THE EFFECTS OF CLEARCUTTING ON HEADWATER STREAMS IN SOUTHEASTERN OKLAHOMA

By

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THE EFFECTS OF CLEARCUTTING ON HEADWATER

STREAMS IN SOUTHEASTERN OKLAHOMA

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PREFACE

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CHAPTER I

INTRODUCTION

Commercial timber harvest is a relatively old practice in the United States but is comparatively new in Oklahoma. Timber harvesting began in Oklahoma (Indian Territory) during the mid 1800's but did not become an important industry until about 1910 (Honess 1923). Commercial timber harvest has steadily increased since the early 1900's and remains a minor industry in the state (Walker 1962).

Softwood timber, primarily short-leaf pine (*Pinus echinata*) and loblolly pine (*Pinus taeda*), comprises the largest percentage of timber harvested in Oklahoma (Walker 1962). Approximately 70% of the softwood timber is harvested from only 36% of the total forested area (Murphy 1977). Timber harvest reached an all time high in 1978, when a new state record (3,488,000 cords) for round pulpwood production was established (Bertelson 1979). Clearcutting is the major harvest technique used in southeastern Oklahoma and is usually defined as the complete removal of all vegetation from a timber stand.

Presently, the majority of Oklahoma's forest land is concentrated in eighteen eastern counties (Figure 1) where forests cover 49% (4.9 million acres) of the total land area (Murphy 1977). Commercial forest constitutes approximately 88% of the forested land of Oklahoma. The largest concentration of commercial timber holdings is located in southeastern Oklahoma. Four counties, Choctaw, Le Flore, McCurtain, and

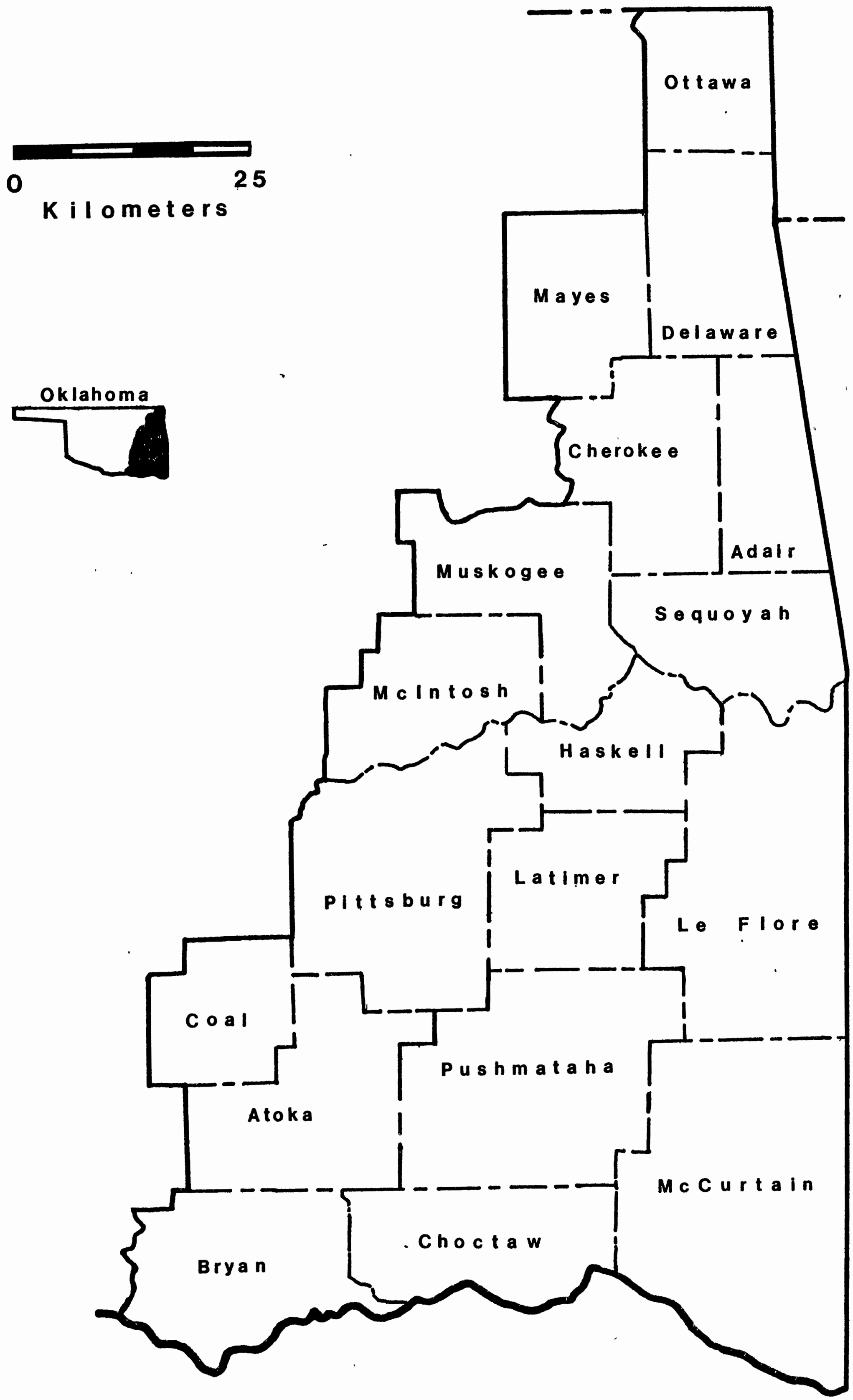

Figure 1. Eastern counties that constitute the majority of forested land in Oklahoma.

Pushmataha, produced 90% of the timber harvested in the state in 1980 (Rudis 1982). McCurtain county alone accounts for almost 50% of the annual harvest in Oklahoma (Rudis and Jones 1981). The Weyerhaeuser Corporation owns the majority of the commercial forested land in southeastern Oklahoma. Several other timber companies have small commercial holdings in Oklahoma but most are concentrated in the northeastern portion of the state.

Concentration of silvicultural activities in southeastern Oklahoma provides the potential for deleterious impacts on both the physical and biological components of aquatic systems. Many studies, conducted largely in the northeastern and northwestern United States, have shown that stream organisms can be affected by logging activities (Tebo 1955, Chapman 1962, Lantz 1967, Burns 1972, Gibbons and Salo 1973, Hansmann and Phinney 1973, Lee and Samuel 1976, Murphy and Hall 1981). However, few studies have addressed the impacts of clearcutting on warm water stream fish in mixed oak and pine forests (Gibbons and Salo 1973, Boschung and O'Neil 1981).

Forestry practices have also been shown to impact the physical characteristics of streams. Logging roads and skid trails (Tebo 1955, Cordone and Kelley 1961, Haupt and Kidd 1965, Megahan and Kidd 1972) and removal of vegetation or logging slash with heavy equipment (Beschta 1979) caused soil erosion and increased stream silt loads. Sediment input can impact stream communities through a reduction in light penetration and habitat variability and the introduction of absorbed pollutants and nutrients, especially pesticides, herbicides and metals (Oschwald 1972).

Other studies have shown that clearcutting can also lead to modification of stream flows and flow periodicity (Rothacher 1970, Hornbeck 1973, Patric 1973, Harr et al. 1975) or temperature regimes (Eschner and Larmoyeux 1963, Brown 1969, Gray and Edington 1969, Brown 1970, Brown and Krygier 1971, Kopperdahl et al. 1971, Burns 1972, Moring 1975, Newbold et al. 1980). Stream changes resulting from increased siltation, modification of flow regimes and water levels, and alteration of the chemical characteristics can affect the amount of habitat available to stream organisms. The resultant changes in habitat availability can lead to alteration of the stream fish fauna (Karr and Schlosser 1978, Gorman and Karr 1978).

The purpose of this study was to describe the effects of clearcutting on water quality, habitat availability and the population structure of fishes in headwater streams in southeastern Oklahoma. Specific objectives were 1) to compare water quality, water depth, water velocity, substrate type and fish community structure before and after clearcutting, and 2) to correlate any changes with factors related to silvicultural activity.

CHAPTER II

DESCRIPTION OF STUDY AREA

This study was conducted in the Ouachita Mountains of southeastern Oklahoma which is the southwestern extension of a mountain range that extends from Atoka, Oklahoma to Little Rock, Arkansas. Elevation in the Oklahoma portion of the Ouachita Mountains varies from 160 to 750 m above mean sea level. The mountains are largely composed of Pennsylvanian and Mississippian deposits of shale and limestone (Branson et al. 1979). The slopes are heavily forested with oak and pine; short-leaf pine is the most abundant native species of softwood in the area.

Three major rivers, Little River, Mountain Fork River and Glover River, flow through the Ouachitas. The Little River is the largest with a drainage area of approximately 5700 km^2. The Little River originates in southwestern Le Flore County and generally flows southeasterly into Arkansas where it joins the Red River. Pine Creek Reservoir impounds the Little River about 5 km northwest of Wright City, Oklahoma.

The Mountain Fork River, a tributary of the Little River, has a drainage area of about 2180 km^2. The river originates in Polk County, Arkansas and generally flows south along the Oklahoma-Arkansas border. The Mountain Fork flows into the Little River approximately 10 km west of the Oklahoma state line. Broken Bow Reservoir is the only major impoundment on the Mountain Fork River.

The Glover River is also a major tributary of the Little River in Oklahoma. The Glover drains an area of approximately 876 km^2 and is not presently impounded. The confluence of the Glover River with the Little River occurs approximately 19 km west of Broken Bow, Oklahoma.

These rivers and their tributaries are locally renowned for smallmouth bass (Micropterus dolomieui), largemouth bass (M. salmoides), and green sunfish (Lepomis cyanellus) angling (Finnell et al. 1956). The tributaries have fairly steep gradients with rubble, boulder and bedrock comprising the substrate types in the headwater areas. Leaf litter is often the dominant substrate type of pools in heavily forested areas. Water chemistry is highly variable but tends to be slightly acidic with a low specific conductance (Ming 1968).

The climate of the Little River drainage in Oklahoma is characterized by long hot summers and short mild winters. Average annual air temperature is 17.2° C with monthly averages of 27.8° C in July and 6.7° C in January (Orth 1980). Average annual precipitation is approximately 126 cm with an average runoff of 47 cm (U.S. Army, Corps of Engineers 1975). In the spring, heavy rains often result in flash floods. Stream flows are erratic with peak discharges occurring in the spring and winter months. During the summer, many streams dry up with only the deepest pools containing any water. Subsurface flow helps maintain water exchange between the pools.

Three small headwater drainages, Little Cow Creek, Big Eagle Creek and the Upper Little River located in southwestern Le Flore County were selected as specific study areas (Figure 2).

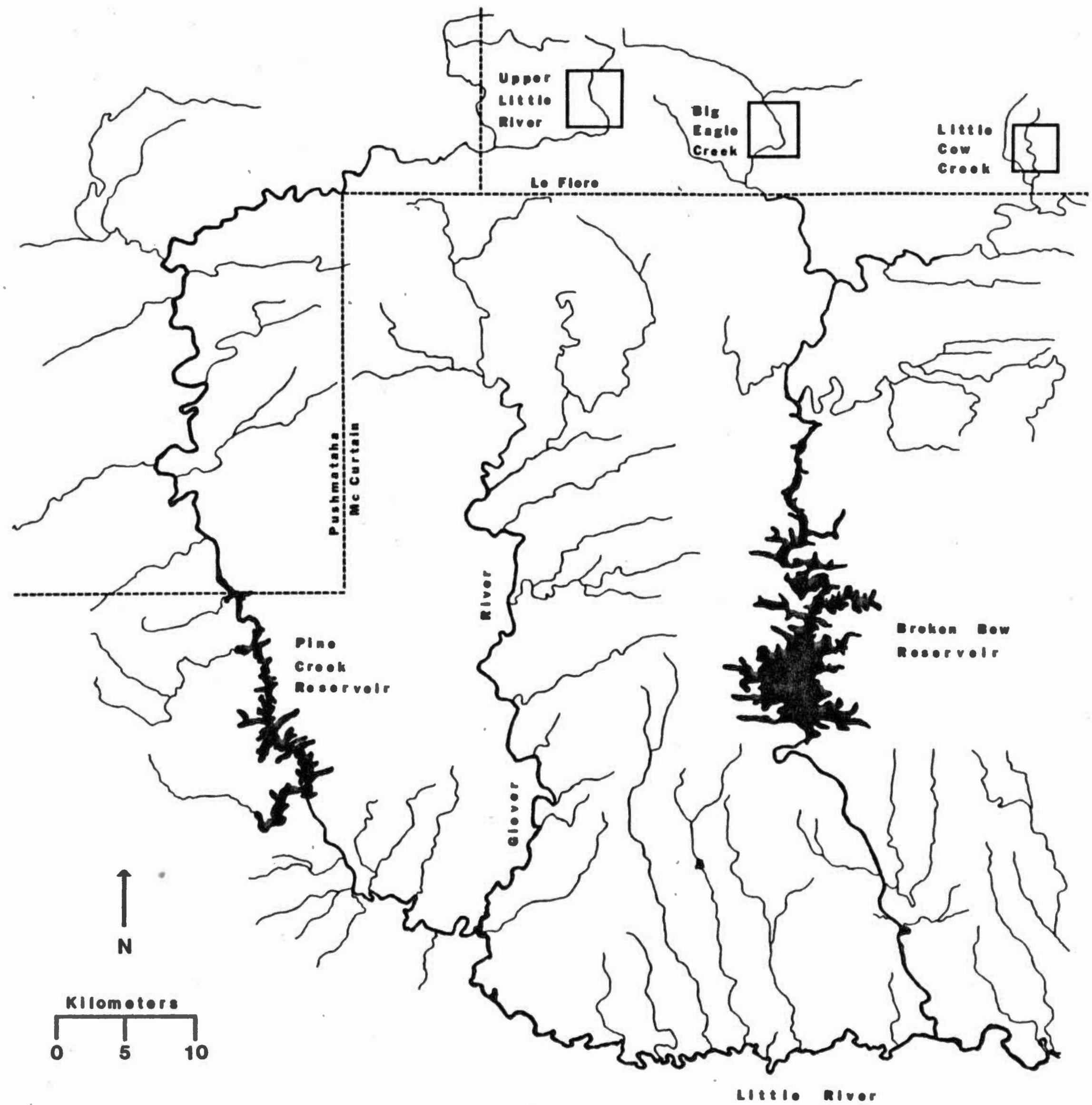

Figure 2. Portion of the Little River Drainage showing location of study areas in Le Flore County, Oklahoma.

Little Cow Creek

The Little Cow Creek (LCC) study area was a third order stream located within the Ouachita National Forest (R27E, T1N, Sec. 29). Primary logging roads in the area had been constructed prior to May 1981 and timber harvest was scheduled to begin in the fall of 1981. However, actual harvest was not begun until the latter part of 1982, and had not been completed by January of 1984. Three sampling sites were established on LCC, all located on soils of the Kenn-Ceda Complex (Soil Conservation Service 1981).

The control site (site one) was located approximately 50 m upstream of the proposed clearcut boundary. The total length of the site was 22 m. The majority of the site was shaded by large oak (*Quercus* spp.) and sycamore (*Platanus occidentalis*) trees. Approximately 35% of the total length of the site was composed of riffle habitat.

Site two was established within the boundaries of the proposed clearcut. The total length of the site was 26 m and approximately 35% was riffle habitat. The site was partially shaded by holly (*Ilex* sp.) and alder (*Alnus* sp.) trees.

The third site was located approximately 50 m downstream of the clearcut boundary. The site was shaded by alder, sweet gum (*Liquidambar styraciflua*), and oaks. The site was 30.5 m in length with about 55% of the length composed of riffle habitat.

Upper Little River

Two sampling sites were established on the Upper Little River (ULR) study area, located in the headwaters of the Little River on property belonging to the Weyerhaeuser Company (R23E, T1N, Sec. 1 and 12). The stream reach under investigation was a fourth order stream located on soils of the Ceda-Rubble Complex (Soil Conservation Service 1981).

A 355 acre stand of timber was harvested near the stream during the winter and early spring of 1979 and a buffer strip approximately 10 m wide was left along the stream. Logging roads had been constructed prior to 1978. A total of four low-water stream crossings were constructed upstream of site two.

In 1981, a clearcut was made in the headwaters of the stream which prevented establishment of another control site. An additional clearcut was made within the study area in 1983. Harvest began sometime after May and had been completed prior to August. A buffer strip approximately 9 m wide was left along the stream.

Site two (Sec. 12) was located downstream of the older clearcuts and was within the boundaries of the 1983 clearcut. The site was shaded by large oak and sycamore trees. Total length of the site was 34.5 m with approximately 50% of the length composed of riffle habitat.

Big Eagle Creek

The Big Eagle Creek (BEC) study area was located approximately 9 km east southeast of the Upper Little River study area. Primary logging roads were constructed prior to May 1981. Timber harvest began in late fall of 1982 and was completed by January 1983. The clearcut was approximately 310 acres with a large buffer strip 20 to 25 m wide on the creek and smaller buffer strips 3 to 22 m wide on the two tributaries which drained the clearcut. The stream segment under study was a second order stream located on soils of the Ceda-Rubble Complex (Soil Conservation Service 1981).

The control site (site one) was located upstream of the clearcut boundaries on Weyerhaueser land (R24E T1N Sec. 3) and was established in winter 1982. The site was 28.5 m long with approximately 40% of the length composed of riffle habitat. The stream was shaded by green ash (*Fraxinus pennsylvanica*), alder and oak trees.

Site two was located immediately downstream of the clearcut on private land owned by Mr. Neil Ashby (R24E T1N Sec. 1). The site was 42.5 m in length of which 45% was composed of riffle habitat. The riffle was shaded by small alder trees and the pool was shaded by small green ash and cedar (*Juniperus virginianus*) trees. Portions of the pool banks were undercut.

CHAPTER III

METHODS AND MATERIALS

In order to accurately evaluate the impacts of clearcutting, two major criteria were used to select the study areas: (1) the headwaters of each drainage had to be unharvested and relatively free of other logging activity and (2) clearcutting was scheduled to begin on the study areas during the early stages of the project.

Collections were made quarterly beginning in the fall of 1981 and continued until the winter of 1984. To facilitate analysis, the year was divided into four seasons as follows: Winter (January, February, March), Spring (April, May, June), Summer (July, August, September), Fall (October, November, December). An attempt was made to obtain collections during the same time period within each season to reduce seasonal and yearly variation. Collections consisted of measurements of the habitat variables: water depth, water velocity, and substrate types, and an assessment of the existing fish populations.

Fish were collected with a streamside, pulsed direct current electrofishing unit composed of two hand-held electrodes and a copper plate cathode. A variable voltage pulsator manufactured by the Coffelt Electronics Corporation (VVP-2C)* regulated the output of the power source (a gasoline powered generator). The electrodes were used to

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*Mention of trade names or corporations does not constitute endorsement of commercial products.

disturb the substrate in riffle habitats allowing stunned fish to be swept by the current into dipnets held downstream.

A modified depletion method (Carle and Maughan 1980) was used to sample fish populations. The assumptions underlying the use of depletion sampling have been outlined by Raleigh and Short (1981). This technique consisted of blocking each site on the upstream and downstream ends with 6 mm mesh nets to prevent free movement of fish into or out of the site. The block nets were secured by placing large boulders on the lead lines. One sampling unit of effort normally consisted of one pass from the downstream net to the upstream net and back. This procedure was repeated until all species were depleted. A minimum of three units of effort per site were used each season.

After each sampling effort, the fish collected were weighed and total lengths were measured. Small fish were grouped by species and weighed in batches. Fish that could not be identified in the field were preserved in a 10% formalin solution and returned to the laboratory. All fish that had been identified and measured were released several meters below the downstream net. During low water conditions the fish were released in the nearest pool.

Upon completion of sampling, the block nets were removed and habitat measurements were taken along three or four permanent transects established perpendicular to the direction of stream flow at each sampling site. Measurements were taken at one meter intervals in pool habitats and 0.5 m intervals in riffle areas. These point measurements represented average values of water depth, velocity and substrate types for a segment one meter wide, extending halfway from the closest upstream and downstream transects (Orth 1980, Figure 3). Water velocity

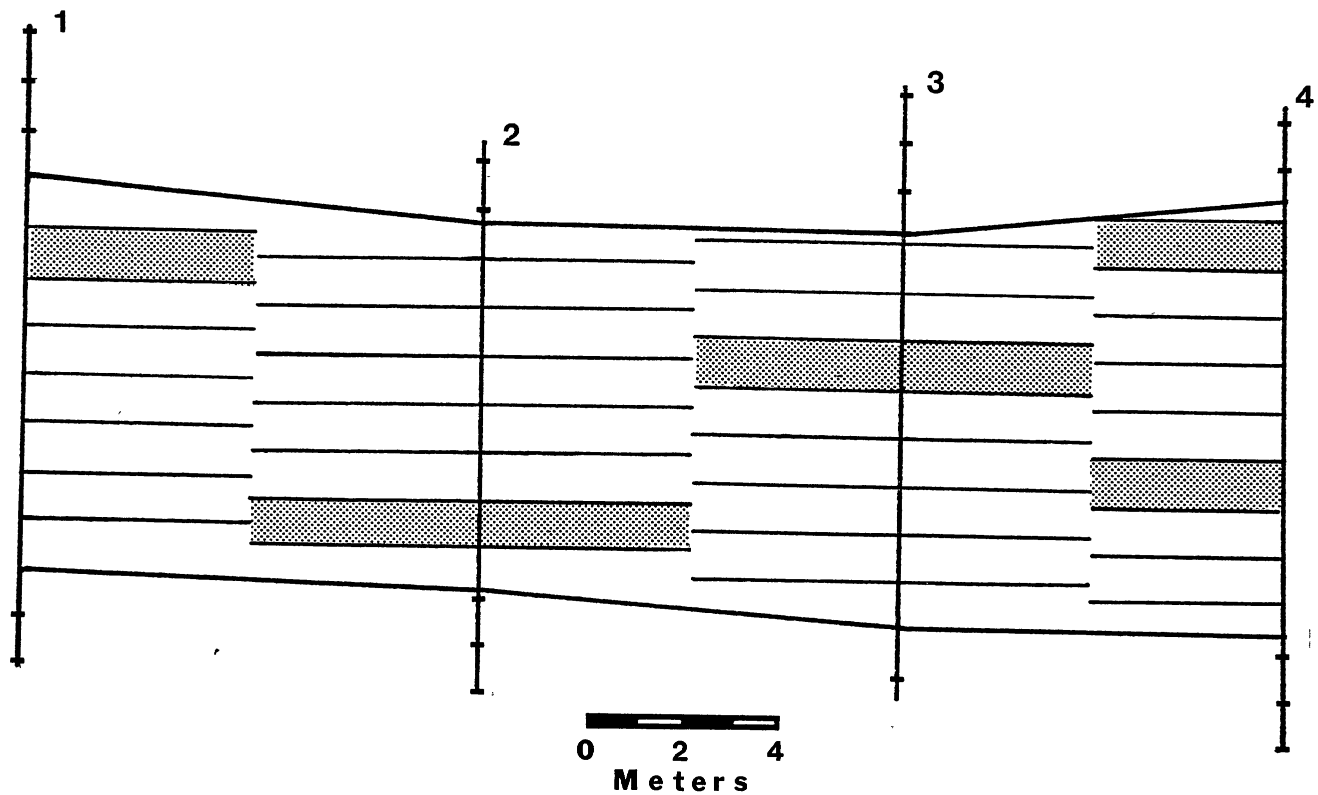

Figure 3. Schematic representation of a site subdivided along each transect. Habitat availability is estimated by summing the surface area of each segment (depicted by stippled areas) for each respective interval of water depth, water velocity, or substrate type (Orth 1980).

was measured at 0.6 of the depth using a pygmy-gurley type flow meter. Water depth was measured using a metric wading rod and substrate types were classified using the modified Wentworth Particle Size Scale (Bovee and Cochnauer 1977).

Limited water quality data were collected between June 1981 and June 1983. Analyses were performed by personnel from the Oklahoma State University Water Quality Research Laboratory for nutrient levels (phosphorus, nitrate and nitrite), dissolved oxygen, specific conductance, turbidity, non-filterable residue, total organic carbon and hydrogen ion concentration. Special analyses for pesticides, polychlorinated biphenols (PCBs) and heavy metals were conducted once in 1981 and 1983. Herbicide analysis was conducted only in June 1983 following clearcutting on Big Eagle Creek. Collections and analysis were generally conducted as outlined by the Environmental Protection Agency (1979) or the APHA standard methods (1971). A detailed description of the exact procedures followed can be found in Maughan et al. (1983).

Data Analysis

Fish population size was estimated from a program developed by Carle (1976) utilizing the Maximum Weighted Likelihood Estimator of Carle and Strub (1978). Densities were computed on a per-unit-area basis by dividing the total number of fish of a given species collected by the total area of the sampling site. Biomass of fish collected was measured, and total estimated biomass was calculated by multiplying the mean weight of a given species by the estimated population size of that species. The estimated biomass was then used to arrive at an estimated biomass per-unit-area. Fish species diversity was calculated using the formula $\overline{D} = -\Sigma P_i \log_e P_i$ in which $P_i = n_i/N$, n_i = number of individuals collected for a given taxa "i", and N = total number of individuals collected (Shannon and Weaver 1963).

Surface area was calculated for each site by season. The amount of surface area at each site for each interval of depth, velocity and substrate type was calculated by summing the areas of those segments for each respective interval of depth, velocity and substrate type (Orth 1980). Diversity for each habitat variable was calculated using the diversity formula of Shannon and Weaver (1963) where n_i was the amount of area for a given interval and N was the total area. Habitat diversity was calculated by averaging the diversity values for depth, velocity and substrate type.

_T_-tests were used to test the hypothesis that pre-treatment populations were not significantly different from post-treatment populations. Comparisons involving the _t_ statistic assumes that the populations were normally distributed and the variances of the two populations were equal. Consequently, before any comparisons were made, the sample variances were tested for equality. If the assumption of equality of variances could not be met, a _t_' statistic was calculated in order that a comparison could be made (Steel and Torrie 1980). An alpha value (P) of 0.1 or less was considered to be statistically significant.

Comparisons between pre- and post-treatment populations assume that data collected before clearcutting represent normal patterns of abundance and distribution. Because the control sites were not affected by the treatment, pre-and post-clearcutting populations should be relatively stable. Significant differences in community characteristics following clearcutting at the experimental sites represent a disruption of the normal pattern and the differences were assumed to be the result of the treatment. Gear and methods used were consistent throughout the study and biases associated with them were consistent.

CHAPTER IV

RESULTS

Several factors complicated analysis of the data. The unscheduled clearcutting within the headwaters of the Upper Little River study area eliminated the possibility of obtaining pre-logging data. The pre-logging data collected at site 2 actually represented conditions after the stream had previously been impacted by a clearcut. Delayed logging in the Little Cow Creek study area greatly reduced the impact. Harvest had not been completed by the end of the study and only slightly more than one-half of the sale had been harvested. Data collected after harvesting had been initiated was considered post-logging. The clearcut located on BEC was not typical of other clearcuts in the area. Buffer strips (streamside management zones) on other clearcuts in the area were usually less than 15 m in width and ephemeral streams within the clearcut usually had strips limited to one or two trees in width. In addition, summer water flow at the control site tended to be very low and a limited amount of data were collected. Small sample sizes increased the variance and decreased the accuracy of the estimation of the actual population mean.

Species Composition

A total of sixteen species of fish were collected during the study period from the three study areas (Table 1). Four species were

Table 1. Fish species collected during the study by site.

Species	BEC1	BEC2	LCC1	LCC2	LCC3	ULR2
Esox americanus	X	X	X	X	X	X
Erimyzon oblongus	X	X	X	X	X	X
Campostoma anomalum	X	X	X	X	X	X
Etheostoma radiosum	X	X	X	X	X	X
Ictalurus natalis		X	X	X	X	X
Lepomis cyanellus		X	X	X	X	X
Lepomis megalotis		X	X	X	X	X
Notropis fumeus		X	X	X	X	X
Notropis boops		X	X	X	X	X
Pimephales notatus			X	X	X	X
Micropterus punctulatus			X		X	
M. dolomieui						X
Semotilus atromaculatus	X	X				
Percina caprodes				X		
Noturus nocturnus						X
Labidesthes sicculus						X
Total Number of Taxa	5	10	11	11	11	13

collected at every site, although not necessarily every season. The centrarchids were almost exclusively represented by green sunfish and longear sunfish (*L. megalotis*). Smallmouth bass were collected only from ULR2 while spotted bass (*M. punctulatus*) were found only in the LCC study area. Ictalurids were represented by the yellow bullhead (*Ictalurus natalis*) and the freckled madtom (*Noturus nocturnus*). Madtoms occurred in very low densities and were collected only from the Little River. Grass pickerel (*Esox americanus*), the only native esocid in Oklahoma, were collected at every site. They were usually found in shallow water and were closely associated with emergent plants or overhanging banks. Typically only one species of darter (*Etheostoma radiosum*) was collected. One logperch (*Percina caprodes*) was collected at LCC2. Cyprinids were abundant at each site. Creek chubs (*Semotilus atromaculatus*) were collected only from BEC.

The number of taxa increased with an increase in stream order. The lowest number of taxa were collected from BEC1. The highest number of taxa, including several species which were found only at this site, were collected from ULR2.

Water Quality

Big Eagle Creek and Little Cow Creek were the only drainages where data were collected before and after clearcutting and values tended to vary between sites and seasons. Ammonia was consistently below the level of detection (0.10 mg/l) in both drainages. Nitrates, nitrites, and phosphates exhibited little variation, although changes were observed following clearcutting, particularly at Little Cow Creek.

Pesticide, herbicide, and PCB concentrations were below the limits of detection for all sites, as were a majority of the heavy metals.

Big Eagle Creek

Values for most water quality parameters (except specific conductance and total organic carbon) differed only slightly between pre-and post-logging at the control site (BEC1) (Tables 2 and 3). Total organic carbon declined significantly from a mean value of 33.15 mg/l to a mean of 2.0 mg/l after clearcutting. Although a lack of data prevented statistical analysis, conductivity appeared to decline drastically in 1982 compared to values in 1980 and 1981. Water temperature increased slightly following clearcutting. Hydrogen ion concentration remained constant throughout the study.

Pre- and post-logging water quality data at the impact site on Big Eagle Creek (BEC2) tended to be more variable than did that on BEC1 (Tables 4 and 5). An increase in water temperature following clearcutting also occurred at BEC2. PH decreased from 6.5 to 5.5 after clearcutting.

Mean nitrate and nitrite concentration increased significantly following clearcutting and phosphate concentration increased slightly. Although total organic carbon concentration was lower following clearcutting, comparison of the magnitude of change with that at BEC1 indicates that total organic carbon actually increased slightly. Mean turbidity and non-filterable residue declined following clearcutting; however, no post-rainfall data were collected after clearcutting. Pre-clearcutting data indicated that turbidity and non-filterable residues were generally much higher after a rainstorm event.

Table 2. Water quality data collected at BEC1.

Logged	Date	H_2O Temp (°C)	DO (mg/l)	Conductivity (umhos/cm)	pH
Pre	12-29-81	5.0	11.0	20	6.7
	01-06-82	9.0	*	*	6.7
	05-11-82	16.0	9.0	22	6.7
	$\bar{x}$	8.3	10.0	21	6.7
Post	01-08-83	8.5	9.4	12	6.7

* No data were collected for these parameters.

Table 3. Statistical comparisons of pre- and post-logging water quality data collected at BEC1.

Logged	Date	Turbidity (NTU)	Non-filterable Residue (mg/l)	Ammonia (mg/l)	Nitrates and Nitrites (mg/l)	Phosphate (mg/l)	Total Organic Carbon (mg/l)
Pre	12-29-81	19.0	0.88	<0.10	0.03	<0.01	36.8
	05-11-82	28.5	0.94	<0.10	0.02	<0.01	29.5
	$\bar{x}$	23.75	0.91	<0.10	0.025	<0.01	33.15
Post	01-08-83	12.0	0.89	<0.10	0.03	<0.02	2.9
	06-29-83	36.0	1.15	<0.10	0.03	<0.01	1.1
	$\bar{x}$	24.0	1.02	<0.10	0.03	<0.015	2.0
	T calc	-0.019	-0.824	1.00	-1.00	-1.00	8.286
	P value	P>0.5	P>0.4	P>0.4	P>0.4	P>0.4	P<0.02

Table 4. Water quality data collected at BEC2.

Logged	Date	H_2O Temp (°C)	DO (mg/l)	Conductivity (umhos/cm)	pH
Pre	06-01-81	17.8	10.0	20	7.0
	08-04-81	25.0	5.2	30	*
	08-07-81	22.5	5.2	30	*
	10-15-81	22.0	4.0	30	*
	12-29-81	5.0	10.5	17	6.5
	01-06-82	4.0	*	*	6.5
	05-11-82	16.0	9.0	22	6.8
	08-26-82	27.5	6.5	38	6.1
	10-23-82	14.0	8.9	31	6.3
	$\bar{x}$	17.1	7.3	27.2	6.53
Post	01-08-83	9.0	9.2	14	5.5

* No data were collected for these parameters.

Table 5. Statistical comparisons of pre- and post-logging water quality data collected at BEC2.

Logged	Date	Turbidity (NTU)	Non-filterable Residue (mg/l)	Ammonia (mg/l)	Nitrates and Nitrites (mg/l)	Phosphate (mg/l)	Total Organic Carbon (mg/l)
Pre	06-01-81	13	2.88	<0.10	0.02	<0.01	11.2
	08-04-81	15	0.63	<0.10	0.02	<0.01	11.2
	08-07-81	51	0.68	*	*	*	*
	10-15-81	80	0.45	<0.10	0.03	<0.01	20.4
	12-29-81	17	0.44	<0.10	0.03	<0.01	7.8
	05-11-82	9	7.73	<0.10	0.02	<0.01	2.9
	05-22-82	13	0.48	*	*	*	*
	07-12-82	13	0.33	*	*	*	*
	08-26-82	16	4.74	*	0.03	<0.01	32.2
	10-23-82	17	2.94	<0.10	0.01	0.02	4.1
	$\bar{x}$	24.4	2.13	<0.10	0.023	<0.011	12.83
Post	01-08-83	9	0.84	<0.10	0.03	<0.02	3.5
	06-29-83	26	1.18	<0.10	0.05	<0.01	0.0
	$\bar{x}$	17.5	1.01	<0.10	0.04	<0.015	1.75
	T calc	0.405	0.614	1.00	-2.408	-1.133	1.441
	P value	P>0.5	P>0.5	P>0.3	P<0.05	P>0.2	P>0.1

* No values were collected for these parameters.

Little Cow Creek

A comparison of pre- and post-logging water quality data at the control site on Little Cow Creek (LCC1) indicated minor increases in water temperature, phosphates and dissolved oxygen (D.O.) following clearcutting (Tables 6 and 7). Turbidity, nitrates, and nitrites remained fairly constant throughout the study. Non-filterable residues and total organic carbon concentrations declined following clearcutting.

As was observed at BEC2, water quality parameters at the impacted stations on Little Cow Creek (LCC2 and LCC3) tended to be more variable than at the control site. Water temperature, D.O., phosphates, and turbidity were all higher following clearcutting (Tables 8, 9, 10, and 11). Nitrate and nitrite concentrations at LCC2 increased significantly following clearcutting. Hydrogen ion concentration, conductivity, non-filterable residues and total organic carbon concentration declined at all three sites following clearcutting. The magnitude of the declines in total organic carbon concentration were not as great following clearcutting at LCC2 and LCC3 as was observed at the control site.

Fish Populations

Upper Little River

Site two was the only site on the Little River in which data allowed pre-and post-logging comparisons of fish populations. All parameters except mean species diversity declined following clearcutting but the declines were not statistically significant (Table 12).

Table 6. Water quality data collected at site 1, Little Cow Creek.

Logged	Date	H_2O Temp (°C)	DO (mg/l)	Conductivity (umhos/cm)	pH
Pre	06-04-81	18.0	10.9	60	6.8
	08-05-81	29.0	4.6	44	*
	08-07-81	24.0	6.9	41	*
	10-15-81	21.0	7.0	42	*
	12-28-81	5.0	10.7	25	6.8
	01-03-82	4.0	*	*	6.8
	05-11-82	16.0	8.7	33	6.8
	06-23-83	*	*	*	6.8
	08-25-82	30.0	8.3	61	6.5
	10-24-82	11.0	8.7	31	7.0
	$\overline{x}$	17.56	8.22	42.1	6.78
Post	01-07-83	9.0	9.8	20	6.3

* No values were collected for these parameters.

Table 7. Statistical comparisons of pre- and post-logging water quality data collected at LCCl.

Logged	Date	Turbidity (NTU)	Non-filterable Residue (mg/l)	Ammonia (mg/l)	Nitrates and Nitrites (mg/l)	Phosphate (mg/l)	Total Organic Carbon (mg/l)
Pre	06-04-81	19	1.23	<0.10	0.03	<0.01	13.20
	08-05-81	23	3.25	<0.10	0.01	<0.01	14.50
	08-07-81	25	4.48	*	*	*	*
	10-15-81	60	1.82	<0.10	0.05	<0.01	10.90
	12-28-81	18	1.00	<0.10	0.04	<0.01	26.90
	05-11-82	21	5.96	<0.10	0.04	<0.01	32.50
	05-22-82	41	11.03	*	*	*	*
	07-12-82	12	1.41	*	*	*	*
	08-25-82	19	3.34	*	0.04	<0.01	12.90
	10-24-82	17	3.15	<0.10	0.01	0.02	2.90
	$\bar{x}$	25.5	3.667	<0.10	0.031	0.0114	16.257
Post	01-07-83	13	1.03	<0.10	0.03	<0.02	3.75
	06-29-83	38	1.28	<0.10	0.03	0.02	2.70
	$\bar{x}$	25.5	1.155	<0.10	0.03	<0.02	3.225
	T calc	0.00	1.131	1.00	0.235	-6.017	1.713
	P value	P>0.5	P>0.2	P>0.3	P>0.5	P<0.001	P>0.1

* No values were collected for these parameters.

Table 8. Water quality data collected at site 2, Little Cow Creek.

Logged	Date	H_2O Temp (°C)	DO (mg/l)	Conductivity (umhos/cm)	pH
Pre	06-04-81	18.0	10.9	60	6.8
	08-05-81	28.5	6.8	42	*
	08-07-81	24.0	7.4	49	*
	10-15-81	21.0	7.4	40	6.7
	12-28-81	5.0	11.2	26	6.8
	01-04-82	4.0	*	*	6.8
	05-12-82	16.0	9.5	33	*8
	06-23-82	*	*	*	6.2
	08-25-82	26.5	7.8	51	6.7
	10-24-82	11.0	7.4	32	6.6
	$\bar{x}$	17.11	8.55	41.6	6.66
Post	01-07-83	10.0	9.6	20	6.5

* No values were collected for these parameters.

Table 9. Statistical comparisons of pre- and post-logging water quality data collected at LCC2.

Logged	Date	Turbidity (NTU)	Non-filterable Residue (mg/l)	Ammonia (mg/l)	Nitrates and Nitrites (mg/l)	Phosphate (mg/l)	Total Organic Carbon (mg/l)
Pre	06-04-81	19	1.24	<0.10	0.03	<0.01	11.9
	08-05-81	12	1.40	<0.10	0.02	<0.01	7.3
	08-07-81	23	3.02	*	*	*	*
	10-15-81	60	1.82	<0.10	0.04	<0.01	7.7
	12-28-81	17	0.77	<0.10	0.03	<0.01	11.9
	05-12-82	19	2.29	<0.10	0.03	<0.01	14.5
	05-22-82	30	13.14	*	*	*	*
	08-25-82	13	3.08	*	0.04	<0.01	9.0
	10-24-82	16	1.31	<0.10	0.01	0.02	4.0
	$\bar{x}$	23.2	3.12	<0.10	0.029	0.011	9.47
Post	01-07-83	13	1.97	<0.10	0.03	<0.02	5.8
	06-29-83	38	1.48	<0.10	0.04	0.05	2.5
	$\bar{x}$	25.5	1.75	<0.10	0.035	<0.035	4.15
	T calc	-0.192	0.483	1.00	-0.782	-1.564	1.957
	P value	P>0.5	P>0.5	P>0.3	P>0.5	P>0.4	P>0.1

* No values were collected for these parameters.

Table 10. Water quality data collected at site 3, Little Cow Creek.

Logged	Date	H_2O Temp (°C)	DO (mg/l)	Conductivity (umhos/cm)	pH
Pre	06-04-81	18.0	10.9	50	7.1
	08-05-81	25.5	7.8	42	*
	08-07-81	24.0	7.5	46	*
	10-15-81	21.0	6.8	40	*
	12-28-81	5.0	12.0	27	6.8
	01-04-82	4.0	*	*	6.8
	05-12-82	16.0	9.5	33	6.8
	06-23-82	*	*	*	6.7
	08-25-82	28.0	8.5	65	6.4
	10-24-82	13.0	8.9	45	6.6
	$\bar{x}$	16.06	8.99	43.5	6.74
Post	01-07-83	6.0	10.8	20	6.2

* No values were collected for these parameters.

Table 11. Statistical comparisons of pre- and post-logging water quality data collected at LCC3.

Logged	Date	Turbidity (NTU)	Non-filterable Residue (mg/l)	Ammonia (mg/l)	Nitrates and Nitrites (mg/l)	Phosphate (mg/l)	Total Organic Carbon (mg/l)
Pre	06-04-81	19	1.63	<0.10	0.03	<0.01	22.5
	08-05-81	10	1.08	<0.10	0.02	<0.01	4.9
	08-07-81	16	2.38	*	*	*	*
	10-15-81	57	5.08	<0.10	0.04	<0.01	10.3
	12-28-81	16	0.83	<0.10	0.03	<0.01	15.3
	05-12-82	19	2.55	<0.10	0.04	<0.01	2.7
	05-22-82	28	13.40	*	*	*	*
	07-12-82	12	1.04	*	*	*	*
	08-25-82	37	17.63	*	0.04	<0.01	13.4
	10-24-82	15	4.77	<0.10	0.01	0.02	6.5
	$\bar{x}$	22.9	5.039	<0.10	0.030	0.011	10.80
Post	01-07-83	13	2.42	<0.10	0.03	<0.02	6.0
	06-29-83	39	1.35	<0.10	0.03	0.05	2.5
	$\bar{x}$	26.0	1.885	<0.10	0.030	<0.035	4.25
	T calc	-0.270	0.739	1.00	0.00	-1.564	1.271
	P value	P>0.5	P>0.4	P>0.3	P>0.5	P>0.4	P>0.2

* No values were collected for these parameters.

Table 12. Pre- and post-logging fish population parameters at Upper Little River, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Diversity
Pre	Fall 81	140	172	0.423	362	403	1.216	2.70
	Winter 82	186	209	0.554	747	782	2.327	2.05
	Spring 82	213	312	0.606	1201	1375	3.916	2.67
	Summer 82	428	487	3.012	1974	2073	14.589	3.02
	Fall 82	311	824	1.086	1331	1600	5.587	2.67
	Winter 83	209	222	0.609	809	816	2.375	2.03
	Spring 83	189	192	0.562	618	624	1.857	2.52
	$\bar{x}$	239	345	0.979	1006	1096	4.552	2.53
Post	Summer 83	155	173	0.916	943	970	5.773	2.82
	Fall 83	220	222	0.724	460	486	1.599	2.91
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	188	198	0.820	701	728	3.666	2.87
	T calc	0.701	0.839	0.232	0.735	0.804	0.248	-1.264
	P value	P>0.5	P>0.4	P>0.5	P>0.4	P>0.4	P>0.5	P>0.2

* Site was frozen, no collections were taken.

Mean diversity was slightly higher after clearcutting, increasing from 2.53 to 2.87. Comparisons of data from similar seasons before and after clearcutting showed decreases in all parameters except diversity, following clearcutting (Table 13). However, only the change in mean estimated biomass was statistically significant.

Data were combined in three species groupings for further analysis. The first grouping was composed of minnow species of the families Antherinidae, Cyprinidae, and Catostomidae which typically inhabit pool or quiet water areas. The second grouping was composed of those species that normally inhabit riffle habitats. This grouping included the orangebelly darter and the stoneroller (C. anomalum). The last group was composed of all other species, each typically characterized by a larger body size and occupying a higher position within the food chain. These species were most often found in pools in association with the species comprising the minnow category.

Pre- and post-logging comparisons of the minnow group indicated that following clearcutting all parameters increased except mean biomass and mean estimated population size (Table 14). Relative abundance increased from 26.2% before harvest to 45.5% after harvest. The riffle and larger species categories declined in all population parameters (Tables 15 and 16, respectively). The riffle species declined in mean relative abundance from 45.2% to 18.8% but the larger species declined only slightly in abundance.

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Changes in fish populations following clearcutting were not as pronounced in LCC as they were on the ULR study area. All population

Table 13. Pre- and post-logging fish population parameters at Upper Little River during similar seasons, 1982-1983.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g)			Diversity
					Actual	Estimated	/m^2	
Pre	Summer 82	428	487	3.012	1974	2073	14.589	3.03
	Fall 82	311	824	1.086	1331	1600	5.587	2.67
	$\bar{x}$	370	656	2.049	1653	1836	10.088	2.85
Post	Summer 83	155	173	0.916	943	970	5.733	2.82
	Fall 83	220	222	0.724	460	486	1.599	2.91
	$\bar{x}$	188	198	0.820	701	728	3.666	2.87
	T calc	2.720	2.690	1.270	2.365	3.274	1.297	-0.097
	P value	$P>0.1$	$P>0.1$	$P>0.3$	$P>0.1$	$P<0.1$	$P>0.3$	$P>0.5$

Table 14. Pre- and post-logging minnow population parameters at Upper Little River, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	33	43	0.099	41	51	0.155	23.6
	Winter 82	5	5	0.015	8	8	0.023	2.7
	Spring 82	57	120	0.160	260	384	1.093	26.8
	Summer 82	134	179	0.942	148	207	1.458	31.3
	Fall 82	228	740	0.797	131	399	1.393	73.3
	Winter 83	14	14	0.040	10	10	0.030	6.7
	Spring 83	36	36	0.107	72	74	0.220	19.0
	$\bar{x}$	72	162	0.309	96	162	0.625	26.2
Post	Summer 83	67	68	0.392	98	102	0.603	43.2
	Fall 83	105	105	0.345	72	75	0.247	47.7
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	86	86	0.368	85	88	0.425	45.5
	T calc	-0.224	0.390	-0.060	0.155	0.580	0.403	-1.116
	P value	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5	P>0.3

* Site was frozen, no collections were taken.

Table 15. Pre- and post-logging population parameters for riffle species at Upper Little River, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	65	82	0.196	54	68	0.203	46.4
	Winter 82	114	135	0.339	59	70	0.208	61.3
	Spring 82	99	134	0.281	110	146	0.417	46.5
	Summer 82	143	154	1.006	101	112	0.792	33.4
	Fall 82	27	28	0.094	15	16	0.054	8.7
	Winter 83	147	157	0.428	124	130	0.379	70.3
	Spring 83	94	97	0.279	64	66	0.197	49.7
	$\bar{x}$	98	112	0.375	75	87	0.321	45.2
Post	Summer 83	11	11	0.065	7	7	0.041	7.1
	Fall 83	67	69	0.221	41	42	0.138	30.4
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	39	40	0.143	24	24	0.090	18.8
	T calc	1.761	1.974	1.037	1.766	1.819	1.289	1.690
	P value	P>0.1	P<0.1	P>0.3	P>0.1	P>0.1	P>0.2	P>0.1

* Site was frozen, no collections were taken.

Table 16. Pre- and post-logging population parameters for larger fish species at Upper Little River, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density ($\#/m^2$)	Biomass (g) Actual	Estimated	$/m^2$	Relative Abundance (%)
Pre	Fall 81	42	47	0.126	267	284	0.856	30.0
	Winter 82	65	67	0.194	680	704	2.096	35.0
	Spring 82	57	58	0.162	831	845	2.406	26.8
	Summer 82	114	117	0.801	1720	1747	12.294	26.6
	Fall 82	46	46	0.160	1183	1183	4.131	14.8
	Winter 83	37	37	0.108	669	669	1.947	17.7
	Spring 83	41	41	0.122	471	471	1.400	21.7
	$\bar{x}$	57	108	0.239	832	834	3.590	24.6
Post	Summer 83	52	52	0.307	804	804	4.752	33.6
	Fall 83	33	33	0.108	363	363	1.196	15.0
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	42	42	0.208	583	583	2.974	24.3
	T calc	0.735	0.720	0.166	0.667	0.669	0.202	0.057
	P value	P>0.4	P>0.4	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5

* Site was frozen, no collections were taken.

parameters at the control site increased except for mean density and mean estimated biomass per square meter (Table 17). The species groupings tended to be stable with slight increases in the minnow and riffle groups and a slight decline in the larger species category (Tables 18, 19, and 20, respectively).

Both of the impacted sites on Little Cow Creek exhibited similar trends after clearcutting. At LCC2, all population parameters declined (Table 21). Population parameters of minnow species declined slightly (Table 22) as did most of those of riffle species. However, mean relative abundance of riffle species increased from 58.9% to 71.3% (Table 23). The population structure of larger species exhibited the greatest changes. All population parameters declined with statistically significant declines observed for mean number of individuals collected, estimated population size and density (Table 24). Mean relative abundance decreased from 34.6% to 21.3%.

Declines in the average values of all population parameters also occurred at LCC3 after clearcutting (Table 25). Population parameters of minnow species declined except for mean density and relative abundance (Table 26). Mean relative abundance increased from 14.8% to 28.9%. Riffle species declined in all population parameters. Mean relative abundance of riffle species declined from 47.6% to 36.5% (Table 27). A statistically significant decline occurred for mean biomass and estimated biomass per square meter. The larger species also showed a similar decline for all population parameters (Table 28). Mean relative abundance decreased from 34.6% to 25.6%.

Table 17. Pre- and post-logging fish population parameters at Little Cow Creek 1 (control), 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Diversity
Pre	Fall 81	93	107	0.705	722	741	5.616	2.84
	Winter 82	63	63	0.462	408	408	2.898	2.47
	Spring 82	75	77	0.567	424	456	3.444	2.10
	Summer 82	87	87	2.472	251	281	7.977	2.79
	Fall 82	1	1	0.022	1	1	0.022	0.00
	$\bar{x}$	64	67	0.846	361	377	4.010	2.04
Post	Winter 83	111	125	0.764	687	708	4.877	2.62
	Spring 83	65	73	0.468	753	759	5.459	2.07
	Summer 83	37	43	0.294	394	414	3.286	2.21
	Fall 83	23	23	0.227	17	18	0.178	1.59
	Winter 84	85	104	0.639	396	401	3.013	2.89
	$\bar{x}$	64	74	0.478	449	460	3.363	2.28
	T calc	-0.017	-0.254	0.845	-0.501	-0.462	0.399	-0.417
	P value	P>0.5	P>0.5	P>0.4	P>0.5	P>0.5	P>0.5	P>0.5

Table 18. Pre- and post-logging minnow population parameters at Little Cow Creek 1 (control), 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	31	43	0.235	47	60	0.451	33.3
	Winter 82	19	19	0.139	69	69	0.506	30.2
	Spring 82	12	12	0.091	35	35	0.265	16.0
	Summer 82	37	37	1.052	16	16	0.450	42.5
	Fall 82	0	0	0.000	0	0	0.000	0.0
	$\bar{x}$	20	22	0.303	33	33	0.334	24.4
Post	Winter 83	46	56	0.317	17	25	0.171	41.4
	Spring 83	6	6	0.043	26	26	0.187	9.2
	Summer 83	1	1	0.008	*	*	*	2.7
	Fall 83	10	10	0.099	8	9	0.089	43.5
	Winter 84	47	65	0.353	35	39	0.296	55.3
	$\bar{x}$	22	28	0.164	22	25	0.186	30.4
	T calc	-0.182	-0.343	0.683	0.817	0.712	1.328	-0.474
	P value	P>0.5	P>0.5	P>0.5	P>0.4	P>0.4	P>0.2	P>0.5

* Fish was too small to obtain a weight in the field.

Table 19. Pre- and post-logging population parameters for riffle species at Little Cow Creek 1 (control), 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density ($\#/m^2$)	Biomass (g) Actual	Estimated	$/m^2$	Relative Abundance (%)
Pre	Fall 81	24	25	0.182	24	25	0.191	25.8
	Winter 82	20	20	0.146	26	26	0.195	31.7
	Spring 82	48	48	0.363	102	102	0.772	61.5
	Summer 82	26	26	0.738	22	23	0.645	29.9
	Fall 82	1	1	0.022	1	1	0.022	100.0
	$\bar{x}$	24	24	0.290	35	36	0.365	49.8
Post	Winter 83	43	46	0.296	39	43	0.296	38.7
	Spring 83	43	51	0.309	36	42	0.301	66.2
	Summer 83	18	24	0.143	58	78	0.620	48.6
	Fall 83	12	12	0.119	8	8	0.079	52.2
	Winter 84	20	21	0.150	25	26	0.192	23.5
	$\bar{x}$	27	31	0.203	33	39	0.299	45.8
	T calc	-0.341	-0.640	0.662	-0.099	-0.181	0.384	0.250
	P value	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5

Table 20. Pre- and post-logging population parameters for larger species at Little Cow Creek 1 (control), 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g)			Relative Abundance (%)
					Actual	Estimated	/m^2	
Pre	Fall 81	38	39	0.288	651	656	4.973	40.9
	Winter 82	24	24	0.176	312	312	2.288	38.1
	Spring 82	14	15	0.106	287	317	2.396	18.7
	Summer 82	15	15	0.427	213	242	6.870	17.2
	Fall 82	0	0	0.000	0	0	0.000	0.0
	$\bar{x}$	18	19	0.199	292	305	3.305	23.0
Post	Winter 83	19	20	0.131	630	639	4.400	17.1
	Spring 83	16	16	0.116	691	691	4.971	24.6
	Summer 83	17	17	0.136	334	334	2.651	46.0
	Fall 83	1	1	0.010	1	1	0.010	4.4
	Winter 84	18	18	0.137	336	336	2.527	21.2
	$\bar{x}$	14	14	0.106	398	400	2.912	22.6
	T calc	0.564	0.579	1.203	-0.652	-0.582	0.267	0.032
	P value	P>0.5	P>0.5	P>0.2	P>0.5	P>0.5	P>0.5	P>0.5

Table 21. Pre- and post-logging fish population parameters at Little Cow Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Diversity
Pre	Fall 81	90	106	0.599	999	1020	6.793	2.52
	Winter 82	85	98	0.616	672	708	5.127	2.23
	Spring 82	108	112	0.766	785	842	5.970	2.09
	Summer 82	*	*	*	*	*	*	*
	Fall 82	*	*	*	*	*	*	*
	$\bar{x}$	94	105	0.066	819	857	5.963	2.28
Post	Winter 83	79	87	0.524	427	439	2.907	2.09
	Spring 83	94	102	0.613	912	952	6.210	2.24
	Summer 83	72	77	0.633	116	126	1.110	1.21
	Fall 83	15	15	0.126	13	13	0.109	0.72
	Winter 84	50	53	0.363	491	496	3.601	2.15
	$\bar{x}$	62	67	0.452	392	405	2.787	1.68
	T calc	1.702	1.880	1.582	1.919	1.973	2.185	1.435
	P value	P>0.1	P>0.1	P>0.1	P>0.1	P<0.1	P<0.1	P>0.2

* Site was dry.

Table 22. Pre- and post-logging minnow population parameters at Little Cow Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	8	8	0.053	26	26	0.173	8.9
	Winter 82	5	5	0.036	37	37	0.267	5.9
	Spring 82	5	5	0.035	39	39	0.304	4.6
	Summer 82	*	*	*	*	*	*	*
	Fall 82	*	*	*	*	*	*	*
	$\bar{x}$	6	6	0.041	34	34	0.248	6.5
Post	Winter 83	9	9	0.060	18	18	0.119	11.4
	Spring 83	7	7	0.046	88	88	0.573	7.4
	Summer 83	5	5	0.044	2	2	0.013	6.9
	Fall 83	0	0	0.000	0	0	0.000	0.0
	Winter 84	3	3	0.021	1	1	0.007	6.0
	$\bar{x}$	5	5	0.034	22	22	0.142	6.4
	T calc	0.544	0.544	0.481	0.546	0.546	0.708	0.042
	P value	P>0.2	P>0.2	P>0.5	P>0.5	P>0.5	P>0.5	P>0.5

* Site was dry.

Table 23. Pre- and post-logging population parameters for riffle species at Little Cow Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Estimated	/m^2	Relative Abundance (%)
Pre	Fall 81	41	57	0.273	101	122	0.814	45.6
	Winter 82	46	58	0.333	52	65	0.470	54.1
	Spring 82	82	84	0.581	197	203	1.439	75.9
	Summer 82	*	*	*	*	*	*	*
	Fall 82	*	*	*	*	*	*	*
	$\bar{x}$	56	66	0.396	116	130	0.908	58.5
Post	Winter 83	51	59	0.338	66	77	0.508	64.6
	Spring 83	57	64	0.372	69	76	0.494	60.6
	Summer 83	50	55	0.440	107	118	1.035	69.4
	Fall 83	15	15	0.126	13	13	0.109	100.0
	Winter 84	31	34	0.225	41	46	0.332	62.0
	$\bar{x}$	41	43	0.300	59	66	0.496	71.3
	T calc	1.107	1.445	0.942	1.529	1.719	1.418	-1.085
	P value	P>0.3	P>0.1	P>0.3	P>0.1	P>0.1	P>0.2	P>0.3

* Site was dry.

Table 24. Pre- and post-logging population parameters for larger fish species at Little Cow Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	41	41	0.273	872	872	5.804	45.6
	Winter 82	33	34	0.239	556	578	4.183	38.8
	Spring 82	21	23	0.148	549	600	4.253	19.4
	Summer 82	*	*	*	*	*	*	*
	Fall 82	*	*	*	*	*	*	*
	$\bar{x}$	32	33	0.220	659	683	4.747	34.6
Post	Winter 83	17	17	0.112	342	342	2.267	21.5
	Spring 83	29	30	0.188	754	788	5.135	30.8
	Summer 83	16	16	0.141	7	7	0.062	22.2
	Fall 83	0	0	0.000	0	0	0.000	0.0
	Winter 84	16	16	0.116	449	449	3.263	32.0
	$\bar{x}$	16	16	0.111	310	317	2.145	21.3
	T calc	2.151	2.277	2.195	1.698	1.755	1.912	1.390
	P value	P<0.1	P<0.1	P<0.1	P>0.1	P>0.1	P>0.1	P>0.2

* Site was dry.

Table 25. Pre- and post-logging fish population parameters at Little Cow Creek 3, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m²)	Biomass (g) Actual	Estimated	/m²	Diversity
Pre	Fall 81	166	217	0.741	1154	1366	6.098	2.84
	Winter 82	62	67	0.306	796	822	4.050	2.15
	Spring 82	124	145	0.628	1011	1163	5.893	2.22
	Summer 82	498	1029	1.474	4408	5051	14.938	2.56
	Fall 82	193	210	0.495	1835	1853	4.754	2.24
	$\bar{x}$	209	334	0.729	1841	2051	7.129	2.40
Post	Winter 83	112	119	0.526	380	386	1.814	2.49
	Spring 83	100	107	0.482	757	762	3.668	2.36
	Summer 83	99	102	0.362	1418	1422	5.194	2.49
	Fall 83	83	89	0.535	369	384	2.474	2.80
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	98	104	0.476	561	738	2.288	2.54
	T calc	1.451	1.303	1.239	1.606	1.463	1.638	-0.776
	P value	P>0.2	P>0.2	P>0.2	P>0.1	P>0.1	P>0.1	P>0.4

* Site was frozen, no collections were taken.

Table 26. Pre- and post-logging minnow population parameters at Little Cow Creek 3, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	62	66	0.276	150	160	0.714	37.4
	Winter 82	0	0	0.000	0	0	0.000	0.0
	Spring 82	4	4	0.030	69	69	0.350	3.2
	Summer 82	51	72	0.151	176	239	0.708	10.2
	Fall 82	45	53	0.115	73	80	0.205	23.3
	$\bar{x}$	32	39	0.112	94	110	0.395	14.8
Post	Winter 83	64	64	0.301	23	23	0.106	57.4
	Spring 83	23	23	0.111	14	14	0.070	23.0
	Summer 83	9	9	0.033	76	76	0.278	9.1
	Fall 83	19	23	0.122	41	55	0.357	22.9
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	29	30	0.142	39	42	0.203	28.0
	T calc	0.204	0.454	-0.390	1.464	1.398	1.132	-1.107
	P value	P>0.5	P>0.5	P>0.5	P>0.1	P>0.2	P>0.2	P>0.3

* Site was frozen, no collections were taken.

Table 27. Pre- and post-logging population parameters for riffle species at Little Cow Creek 3, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	40	77	0.178	47	98	0.436	24.1
	Winter 82	33	36	0.162	91	95	0.468	53.2
	Spring 82	78	87	0.395	133	144	0.732	62.9
	Summer 82	256	737	0.757	133	327	0.966	51.4
	Fall 82	89	90	0.288	52	53	0.136	46.1
	$\bar{x}$	99	205	0.356	91	143	0.548	47.6
Post	Winter 83	35	42	0.164	34	40	0.190	31.2
	Spring 83	50	55	0.241	42	46	0.224	50.0
	Summer 83	32	35	0.117	62	64	0.235	32.3
	Fall 83	27	27	0.174	30	30	0.193	32.5
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	36	40	0.174	42	45	0.210	36.5
	T calc	1.544	1.242	1.630	2.228	2.017	2.384	1.324
	P value	P>0.1	P>0.2	P>0.1	P<0.1	P>0.1	P<0.1	P>0.2

* Site was frozen, no collections were taken.

Table 28. Pre- and post-logging population parameters for larger fish species at Little Cow Creek 3, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	64	74	0.286	957	1109	4.950	38.6
	Winter 82	29	31	0.143	705	727	3.582	46.8
	Spring 82	42	54	0.212	809	950	4.812	33.9
	Summer 82	177	202	0.524	4096	4481	13.255	35.5
	Fall 82	89	40	0.099	1706	1715	4.400	20.2
	$\bar{x}$	70	80	0.253	1655	1796	6.200	34.6
Post	Winter 83	10	10	0.046	322	322	1.512	8.9
	Spring 83	16	16	0.078	695	695	3.346	16.0
	Summer 83	51	51	0.186	1272	1272	4.645	51.5
	Fall 83	22	22	0.141	294	294	1.894	26.5
	Winter 84	*	*	*	*	*	*	*
	$\bar{x}$	25	25	0.113	646	646	2.849	25.7
	T calc	1.422	1.524	1.569	1.350	1.423	1.585	1.928
	P value	P>0.1	P>0.1	P>0.1	P>0.2	P>0.1	P>0.1	P>0.3

* Site was frozen.

Big Eagle Creek

The effects of clearcutting on fish populations in Big Eagle Creek were less definitive than it was on other streams, because wide seasonal fluctuations at BEC1 (the control site) limited the strength of the comparisons. The fish population at BEC1 normally only consisted of three species, two which were almost always collected only in the riffle habitats. Average population parameters at BEC1 were all slightly lower following clearcutting (Table 29).

At BEC2, the average population parameters were all lower, except estimated population size, following clearcutting (Table 30). The increase in estimated population size was due to a large increase in the minnow population.

Population parameters of minnow species generally increased following clearcutting (Table 31). Relative abundance increased from an average of 32.8% to 41.5%. In contrast, the larger species category declined following clearcutting (Table 32); average relative abundance dropped from 20.8% to 11.2%. Riffle species also showed a slight decline in all population parameters following clearcutting (Table 33). However, mean relative abundance increased slightly from 46.4% to 46.6%. Compared to the decline exhibited by these species at BEC1, riffle species may have increased slightly following clearcutting.

Habitat Characteristics

Upper Little River

The effects of clearcutting on habitat parameters tended to be quite variable, especially during winter and spring when water levels

Table 29. Pre- and post-logging fish population parameters at Big Eagle Creek 1 (control), 1982-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Diversity
Pre	Winter 82	36	36	0.197	56	56	0.300	1.22
	Spring 82	15	15	0.084	131	131	0.730	1.40
	Summer 82	*	*	*	*	*	*	*
	Fall 82	*	*	*	*	*	*	*
	$\bar{x}$	26	26	0.140	93	93	0.515	1.31
Post	Winter 83	11	11	0.064	70	70	0.040	1.28
	Spring 83	12	12	0.066	94	94	0.520	0.98
	Summer 83	*	*	*	*	*	*	*
	Fall 83	*	*	*	*	*	*	*
	Winter 84	5	5	0.042	47	47	0.399	1.00
	$\bar{x}$	9	9	0.058	70	70	0.440	1.58
	T calc	1.943	1.943	1.445	0.700	0.700	0.562	1.462
	P value	P>0.1	P>0.1	P>0.2	P>0.5	P>0.5	P>0.5	P>0.2

* Site was dry.

Table 30. Pre- and post-logging fish population parameters at Big Eagle Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Diversity
Pre	Fall 81	217	246	0.962	904	984	4.360	2.58
	Winter 82	123	123	0.544	340	340	1.500	2.68
	Spring 82	80	97	0.360	354	406	1.830	1.69
	Summer 82	127	127	1.451	1672	1673	19.110	2.66
	Fall 82	179	194	1.956	600	607	6.640	2.28
	$\bar{x}$	145	157	1.055	774	802	6.688	2.38
Post	Winter 83	25	30	0.108	141	160	0.690	1.55
	Spring 83	44	44	0.185	498	498	2.090	2.29
	Summer 83	182	505	1.265	1302	1412	9.810	2.53
	Fall 83	259	292	2.085	361	384	3.093	1.73
	Winter 84	108	196	0.509	114	151	0.711	2.45
	$\bar{x}$	124	213	0.830	483	521	3.279	2.11
	T calc	0.434	0.696	0.471	0.886	0.832	0.932	0.993
	P value	P>0.5	P>0.5	P>0.5	P>0.4	P>0.4	P>0.3	P>0.3

Table 31. Pre- and post-logging minnow population parameters at Big Eagle Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m^2)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m^2	Relative Abundance (%)
Pre	Fall 81	116	135	0.515	208	240	1.066	53.5
	Winter 82	60	60	0.265	103	103	0.455	48.8
	Spring 82	8	9	0.036	19	22	0.097	10.0
	Summer 82	12	12	0.137	55	55	0.629	9.4
	Fall 82	76	91	0.831	43	50	0.550	42.5
	$\bar{x}$	54.4	61.4	0.357	86	94	0.559	32.8
Post	Winter 83	2	2	0.008	1	1	0.004	8.0
	Spring 83	10	10	0.042	68	68	0.286	22.7
	Summer 83	55	378	0.383	21	131	0.907	30.2
	Fall 83	202	235	1.625	208	230	1.854	78.0
	Winter 84	74	162	0.348	47	80	0.377	68.5
	$\bar{x}$	68.6	157	0.481	69	102	0.686	41.5
	T calc	-0.344	-1.280	-0.378	0.336	-0.144	-0.349	-0.522
	P value	P>0.5	P>0.2	P>0.5	P>0.5	P>0.5	P>0.5	P>0.4

Table 32. Pre- and post-logging population parameters for larger fish species at Big Eagle Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density (#/m²)	Biomass (g) Actual	Biomass (g) Estimated	Biomass (g) /m²	Relative Abundance (%)
Pre	Fall 81	48	57	0.213	660	707	3.133	22.1
	Winter 82	13	13	0.057	122	122	0.539	10.6
	Spring 82	9	9	0.042	253	253	1.138	11.2
	Summer 82	53	53	0.605	1579	1579	18.040	41.7
	Fall 82	33	33	0.361	511	511	5.585	18.4
	$\bar{x}$	31	33	0.256	625	634	5.687	20.9
Post	Winter 83	1	1	0.004	101	101	0.436	4.0
	Spring 83	9	9	0.038	385	385	1.615	20.4
	Summer 83	39	39	0.272	1193	1193	8.294	21.4
	Fall 83	12	12	0.096	134	134	1.378	4.6
	Winter 84	6	6	0.029	29	29	0.137	5.6
	$\bar{x}$	13	13	0.088	368	368	2.372	11.2
	T calc	1.602	1.646	1.452	0.767	0.794	0.934	1.388
	P value	P>0.1	P>0.1	P>0.1	P>0.4	P>0.4	P>0.3	P>0.2

Table 33. Pre- and post-logging population parameters for riffle species at Big Eagle Creek 2, 1981-1984.

Logged	Season	Number Collected	Estimated Population	Density ($\#/m^2$)	Biomass (g) Actual	Estimated	$/m^2$	Relative Abundance (%)
Pre	Fall 81	53	54	0.235	36	37	0.164	24.4
	Winter 82	50	50	0.221	115	115	0.510	40.6
	Spring 82	63	79	0.284	82	131	0.591	78.8
	Summer 82	62	62	0.708	38	38	0.443	48.8
	Fall 82	70	70	0.765	46	46	0.503	38.1
	$\bar{x}$	60	63	0.443	64	74	0.442	46.4
Post	Winter 83	22	27	0.094	39	59	0.253	88.0
	Spring 83	25	25	0.105	45	45	0.188	56.8
	Summer 83	88	88	0.611	88	88	0.608	49.3
	Fall 83	39	39	0.314	19	19	0.161	15.1
	Winter 84	27	27	0.127	38	38	0.056	25.0
	$\bar{x}$	40	41	0.250	46	51	0.253	46.6
	T calc	1.514	1.668	1.233	0.932	0.992	1.582	-0.019
	P value	P>0.1	P>0.1	P>0.2	P>0.3	P>0.3	P>0.1	P>0.5

and discharge were high. Average values for substrate diversity tended to be slightly higher following clearcutting (Table 34) but values for all other parameters were lower. A comparison of pre-and post-logging values utilizing similar seasons indicated that habitat diversity and depth diversity increased after clearcutting (Table 35). Average values for velocity diversity did not change and those for discharge and substrate diversity were lower.

Little Cow Creek

At the control site, values for all the habitat parameters were much higher following clearcutting (Table 36). Downstream, at LCC2, the values tended to be more variable (Table 37). Average values for discharge, and substrate diversity were slightly higher following clearcutting while habitat diversity, depth diversity, and velocity diversity were slightly lower. Little Cow Creek 3 exhibited identical trends with increases in discharge and substrate diversity following clearcutting (Table 38). Average values for habitat, depth and velocity diversities declined after timber harvest.

Big Eagle Creek

Non-significant declines were observed for habitat variables at the control site (Table 39). Average values for discharge and velocity diversity increased following clearcutting on BEC2 (Table 40). Habitat, depth, and substrate diversities exhibited slight declines following clearcutting with the largest decline occurring in substrate diversity.

Table 34. Habitat parameters collected at Upper Little River, 1981-1984.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Fall 1981	-	1.846	2.215	1.478	-
	Winter 1982	0.151	1.508	2.326	1.389	0.807
	Spring 1982	0.220	1.697	2.535	1.433	1.212
	Summer 1982	0.000	0.947	1.464	1.377	0.000
	Fall 1982	0.008	1.258	1.894	1.740	0.141
	Winter 1983	0.130	1.643	2.451	1.730	0.747
	Spring 1983	0.179	1.325	2.050	1.083	0.842
	$\bar{x}$	0.115	1.456	2.134	1.461	0.625
Post	Summer 1983	0.000	1.006	1.785	1.235	0.000
	Fall 1983	0.004	1.350	2.082	1.825	0.141
	Winter 1984	*	*	*	*	*
	$\bar{x}$	0.002	1.178	1.933	1.530	0.071
	T calc	3.036	1.150	0.712	-0.326	1.583
	P value	$P<0.05$	$P>0.2$	$P>0.4$	$P>0.5$	$P>0.1$

- Equipment malfunction.
* Site was frozen, no measurements were taken.

Table 35. Habitat parameters collected at Upper Little River during similar seasons, 1982-1983.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Summer 1982	0.000	0.947	1.464	1.377	0.000
	Fall 1982	0.008	1.258	1.894	1.740	0.141
	$\bar{x}$	0.004	1.103	1.679	1.558	0.071
Post	Summer 1983	0.000	1.006	1.785	1.235	0.000
	Fall 1983	0.004	1.350	2.082	1.825	0.141
	$\bar{x}$	0.002	1.178	1.933	1.530	0.071
	T calc	0.447	-0.325	-0.973	0.082	0.000
	P value	P>0.5	P>0.5	P>0.4	P>0.5	P>0.5

Table 36. Habitat parameters collected at Little Cow Creek 1, 1981-1984.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Fall 1981	0.066	1.644	2.829	1.574	0.529
	Winter 1982	0.028	1.564	2.819	1.470	0.402
	Spring 1982	0.015	1.250	2.623	1.126	0.000
	Summer 1982	0.000	0.000	0.000	0.000	0.000
	Fall 1982	0.000	0.247	0.000	0.742	0.000
	$\overline{x}$	0.022	0.941	1.654	0.982	0.186
Post	Winter 1983	0.077	1.745	2.763	1.862	0.610
	Spring 1983	0.077	1.566	2.767	0.845	0.845
	Summer 1983	0.001	1.357	2.296	1.776	0.000
	Fall 1983	0.001	1.286	2.450	1.408	0.000
	Winter 1984	0.028	1.557	2.321	2.022	0.327
	$\overline{x}$	0.037	1.502	2.520	1.582	0.356
	T calc	-0.720	-1.590	-1.264	-1.690	-0.837
	P value	P>0.4	P>0.1	P>0.2	P>0.1	P>0.4

Table 37. Habitat parameters collected at Little Cow Creek 2, 1981-1984.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Fall 1981	0.038	1.423	1.840	1.025	1.404
	Winter 1982	0.074	1.379	2.002	0.961	1.174
	Spring 1982	0.027	1.116	1.884	0.893	0.570
	Summer 1982	*	*	*	*	*
	Fall 1982	*	*	*	*	*
	$\bar{x}$	0.046	1.306	1.909	0.960	1.049
Post	Winter 1983	0.145	1.666	2.136	1.248	1.613
	Spring 1983	0.068	1.416	2.119	0.999	1.129
	Summer 1983	0.003	0.849	1.584	0.965	0.000
	Fall 1983	0.004	0.986	1.486	1.473	0.000
	Winter 1984	0.018	1.094	1.844	0.855	0.584
	$\bar{x}$	0.048	0.111	1.834	1.108	0.665
	T calc	-0.040	0.491	0.412	-0.981	0.836
	P value	P>0.5	P>0.5	P>0.5	P>0.3	P>0.4

* Site was dry, no measurements were taken.

Table 38. Habitat parameters collected at Little Cow Creek 3, 1981-1984.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Fall 1981	0.127	1.980	2.191	1.796	1.954
	Winter 1982	0.125	1.994	2.262	1.840	1.881
	Spring 1982	0.028	1.606	2.008	1.720	1.089
	Summer 1982	0.000	1.249	1.929	1.642	0.000
	Fall 1982	0.000	1.194	2.155	1.428	0.000
	$\bar{x}$	0.056	1.605	2.109	1.685	0.540
Post	Winter 1983	0.104	1.816	1.808	2.286	0.747
	Spring 1983	0.075	1.727	2.075	1.690	0.842
	Summer 1983	0.082	1.245	1.849	1.886	0.000
	Fall 1983	0.006	1.358	2.137	1.937	0.000
	Winter 1984	*	*	*	*	*
	$\bar{x}$	0.067	1.536	1.967	1.950	0.397
	T calc	-0.285	0.297	1.421	-1.939	0.405
	P value	$P>0.5$	$P>0.5$	$P>0.1$	$P>0.05$	$P>0.5$

* Site was dry, no measurements were taken.

Table 39. Habitat parameters collected at Big Eagle Creek 1, 1981-1984.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Winter 1982	0.086	1.891	2.387	1.844	1.442
	Spring 1982	0.045	1.710	2.312	1.600	1.217
	Summer 1982	*	*	*	*	*
	Fall 1982	*	*	*	*	*
	$\bar{x}$	0.066	1.800	2.350	1.722	1.329
Post	Winter 1983	0.098	1.801	2.260	1.782	1.378
	Spring 1983	0.064	1.822	2.350	1.899	1.216
	Summer 1983	*	*	*	*	*
	Fall 1983	*	*	*	*	*
	Winter 1984	0.011	0.927	1.033	1.048	0.699
	$\bar{x}$	0.058	1.518	1.881	1.576	1.098
	T calc	0.218	0.727	0.854	0.409	0.835
	P value	$P>0.5$	$P>0.5$	$P>0.4$	$P>0.5$	$P>0.4$

* Site was dry, no measurements were taken.

Table 40. Habitat parameters collected at Big Eagle Creek 2, 1981-1984.

Logged	Season	Discharge (m^3/s)	Habitat Diversity	Depth Diversity	Substrate Diversity	Velocity Diversity
Pre	Fall 1981	0.034	1.984	3.031	1.890	1.030
	Winter 1982	0.028	1.822	2.937	1.524	1.004
	Spring 1982	0.049	1.718	3.062	1.105	0.968
	Summer 1982	0.000	1.323	2.482	1.487	0.000
	Fall 1982	0.000	1.502	2.535	1.971	0.000
	$\bar{x}$	0.022	1.668	2.809	1.596	0.600
Post	Winter 1983	0.090	2.008	2.790	1.654	1.572
	Spring 1983	0.090	1.779	2.909	1.008	1.420
	Summer 1983	0.007	1.267	2.390	1.254	0.156
	Fall 1983	0.005	1.434	2.765	1.538	0.000
	Winter 1984	0.011	1.604	2.951	1.495	0.366
	$\bar{x}$	0.041	1.618	2.761	1.390	0.703
	T calc	-0.820	0.287	0.303	1.059	-0.248
	P value	P>0.4	P>0.5	P>0.5	P>0.3	P>0.5

CHAPTER V

DISCUSSION

Water Quality

The effects of clearcutting on stream water quality (particularly erosion, sedimentation and instream temperature changes) have been widely documented (Gibbons and Salo 1973) but changes in water quality following clearcutting have varied widely from one drainage to another and appear to depend on the geochemical morphology of the basins (Kopperdahl et al. 1970, Burns 1972). The inconsistencies between drainages encountered in this study appear somewhat similar to those found in the previously cited studies and may be related to the amount of upstream watershed that had been harvested.

In California, Kopperdahl et al. (1971) and Burns (1972) failed to find increases in concentrations of phosphates or nitrates after logging. However, Likens et al. (1970) reported a significant increase in nitrate concentrations following forest clearing in New Hampshire. The latter authors attributed the change in nitrates to an alteration of the nitrogen cycle as a result of a decrease in demand for these nutrients from the cleared watershed. Similar results were also found after clearcutting in Oregon (Brown et al. 1973).

Nitrates and nitrites, phosphates, hydrogen ion and total organic carbon concentrations changed consistently in my study following clearcutting. Mean phosphate, nitrate, nitrite and total organic carbon concentrations increased on both Big Eagle and Little Cow Creeks. One possible explanation of the changes in these factors was increased input of nutrients within the streams, presumably the result of a decrease in uptake of these nutrients. However, little research has been conducted on the cycling of these nutrients in the systems studied and this hypothesis cannot be verified.

Changes in hydrogen ion concentration, as measured by pH, have also been reported following clearcutting (Eschner and Larmoyeux 1963, Likens et al. 1973). Changes in pH are particularly important because many other water chemistry parameters, as well as stream biota, are affected by changes in pH (Wiener et al. 1984). In West Virginia, increases in pH (decreased hydrogen ion concentration) as well as alkalinity and specific conductance were observed in the stream impacted by clearcutting (Eschner and Larmoyeux 1963). Eschner and Larmoyeux (1963) attributed the increase in pH and alkalinity to an increase in the release of bases from litter and other organic matter. The changes persisted for several years.

Likens et al. (1970) found contrasting results and detected a five-fold increase in hydrogen ion concentration following clearcutting in New Hampshire. The decline in pH was attributed to an increase in nitrification leading to the production of nitric acid. The decline in pH observed in BEC and LCC following clearcutting could have resulted from a similar process since the impacted sites in both drainages exhibited increases in nitrate and nitrite concentrations.

Conductivity declined after clearcutting in both the experimental and control sites. These data seem to indicate that the changes were not associated with clearcutting. However, changes in conductivity have been reported after clearcutting especially when a change in pH occurred (Eschner and Larmoyeux 1963, Likens et al. 1970). Variable responses in conductivity following clearcutting have been reported in other studies (Likens et al. 1970).

Changes in stream temperature after clearcutting were extremely important in streams supporting cold water fauna but may not be as critical in warm water streams (Gibbons and Salo 1973). The minor changes in water temperature observed in BEC and LCC probably reflected climatic changes rather than changes induced by clearcutting. Both streams studied were protected by large buffer strips and buffer strips have previously been shown to drastically reduce the influence of clearcutting on instream temperature changes (Eschner and Larmoyeux 1963, Gray and Edington 1969, Brown 1970, Brown and Krygier 1970, Swift and Messer 1971, Burns 1973, Lee and Samuel 1976, Boschung and O'Neil 1981).

Sufficient pre- and post-logging data were not collected to allow formulation of specific conclusions concerning turbidity and non-filterable residues. Pre-clearcutting data included several collections taken immediately after rainstorm events whereas such conditions were absent from post-logging samples. Generally, areas of extensive road construction tended to have higher levels of turbidity and non-filterable residues (Maughan et al. 1983) but no build up of sediment or logging slash was detected in the streams. If such build up occurred, it was flushed from the system during periods of high discharge during spring and fall flooding.

Concentrations of herbicides and pesticides were also low throughout the study. The chemicals are not normally applied to harvested areas until the clearcuts have been replanted and the young pines have become established. Application of these chemicals have been found to affect stream communities (Likens et al. 1970).

Habitat Characteristics

Clearcutting also appeared to have an effect on the physical characteristics of the stream. Discharge at ULR2, all three sites on LCC, and BEC1 declined after clearcutting. The data appear to contradict a number of studies where pre- and post-logging comparisons of stream flows and water yield revealed increased discharge, stream flows and water yields following timber removal (Hoover 1944, Lieberman and Hoover 1948, Rowe 1963, Rothacher 1965, 1970, 1971, Hornbeck 1973, Patric 1973). Annual increases in stream flow following clearcutting ranged from 0.6 inches (Reinhart et al. 1963) to 13.5 inches (Hornbeck et al. 1970) per acre.

Increases in stream flow, discharge, and water yield after clearcutting are generally reported to result from a decline in water uptake by forest vegetation and increased runoff from the cleared portions of the watershed. Thus, the amount of vegetation removed can determine the magnitude of changes in stream flow and water yield following clearcutting (Eschner and Larmoyeux 1963, Rothacher 1970, 1971).

Annual weather conditions can also affect water yield and stream flow responses following clearcutting. Yearly variation in the timing, form and amount of precipitation may cause the actual treatment response to deviate considerably from the norm (Satterlund 1972). Rainfall in 1983 (post-logging collections), for northern McCurtain and southern

Le Flore counties, was approximately 27.2 cm less than the annual 1982 (pre-logging collections) rainfall. The decline in rainfall was probably responsible for the reduced discharge at ULR2, LCC, and BEC1. Post-logging collections at ULR2 consisted solely of collections taken during the drier summer months of 1983 and may not accurately reflect changes in discharge following clearcutting.

Additionally, only a small percentage of the vegetation on LCC was removed, with the remaining vegetation essentially serving as a buffer strip over 100 m in width. Timber harvest was also extended over several seasons, resulting in a reduction in the amount of runoff the stream received at any one time. Because the clearcut had not been completely cleared of trees, the water yield was near normal and discharge probably reflected only the decline in annual rainfall.

Mean discharge following clearcutting at BEC2 was almost double pre-harvest values whereas discharge at the control site declined after clearcutting. Timber harvest was apparently responsible for the increase in discharge following clearcutting on BEC, presumably the result of increased water yield and decreased water uptake from the cleared area. Discharge at BEC1 reflected only the decline in annual rainfall.

Clearcutting may also have led to changes in stream flow periodicity, as evidenced by changes in the diversity of water velocities at LCC and BEC. Values collected at the control sites represent normal patterns of stream flow and should also occur at the impact sites if clearcutting did not effect flow periodicity. The control sites on LCC and BEC showed higher velocity diversity after clearcutting than the impact sites on these streams. In these cases clearcutting appeared to have altered the seasonality of the stream flows.

Water depth and substrate diversities in the three streams did not change consistently in relation to clearcutting. A reduction in habitat diversity has been reported following clearcutting (Karr and Schlosser 1978, Erman and Mahoney 1983) and is largely the result of sediment deposition which leads to simplification of substrate complexity (Karr and Schlosser 1978). The substrate types of the stream segments under study were usually composed of rubble and boulder but some gravel occurred in the riffle habitats and detritus (leaf litter) comprised a small percentage of the substrate types found in pools. Removal of vegetation from the watershed probably reduced the amount of material that entered the stream and partially accounted for the reduction in substrate diversity following clearcutting at ULR2 and BEC2. Substrate diversity also declined at BEC1, indicating that clearcutting was not the only factor responsible for the reduction in substrate diversity. Increases in substrate diversity after partial clearcutting in LCC were also believed to be unrelated to clearcutting.

Increased uniformity of water depth and velocity has also been reported to lead to a reduction in habitat diversity, especially in intermittent streams and channelized segments (Gorman and Karr 1978). Seasonal fluctuations in water levels could also have altered depth and velocity diversity and, to some extent, substrate diversity. Changes in discharge, flow periodicity, and water yield associated with clearcutting could also have induced changes in water depth and velocity. In spite of the data from previous studies, the inconsistencies observed in depth diversity in this study following clearcutting indicated that factors other than those associated with logging activity were probably responsible for the changes observed.

Fish Populations

Clearcutting induced habitat alterations, primarily the result of increased siltation and changes in water chemistry, have been related to changes in fish populations. Aitkin (1936) detected a shift in species composition from clear-water forms such as smallmouth bass to forms more tolerant of turbidity. Moring (1981) found that habitat alterations resulted in a significant decline in fish numbers after clearcutting in Oregon. Reproductive success has also been reported to decline due to increased siltation following clearcutting (Gangmark and Bakkala 1960, Cordone and Kelley 1961, Shapley and Bishop 1965).

Declines in fish biomass, number of individuals collected, and density after clearcutting at LCC, BEC, and ULR2 were possibly related to the habitat modifications since the structure of biotic communities is highly correlated with habitat availability and complexity (MacArthur 1964, Pianka 1969, Lewis 1969, Gorman and Karr 1978, Oswood and Barber 1982). Moring and Lantz (1975) and Moring (1981) concluded that increased sedimentation and stream flow were partly responsible for declines in fish population size. Theoretically, a reduction in the amount of available habitat or the quality of the habitat when populations are at carrying capacity should lead to competitive exclusion of some individuals (Hardin 1960). However, such cause and effect relationships could not be verified in this study.

Changes in water quality may also have affected the amount of habitat available to the fish. Moring and Lantz (1975) and Moring (1981) also concluded that declining fish populations after clearcutting were the result of increased stream temperature and decreased dissolved oxygen levels. Increased discharge after clearcutting, along with a decline in pH, possibly could have resulted in habitat modifications in LCC, BEC and ULR which in turn negatively effected stream fish populations.

Fish typically have a wide range of tolerances to pH. However, some species, such as darters and cyprinids, are extremely sensitive to low pH (Rahel and Magnuson 1983, Weiner et al. 1984). In Wisconsin, Wiener (1983) found that acidic lakes (pH range, 5.1-6.0) contained fewer species of fish than more alkaline lakes. No darters (Etheostoma sp.) were found in the acidic lakes whereas the circumneutral waters (pH range, 6.7-7.5) contained a much larger, diverse fauna including several darter species. No darters and few cyprinids were collected from waters with a pH of 6.2 or lower (Rahel and Magnuson 1983). Hydrogen ion concentration below the clearcut areas varied from 6.5 to 5.5 and low pH could possibly be partially responsible for the decline in the number of fish collected.

The pH changes associated with clearcutting may have affected some of the minnow species present. Large increases in minnow populations after clearcutting at ULR and BEC2 were primarily due to an increase in abundance of creek chubsuckers (Erimyzon oblongus) and big-eye shiners (Notropis boops). At BEC2 these two species accounted for 83% of the minnow population before clearcutting and 94% after clearcutting. Creek chubsuckers and big-eye shiners accounted for 57% before clearcutting on

ULR and 68% after clearcutting. The percent composition of all other minnow species declined after clearcutting. No information on pH tolerances of creek chubsuckers or big-eye shiners was available in the literature.

Habitat modifications may also have impacted the benthic macroinvertebrate population, resulting in disruption of the food web and changes in fish species composition. Adams (1983) found that benthic macroinvertebrates, following clearcutting at these same sites, declined in total density, species diversity and number of taxa. The declining benthic populations could have led to a decline in the forage base of the insectivorous species (primarily percids and some cyprinids). These species in turn serve as important forage for larger piscivorous-insectivorous fish. Most of the fish collected were benthic-insectivore or insectivore-piscivores (Miller and Robison 1973, Pflieger 1975, Jones 1981). Adult grass pickerel was the only species reported to feed almost exclusively on fish (Ming 1968). Schlosser (1982) reported a shift in species composition from benthic insectivores and piscivore-insectivores to generalized insectivores, ominvores and herbivore-detritivores following removal of riperian vegetation and channelization. The decline in relative abundance of orangebelly darters, larger fish and certain minnow species seen in this study may have resulted from changes in the benthic or forage populations.

Failure of logging to affect certain food sources may have allowed stonerollers, bigeye shiners, and creek chubsuckers to increase in abundance following clearcutting. Stonerollers feed primarily on diatoms and other forms of algae (Kraatz 1923). Diatoms, filamentous algae and silt comprised over 50% of the gut contents of creek chubsuckers in North Carolina (Gatz 1979), and bigeye shiners are reported to feed primarily on insects flying above the water surface (Trautman 1981). These species would be the least affected by a decline in benthic populations. More detailed studies would be required to adequately evaluate the effects of clearcutting on the food resources of these fish populations.

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