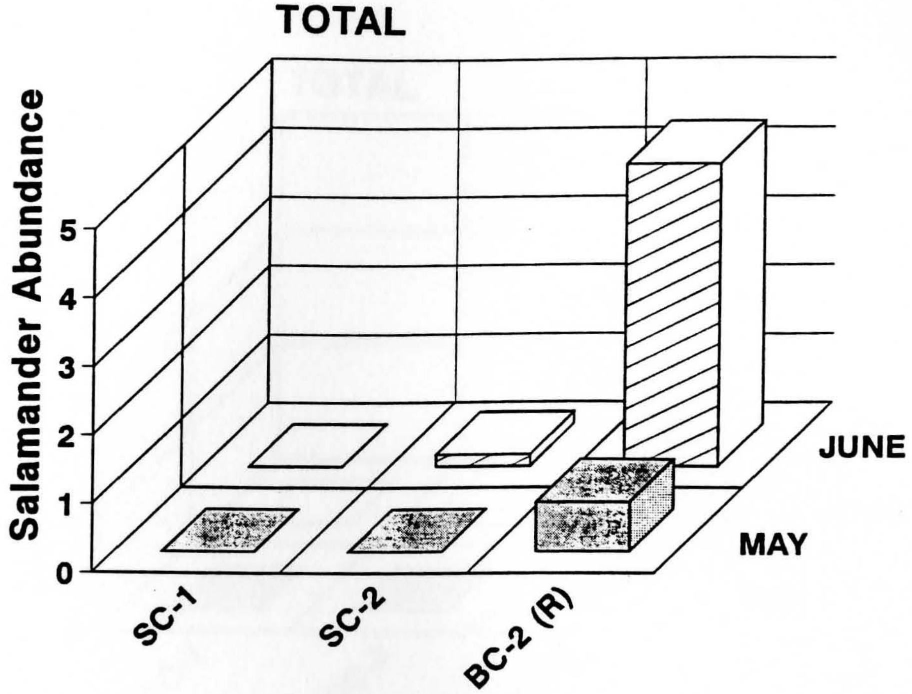

NCC1 NCC2 NCC3 FWC
CONDUCTIVITY (umhos/cm)
140
120
100
80
60
40
20
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
1996

Figure 6. Total and dusky salamander abundances from kick-net sampling efforts in first-order streams, May-June 1996.


TOTAL
Salamander Abundance
0
1
2
3
4
5
SC-1
SC-2
BC-2 (R)
JUNE
MAY

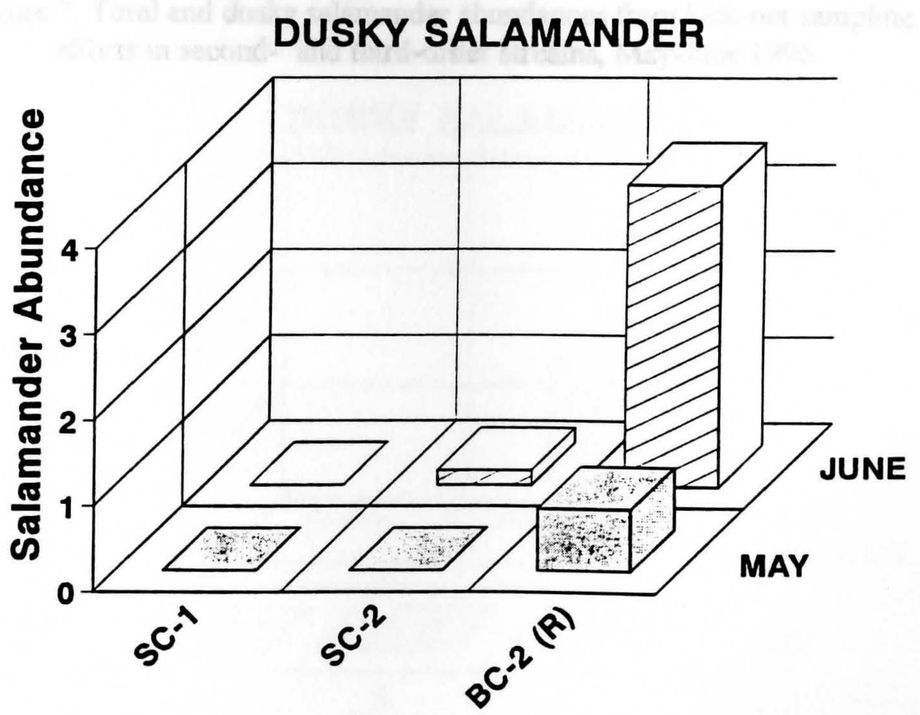
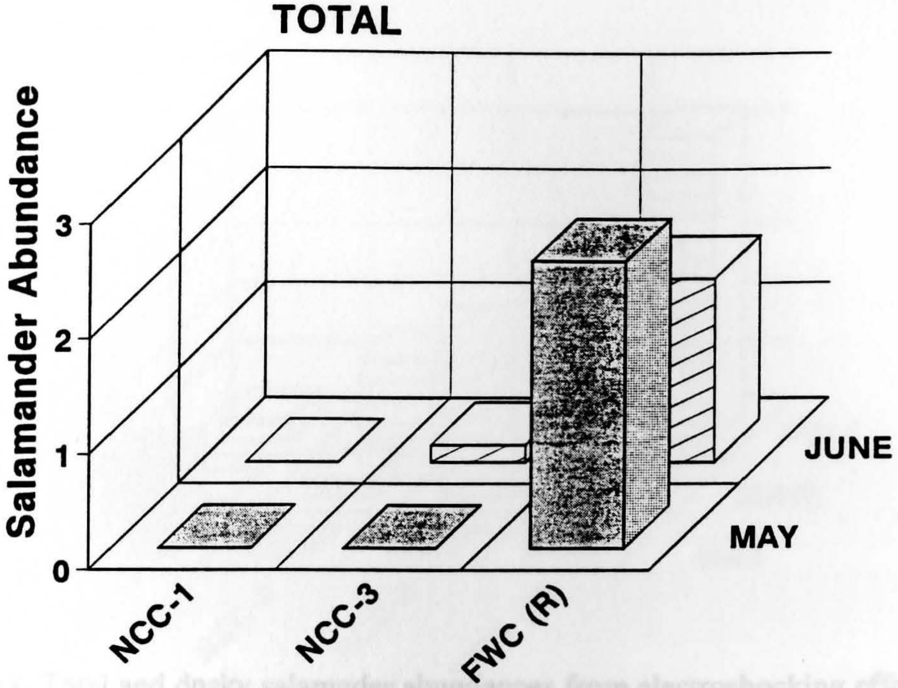

DUSKY SALAMANDER
Salamander Abundance
0
1
2
3
4
SC-1
SC-2
BC-2 (R)
JUNE
MAY

Figure 7. Total and dusky salamander abundances from kick-net sampling efforts in second- and third-order streams, May-June 1996.


TOTAL
Salamander Abundance
0
1
2
3
JUNE
MAY
NCC-1
NCC-3
FWC (R)

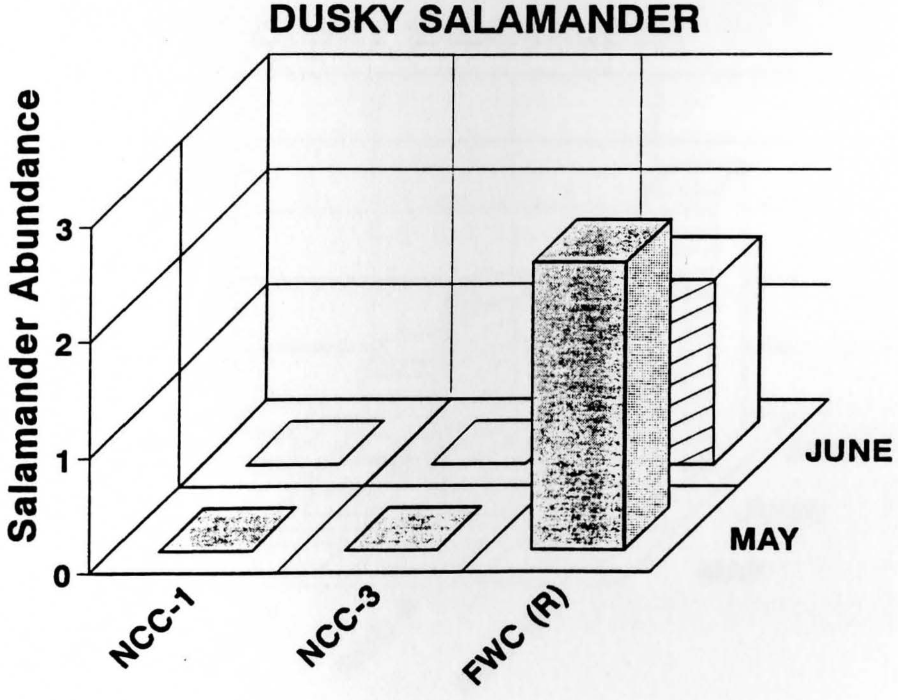
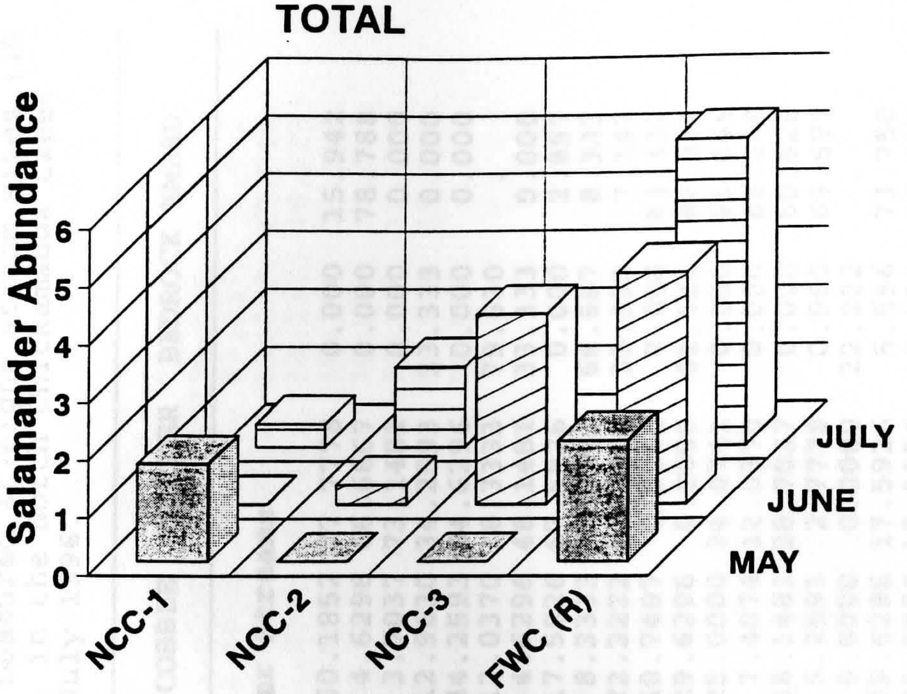
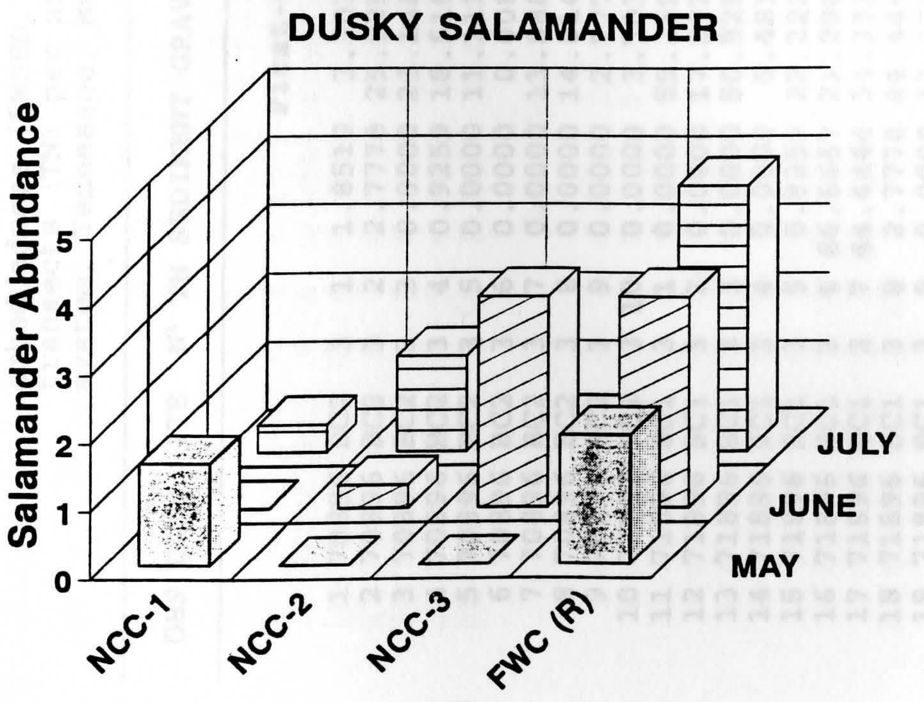

DUSKY SALAMANDER
Salamander Abundance
0
1
2
3
JUNE
MAY
NCC-1
NCC-3
FWC (R)

Figure 8. Total and dusky salamnder abundances from electroshocking efforts May-July 1996.


TOTAL
Salamander Abundance
0
1
2
3
4
5
6
NCC-1
NCC-2
NCC-3
FWC (R)
MAY
JUNE
JULY


DUSKY SALAMANDER
Salamander Abundance
0
1
2
3
4
5
NCC-1
NCC-2
NCC-3
FWC (R)
MAY
JUNE
JULY

Appendix A. Channel substrate composition (% of stream bottom) and embeddedness (EMBED, %) measured at eight stream sites (10 transects (TN) per site) in the North Chickamauga Creek system, Tennessee, May-July 1996.

OBS	DATE	SITE	N[1]	TN	SEDIMENT	GRAVEL	COBBLE	BOULDER	BEDROCK	EMBED
					First-Order Streams					
1	70896	BC2	3	1	1.8519	3.7037	60.1852	27.7778	0.000	15.942
2	70896	BC2	3	2	2.7778	25.9259	4.6296	66.6667	0.000	78.788
3	70896	BC2	3	3	0.0000	23.1481	3.7037	73.1481	0.000	0.000
4	70896	BC2	3	4	0.9259	18.5185	12.9630	34.2593	33.333	0.000
5	70896	BC2	3	5	0.0000	11.1111	34.2593	54.6296	0.000	0.000
6	70896	BC2	3	6	0.0000	0.0000	12.0370	8.3333	79.630	.
7	70896	BC2	3	7	0.0000	13.8889	4.6296	48.1481	33.333	0.000
8	70896	BC2	3	8	0.0000	14.8148	17.5926	67.5926	0.000	2.857
9	70896	BC2	3	9	0.0000	2.7778	8.3333	22.2222	66.667	8.333
10	70896	BC2	3	10	0.0000	3.7037	22.2222	40.7407	33.333	7.143
11	71896	SC1	3	1	0.0000	59.2593	40.7407	0.0000	0.000	83.333
12	71896	SC1	3	2	0.0000	17.5926	29.6296	0.0000	61.111	88.235
13	71896	SC1	3	3	0.0000	50.9259	25.0000	24.0741	0.000	85.366
14	71896	SC1	3	4	0.0000	6.4815	7.4074	12.0370	0.000	80.000
15	71896	SC1	3	5	0.9259	22.2222	48.1481	28.7037	0.000	60.526
16	71896	SC1	3	6	66.6667	21.2963	9.2593	2.7778	0.000	69.697
17	71896	SC1	3	7	44.4444	33.3333	0.0000	0.0000	22.222	.
18	71896	SC1	3	8	2.7778	44.4444	29.6296	17.5926	5.556	73.750
19	71896	SC1	3	9	0.0000	33.3333	25.9259	17.5926	17.593	65.625
20	71896	SC1	3	10	66.6667	28.7037	4.6296	0.0000	0.000	100.000

Appendix A. (Continued)

OBS	DATE	SITE	N[1]	TN	SEDIMENT	GRAVEL	COBBLE	BOULDER	BEDROCK	EMBED
21	70896	SC2	3	1	9.2593	2.7778	9.2593	7.4074	79.630	100.000
22	70896	SC2	3	2	0.0000	0.0000	0.0000	0.0000	100.000	.
23	70896	SC2	3	3	0.0000	0.0000	6.4815	6.4815	87.037	0.000
24	70896	SC2	3	4	0.0000	4.6296	14.8148	47.2222	33.333	19.048
25	70896	SC2	3	5	0.0000	12.0370	13.8889	40.7407	33.333	46.429
26	70896	SC2	3	6	5.5556	6.4815	16.6667	15.7407	55.556	36.000
27	70896	SC2	3	7	0.0000	4.6296	20.3704	0.0000	75.000	37.037
28	70896	SC2	3	8	0.0000	12.9630	28.7037	25.0000	33.333	35.556
29	70896	SC2	3	9	0.0000	6.4815	30.5556	29.6296	33.333	15.000
30	70896	SC2	3	10	0.0000	0.0000	0.0000	10.1852	89.815	.
					Second-and Third-Order Streams					
1	62796	CC	4	1	4.8611	36.1111	28.4722	15.2778	8.333	63.441
2	62796	CC	4	2	4.1667	25.6944	27.0833	18.0556	0.000	26.316
3	62796	CC	4	3	0.0000	8.3333	32.6389	34.0278	0.000	13.559
4	62796	CC	4	4	0.6944	18.0556	26.3889	8.3333	21.528	15.625
5	62796	CC	4	5	0.0000	5.5556	4.1667	2.0833	88.194	71.429
6	62796	CC	4	6	1.3889	0.0000	11.1111	6.2500	56.250	25.000
7	62796	CC	4	7	23.6111	0.6944	6.2500	14.5833	61.111	50.000
8	62796	CC	1	8	0.0000	9.0278	4.1667	11.8056	0.000	5.263
9	62796	CC	4	9	18.7500	6.9444	40.2778	31.9444	2.083	35.294
10	62796	CC	4	10	1.3889	21.5278	40.2778	6.9444	4.861	17.978

Appendix A. (Continued)

OBS	DATE	SITE	N[1]	TN	SEDIMENT	GRAVEL	COBBLE	BOULDER	BEDROCK	EMBED
11	61296	FWC	4	1	0.0000	0.6944	31.9444	42.3611	0.000	2.128
12	61296	FWC	4	2	1.3889	5.5556	27.7778	65.2778	0.000	25.000
13	61296	FWC	4	3	0.0000	7.6389	28.4722	63.8889	0.000	7.692
14	61296	FWC	4	4	6.2500	31.2500	36.1111	26.3889	0.000	30.928
15	61296	FWC	4	5	50.6944	8.3333	4.8611	36.1111	0.000	78.947
16	61296	FWC	4	6	9.7222	2.7778	6.9444	35.4167	45.139	100.000
17	61296	FWC	4	7	0.0000	6.2500	36.1111	57.6389	2.083	22.951
18	61296	FWC	4	8	4.8611	33.3333	4.8611	40.9722	15.972	49.091
19	61296	FWC	4	9	1.3889	15.2778	18.0556	65.9722	0.000	100.000
20	61296	FWC	4	10	25.0000	0.0000	0.0000	0.0000	75.000	.
21	61796	NCC1	4	1	1.3889	31.9444	14.5833	52.0833	0.000	92.537
22	61796	NCC1	4	2	0.0000	15.2778	18.7500	56.2500	9.722	53.061
23	61796	NCC1	4	3	0.0000	40.9722	22.2222	14.5833	26.389	85.714
24	61796	NCC1	4	4	2.0833	34.7222	29.8611	25.0000	8.333	45.161
25	61796	NCC1	4	5	0.0000	0.0000	0.0000	0.0000	100.000	.
26	61796	NCC1	4	6	0.0000	13.1944	16.6667	68.7500	1.389	62.791
27	61796	NCC1	4	7	0.0000	3.4722	5.5556	35.4167	62.500	100.000
28	61796	NCC1	4	8	0.0000	0.0000	0.0000	0.0000	100.000	.
29	61796	NCC1	4	9	0.0000	10.4167	77.7778	11.8056	0.000	25.197
30	61796	NCC1	4	10	0.0000	23.6111	30.5556	25.6944	20.139	56.410

Appendix A. (Continued)

OBS	DATE	SITE	N[1]	TN	SEDIMENT	GRAVEL	COBBLE	BOULDER	BEDROCK	EMBED
31	61496	NCC2	4	1	9.0278	1.3889	40.9722	48.6111	0.000	54.098
32	61496	NCC2	4	2	0.0000	14.5833	42.3611	43.0556	0.000	23.171
33	61496	NCC2	4	3	5.5556	16.6667	18.7500	59.0278	0.000	37.255
34	61496	NCC2	4	4	0.0000	15.9722	54.1667	30.5556	0.000	14.851
35	61496	NCC2	4	5	0.0000	7.6389	38.1944	54.1667	0.000	63.636
37	61496	NCC2	4	7	0.6944	22.9167	22.9167	53.4722	0.000	100.000
38	61496	NCC2	4	8	4.1667	13.8889	43.0556	38.8889	0.000	43.902
39	61496	NCC2	4	9	2.0833	34.0278	43.0556	20.8333	0.000	62.162
40	61496	NCC2	4	10	0.0000	4.8611	14.5833	80.5556	0.000	7.143
41	62096	NCC3	4	1	4.1667	20.8333	46.5278	28.4722	0.000	60.825
42	62096	NCC3	4	2	1.3889	48.6111	38.1944	13.1944	0.000	16.000
43	62096	NCC3	4	3	0.0000	53.4722	9.7222	35.4167	0.000	93.407
44	62096	NCC3	4	4	0.0000	0.0000	2.0833	22.9167	75.000	100.000
45	62096	NCC3	4	5	0.0000	14.5833	15.9722	44.4444	0.000	0.000
46	62096	NCC3	4	6	0.0000	25.6944	23.6111	50.6944	0.000	0.000
47	62096	NCC3	4	7	0.0000	9.7222	13.1944	81.2500	0.000	0.000
48	62096	NCC3	4	8	0.6944	4.1667	4.1667	66.6667	0.000	0.000
49	62096	NCC3	4	9	0.6944	17.3611	9.7222	47.9167	25.000	0.000
50	62096	NCC3	4	10	0.0000	2.0833	0.0000	22.9167	75.000	100.000

[1] Number of sampling points on each transect.

Appendix B. Instream sediment depth (cm) and detritus/vegetation (% of stream bottom) measured at eight stream sites (10 transects (TN) per site) in the North Chickamauga Creek system, Tennessee, May-July 1996.

OBS	DATE	SITE	N[1]	TN	SEDIMENT DEPTH	DETRITUS	ALGAE	MOSS	VASCULAR PLANTS
					First-Order Streams				
1	70896	BC2	3	1	4.6296	18.519	0.0000	12.9630	0
2	70896	BC2	3	2	0.4630	15.741	0.0000	0.0000	0
3	70896	BC2	3	3	0.0000	0.000	0.0000	0.0000	0
4	70896	BC2	3	4	1.3889	7.407	0.0000	6.4815	0
5	70896	BC2	3	5	0.0000	0.000	0.0000	0.0000	0
6	70896	BC2	.	6	.	.	.	.	.
7	70896	BC2	3	7	1.3889	2.778	0.0000	0.0000	0
8	70896	BC2	3	8	1.3889	4.630	0.0000	0.0000	0
9	70896	BC2	3	9	1.3889	5.556	0.0000	0.0000	0
10	70896	BC2	3	10	1.3889	11.111	0.0000	0.0000	0
11	71896	SC1	3	1	1.3889	12.963	0.0000	0.0000	0
12	71896	SC1	3	2	1.3889	25.000	0.0000	0.0000	0
13	71896	SC1	3	3	7.4074	6.481	0.0000	0.0000	0
14	71896	SC1	3	4	3.7037	3.704	0.0000	0.0000	0
15	71896	SC1	3	5	6.0185	7.407	0.0000	0.9259	0
16	71896	SC1	3	6	7.4074	100.000	0.0000	0.0000	0
17	71896	SC1	2	7	5.5556	0.926	0.0000	0.0000	0
18	71896	SC1	3	8	8.3333	7.407	0.0000	0.0000	0
19	71896	SC1	3	9	7.4074	9.259	0.0000	0.0000	0

Appendix B. (Continued)

OBS	DATE	SITE	N[1]	TN	SEDIMENT DEPTH	DETRITUS	ALGAE	MOSS	VASCULAR PLANTS
20	71896	SC1	3	10	11.1111	30.556	0.0000	0.0000	0
21	70896	SC2	3	1	1.3889	14.815	33.3333	40.7407	0
22	70896	SC2	3	2	1.3889	5.556	8.3333	8.3333	0
23	70896	SC2	3	3	1.3889	5.556	26.8519	33.3333	0
24	70896	SC2	3	4	1.3889	7.407	26.8519	26.8519	0
25	70896	SC2	3	5	1.3889	20.370	4.6296	4.6296	0
26	70896	SC2	3	6	2.7778	18.519	4.6296	4.6296	0
27	70896	SC2	3	7	1.3889	2.778	10.1852	10.1852	0
28	70896	SC2	3	8	1.3889	12.963	30.5556	30.5556	0
29	70896	SC2	3	9	1.3889	4.630	50.0000	50.0000	0
30	70896	SC2	3	10	1.3889	8.333	0.0000	0.0000	0

Second- and Third-Order Streams

OBS	DATE	SITE	N[1]	TN	SEDIMENT DEPTH	DETRITUS	ALGAE	MOSS	VASCULAR PLANTS
1	62796	CC	4	1	5.5556	20.8333	0.0000	0.0000	0.0000
2	62796	CC	4	2	2.7778	5.5556	0.0000	2.0833	0.0000
3	62796	CC	4	3	0.3472	2.7778	0.0000	0.0000	0.0000
4	62796	CC	4	4	1.3889	8.3333	0.0000	0.0000	0.0000
5	62796	CC	4	5	0.3472	2.0833	0.0000	9.7222	0.0000
6	62796	CC	4	6	1.3889	4.8611	0.0000	0.0000	0.0000
7	62796	CC	4	7	4.5139	30.5556	0.0000	0.0000	0.0000
8	62796	CC	4	8	0.3472	6.2500	0.0000	0.0000	0.0000
9	62796	CC	4	9	3.4722	23.6111	0.0000	0.0000	0.0000
10	62796	CC	4	10	4.1667	3.4722	0.0000	3.4722	0.0000

Appendix B. (Continued)

OBS	DATE	SITE	N[1]	TN	SEDIMENT DEPTH	DETRITUS	ALGAE	MOSS	VASCULAR PLANTS
11	61296	FWC	4	1	0.4167	6.2500	0.0000	6.9444	17.3611
12	61296	FWC	4	2	1.3889	19.4444	0.0000	6.9444	15.2778
13	61296	FWC	4	3	0.6944	6.9444	0.0000	18.0556	22.2222
14	61296	FWC	4	4	4.1667	15.2778	0.0000	0.0000	0.0000
15	61296	FWC	4	5	30.5556	43.7500	6.2500	0.0000	0.0000
16	61296	FWC	4	6	3.8194	20.1389	0.0000	40.2778	0.0000
17	61296	FWC	4	7	4.1667	15.9722	0.0000	25.6944	0.0000
18	61296	FWC	4	8	17.3611	50.6944	0.0000	0.0000	68.0556
19	61296	FWC	4	9	10.4167	13.8889	0.0000	38.1944	37.5000
20	61296	FWC	4	10	21.5278	44.4444	0.0000	6.2500	5.5556
21	61796	NCC1	4	1	2.0833	25.0000	35.4167	0.0000	0.0000
22	61796	NCC1	4	2	2.0833	16.6667	34.7222	0.0000	0.0000
23	61796	NCC1	4	3	2.7778	85.4167	8.3333	0.0000	0.0000
24	61796	NCC1	4	4	2.7778	8.3333	13.1944	0.0000	0.0000
25	61796	NCC1	4	5	1.3889	56.9444	0.0000	0.0000	0.0000
26	61796	NCC1	4	6	1.0417	22.2222	33.3333	2.0833	0.0000
27	61796	NCC1	4	7	3.4722	43.7500	0.0000	0.0000	0.0000
28	61796	NCC1	4	8	1.3889	67.3611	0.0000	0.0000	0.0000
29	61796	NCC1	4	9	1.7361	55.5556	13.8889	0.0000	17.3611
30	61796	NCC1	4	10	3.4722	46.5278	19.4444	0.6944	0.0000
31	61496	NCC2	4	1	8.3333	29.1667	25.0000	0.0000	0.0000
32	61496	NCC2	4	2	2.4306	9.0278	11.8056	0.0000	0.0000
33	61496	NCC2	4	3	2.4306	13.1944	15.9722	0.0000	0.0000
34	61496	NCC2	4	4	3.1250	6.9444	20.8333	0.0000	0.0000

Appendix B. (Continued)

OBS	DATE	SITE	N[1]	TN	SEDIMENT DEPTH	DETRITUS	ALGAE	MOSS	VASCULAR PLANTS
35	61496	NCC2	4	5	1.3889	20.1389	15.2778	0.0000	0.0000
36	61496	NCC2	-	6	.	.	.	.	.
37	61496	NCC2	4	7	2.0833	10.4167	4.8611	0.0000	0.0000
38	61496	NCC2	4	8	3.4722	27.0833	22.2222	0.0000	0.6944
39	61496	NCC2	4	9	4.1667	4.1667	22.2222	0.0000	31.2500
40	61496	NCC2	4	10	2.0833	5.5556	6.2500	0.6944	0.0000
41	62096	NCC3	4	1	1.7361	27.0833	29.8611	0.0000	0.0000
42	62096	NCC3	4	2	1.0417	9.7222	9.7222	13.8889	0.0000
43	62096	NCC3	4	3	2.4306	29.1667	14.5833	2.7778	2.7778
44	62096	NCC3	4	4	3.47222	30.5556	4.8611	0.0000	0.0000
45	62096	NCC3	4	5	1.04167	5.5556	46.5278	20.1389	0.0000
46	62096	NCC3	4	6	1.04167	19.4444	57.6389	12.5000	0.0000
47	62096	NCC3	4	7	1.04167	5.5556	79.8611	11.1111	0.0000
48	62096	NCC3	4	8	1.38889	3.4722	54.8611	14.5833	0.0000
49	62096	NCC3	4	9	3.12500	15.9722	9.7222	6.2500	0.0000
50	62096	NCC3	4	10	2.77778	47.2222	0.0000	0.0000	0.0000

[1] Number of sampling points on each transect.

Appendix C. Stream width (m) at nine stream sites (10 transects (TN) per site) in the North Chickamauga Creek watershed, Tennessee, May-July 1996.

		Site								
OBS	TN	SC1	SC2	BC1	BC2	NCC1	NCC2	NCC3	MC	CC	FWC
1	1	5.0	3.9	3.6	2.7	12.3	14.9	12.7	7.8	6.7	9.4
2	2	2.9	3.9	5.4	2.4	9.0	17.1	22.3	9.3	10.1	7.6
3	3	3.3	2.4	7.2	9.3	7.8	6.9	10.1	8.8	6.7	9.4
4	4	1.6	3.0	5.8	4.6	6.6	8.7	12.3	7.1	6.3	4.6
5	5	2.7	4.6	4.6	2.7	8.4	20.2	6.1	9.0	6.6	15.8
6	6	3.0	6.5	9.7	4.5	5.5	17.1	9.0	12.1	7.8	7.2
7	7	3.5	7.8	6.7	5.1	9.9	15.2	4.5	7.6	11.5	12.2
8	8	2.8	6.6	6.1	5.0	10.8	13.6	6.4	20.0	9.5	11.9
9	9	3.6	6.3	5.0	5.8	16.8	14.0	11.6	19.5	13.8	10.5
10	10	3.1	6.8	3.9	4.3	13.1	7.6	11.5	8.7	6.1	10.7

Appendix D. Mean stream depth (m) at nine stream sites (10 transects (TN) per site) in the North Chickamauga Creek watershed, Tennessee, May-July 1996.

		Site								
OBS	TN	SC1	SC2	BC2	NCC1	NCC2	NCC3	MC	CC	FWC
1	1	0.034	0.17273	0.10909	0.05955	0.06364	0.260	0.20000	0.18400	0.11540
2	2	0.140	0.04409	0.07091	0.01864	0.07318	0.026	0.07636	0.03800	0.03000
3	3	0.142	0.08227	0.05273	0.11545	0.05400	0.144	0.22000	0.12500	0.06000
4	4	0.084	0.07318	0.27182	0.06591	0.04591	0.182	0.04909	0.05455	0.02160
5	5	0.080	0.04182	0.12455	0.34909	0.12364	0.097	0.13545	0.05200	0.17000
6	6	0.204	0.02909	0.01955	0.08136	2.32200	0.065	0.26727	0.13800	0.01600
7	7	0.094	0.02818	0.11273	0.36364	0.59800	0.120	0.15818	0.32800	0.04600
8	8	0.064	0.12818	0.07727	0.46273	0.05818	0.112	0.66455	0.11000	0.02200
9	9	0.026	0.05682	0.13636	0.09909	0.04364	0.146	0.55800	0.20800	0.02091
10	10	0.130	0.07000	0.03682	0.24318	0.07273	0.278	0.08909	0.20273	0.13000

Appendix E. Stream discharge (m^3/s) in the upper, middle, and lower stream sections at nine sites in the North Chickamauga Creek watershed, Tennessee, May-July 1996.

				Stream section		
OBS	DATE	SITE	N[1]	UPPER	MIDDLE	LOWER
1	51696	SC2	10	0.20067	0.29824	0.19132
2	52096	BC1	10	0.05600	0.02889	0.04418
3	52096	SC1	10	0.04351	0.03541	0.03723
4	52396	FWC	10	0.01769	0.03016	.
5	52396	NCC3	10	0.07426	0.22649	0.13058
6	52996	CC	10	0.07948	0.10902	0.15410
7	53096	NCC2	10	0.11150	0.16106	0.13989
8	60796	BC2	10	0.01438	0.02533	0.02530
9	60796	NCC1	10	0.04018	0.03904	.
10	60796	SC2	10	0.01294	0.02330	0.02067

[1] N = Number of sampling intervals (along stream-width transects) on upper, middle, and lower stream sections.

Appendix F. Instream shading (% canopy cover) at eight stream sites (10 transects (TN) per site) in the North Chickamauga Creek watershed, Tennessee, May-July 1996.

				CHANNEL LOCATION (FACING DOWNSTREAM)			
OBS	DATE	SITE	TN	RIGHT	MIDDLE	LEFT	MEAN
1	7596	SC1	1	99.75	99.75	99.50	99.667
2	7596	SC1	2	99.25	99.50	99.75	99.500
3	7596	SC1	3	99.75	99.50	100.00	99.750
4	7596	SC1	4	99.50	99.25	100.00	99.583
5	7596	SC1	5	100.00	100.00	99.75	99.917
6	7596	SC1	6	98.25	99.25	100.00	99.167
7	7596	SC1	7	100.00	99.75	100.00	99.917
8	7596	SC1	8	99.75	100.00	99.75	99.833
9	7596	SC1	9	100.00	100.00	100.00	100.000
10	7596	SC1	10	100.00	100.00	100.00	100.000
11	7796	BC2	1	100.00	99.75	100.00	99.917
12	7796	BC2	2	100.00	98.75	100.00	99.583
13	7796	BC2	3	97.00	85.75	97.75	93.500
14	7796	BC2	4	100.00	99.25	100.00	99.750
15	7796	BC2	5	100.00	96.75	98.75	98.500
16	7796	BC2	6	99.50	93.75	99.00	97.417
17	7796	BC2	7	100.00	100.00	97.25	99.083
18	7796	BC2	8	98.00	93.00	97.75	96.250

Appendix F. (Continued)

OBS	DATE	SITE	TN	CHANNEL LOCATION (FACING DOWNSTREAM) RIGHT	MIDDLE	LEFT	MEAN
19	7796	BC2	9	97.00	100.00	100.00	99.000
20	7796	BC2	10	100.00	100.00	100.00	100.000
21	7796	SC2	1	98.75	98.75	98.25	98.583
22	7796	SC2	2	97.00	99.00	100.00	98.667
23	7796	SC2	3	98.00	97.75	99.75	98.500
24	7796	SC2	4	99.75	98.75	97.25	98.583
25	7796	SC2	5	100.00	99.75	94.25	98.000
26	7796	SC2	6	98.50	96.25	99.50	98.083
27	7796	SC2	7	99.75	95.75	97.75	97.750
28	7796	SC2	8	97.75	99.75	98.50	98.667
29	7796	SC2	9	92.00	92.75	97.00	93.917
30	7796	SC2	10	100.00	100.00	100.00	100.000
31	51696	FWC	1	84.75	64.25	79.50	76.167
32	51696	FWC	2	97.25	94.75	90.50	94.167
33	51696	FWC	3	75.00	73.00	89.50	79.167
34	51696	FWC	4	95.00	76.75	83.75	85.167
35	51696	FWC	5	97.75	93.00	99.50	96.750
36	51696	FWC	6	99.50	97.50	98.50	98.500
37	51696	FWC	7	98.00	98.75	100.00	98.917
38	51696	FWC	8	59.00	96.50	98.00	84.500

Appendix F. (Continued)

				CHANNEL LOCATION (FACING DOWNSTREAM)			
OBS	DATE	SITE	TN	RIGHT	MIDDLE	LEFT	MEAN
39	51696	FWC	9	99.50	88.00	84.50	90.667
40	51696	FWC	10	99.00	89.25	100.00	96.083
41	6696	CC	1	88.25	95.00	97.50	93.583
42	6696	CC	2	96.50	100.00	100.00	98.833
43	6696	CC	3	84.75	89.00	100.00	91.250
44	6696	CC	4	87.00	77.25	97.25	87.167
45	6696	CC	5	81.50	65.50	74.75	73.9167
46	6696	CC	6	99.00	99.25	100.00	99.4167
47	6696	CC	7	92.25	84.00	91.00	89.0833
48	6696	CC	8	83.00	70.50	73.25	75.5833
49	6696	CC	9	86.25	47.00	92.00	75.0833
50	6696	CC	10	89.50	89.50	94.00	91.0000
51	7796	NCC1	1	85.00	87.00	93.25	88.4167
52	7796	NCC1	2	99.50	67.50	69.75	78.9167
53	7796	NCC1	3	100.00	93.00	100.00	97.6667
54	7796	NCC1	4	98.00	90.25	99.50	95.9167
55	7796	NCC1	5	100.00	99.75	99.00	99.5833
56	7796	NCC1	6	99.75	97.00	97.75	98.1667
57	7796	NCC1	7	99.75	99.75	100.00	99.8333
58	7796	NCC1	8	100.00	90.75	100.00	96.9167

Appendix F. (Continued)

				CHANNEL LOCATION (FACING DOWNSTREAM)			
OBS	DATE	SITE	TN	RIGHT	MIDDLE	LEFT	MEAN
59	7796	NCC1	9	99.50	84.75	91.25	91.8333
60	7796	NCC1	10	99.50	96.50	98.00	98.0000
61	7596	NCC2	1	97.00	77.50	98.75	91.0833
62	7596	NCC2	2	100.00	67.25	100.00	89.0833
63	7596	NCC2	3	99.75	94.25	99.50	97.8333
64	7596	NCC2	4	90.75	88.50	98.50	92.5833
65	7596	NCC2	5	93.00	70.00	99.50	87.5000
66	7596	NCC2	6	88.25	92.50	.	.
67	7596	NCC2	8	95.75	81.00	99.25	92.0000
68	7596	NCC2	9	99.50	81.00	82.00	87.5000
69	7596	NCC2	10	97.75	76.00	82.00	85.2500
70	71896	NCC3	1	55.75	18.00	14.75	29.5000
71	71896	NCC3	2	47.25	20.75	23.00	30.3333
72	71896	NCC3	3	43.25	60.00	96.50	66.5833
73	71896	NCC3	4	70.00	26.25	41.25	45.8333
74	71896	NCC3	5	29.00	41.25	57.75	42.6667
75	71896	NCC3	6	74.50	80.25	94.75	83.1667
76	71896	NCC3	7	89.50	87.50	96.25	91.0833
77	71896	NCC3	8	72.50	62.50	64.75	66.5833
78	71896	NCC3	9	63.75	46.50	58.75	56.3333
79	71896	NCC3	10	78.75	51.50	36.00	55.4167

Appendix G. Streambank erosion (% bare soil) at eight stream sites (10 transects (TN) per site) in the North Chickamauga Creek watershed, Tennessee, May-July 1996.

			STREAM BANK		
OBS	DATE	SITE	RIGHT	LEFT	MEAN
1	72496	SC1	0.80	0.80	80.0
2	72496	SC1	0.92	0.99	95.5
3	72496	SC1	0.97	1.00	98.5
4	72496	SC1	0.05	0.00	2.5
5	72496	SC1	0.97	0.99	98.0
6	72496	SC1	0.99	0.92	95.5
7	72496	SC1	1.00	0.60	80.0
8	72496	SC1	0.70	0.87	78.5
9	72496	SC1	0.50	0.98	74.0
10	72496	SC1	0.89	0.87	88.0
11	72496	SC2	0.97	0.80	88.5
12	72496	SC2	0.96	0.70	83.0
13	72496	SC2	0.60	0.20	40.0
14	72496	SC2	0.02	0.05	3.5
15	72496	SC2	0.45	0.17	31.0
16	72496	SC2	0.67	0.02	34.5
17	72496	SC2	0.70	0.70	70.0
18	72496	SC2	0.95	0.97	96.0
19	72496	SC2	0.25	0.60	42.5

Appendix G. (Continued)

OBS	DATE	SITE	STREAM BANK RIGHT	LEFT	MEAN
20	72496	BC2	0.00	0.50	25.0
21	72496	BC2	0.00	0.05	2.5
22	72496	BC2	0.20	0.20	20.0
23	72496	BC2	0.15	0.53	34.0
24	72496	BC2	0.50	0.63	56.5
25	72496	BC2	0.95	0.00	47.5
26	72496	BC2	0.43	0.25	34.0
27	72496	BC2	0.07	0.15	11.0
28	72496	BC2	0.35	0.65	50.0
29	72496	BC2	0.43	0.45	44.0
30	72596	NCC1	0.28	0.90	59.0
31	72596	NCC1	0.05	0.58	31.5
32	72596	NCC1	0.30	0.40	35.0
33	72596	NCC1	0.40	0.90	65.0
34	72596	NCC1	0.30	0.44	37.0
35	72596	NCC1	0.80	0.35	57.5
36	72596	NCC1	0.05	0.90	47.5
37	72596	NCC1	0.35	0.20	27.5
38	72596	NCC1	0.10	0.10	10.0
39	72696	NCC2	0.00	0.00	0.0
40	72696	NCC2	0.30	0.00	15.0

Appendix G. (Continued)

			STREAM BANK		
OBS	DATE	SITE	RIGHT	LEFT	MEAN
41	72696	NCC2	0.10	0.25	17.5
42	72696	NCC2	0.10	0.15	12.5
43	72696	NCC2	0.20	0.90	55.0
44	72696	NCC2	0.20	0.10	15.0
45	72696	NCC2	0.60	0.19	39.5
46	72696	NCC2	0.10	0.13	11.5
47	72696	NCC2	0.67	0.70	68.5
48	72696	NCC2	0.30	0.17	23.5
49	72696	NCC3	0.20	0.10	15.0
50	72696	NCC3	0.30	0.00	15.0
51	72696	NCC3	0.80	0.00	40.0
52	72696	NCC3	0.00	0.10	5.0
53	72696	NCC3	0.70	0.30	50.0
54	72696	NCC3	0.13	0.30	21.5
55	72696	NCC3	0.10	0.95	52.5
56	72696	NCC3	0.20	0.25	22.5
57	72696	NCC3	0.00	0.20	10.0
58	72696	FWC	0.00	0.15	7.5
59	72696	FWC	0.00	0.10	5.0
60	72696	FWC	0.05	0.17	11.0
61	72696	FWC	0.00	0.20	10.0
62	72696	FWC	0.37	0.70	53.5

Appendix G. (Continued)

			STREAM BANK		
OBS	DATE	SITE	RIGHT	LEFT	MEAN
63	72696	FWC	0.75	0.85	80.0
64	72696	FWC	0.00	0.10	5.0
65	72696	FWC	0.00	0.05	2.5
66	72696	FWC	0.15	0.05	10.0
67	72696	FWC	1.00	0.80	90.0
68	72696	CC	0.10	0.20	15.0
69	72696	CC	0.00	0.20	10.0
70	72696	CC	0.00	0.10	5.0
71	72696	CC	0.00	0.00	0.0
72	72696	CC	0.00	0.00	0.0
73	72696	CC	0.00	0.04	2.0
74	72696	CC	0.60	0.30	45.0
75	72696	CC	0.05	0.00	2.5
76	72696	CC	0.10	0.00	5.0
77	72696	CC	0.00	0.00	0.0

Appendix H. Abundance (number of individuals per m^2) of aquatic macroinvertebrates in kick-net samples collected at six stream sites (three sections per site) in the North Chickamauga Creek watershed, Tennessee, May-June 1996.

OBS	DATE	SITE	SECTION	AREA (m^2)	INVERTEBRATE ABUNDANCE
1	52096	SC1	1	2.6660	129.41
2	52096	SC1	7	2.4080	66.03
3	52096	SC1	8	2.3220	252.37
4	52096	SC2	2	1.4620	.
5	52096	SC2	6	2.0210	194.95
6	52096	SC2	7	2.2790	123.30
7	51396	BC2	4	2.0210	381.99
8	51396	BC2	7	1.5480	879.84
9	51396	BC2	10	1.8920	579.28
10	51596	NCC1	2	2.2790	193.94
11	51596	NCC1	5	2.0210	369.12
12	51596	NCC1	9	1.7200	283.14
13	53096	NCC3	12	1.7200	297.67
14	53096	NCC3	7	1.5910	296.67
15	53096	NCC3	10	1.5910	408.55
16	53096	FWC	1	1.8490	1368.85
17	53096	FWC	6	2.2360	903.85
18	53096	FWC	9	2.1070	2407.69

Appendix H. (Continued)

OBS	DATE	SITE	SECTION	AREA (m^2)	INVERTEBRATE ABUNDANCE
19	62096	SC1	4	1.2040	120.43
20	62096	SC1	7	1.9350	58.91
21	62096	SC1	10	1.8490	41.64
22	61896	SC2	2	1.6899	537.90
23	61896	SC2	4	1.9350	281.65
24	61896	SC2	9	1.9350	479.07
25	61896	BC2	1	1.4835	848.67
26	61896	BC2	3	1.4405	489.41
27	61896	BC2	10	1.5609	736.75
28	62096	NCC1	3	1.1180	353.31
29	62096	NCC1	6	1.3330	385.60
30	62096	NCC1	10	1.8232	316.48
31	62096	NCC3	3	2.2661	409.07
32	62096	NCC3	5	1.6469	422.00
33	62096	NCC3	7	1.5308	308.99
34	62096	FWC	1	1.8490	587.34
35	62096	FWC	3	1.9350	620.16
36	62096	FWC	8	1.2040	1294.85

Appendix I. Salamander abundance (number of individuals per 1 m^2) in kick-net samples collected at six stream sites (three sections per site) in the North Chickamauga Creek watershed, Tennessee, May-June 1996.

OBS	DATE	SITE	SECTION	AREA (m^2)	SALAMANDER ABUNDANCE: DUSKY SALAMANDER	SALAMANDER ABUNDANCE: TWO-LINED SALAMANDER	SALAMANDER ABUNDANCE: TOTAL
1	51396	BC2	4	2.021	0.98961	0.00000	0.98961
2	51396	BC2	7	1.548	0.64599	0.00000	0.64599
3	51396	BC2	10	1.892	0.52854	0.00000	0.52854
4	61896	BC2	1	1.505	2.65781	0.66445	3.32226
5	61896	BC2	3	1.462	3.41997	2.05198	5.47196
6	61896	BC2	10	1.548	4.52196	0.00000	4.52196
7	53096	FWC	1	1.849	0.54083	0.00000	0.54083
8	53096	FWC	6	2.236	3.13059	0.00000	3.13059
9	53096	FWC	9	2.107	3.79687	0.00000	3.79687
10	62496	FWC	1	1.849	2.70416	0.00000	2.70416
11	62496	FWC	3	1.935	2.06718	0.00000	2.06718
12	62496	FWC	8	1.204	0.00000	0.00000	0.00000
13	51596	NCC1	2	2.279	0.00000	0.00000	0.00000
14	51596	NCC1	5	2.021	0.00000	0.00000	0.00000
15	51596	NCC1	9	1.720	0.00000	0.00000	0.00000
16	62096	NCC1	3	1.118	0.00000	0.00000	0.00000
17	62096	NCC1	6	1.333	0.00000	0.00000	0.00000
18	62096	NCC1	10	1.806	0.00000	0.00000	0.00000

Appendix I. (Continued)

OBS	DATE	SITE	SECTION	AREA (m²)	SALAMANDER ABUNDANCE[1] DS	TLS	TOTAL
19	53096	NCC3	7	1.591	0.00000	0.00000	0.00000
20	53096	NCC3	10	1.591	0.00000	0.00000	0.00000
21	53096	NCC3	12	1.720	0.00000	0.00000	0.00000
22	62096	NCC3	3	2.279	0.00000	0.43879	0.43879
23	62096	NCC3	5	1.677	0.00000	0.00000	0.00000
24	62096	NCC3	7	1.548	0.00000	0.00000	0.00000
25	52096	SC1	1	2.666	0.00000	0.00000	0.00000
26	52096	SC1	7	2.408	0.00000	0.00000	0.00000
27	52096	SC1	8	2.322	0.00000	0.00000	0.00000
28	62096	SC1	4	1.204	0.00000	0.00000	0.00000
29	62096	SC1	7	1.935	0.00000	0.00000	0.00000
30	62096	SC1	10	1.849	0.00000	0.00000	0.00000
31	52096	SC2	2	1.462	0.00000	0.00000	0.00000
32	52096	SC2	6	2.021	0.00000	0.00000	0.00000
33	52096	SC2	7	2.279	0.00000	0.00000	0.00000
34	61896	SC2	2	1.720	0.00000	0.00000	0.00000
35	61896	SC2	4	1.935	0.00000	0.00000	0.00000
36	61896	SC2	9	1.935	0.51680	0.00000	0.51680

[1] Salamander abbreviations: DS=dusky salamander, TLS=two-lined salamander.

Appendix J. Salamander abundance (number of individuals per 100 m²) in electroshocking samples collected at six stream sites (three sections per site) in the North Chickamauga Creek watershed, Tennessee, May-June 1996.

					SALAMANDER ABUNDANCE			
OBS	DATE	SITE	SECTION	AREA (m^2)	DS	TLS	SS	RS
1	51096	FWC	d	154.80	0.00000	0.00000	0.00000	0.00000
2	51096	FWC	m	270.90	0.00000	0.00000	0.00000	0.00000
3	51096	FWC	u	130.70	0.00000	0.00000	0.00000	0.00000
4	62196	FWC	d	124.00	4.03226	0.00000	0.00000	0.80645
5	62196	FWC	m	166.32	2.40500	1.20250	0.00000	0.00000
6	62196	FWC	u	167.40	2.98686	0.00000	0.00000	0.59737
7	71096	FWC	a	125.80	3.17965	0.00000	0.00000	0.00000
8	71096	FWC	a	113.30	4.41306	0.00000	0.00000	0.00000
9	71096	FWC	a	24.50	4.08163	4.08163	0.00000	0.00000
10	51796	NCC1	d	209.30	0.95557	0.00000	0.47778	0.00000
11	51796	NCC1	m	85.10	3.52526	0.00000	0.00000	0.00000
12	51796	NCC1	u	116.30	0.00000	0.00000	0.00000	0.00000
13	61996	NCC1	d	119.50	0.00000	0.00000	0.00000	0.00000
14	61996	NCC1	m	119.80	0.00000	0.00000	0.00000	0.00000
15	61996	NCC1	u	204.00	0.00000	0.00000	0.00000	0.00000
16	71096	NCC1	d	121.70	0.00000	0.00000	0.00000	0.00000
17	71096	NCC1	m	84.70	1.18064	0.00000	0.00000	0.00000
18	71096	NCC1	u	199.20	0.00000	0.00000	0.00000	0.00000
19	52196	NCC2	d	114.00	0.00000	0.00000	0.00000	0.00000

Appendix J. (Continued)

OBS	DATE	SITE	SECTION	AREA (m^2)	SALAMANDER ABUNDANCE DS	TLS	SS	RS
20	52196	NCC2	m	91.90	0.00000	0.00000	0.00000	0.00000
21	52196	NCC2	u	133.90	0.00000	0.00000	0.00000	0.00000
22	62596	NCC2	a	234.00	0.42735	0.00000	0.00000	0.00000
23	62596	NCC2	a	130.80	0.00000	0.00000	0.00000	0.00000
24	62596	NCC2	a	167.40	0.59737	0.00000	0.00000	0.00000
25	71796	NCC2	d	215.50	0.92807	0.00000	0.00000	0.00000
26	71796	NCC2	m	111.50	0.89686	0.00000	0.00000	0.00000
27	71796	NCC2	u	199.60	2.50501	0.00000	0.00000	0.00000
28	52296	NCC3	d	154.80	0.00000	0.00000	0.00000	0.00000
29	52296	NCC3	m	270.90	0.00000	0.00000	0.00000	0.00000
30	52296	NCC3	u	172.20	0.00000	0.00000	0.00000	0.00000
31	62596	NCC3	a	158.50	7.57098	0.00000	0.00000	0.00000
32	62596	NCC3	a	157.70	0.63412	0.00000	0.00000	0.00000
33	62596	NCC3	a	352.40	1.13507	0.00000	0.56754	0.00000
34	71796	NCC3	d	177.70	0.00000	0.00000	0.00000	0.00000
35	71796	NCC3	m	188.00	0.00000	0.00000	0.00000	0.00000
36	71796	NCC3	u	178.90	1.11794	0.00000	0.00000	0.00000

[1] Salamander abbreviations: DS=dusky salamander, TLS=two-lined salamander, SS=spring salamander, RS=red salamander.

Appendix K. Fish abundance (number of individuals per 100 m²) in electroshocking samples collected at six stream sites (three sections per site) in the North Chickamauga Creek watershed, Tennessee, May-June 1996.

OBS	DATE	SITE	SECTION	AREA (m^2)	FISH ABUNDANCE
1	52996	CC	d	90.70	8.820
2	52996	CC	m	140.70	16.347
3	52996	CC	u	109.40	21.938
4	62696	CC	d	113.80	68.541
5	62696	CC	m	142.40	47.753
6	62696	CC	u	143.90	52.120
7	71296	CC	d	101.70	118.977
8	71296	CC	m	70.00	31.429
9	71296	CC	u	140.20	52.068
10	51096	FWC	m	270.90	11.443
11	51096	FWC	u	172.20	4.646
12	52196	FWC	d	154.80	18.734
13	62196	FWC	d	124.00	25.000
14	62196	FWC	m	166.32	21.645
15	62196	FWC	u	167.40	23.895
16	71096	FWC	d	125.80	48.490
17	71096	FWC	m	113.60	16.725
18	71096	FWC	u	24.50	142.857
19	51796	NCC1	d	209.30	0.000
20	51796	NCC1	m	85.10	0.000
21	51796	NCC1	u	116.30	0.000

Appendix K. (Continued)

OBS	DATE	SITE	SECTION	AREA (m^2)	FISH ABUNDANCE
22	61996	NCC1	d	119.50	0.000
23	61996	NCC1	m	119.80	0.000
24	61996	NCC1	u	204.00	0.000
25	71096	NCC1	d	121.70	0.000
26	71096	NCC1	m	84.70	0.000
27	71096	NCC1	u	199.20	0.000
28	52196	NCC2	d	114.00	0.000
29	52196	NCC2	m	91.90	0.000
30	52196	NCC2	u	133.90	1.494
31	62596	NCC2	d	234.00	0.000
32	62596	NCC2	m	130.80	9.939
33	62596	NCC2	u	167.40	2.987
34	71796	NCC2	d	215.50	0.000
35	71796	NCC2	m	111.50	0.000
36	71796	NCC2	u	199.60	15.531
37	52296	NCC3	d	154.80	0.000
38	52296	NCC3	m	270.90	0.000
39	52296	NCC3	u	172.20	0.000
40	62596	NCC3	d	158.50	0.000
41	62596	NCC3	m	157.70	0.000
42	62596	NCC3	u	352.40	0.000
43	71796	NCC3	d	177.70	0.000
44	71796	NCC3	u	178.9	1.1179

Appendix L. Fish abundance (number of individuals per 24 hours) estimated by hoop-netting at five stream sites (five nets per site) in the North Chickamauga Creek watershed, Tennessee, August-September 1996.

DATE	SITE	NET	FISH ABUNDANCE
83096	CC	1	0.0000
83096	CC	2	1.0000
83096	CC	3	2.0000
83096	CC	4	0.0000
83096	CC	5	2.0000
81496	FWC	1	17.0000
81496	FWC	2	0.0000
81496	FWC	3	2.0000
81496	FWC	4	0.0000
81496	FWC	5	9.0000
92496	NCC1	1	0.0000
92496	NCC1	2	0.0000
92496	NCC1	3	0.0000
92496	NCC1	4	0.0000
92496	NCC1	5	0.0000
90996	NCC2	1	0.0000
90996	NCC2	2	1.0000
90996	NCC2	3	0.0000
90996	NCC2	4	0.0000
90996	NCC2	5	0.0000
90696	NCC3	1	0.0000
90696	NCC3	2	0.0000
90696	NCC3	3	0.0000
90696	NCC3	4	2.0000
90696	NCC3	5	1.0000

RELATIONSHIPS BETWEEN WATER QUALITY AND THE ABUNDANCE OF SALAMANDERS IN MOUNTAIN STREAMS IN SOUTHEASTERN TENNESSEE

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Abstract.--Amphibian communities provide valuable information on water quality and aquatic ecosystem integrity. I investigated the potential effects of four water quality variables (temperature, dissolved oxygen, pH, conductivity) on the relative abundance of salamanders. Specimens were collected by kick-sampling, with a 500-μm mesh dip net, at six stream sites in the North Chickamauga Creek watershed, Tennessee, January-October 1996. Salamander abundance varied significantly among sites ($\underline{P} < 0.1$) relative to pH and conductivity. Abundance was lowest at sites characterized by low pH (3.7-5.3) and high conductivity (44-406 μS/cm); these conditions reflect high concentrations of sulfuric acid and dissolved metals in discharges from abandoned coal mines. Our findings underscore the negative effects of coal mining on water quality and aquatic organisms in stream ecosystems.

Appendix M. Abstract of a paper presented at the 1997 Annual Meeting of the Tennessee Chapter of the American Fisheries Society and published in the proceedings.

Effects of Acid Mine Drainage on Salamander Assemblages in the North Chickamauga Creek System, Tennessee

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Abstract.--In Appalachia's coal mining regions, acid mine drainage (AMD) has contributed to the widespread degradation of stream ecosystems. Salamanders are common inhabitants of healthy headwater streams and have been studied as indicators of ecosystem integrity. Hence, we investigated the potential effects of AMD on the species richness and relative abundance of aquatic salamanders in selected stream reaches (sites) of the North Chickamauga Creek (NCC) system, Tennessee. Specimens were collected by kick-sampling with a 500-μm mesh dip net and/or electroshocking at four AMD-impacted sites (pH <5.6) and two reference sites (pH > 6.2), May-July 1996. Species richness was similarly low at reference sites, 2 - 3 species, and AMD-impacted sites, 1 - 2 species. No salamanders were observed at sites with pH values < 4 and aluminum concentrations > 2500 μg/L. Dusky salamander <u>Desmognathus</u> <u>fuscus</u> (present at all sites) and total salamander (all species) abundances were greater ($\underline{P}$ < 0.05) at reference sites versus AMD-impacted sites, regardless of the sampling method. Dusky salamander and total salamander abundances were directly correlated with pH (r = 0.99; $\underline{P}$ < 0.001) and inversely correlated with the aluminum concentration (r = -0.82; $\underline{P}$ < 0.10). Findings from this (ongoing) study underscore the negative effects of coal mining on stream-dwelling salamanders and provide baseline data for AMD-mitigation projects.

Appendix N. Abstract of a paper accepted for presentation at the 1997 Annual Meeting of the National Conference of Undergraduate Research and published in the proceedings.