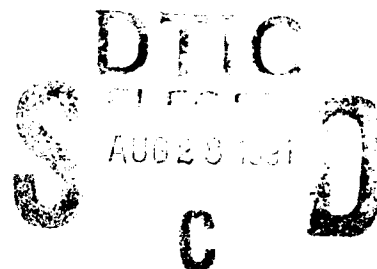


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**Compilation of 1990 Annual Reports
of the Navy ELF Communications System
Ecological Monitoring Program**

Volume 3 of 3 Volumes:
Tabs G-I

AD-A239 870



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Contract No. N00039-88-C-0065
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FOREWORD

During 1990, the Navy continued to conduct long-term studies monitoring for possible effects to biota from operation of their ELF Communications System. The Space and Naval Warfare Systems Command (SPAWAR) funded these studies through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management of monitoring studies performed by university subcontractors.

The reports compiled (Tabs A-H) in this three-volume document present the progress and findings of ongoing studies located near the Naval Radio Transmitting Facility--Republic, Michigan. At least four scientific peers reviewed each report. Study investigators considered the peer critiques prior to providing a final copy of their annual report to IITRI. These annual reports are compiled here without further change or editing by SPAWAR or IITRI. As is done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Past compilations and other program documents are listed under Tab I.

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:
BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1989-1990
SUBCONTRACT NUMBER: E06549-88-C-011

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Report Number: NRR/IR-90/16

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ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:
BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1989-1990

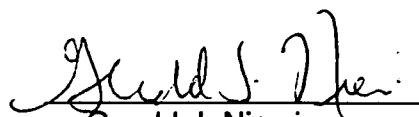
SUBCONTRACT NUMBER: E06549-88-C-011

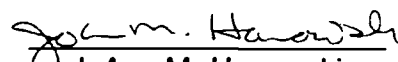
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SUMMARY

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our monitoring program has included bird censuses in both states over a five month period from May to September, 1986-1989. Additional data were collected in August-September 1984 and in June 1985, in both states. Bird censuses were terminated in Wisconsin after 1989 but are continuing in Michigan.

No consistent patterns have yet emerged to demonstrate that birds are more or less abundant on treatment relative to control segments in either state after effects of habitat are accounted for. Further, few significant differences have been found at the community or species level; differences in one season or year are not always repeated in subsequent years or seasons. Most differences that exist between treatment and control transects can be attributed to habitat differences rather than to electromagnetic field differences.

ABSTRACT

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our monitoring program has included bird censuses over a five month period from May to September (1986-1989). Additional data were collected in both states in August-September of 1984 and June of 1985. Research in Wisconsin was completed in 1989 but has continued in Michigan. A final report summarizing work in Wisconsin has been completed (Hanowski et al. in press).

Here we summarize results of our 1990 research activities in Michigan. The Michigan transmitter began 150 amp tuning and testing intermittently in the first part of May 1989. On 14 May, the transmitter began continuous 150 amp operation for 16 hrs/day on weekdays and all day on weekends. On 7 October 1989, the Michigan transmitter began continuous operation at full power. We therefore consider 1990 to be the first full impact year.

Overall, bird abundance and species diversity were highest and approximately the same during May, June, and July. Species diversity was significantly greater on control areas during June and September, but no other differences in community level parameters were significant. Considerable annual variation in numbers of individuals and species was noted. Particularly abundant species (all seasons included) included the

Ovenbird, Black-capped Chickadee, and Nashville Warbler. Other common species included Red-eyed Vireo, White-throated Sparrow, Golden-crowned Kinglet, Hermit Thrush, and Black-throated Green Warbler. *The most abundant species present on treatment and control segments varied among seasons. Among "abundant" species (>1 individual observed/500 m segment), five of 24 comparisons (21%; all seasons combined) revealed a significant difference between treatment and control segments in Michigan; two indicated a greater abundance on control segments.*

Previous analyses of vegetation on Michigan study sites (Blake et al. 1988) revealed differences between treatment and control plots. The difference most likely to influence bird populations was distribution of coniferous and deciduous habitats. Treatment segments supported more coniferous and lowland habitats than did control segments. *It is important to note that habitat differences that exist between treatment and control areas will not affect our analysis of antenna effects. The Michigan study is designed as a before-and-after experiment; we can compare changes in bird abundance over time on treatment segments and on control segments. If electromagnetic fields produced by antenna operation affect bird distribution patterns, we expect to detect a change in patterns of abundance between treatment and control areas. Such changes, if they occur, would be independent of already present habitat differences.*

Seventeen of 114 comparisons (15%) of common species (based on prominence values, see page 7) between treatment and control segments (all segments) in Michigan were significant. *Values were higher on control segments in 10 cases. Few species were consistently and significantly more abundant on either treatment or control segments among seasons within a year or within seasons among years. Differences between treatment and control segments were most likely due to habitat differences.*

Species were classified into guilds on the basis of foraging behavior and preferred breeding habitat. Few significant differences in abundance of birds within different guilds were found between treatment and control segments. Differences were most consistent for habitat categories (e.g., birds that prefer deciduous forest were more abundant on control segments in 4 of 5 months), providing further evidence that habitat differences were responsible for many of the observed differences in bird distribution patterns between treatment and control segments.

INTRODUCTION

Effects of extremely low frequency (ELF) electromagnetic (EM) fields on most aspects of a bird species' life history are poorly understood (National Academy of Sciences 1977; Lee et al. 1979; other references in Hanowski et al. 1987). Several investigators have studied effects of transmission lines on structure and composition of bird communities; most have analyzed combined effects of habitat alteration and EM fields (Anderson et al. 1977; Anderson 1979; Dawson and Gates 1979; Meyers and Provost 1979; Stapleton and Kiviat 1979; Bell 1980; Bramble et al. 1984; Niemi and Hanowski 1984). Others have focused on effects of the right-of-way (ROW) edge (Chasko and Gates 1982; Kroodsma 1982), collision with lines (Beaulaurier et al. 1982), and audible noise generated by a transmission line (Lee and Griffith 1978). We are unaware, however, of any previous investigations that have attempted to separate effects of EM fields on bird species and communities from effects due to habitat changes along the ROW.

This investigation was designed to isolate effects of EM fields produced by ELF antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our study has encompassed spring migration (May), early (June) and late (July) breeding, and early (August) and late (September) fall migration. Potential effects of the ELF antenna on birds may vary among seasons. During migration, birds may be present on

study areas for only brief periods. Conversely, breeding birds remain on territories longer (1-3 months), increasing their exposure to EM fields.

Two potential approaches may be used to assess effects of the ELF antenna on bird communities. These are to (1) compare the affected area (treatment) with a similar control area; or (2) conduct a before-and-after study on both control and treatment plots. Because our study was initiated in Michigan before the antenna began operation, we are conducting a before-and-after investigation in that state. By following changes in bird numbers over time on areas affected by the antenna and on areas unaffected, we can separate any effects of the antenna from effects of more regional variables (e.g., annual variation in rainfall) and from differences in vegetation structure between control and treatment areas. The Michigan transmitter began 150 amp tuning and testing intermittently in the first part of May 1989. On the 14th of May, the transmitter began continuous 150 amp operation for 16 hrs/day on weekdays and all day on weekends. On October 7th, the Michigan transmitter began continuous operation at full power. Therefore, 1990 represents the first full impact year.

Research in Wisconsin was completed in 1989 and a final report was completed and submitted (Hanowski et al. in press). The following summarizes the Wisconsin part of our study. The antenna has been operating in Wisconsin periodically since 1969 and on a near continuous basis for the past several years. No pre-impact data on bird populations were available and we could not assume that the antenna system had not already affected bird communities in Wisconsin. Consequently, we could not compare transect segments based on similarities in bird species communities. We could, however, account for habitat differences in our analyses. By incorporating analyses of habitat, we could more clearly isolate potential effects of the EM fields produced by the antenna. To

this end, we conducted a detailed habitat assessment in 1986 and 1987 to document habitat differences and similarities between control and treatment segments in Wisconsin. Our rationale for using habitat structure to compare areas is based on the premise that birds select breeding areas (and, to a lesser extent, migration stop-over points) largely on the basis of vegetation structure (Lack 1933; Hilden 1965; James 1971; Cody 1985). Areas of similar vegetation should also have similar bird communities.

We have found no consistent patterns demonstrating that birds were either attracted to or repelled by EM fields produced by the antenna. Most differences in abundance between control and treatment areas could be attributed to habitat differences. Presence of the antenna right-of-way (ROW) may have affected distribution of species in the study areas; edge species were more abundant in treatment areas. Some differences in abundance could be explained (statistically, by analysis of covariance) by habitat; others could not be explained or could not be tested statistically. However, numbers of species more abundant on control or more abundant on treatment segments were similar (20 and 17, respectively). Because we have no "before" data from Wisconsin sites, we cannot exclude the possibility that these differences between control and treatment areas existed before the ROW was cut; such comparisons, however, are possible for Michigan.

In the following we summarize our research activities in Michigan for 1990, our seventh year of participation in the ELF ecological monitoring program. This is the fifth year in which censuses were conducted during all seasons (above) in Michigan. Unless otherwise noted, results presented below refer to Michigan only.

EXPERIMENTAL DESIGN

The experimental design for this project has been described previously in detail (Hanowski et al. 1987). Briefly, we sample birds along a series of line-transects (Järvinen and Väisänen 1975) located adjacent to (treatment) or away from (control) the ELF antenna. A discussion of the rationale for this procedure is in Appendix 1.

STUDY AREAS

Study areas were the same as in previous years and are described in Appendix 1. Several 500-m transect segments in Michigan have been partially logged since this study started (Appendix 1, Table A2). However, the Michigan Department of Natural Resources has agreed to delay most additional logging along the Michigan study transects until 1992. Analyses of annual variation in bird community composition revealed that segments logged over <20% of total length showed no greater difference between years than did unlogged sites. Segments that were logged over all or most of their length showed significantly greater differences in bird species composition between years than did unlogged segments. Consequently, our analyses of bird distribution patterns between years omit segments logged over more than 20% of their length.

METHODS

Detailed methods employed in the investigation have been described previously (Hanowski et al. 1987; see also Hanowski et al. in press) and are repeated in Appendix 1. Here we only review the main points. Methods specific to the Wisconsin study (e.g., habitat sampling) are described in Hanowski et al. (in press).

BIRD CENSUSES

We censused birds using a line-transect method (e.g., Järvinen and Väisänen 1975). Each 500 m segment (40 control and 40 treatment) was censused during early May (spring migration and arrival of breeding residents), June (early breeding), July (late breeding), August (early fall migration), and September (late fall migration). Censuses were conducted from approximately one half hour before to approximately 4.5 hours after sunrise on days with little wind (<15 km/hr) and little or no precipitation.

We randomly assigned censuses of control and treatment transects (eight 500 m segments/transect) to each of two observers, with the restriction that each observer census the same number of control and treatment segments. Control and treatment transects were censused simultaneously by the two observers.

Eight transect segments were censused by each observer daily. Each observer walked at a rate of 30 min/500 m segment and recorded the following information for each bird that was observed (by sight or sound) within 100 m of the segment center line: (1) species; (2) sex, when possible; (3) behavior (e.g., singing or calling); and (4) location on the segment. We classified each species by (1) nesting area, (2) food or foraging type, (3) breeding habitat preference, and (4) migration strategy (Appendix 2), using published sources (e.g., Martin et al. 1951; Bent 1963, 1964; Green and Niemi 1978; Terres 1982; AOU 1983; Blake and Karr 1984) and personal observations. Previous analyses (Blake et al. 1988) indicated that differences between treatment and control segments were most likely to occur among groups defined on the basis of foraging behavior and breeding habitat. Consequently, we used those guilds in analyses of the effects of the ELF antenna during 1990.

VEGETATION

Methods for sampling vegetation are described in Appendix 1. Habitat categories used in Michigan are in Appendix 3. Vegetation was sampled at 21 points (every 25 m) along each 500 m transect segment. Detailed results of our habitat analyses were presented in Blake et al. (1988) and are not repeated here.

STATISTICAL ANALYSES

COMMUNITY PARAMETERS AND ABUNDANT SPECIES

We used the same criteria to select variables for parametric statistical analysis that we identified in 1985 (Niemi and Hanowski 1986): (1) those species with a mean of more than one observation per 500 m segment ("abundant species") in control or treatment areas of either state in any season; (2) mean number of species observed in a 500 m segment in control or treatment areas of either state and during each season; and (3) mean number of individuals observed in a 500 m segment in control or treatment areas of either state and during each season.

We used one-way analysis-of-variance (ANOVA; Sokal and Rohlf 1981) to test for differences between control and treatment segments within a season. Annual differences were examined by season for number of species and individuals using a two-way ANOVA. Because some segments were affected by logging after the initial census in 1985, we excluded logged segments (>20% logged) in analyses of annual variation.

Variables used in parametric statistical tests were examined for normality of residuals (Wilk-Shapiro test; skewness and kurtosis) and homogeneity of variance (Bartlett's test) prior to statistical analyses (Sokal and Rohlf 1981). Variables were transformed where necessary (e.g., logarithmic, square root) to reduce skewness,

kurtosis, and heterogeneity of variances. Nonparametric tests (Kruskal-Wallis test) were used for variables that did not meet assumptions, even after transformation.

COMMON SPECIES

A second group of less abundant species ("common species") was chosen based on frequency of occurrence. These species had to be present on at least six segments during a season with the restriction that they occur on at least five control or five treatment segments (e.g., a species was not included if it occurred on three control and three treatment segments).

A prominence value was calculated for each species using the formula:

$$PV = D * F^{0.5},$$

where D = number of individuals observed and F = the relative frequency of species occurrence on treatment or control segments. Prominence values were calculated for control and treatment segments separately and differences were tested with a goodness of fit G-test or binomial test (Sokal and Rohlf 1981). The prominence value weights both the frequency of occurrence and number of individuals (Beals 1960; Blake 1982) and thus is preferable to using either total number of individuals observed or number of segments on which a species was observed to test for differences between control and treatment areas. Differences between these methods were more fully explored in a previous report (Hanowski et al. 1987). Briefly, fewer significant differences are found using prominence values than when comparisons are based on individuals but more differences are found when frequency of occurrence only is used.

PROBABILITY VALUES

To simplify and condense the results section, we eliminated all probability (P) values from the text. Any difference stated in this section was significant to at least the P < 0.05 level.

RESULTS

SPECIES RICHNESS AND ABUNDANCE OF INDIVIDUALS

Total number of species and individuals observed varied among seasons on control and treatment transects (Tables 1, 2). Number of observations for all species are in Appendix 4. Total abundance was highest and approximately equal during May, June, and July, but dropped substantially during August and September (Table 1). Bird abundance and species diversity were higher on control segments during each month, but differences were significant only for species richness in June and September (Table 2). No significant differences in mean number of individuals observed per segment were noted in any month.

Considerable annual variation in abundance of individuals and species was noted (Table 2). Abundance has tended to decline during this study (see also Figs. 1,2,4 in Discussion), perhaps reflecting the series of droughts that have affected much of the region (see Blake et al. in press). Treatment effects have been noted for individuals during May and for species during June, July, and September (Table 2). The treatment effect was particularly weak during September, however, and confounded by a weak interaction between year and treatment. Overall, annual variation in abundance and species richness has been considerably greater than variation associated with treatments.

Table 1. Total numbers of individuals and species observed on treatment (T) and control (C) transects in Michigan, 1985-1990. A combined species total for treatment and control segments is in parentheses.

		1985		1986		1987		1988		1989		1990	
		T	C	T	C	T	C	T	C	T	C	T	C
May:													
individuals		949	1210	775	888	815	939	570	607	847	858		
species		54	(76)	50	(67)	53	(66)	44	(60)	65	(76)	65	
June:													
individuals	1629	1098	1169	1131	1162	1061	1014	983	1020	877	880		
species	70	60	(74)	71	(81)	70	(89)	70	(83)	66	(81)	71	
July:													
individuals		938	978	1136	1258	891	907	994	1039	772	818		
species		59	(75)	68	(81)	69	(83)	63	(77)	65	(75)	54	
August:													
individuals		380	478	682	610	564	469	791	551	323	353		
species		53	(61)	59	(68)	50	(66)	62	(69)	38	(52)	45	
September:													
individuals		402	627	634	501	469	574	505	435	389	489		
species		36	(55)	46	(55)	46	(60)	48	(60)	43	(56)	44	

Table 2. Mean observations in a 500m segment on control (C) and treatment (T) segments in Michigan, 1985-90; significance of one-way ANOVAs between treatment and control segments is shown for each year. For two-way ANOVAs, T=treatment effect, Y=year effect, and I=interaction. Two-way ANOVAs were calculated with logged segments excluded.

Month	1985			1986			1987			1988			1989			1990			ANOVA		
	T	C		T	C		T	C		T	C		T	C		T	C		T	Y	I
May:																					
Individuals	23.7 **	30.3		19.4	22.2		20.4 *	23.5		14.3	15.2		21.2	21.4		21.2	21.4		**	***	
species	9.7 **	12.9		8.1 **	10.8		9.5	11.0		7.7	8.2		9.9	11.3		9.9	11.3		***	***	
June:																					
Individuals	40.8 **	33.3		28.3	29.1		26.5	25.4		24.6	25.5		21.9	22.0		21.9	22.0		**	***	*
species	14.2	14.0		12.5	12.9		12.4	13.1		11.7	12.9		10.4 *	12.1		10.4 *	12.1		..	***	
July:																					
Individuals	23.5	24.5		28.4	31.5		22.1	22.7		24.9	26.0		19.3	20.4		19.3	20.4		..	***	
species	9.6	10.4		11.8	14.4		11.1	11.0		10.8	11.8		9.7	9.7		9.7	9.7		..	***	
August:																					
Individuals	9.6	12.0		17.1	15.3		14.1	11.7		19.8	13.8		8.1	8.8		8.1	8.8		..	***	
species	4.6	5.2		7.3	6.7		6.1	5.8		7.7	6.5		4.0	4.5		4.0	4.5		..	***	
September:																					
Individuals	10.1 *	15.7		15.9	12.5		11.7	14.4		12.6	10.9		9.7	12.2		9.7	12.2		.	.	.
species	4.0	5.6		5.4	5.1		5.0	5.6		5.0	4.7		4.7	6.0		4.7	6.0		.	.	.

* P < 0.05; ** P < 0.01; *** P < 0.001

DISTRIBUTION OF ABUNDANT SPECIES

The White-throated Sparrow and Nashville Warbler were the most abundant species on treatment and the Nashville Warbler was the most abundant species on control segments during spring migration (May; Appendix 4). Seven species were recorded with an average abundance of at least one bird per segment (treatment or control) in May, but only Black-throated Green Warblers showed a significant difference between controls and treatments (more abundant on controls; Table 3).

The Ovenbird was the most abundant species in June on both control and treatment segments (Appendix 4). Chestnut-sided Warblers and White-throated Sparrows were more abundant on treatment segments but no other differences (6 species tested) were significant during June (Table 3).

Abundant species during July (late breeding) included the Nashville Warbler and Ovenbird on treatment segments and Red-eyed Vireos and Ovenbirds on control segments (Appendix 4). The Nashville Warbler was more abundant on treatment segments in July (Table 3), but no other abundant species (out of 7 tested) showed a significant difference between treatment and control segments.

Relatively few birds were observed during August (Table 1). The Black-capped Chickadee was the only abundant species (Appendix 4) and abundance did not differ between treatment and control segments (Table 3).

Bird communities during late fall migration (September) were dominated by Black-capped Chickadees; Blue Jays and Red-eyed Vireos also were abundant (Appendix 4). Red-eyed Vireos were significantly more abundant on control segments (Table 3), but the other two abundant species did not differ in distribution between treatment and control segments.

Table 3. Mean number of individuals per segment for abundant species (those with an average of at least one individual per treatment or control segment) that showed a significant difference (one-way ANOVA) in abundance between treatment (T) and control (C) segments in Michigan in 1990.

Species	T		C
<u>MAY</u> ¹			
Black-throated Green Warbler	0.6	**	1.4
<u>JUNE</u> ²			
Chestnut-sided Warbler	1.3	*	0.8
White-throated Sparrow	1.3	*	0.4
<u>JULY</u> ³			
Nashville Warbler	1.8	*	1.1
<u>AUGUST</u> ⁴			
<u>SEPTEMBER</u> ⁵			
Red-eyed Vireo	0.7	**	1.3

¹ Species tested: 7

² Species tested: 6

³ Species tested: 7

⁴ Species tested: 1

⁵ Species tested: 3

* $P < 0.05$; ** $P < 0.01$

DISTRIBUTION PATTERNS OF COMMON SPECIES

Abundances of common species (as indexed by prominence values) differed between treatment and control transects in 17 of 114 comparisons (15%) during 1990 in Michigan (Table 4). In 10 cases, prominence values were higher on control than on treatment segments. Chestnut-sided Warblers were more common (higher prominence value) on treatment segments in both May and July and Yellow-bellied Sapsuckers were more abundant on control segments during July and August. In contrast, Red-breasted Nuthatches were more common on treatment segments in July but on controls in September. No other species showed a significant difference in more than one season.

Only two of 32 species tested (6%) showed a significant difference in distribution during June, the peak period of breeding (Table 4), no more than expected based on chance alone. In contrast, 4 of 15 species (27%) showed a significant difference during August, after most breeding activity was completed.

GUILD COMPOSITION

Few significant differences (4 of 25 tests [16%]) between treatment and control segments existed in abundance of members of different foraging guilds (Table 5). Differences in abundance were not significant in more than one season for any foraging guild. Differences were more pronounced among habitat guilds (7 of 30 tests [23%] significant; Table 5). Birds preferring deciduous forest habitats were more common on control segments during 4 of 5 months (May excepted). Birds preferring early successional habitats were more abundant on treatment segments during June, July, and September.

Table 4. Prominence values (see text) for species showing significant differences (G-test) between treatment (T) and control (C) segments in Michigan in 1990.

Species	T		C
<u>MAY</u> ¹			
Brown Creeper	0.8	*	7.6
Hermit Thrush	22.6	**	8.4
Chestnut-sided Warbler	5.0	*	0.4
Song Sparrow	13.0	***	0.8
Red-winged Blackbird	0.4	***	10.7
<u>JUNE</u> ²			
Great Crested Flycatcher	1.6	*	9.3
Red-breasted Nuthatch	10.0	*	2.8
<u>JULY</u> ³			
Yellow-bellied Sapsucker	1.3	*	9.3
Least Flycatcher	0.5	***	13.4
Chestnut-sided Warbler	1.7	**	3.1
Rose-breasted Grosbeak	1.4	*	8.1
<u>AUGUST</u> ⁴			
Yellow-bellied Sapsucker	0.8	*	6.6
Blue Jay	1.4	***	19.5
American Robin	12.6	**	2.3
Indigo Bunting	0.3	*	5.8
<u>SEPTEMBER</u> ⁵			
Red-breasted Nuthatch	3.8	*	13.5
White-throated Sparrow	10.3	**	1.1

¹ Species tested: 25

² Species tested: 32

³ Species tested: 26

⁴ Species tested: 15

⁵ Species tested: 16

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 5. Mean number of individuals in foraging and habitat guilds that showed a significant difference (one-way ANOVA) between control (C) and treatment (T) in Michigan in 1990.

Guild	Month	T		C
<u>FORAGING GUILDS</u>				
Foliage insects	September	4.1	*	6.2
Ground invertebrates	August	1.4	*	0.7
Ground invertebrates & Seeds	September	0.7	*	0.3
Flycatchers	September	0.1	*	0.2
<u>HABITAT GUILDS</u>				
Deciduous forest	June	7.8	*	9.4
	July	5.5	*	8.4
	August	2.5	*	4.0
	September	4.9	*	6.6
Early successional	June	3.8	*	1.8
	July	2.7	*	1.3
	September	0.8	*	0.1

* $P < 0.05$

DISCUSSION

SPECIES DISTRIBUTION AND ABUNDANCE PATTERNS

No consistent patterns have yet emerged during this study (1985-1990) to demonstrate that distribution patterns of birds, in either state, are affected by electromagnetic fields produced by the ELF antenna (Hanowski et al. in press, this report). Few significant differences in abundance between treatment and control segments have been found at the community or species level; differences in one season or year are not always repeated in subsequent years or seasons. Differences between treatment and control segments were most noticeable in Michigan during May, both for species (Fig. 1) and individuals (Fig. 2). Apart from May, significant differences in abundance within a single year have been noted twice for number of species (June and September 1990) and twice for number of individuals (June 1985, September 1986). Overall treatment effects (all years combined) in Michigan are more pronounced for number of species than for individuals; more species per segment typically are recorded on control segments than on treatment segments (see Table 2, Figs. 1-2).

The Michigan facility was operated well below full strength in 1987 and half of 1988 (15 amperes, 8 hr/day, weekdays, starting June 1 1987 through 2 July 1988) and at 75 amperes (8 hr/day, weekdays) for the remainder of 1988 (Fig. 3). It was operated at 150 amperes for 16-24 hr/day during most of the 1989 sampling period and during all of 1990. There has been, however, little noticeable change in bird populations on treatment segments relative to those on control segments. Populations of many species have declined in abundance during this study (Fig. 4) but declines have occurred on both treatment and control segments, often in concert. Further, major declines occurred before the antenna began operation in 1988. Finally, no consistent pattern is yet evident to

Figure 1. Mean number of species recorded per 500 m on treatment and control segments.

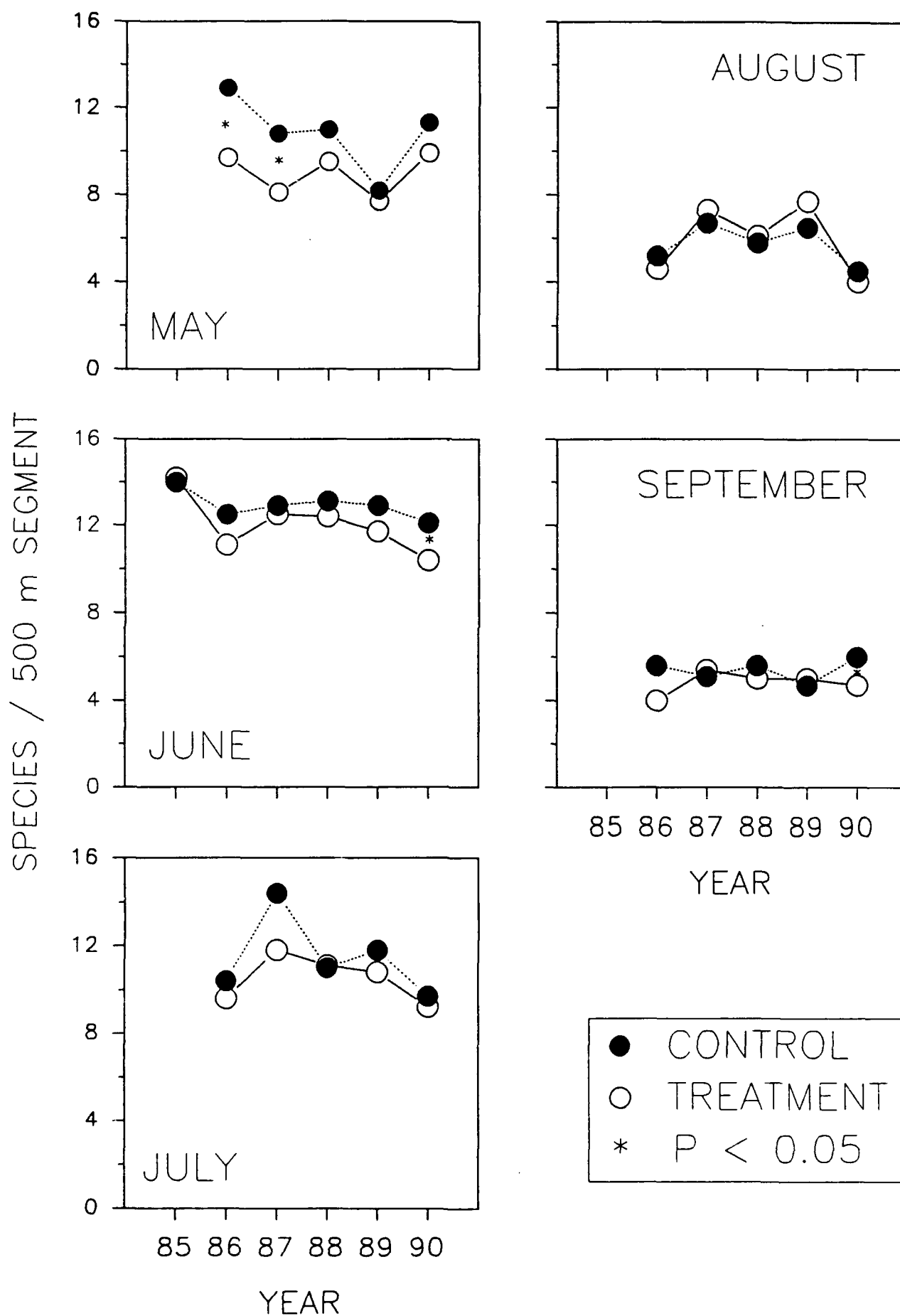
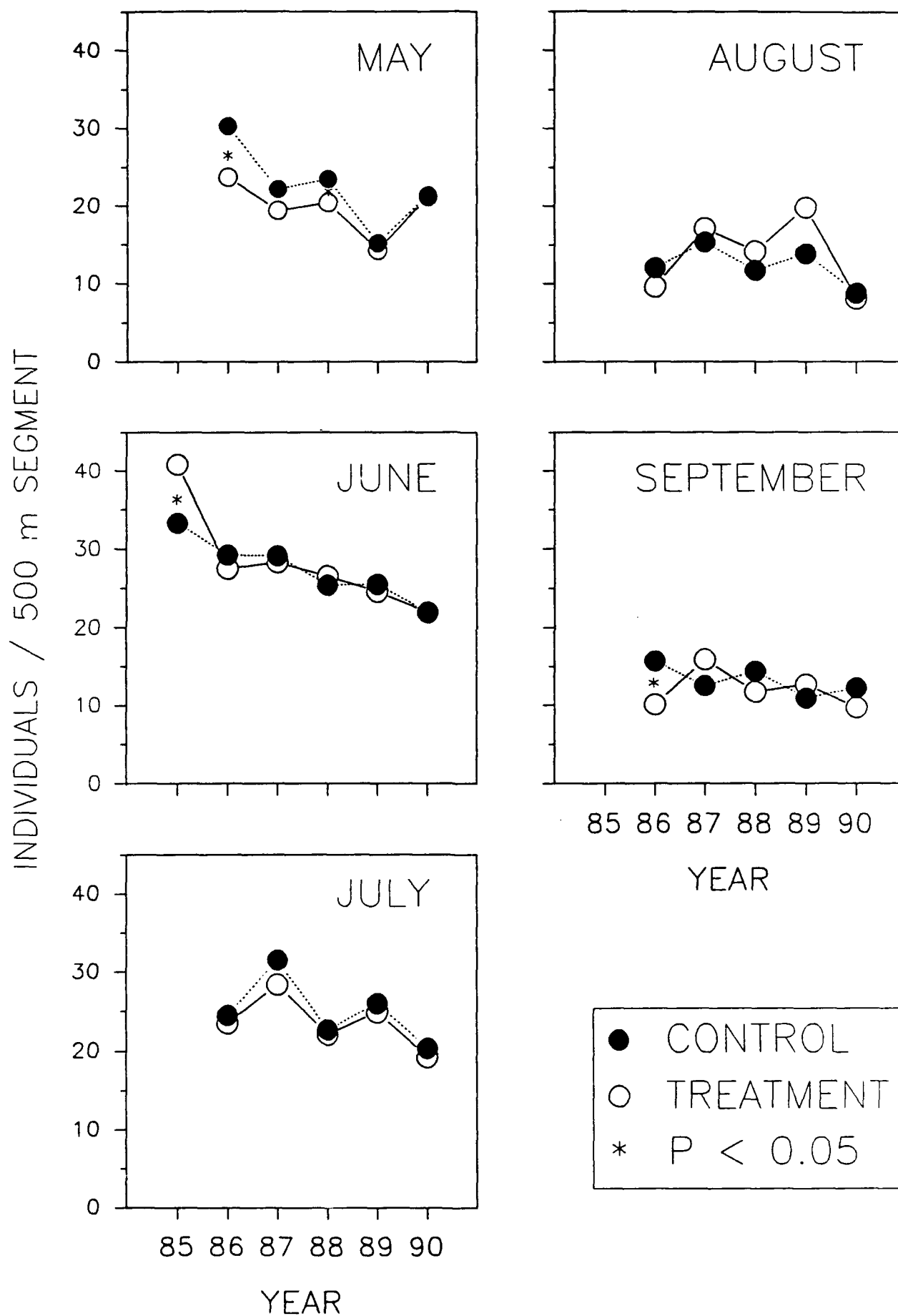


Figure 2. Mean number of individuals recorded per 500 m on treatment and control segments.



ANTENNA OPERATION - MICHIGAN

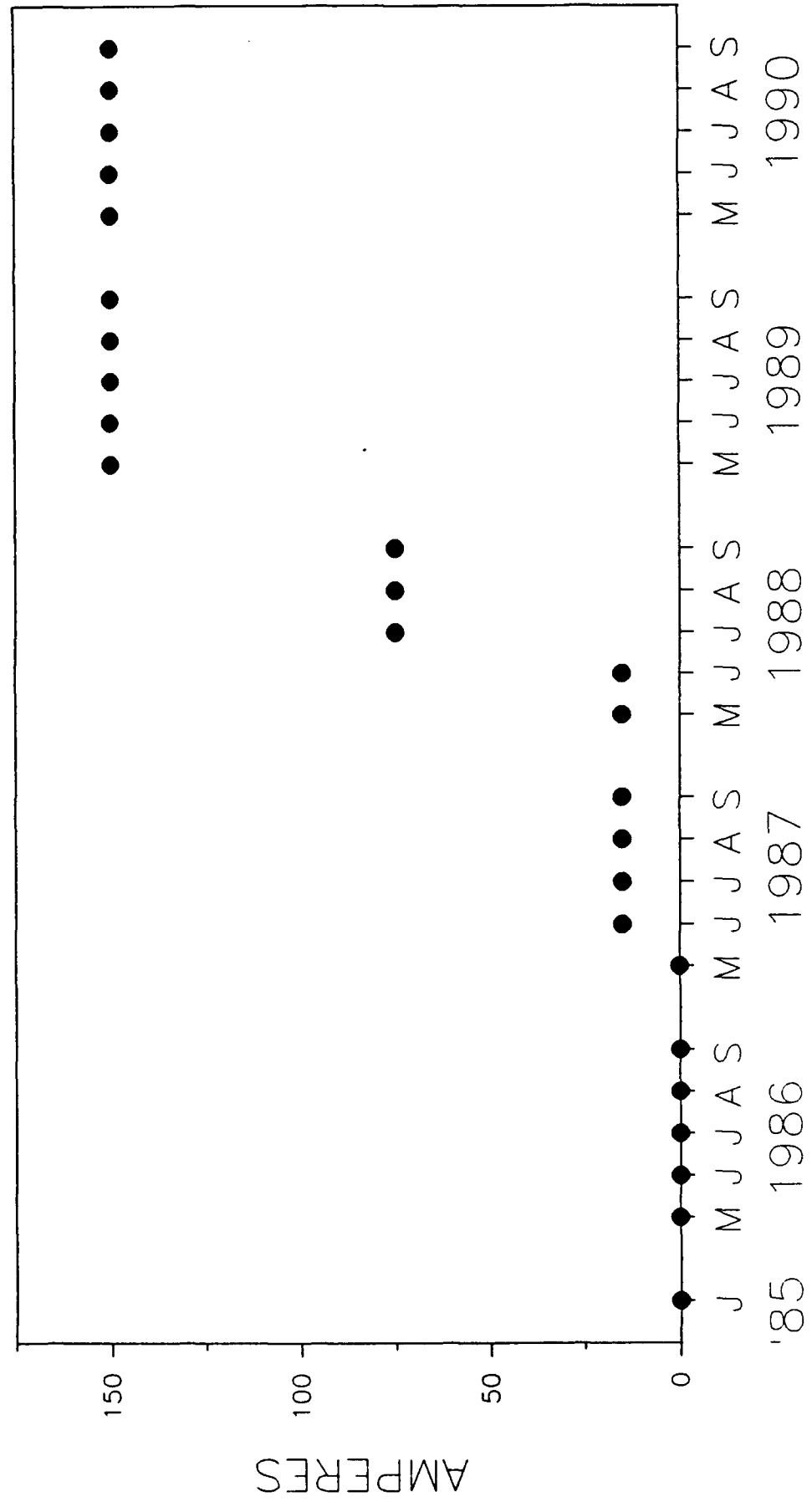
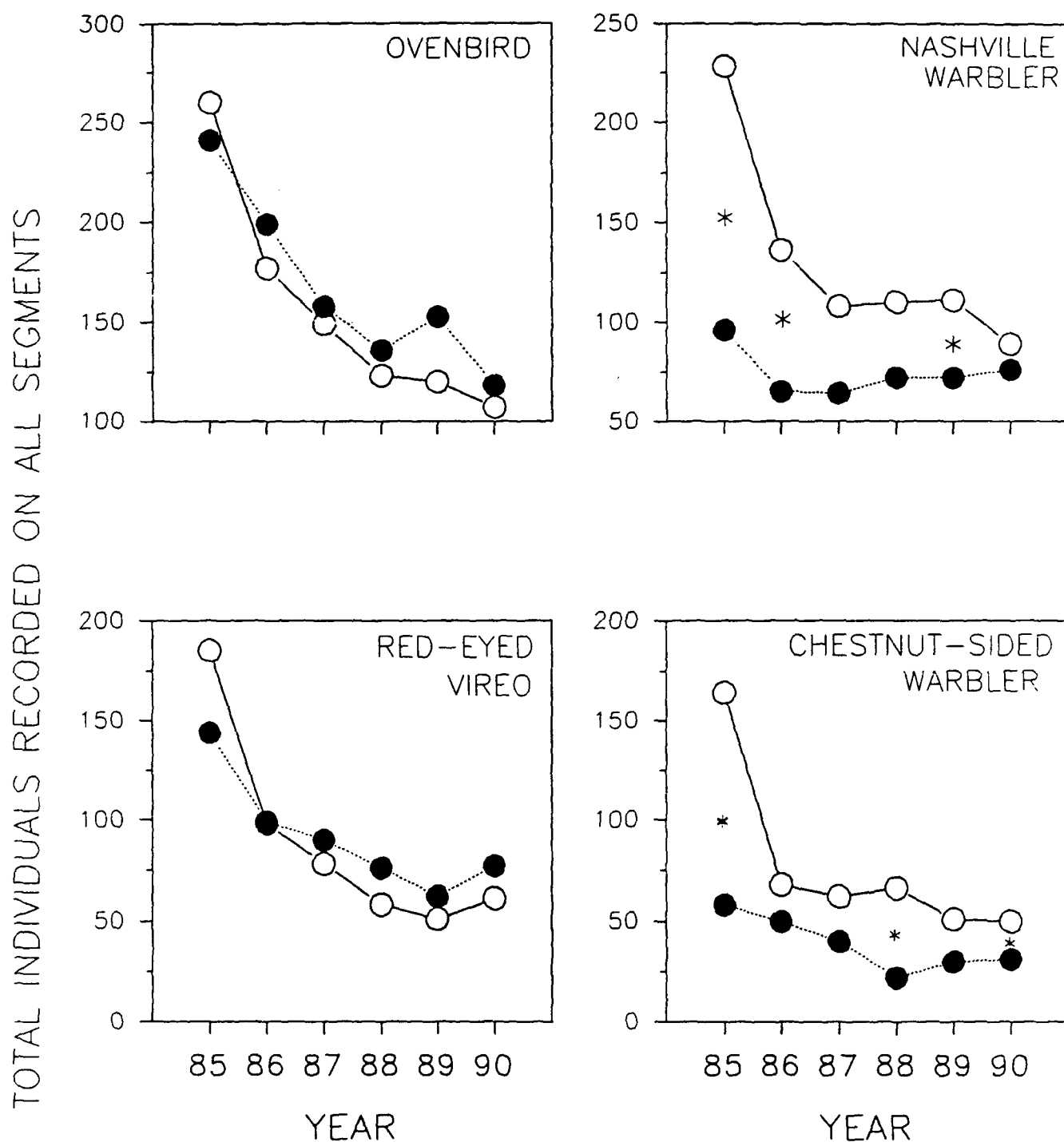


Figure 3. Summary of antenna operations in Michigan during June 1985 and during May-September 1986-1990.

Figure 4. Total number of individuals of four abundant migrants recorded during June, 1985-1990, on all treatment and control segments.



○ TREATMENT ● CONTROL * $P < 0.05$

indicate a change in abundance on treatment segments, relative to control segments, that can be associated with antenna operation. That is, after the antenna became fully operational in 1989, trends in abundance on treatment and control segments have not been significantly altered.

Changes in abundance observed on both treatment and control segments are most likely attributable to some factor other than the antenna operation. In particular, the series of droughts that have occurred in the upper midwest (National Oceanic and Atmospheric Administration 1988, with updates through 1989) may have had an adverse impact on birds (Blake et al. in press). Effects of the droughts may persist for several years and additional years of work will be required to determine the long-term effects. Similarly, effects of the antenna operation, if they occur, may not become evident for several years.

Results from Wisconsin also have shown little consistency among years or seasons in species richness or number of individuals (Hanowski et al. in press). If the ELF transmitter was strongly influencing bird distribution patterns, one might expect that relative abundance of birds on treatment and control segments would remain the same from one year to the next, particularly during the breeding season, and from one season to the next. There was, however, little evidence for such an effect. Species and individuals were more abundant on treatment segments in 1985 and individuals were more abundant on treatment segments in 1986, but no other significant difference at the community level were noted. In fact, throughout 1986-1989, species richness and abundance of individuals were remarkably similar on treatments and controls (Hanowski et al. in press).

Annual variation in abundance

Substantial variation occurred among years in abundance of many bird species (Fig. 4). Overall, abundance has tended to decline from 1985 (Fig. 2) as discussed

above. A potentially confounding factor in examination of annual variation in bird communities relates to sampling. Particularly during spring migration, changes in weather may profoundly influence the abundance of birds in a particular area (Richardson 1978). Differences in weather from one year to the next may produce apparent (as well as real) differences in abundance of birds. We attempt to minimize this problem by sampling over a five to six day period each season. Thus, weather patterns may not be as likely to strongly influence results of that sample. Similarly, we attempt to sample each season during the same calendar time period each year. It is likely, however, that differences of as much as a week from one year to the next have a considerably smaller influence on abundance than differences that may occur as a consequence of weather. This was particularly noticeable during the May 1989 sample in Michigan, where cold weather delayed the arrival of many migrants. Overall abundances were much lower in May 1989 than in previous years or during the 1990 sample (Figs. 1-2).

Guild distribution patterns

Species that belong to the same "guild" share some biological characteristics. Thus, if the ELF antenna system influences distributions of bird species we might expect members of a particular guild to be influenced in a similar fashion. Similarly, habitat related effects may be evident from the distribution patterns of guild members.

Relatively few differences in abundance of birds in different guilds were noted between treatment and control segments in Michigan in 1990 or either state in previous years (Blake et al. 1990). Differences that did exist likely reflected differences in habitat that occur between treatment and control segments. Treatment segments in Michigan had more early successional habitats than did control areas and birds breeding in such habitats showed the strongest treatment effect, being more abundant in treatment

segments (e.g., Chestnut-sided Warbler, Fig. 4). A similar result was noted for earlier years (Blake et al. 1990). Deciduous forest habitat is more common in control areas and coniferous habitats more common in treatment segments in both states (Blake et al. 1988); distribution of birds preferring deciduous habitat followed a similar trend.

Individual species

Habitat or EM related differences that exist between treatment and control segments may not influence all bird species in the same manner. If some species are more abundant on control and others on treatment segments, then such differences might cancel each other, producing nonsignificant results at the community level. If differences between treatment and control segments (either related to habitat or EM fields) are primary factors influencing distribution patterns of individual species, then we might expect those species to show similar patterns among years and seasons.

There have been relatively few cases where differences in abundance of a species between treatment and control segments have remained consistently significant among seasons and years in Michigan (Table 6; Fig. 5). A total of 43 species in Michigan have shown a significant difference in abundance between treatment and control segments in at least one season and year. Somewhat more species (22) were more abundant on control than on treatment segments (13) (Table 6). However, many species have shown a significant difference in only one season in one year (Fig. 5). Moreover, eight species in Michigan have been more abundant on treatment segments in one season and on control segments in another (Table 6, Fig. 5). For example, the Yellow-rumped Warbler was more abundant on treatment segments in June 1985 and 1986 in Michigan but was more common on control segments during September 1986. Such reversals may reflect seasonal changes in habitat selection. For example, a species may breed in one habitat

Table 6. Summary by year and month* of species that were significantly more abundant on treatment or control segments in Michigan. Underlined months indicate that differences were tested by ANOVA (i.e., "abundant" species; see text). Differences for common species (not underlined) were based on goodness-of-fit G-tests.

Species	More abundant on treatment					More abundant on control						
	1985	1986	1987	1988	1989	1990	1985	1986	1987	1988	1989	1990
Northern Flicker					M							
Yellow-bellied Flycatcher	Ju	Ju	Ju									
Golden-crowned Kinglet	Ju		<u>S</u>	<u>Jy</u>	Ju							
Hermit Thrush		<u>Jy</u>				M						
American Robin	Ju			JyA	A	A						
Cedar Waxwing				A	A							
Golden-winged Warbler			Ju									
Nashville Warbler	<u>Ju</u>	<u>JuJy</u>	<u>Jy</u>	<u>JuJy</u>	<u>Ju</u>	<u>Jy</u>						
Chestnut-sided Warbler	<u>Ju</u>	<u>Ju</u>				<u>MJyJy</u>						
Mourning Warbler	<u>Ju</u>				Jy							
Rufous-sided Towhee					A							
White-throated Sparrow	<u>Ju</u>	S	<u>JuJy</u>	<u>JuJy</u>		<u>JuS</u>						
Dark-eyed Junco			<u>A</u>	<u>S</u>	M							

Blue Jay		Ju						S		M		A
Red-breasted Nuthatch						Ju				S		S
Black-capped Chickadee				<u>Jy</u>					<u>MJu</u>		Ju	
Winter Wren				M						Ju	<u>MJu</u>	
Yellow-rumped Warbler	Ju	Ju							M	S		
Rose-breasted Grosbeak	<u>Ju</u>	M										Jy
Chipping Sparrow	<u>Ju</u>			Ju	Jy				M		Ju	
Song Sparrow				<u>MJu</u>		M						

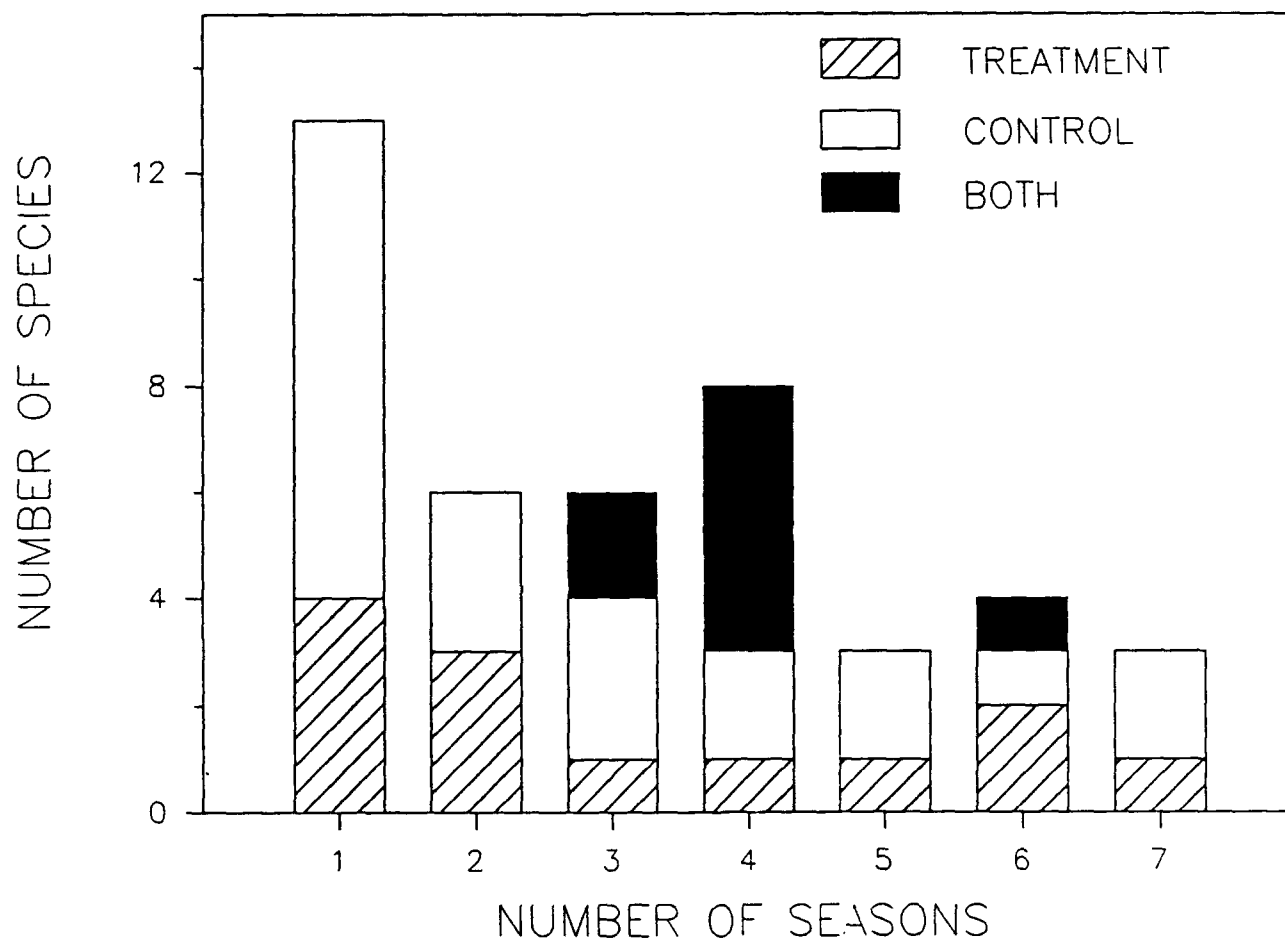
* M - May; Ju - June; Jy - July; A - August; S - September

Table 6 (continued)

Species	More abundant on treatment						More abundant on control					
	1985	1986	1987	1988	1989	1990	1985	1986	1987	1988	1989	1990
American Woodcock									Jy			
Ruffed Grouse								Jy	Jy	Jy		
Yellow-bellied Sapsucker								M	MJyA	MJyS	MJu	JyA
Downy Woodpecker								A				
Eastern Wood-Pewee									A		A	
Least Flycatcher								Jy				Jy
Great Crested Flycatcher									Ju		JuJy	Ju
Brown Creeper									Jy	MJy	M	M
Veery									Jy			S
Red-eyed Vireo												
Northern Parula										Jy		
Black-throated Green Warbler									M	M	Ju	M
Blackburnian Warbler									Ju			
Black-and-white Warbler								M	M	M		
American Redstart								S				
Ovenbird								MS	M	MS	Jy	
Common Yellowthroat								JuJy	Jy	Jy	Ju	A
Indigo Bunting												
Swamp Sparrow									MJy			
Red-winged Blackbird								MJu	MJuJy	M	Ju	M
Brown-headed Cowbird								MJu		Ju		
Purple Finch									M			A

• M - May; Ju - June; Jy - July; A - August; S - September

Figure 5. Number of species significantly more abundant on treatment or control segments in Michigan, during one or more seasons, 1985-1990.



but then move into a different habitat following breeding. If distribution of breeding and nonbreeding habitats differ between treatments and controls, a switch in abundance between treatment and controls also may occur.

Several species have shown a more consistent pattern of distribution between treatment and control segments. White-throated Sparrows, for example, have been more abundant on treatment segments in four of six Junes sampled (Table 6). Chestnut-sided and Nashville warblers also have been consistently more abundant on treatment segments (Fig. 4). Several species (e.g., Yellow-bellied Sapsucker, Ovenbird [Fig. 4], Red-winged Blackbird) consistently have been more abundant on control segments in Michigan.

Differences in abundance of species that showed a consistent difference between treatment and control segments likely are related to habitat in many cases.

White-throated Sparrows, for example, favor early successional habitats. Such habitats were more common on treatment segments than on controls in Michigan. In contrast, deciduous woods are more common on control segments and Yellow-bellied Sapsuckers, which prefer deciduous forests, were more frequently observed on control segments.

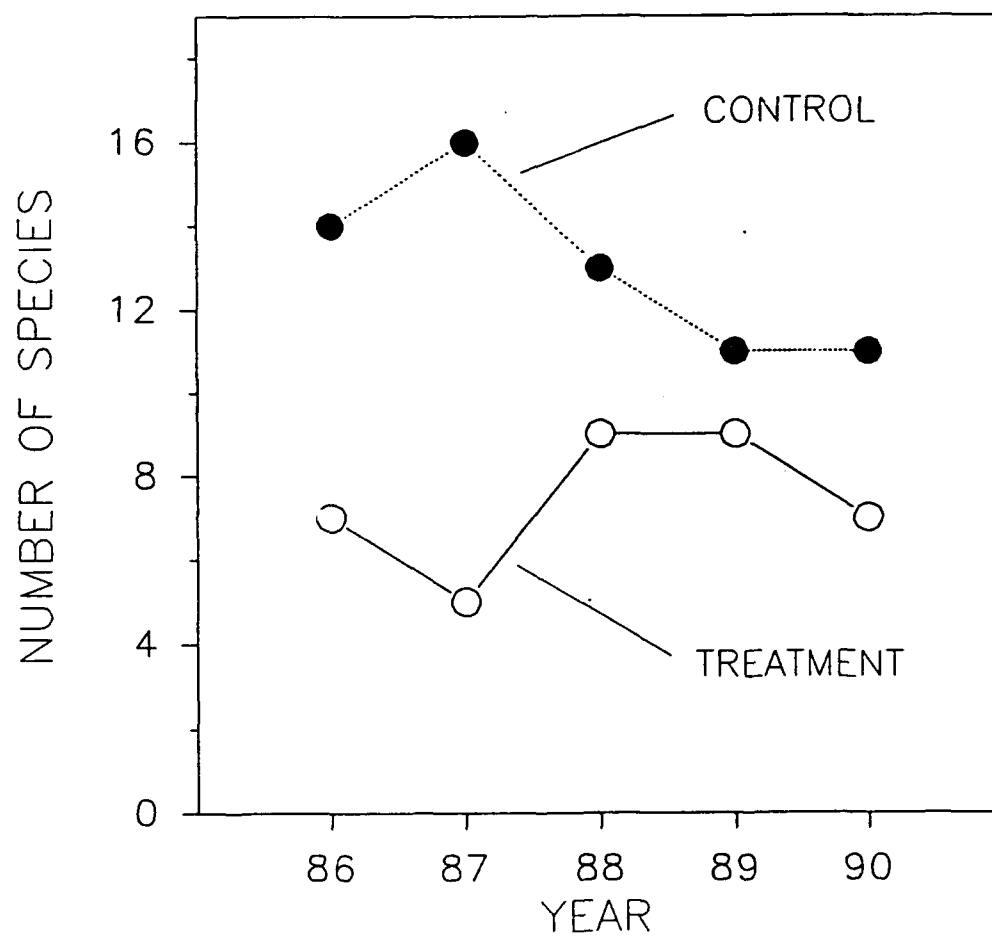
If the antenna operation adversely affected bird species, we might have expected the number of species more abundant on treatment segments to decline after operation began. Birds were sampled during all five months since 1986. Both 1986 and 1987 can be considered preimpact years (although the antenna was tested at low power during part of 1987 [Fig.3]). The antenna was tested at half strength during 1988 and was at full strength during most of 1989 and all of 1990. Thus, we can consider 1988 a transitional year and 1989 and 1990 as impact years. During 1986-1987, 9 species were recorded as being significantly more abundant on treatment and 30 species more abundant on control

segments during at least one season (Table 6, Fig. 6). (We are not including 1985 here as samples were collected only during June.) During 1989-1990, 16 species were more abundant on treatment segments and 22 on control. Thus, after antenna operation reached full strength, a greater proportion of species have become more abundant on treatment segments, although the difference in distribution between the pre- (1986-1987) and post-impact (1989-1990) periods was not significant (comparing number of species more abundant on treatment or control segments during each of the two periods: $\chi^2 = 3.2$, 1 df, $P < 0.075$). It is too early, however, to attribute any change in distribution to the antenna operation. The decrease from 1989 to 1990 in number of species more abundant on treatment segments may indicate a change in this pattern or it may simply reflect the overall low abundance of most birds. Additional years of data will be needed to fully resolve this question.

HABITAT STRUCTURE ON TREATMENT AND CONTROL SEGMENTS

Habitat structure influences the composition of bird communities in many ways (see Cody 1985 for a recent review). Our sample design (long linear transects) was established to sample habitats in approximate proportion to their availability in the study areas in each state. Treatment and control segments sample a wide range of habitats, including deciduous and coniferous woods, bogs, meadows, marshes, and logged areas of different ages. This diversity of habitats ensures that a diverse assemblage of birds will be sampled. The predominant influence of habitat structure on many aspects of bird communities means, however, that areas that differ in structure and species composition of the vegetation will differ (to a greater or lesser extent) in species composition and abundance of birds present.

Figure 6. Number of species significantly more abundant on treatment or control segments in at least one season during 1986-1990.



Placement of treatment segments was constrained by the location of the ELF transmission lines. Thus, our sampling is not strictly random with respect to habitats in the study regions. In both states for example, treatment areas support more coniferous habitat, particularly lowland coniferous habitats, whereas control areas support more deciduous habitats (Blake et al. 1988). Differences in a variety of other habitat features also occur, but the deciduous-coniferous difference was most pronounced and, as has been discussed above, likely influenced composition of related bird communities. Several differences in bird community characteristics observed between treatment and control segments likely were due to differences in habitat and we are accounting for many of these differences with our analyses. It is important to reiterate that, because we can compare changes in abundance over time on both control and treatment segments (i.e., before-and-after impact), existing habitat differences will not affect our ability to detect any effects of electromagnetic fields produced by the ELF antenna. Hanowski et al. (in press) provide a more complete discussion of the effects of habitat on distribution patterns of birds.

OBJECTIVES

Our major objectives for 1990 were to complete bird censuses during all seasons in Michigan and to complete a final report for work done in Wisconsin; both objectives were met. Additionally, a manuscript derived from the Wisconsin final report has been submitted for publication (Hanowski et al. in review). Our objectives for 1991 and beyond are to continue our sampling of bird communities in Michigan, following our established procedures. Further, we will be expanding our analyses to include more consideration of changes in abundance over time. If the antenna operation affects bird distribution patterns, we expect to see a shift in patterns of abundance on treatment relative to control

segments. We have been discussing different statistical approaches with Dr. Ron Regal, Department of Mathematics and Statistics, University of Minnesota-Duluth.

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Appendix 1. Summary of Experimental Design, Study Areas, and Methods used in the design and execution of research on effects of the ELF transmitter on bird communities and populations.

Appendix 1. Summary of Experimental Design, Study Areas, and Methods used in the design and execution of research on effects of the ELF transmitter on bird communities and populations.

EXPERIMENTAL DESIGN

The first steps in the experimental design were to (1) evaluate techniques for quantifying bird community parameters and (2) determine sample sizes required to detect a specified difference between control and treatment areas. Four potential techniques were examined: transect counts, point counts, territorial mapping, and mist-netting (Table A1). Territorial mapping and mist-netting were eliminated from consideration because of the amount of effort required to obtain statistically reliable results.

Transect and point counts are closely related techniques that differ primarily in a) whether the observer is moving (transects) or stationary (point counts) and b) in the size (area) of the experimental unit. For our comparison, we assumed that we could census an area 100 m from the point or transect line (both sides). The point count method would result in an effective census area of about 6.28 ha (assuming two point counts completed in the same time as one 500 m transect); a 500 m transect would cover about 10 ha. We decided to use transect counts because the ELF communications system consists of a long, linear network of the antenna and ROW and transects could be run parallel to this network. Point counts also could have been run adjacent to this network, but because we would walk along the swath adjacent to the ELF network, we decided to use the method that would include the larger census area (transects). In addition, if our estimates of the mean and variances are correct, transect counts are slightly more efficient in terms of effort (Table A1).

Table A1. Comparison of statistics for four bird census methods using the number of species as the community parameter of interest. Difference detectable was set at 15% of the mean and determination of sample size necessary to detect that difference was based on a probability of 0.05 and a power of 80% (Snedecor and Cochran 1967, p. 113). Formula used was: $n = (15.8 \times S^2)/d^2$ where d =the absolute difference detectable or 15% of the mean (Snedecor and Cochran 1967). Statistics were estimated for forested habitats in the upper-midwestern United States based on the authors personal data.

Method	Mean number of species	Variance	Absolute difference detectable	N	Effort per n in hr	Initial effort per n in hr	Total effort in hr
Point count ¹	6.0	10.0	0.90	195	0.25	0.60	169
Transect count ²	12.0	8.0	1.80	39	0.60	3.00	144
Territory mapping ³	18.0	25.0	2.70	54	16.00	16.00	1728
Mist-netting ⁴	1.6	1.8	0.24	494	0.50	0.25	371

¹ Estimates are for all species observed during 10 min count period.

² Estimates are for the number of species observed during a 30 min census of a 500 m transect.

³ Estimates are for the total territorial males mapped in a 12.5 ha area.

⁴ Estimates are for the number of species caught in a 12 m mist-net during a 5 hr period.

In an ideal experimental design, each segment should be randomly assigned to control and treatment areas. From the perspective of censusing in the field, however, this arrangement would be inefficient. To balance statistical rigor with the practicalities of working in the field, we decided to group eight 500 m segments into one long transect line (hereafter called transect). Each segment was separated by a buffer of 50 m to reduce autocorrelation between the experimental units (Figure A1; see Hanowski et al. 1990). We grouped eight segments because our previous experience indicated that bird censuses should be conducted from one half hour before sunrise to about four hours after sunrise. A total of 4 hours and 35 minutes are needed to census eight segments and seven buffers (30 minutes for each segment and 3 minutes for each buffer). We estimated that 39 segments (Table A1) were needed in each group (control and treatment for each state) to detect a 15% difference in number of species. This percent difference was selected based on the ability to detect a difference of one species between control and treatment areas. Therefore, we selected five transect starting points per group or a total of 160 segments (40 segments per group).

Placement of treatment transects with respect to the ELF antenna system was designed to achieve two goals: (1) to reduce or eliminate potential effects of the ROW edge on the bird community (Chasko and Gates 1982), and (2) to maintain an appropriate EM field within the treatment area. We placed the transects parallel to and 125 m from the edge of the ELF antenna ROW (Figure A1). This achieved a 25 m buffer from the limits of where we recorded birds (100 m) from the ROW edge. Although this placement reduced the intensity of EM fields within treatment areas, EM fields were still high enough to achieve the 10:1 ratio between treatment and control areas required in the study specifications (Brosh et al. 1986).

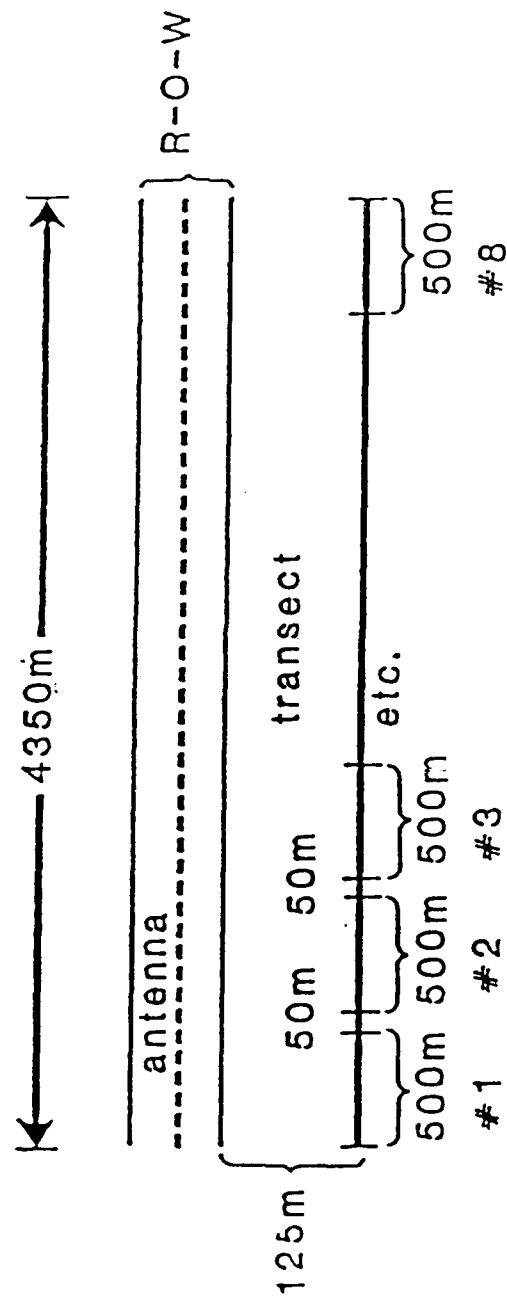


Figure A1. Schematic of a treatment transect layout. ROW = right-of-way.

STUDY AREAS

Starting locations for 5 control and 5 treatment transects were randomly selected in Michigan (Fig. A2) with methods described previously (Niemi and Hanowski 1986). Electromagnetic fields were measured to insure that 76 Hz EM fields at a treatment site were significantly larger than: (1) 76 Hz EM fields at control sites, (2) 60 Hz fields at treatment sites, and (3) 60 Hz fields at control sites. In addition, exposure criteria required that there was no substantial difference in the ambient 60 Hz EM fields between control and treatment transects (Brosh et al. 1986). Electromagnetic fields were measured at the beginning and ending points for each transect; they were not completed for each transect segment because most were not easily reached (e.g., most are 1-4 km from a road). Eight of 25 transect pairs in Michigan were determined to be "conditionally acceptable" with respect to EM field ratios established by IITRI, based on data collected in 1986. Previous data placed all pairs in the "acceptable" category (Haradem et al. 1987). All transects still satisfy the EM exposure criteria and will be used for the remainder of the monitoring period.

Information regarding proposed logging along the transects was obtained from Department of Natural Resources in Michigan. Five control and five treatment transect segments were scheduled for logging in Michigan effective through 1990 (Table A2). However, in an agreement reached with Michigan DNR (September 1988), logging on Carney Lake and Skunk Creek will not be completed until 1992 (Table A2). In 1989 three Michigan segments were affected by logging (Heart Lake, Leemans Road, and Arnold Road) (Table A2). Because of the length of our transects, it is probably impossible to avoid areas affected by logging. We will be sensitive to disturbances along transects in subsequent analyses and if necessary, affected transect segments can be removed from

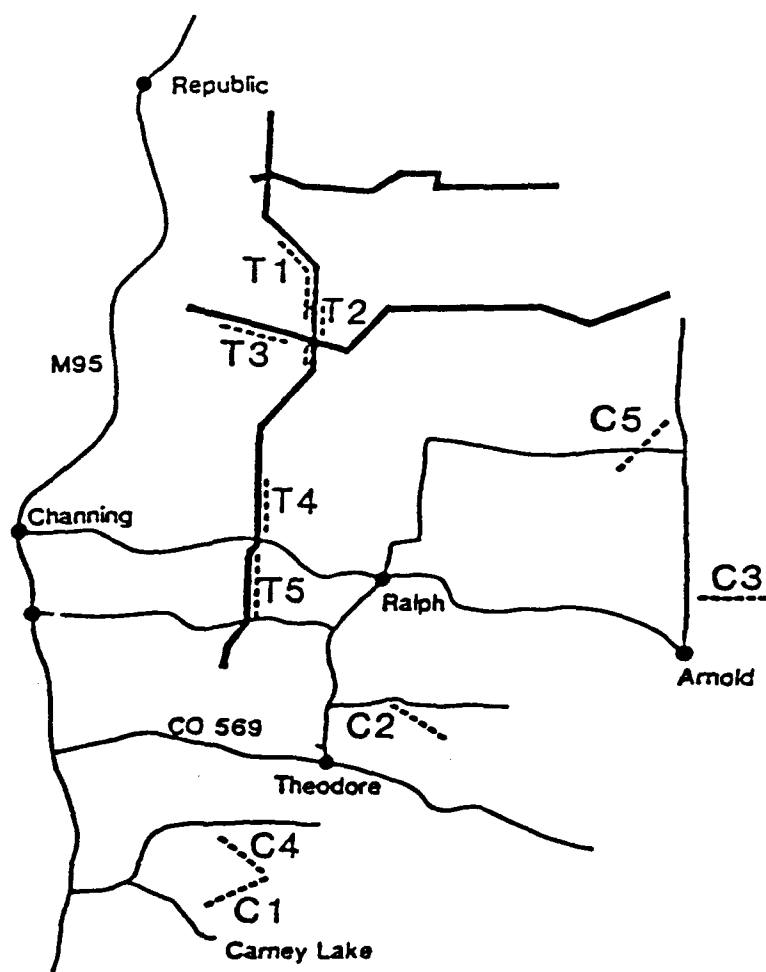


Figure A2. Location of Michigan antenna and study transects.

Table A2. Summary of Michigan transect locations and proposed logging of study areas effective through 1990. Asterisks denote sections that were logged in 1987 (*) 1988 (**) and 1989 (***). No additional study areas in Michigan are scheduled to be logged before the end of the study.

Number and Name		Township	Range	Sections	Number of 500 m segments affected
C1	Carney Lake	41N	29W	33,34,35,36	2 (1992)
C2	Skunk Creek	42N 42N	28W 27W	14,23,24 19,30	2 (1992)
C3	Arnold	43N 43N	25W 25W	31,32,33,34 32	1 * 1 ***
C4	Lost Lake	41N	29W	21,26,27,28,35	2 **
C5	Bob's Creek	44N	26W	13,23,24,26	1 (1989)
T1	Heart Lake	45N 45N	28W 28W	7,18 19	1 1 ***
T2	Flat Rock Creek	44N 45N	28W 28W	6 19,30,31	3 *
T3	Schwartz Creek	45N 45N	28W 29W	31 26,27,35,36	2 **
T4	Turner Road	43N 44N	29W 29W	1,11,12 36	0
T5	Leeman's Road	43N	29W	14,23,26,35	0

analyses. This will allow us to assess potential affect of logging or other disturbances on results of the investigation.

METHODS

Bird censuses

We used the line-transect method to census all transects (Emlen 1971, 1977; Järvinen and Väisänen 1975). Census data were gathered during morning hours (one half hour to four and one half hours after sunrise) on days when wind speed was < 15 km/hr and when there was little or no precipitation. Control and treatment transect segments were censused simultaneously by two observers to eliminate differences that could occur by censusing at different times. Censuses of control and treatment transects were randomly assigned to each of two observers with the restriction that each observer census the same number of control and treatment segments. This was done to control for potential differences in observers.

Eight transect segments were censused daily by each observer. Each observer walked the designated transect segment at a rate of approximately 1 km/hr and recorded the following for each bird observed: (1) species; (2) sex when possible; (3) behavior (e.g., singing or calling); (4) estimated perpendicular distance from the segment center line, in meters; (4) position relative to the segment center line (e.g., right or left side); and (5) distance, in meters, from the start of the segment. Information for each individual bird observed was recorded on microcomputer files. Birds flying over (i.e., above the canopy) were not included. Data were checked for accuracy after entry.

We used the number of individuals observed up to 100 m from the segment center line in all data analyses instead of attempting to calculate a density value. Relative

density could be calculated with a variety of formulae (Emlen 1971, 1977; Järvinen and Väisänen 1975; Burnham et al. 1981) but at the present we have no basis for using one formula over another. We only assume that the number of birds recorded is related to the density of birds in an area. A disadvantage to using a density formula (e.g., LINETRAN; Burnham et al. 1981) is the number of observations required to obtain a reliable density estimate. For example, at least 30 observations/species are recommended to calculate densities with the Fourier series estimator. Such a sample size is prohibitive for this study because we do not observe this many individuals of one species on a 500 m segment. To obtain the specified sample, our segments would have to be about five times longer (about 2500 m) than they are now. This design is not feasible because of the large sample size (number of segments) needed to detect the desired difference between control and treatment areas. It may be possible to use this technique at a later date if we pool data among years or among different experimental units.

An advantage of using total number of observations is that we reduce potential variability between observers in ability to estimate distance (Svensson 1977). Here we only assume that the ability to detect individuals is similar between observers and, therefore, between control and treatment sites because each observer censuses the same number of control and treatment segments.

Bird guilds

We listed all bird species observed in Michigan and Wisconsin and all species that could potentially occur in our study areas. Each species was classified by 1) nesting area, 2) food or foraging type, 3) breeding habitat preference, and 4) migration type (Appendix 2). Classifications were based on published sources (e.g., Martin et. al. 1951; Bent 1963, 1964; Green and Niemi 1978; Terres 1982; AOU 1983) and personal

observations. A hierarchical classification scheme was used if a species occurred in more than one category. When this occurred, we identified primary, secondary, and tertiary areas of use for these species; primary being the predominant category of use. We use this information in analyses to address any differential effects of the ELF antenna on species that use particular feeding strategies, specific nesting areas, or different migration patterns (see Verner 1984). These analyses allow us to test for differences between control and treatment transects for species that have similar life history characteristics and therefore, similar exposures to ELF EM fields.

Michigan vegetation

We classified habitats of the Michigan study areas at 25 m intervals along each segment. Nineteen habitat types were used for classification (Appendix 4) and percentage of occurrence of each type on control and treatment areas was calculated. We did this to identify gross habitat differences between control and treatment segments that might potentially explain differences in bird populations. For example, before the antenna is turned on in Michigan we would expect that any differences between control and treatment transects would be due to some other source of difference between these areas (i.e., habitat). We collected 1750 vegetation samples in Michigan and entered these data onto microcomputer files. A goodness-of-fit G-test was used to test for differences between control and treatment transects using the frequencies of the 19 habitat types observed.

Appendix 2. Nesting, feeding, habitat, and migration classification for bird species observed in Michigan and Wisconsin.

Appendix 2. Nesting, feeding, habitat, and migration classification for bird species observed in Michigan and Wisconsin.

Species	Nesting	Food	Habitat	Migration
Common Loon	1	1	9,8	2
Pied-billed Grebe	1	1	9,8	2
American Bittern	3	1	6,9	2
Great Blue Heron	2	1	9,1,2,3	2
Wood Duck	4	18	9,1	2
Mallard	1	18	9,8	2
Blue-winged Teal	1	18	9,8	3,2
Turkey Vulture	1	3	3,1,5	2,3
Osprey	2	1	9,3	2,3
Bald Eagle	2	1	9,3	2,1
Northern Harrier	1	2	8,5,10	2,3
Sharp-shinned Hawk	2	2	2,3,11	2
Cooper's Hawk	2	2	1,3	2
Northern Goshawk	2	2	2,3	4,1
Broad-winged Hawk	2	2	3,1	3
Red-tailed Hawk	2	2	5,1	2
American Kestrel	4	2	5,4	2,3
Spruce Grouse	1	4	2,11	1
Ruffed Grouse	1	4	1,3,4	1
Virginia Rail	3	19	6,8	2

Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Sora	3	19,18	8,6	2
Sandhill Crane	1	5	8,5,10	2
Solitary Sandpiper	2,3	19	9	3
Spotted Sandpiper	1	19	9	2,3
Common Snipe	1	19	8,6,5	2
American Woodcock	1	6	6,5,4,1	2
Mourning Dove	2,3	7	5,7	2
Black-billed Cuckoo	3	10	1,4,6	3
Yellow-billed Cuckoo	3	10	1,4,6	3
Great Horned Owl	2	2	3,2,1	1
Barred Owl	2	2	1,3	1
Common Nighthawk	1	11	3,7,4	3
Whip-poor-will	1	11	1,3,4	2
Chimney Swift	4	11	7,3,1	3
Ruby-throated Hummingbird	2	17	5,7,4	3
Belted Kingfisher	4	1	9	2
Yellow-bellied Sapsucker	4	17,16	1,3,2	2
Downy Woodpecker	4	16	1,4,3	1
Hairy Woodpecker	4	16	1,3,4	1
Black-backed Woodpecker	4	16	2,11,3	1
Northern Flicker	4	9	1,3,2	2

Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Pileated Woodpecker	4	16	1,3,2	1
Olive-sided Flycatcher	2	12	4,11,2	3
Eastern Wood-Pewee	2	12	3,1,2	3
Yellow-bellied Flycatcher	1	12	11,2	3
Alder Flycatcher	3	12	6	3
Least Flycatcher	2	12	1,3,4	3
Eastern Phoebe	5	12	9,7	2
Great Crested Flycatcher	4	12	1,3	3
Eastern Kingbird	2,3	12	5,4,10,8	3
Tree Swallow	4	11	5,7,4,9	2,3
Gray Jay	2	5	11,3,2	1
Blue Jay	2	5	1,3,2	1
American Crow	2	5	5,1,3,7	2,1
Common Raven	2	5	2,3,7	1
Black-capped Chickadee	4	10	1,3,11,2	1
Boreal Chickadee	4	10	11,2	1
Red-breasted Nuthatch	4	16	2,3,11,1	1
White-breasted Nuthatch	4	16	1,3	1
Brown Creeper	4	16	1,3 2,11	2,1
House Wren	4	10	7,4	2
Winter Wren	1,6	10	3,11,4,2	2

Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Sedge Wren	3	10	8,6,5	2
Marsh Wren	3	10	8	2
Golden-crowned Kinglet	2	10	2,11	2,1
Ruby-crowned Kinglet	2	10	2,11,4,6	2
Veery	1	9	1,4,3,6	3
Gray-cheeked Thrush	3	9	4,11,2	3
Swainson's Thrush	2,3	9	11,2,4	3
Hermit Thrush	1	9	3,11,1,2	2
Wood Thrush	3,1	9	1,3	3
American Robin	2,3,1	9	5,7,4,1	2,1
Gray Catbird	3	13	4,6,7	2,3
Brown Thrasher	3	9	4,7	2
Bohemian Waxwing	2	14	4,3,1	4
Cedar Waxwing	2	14	4,3,1	1,2
European Starling	4	9	7,3	1
Solitary Vireo	2	10	3,11,2	3,2
Yellow-throated Vireo	2	10	1,3	3
Warbling Vireo	2	10	4,3,1	3
Philadelphia Vireo	2,3	10	1,3,6	3
Red-eyed Vireo	2,3	10	1,3,4	3
Golden-winged Warbler	1,3	10	4,6	3

Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Tennessee Warbler	1	10	3,2,6,4	3
Orange-crowned Warbler	1	10	6,4,3	2,3
Nashville Warbler	1	10	3,4,11,2	3
Northern Parula	2	10	11,3,2	3
Yellow Warbler	3	10	6,5,7	3
Chestnut-sided Warbler	3	10	4,3	3
Magnolia Warbler	2,3	10	4,2,3	3
Cape May Warbler	2	10	2,3	3
Black-throated Blue Warbler	3	10	1,3,4	3
Yellow-rumped Warbler	2	13	2,3,11,4	2,3
Black-throated Green Warbler	2	10	3,1	3
Blackburnian Warbler	2	10	2,3	3
Pine Warbler	2	10	2	2
Palm Warbler	1	6	11,10	2,3
Bay-breasted Warbler	2	10	2,3	3
Blackpoll Warbler	2	10	2,4,3	3
Black-and-white Warbler	1	16	3,4,6,1	3
American Redstart	2,3	12,10	4,1,6	3
Ovenbird	1	6	1,3,2,4	3
Northern Waterthrush	1,6	6	9	3
Connecticut Warbler	1	10	11	3

Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Mourning Warbler	1,3	10	4,3	3
Common Yellowthroat	3	10	6,8,4	2,3
Wilson's Warbler	3	10	6	3
Canada Warbler	3	10	3,4	3
Scarlet Tanager	3	10	1,3	3
Rose-breasted Grosbeak	3,2 13	1,4,3	3	
Indigo Bunting	3	15	5,4	3
Rufous-sided Towhee	1,2,3	8	4	2
American Tree Sparrow	3	7	5	4,2
Chipping Sparrow	2	8	2,3,4,11	2
Clay-colored Sparrow	3	8	5,6	2,3
Field Sparrow	1,3	8	5	2
Savannah Sparrow	1	8	5,8,10	2
Fox Sparrow	1,3	8	4,5	2
Song Sparrow	3	8	5,4,6	2
Lincoln's Sparrow	1	8	10,8,4	2
Swamp Sparrow	3	8	6,8	2
White-throated Sparrow	1	8	4,3,2,11,1	2
White-crowned Sparrow	1,3	8	4,6,5	2
Dark-eyed Junco	1	8	11,2,3,4	2,1
Snow Bunting	5	7	5	4

Appendix 2 (continued)

Species	Nesting	Food	Habitat	Migration
Bobolink	1	8	5,8	3
Red-winged Blackbird	3	8	8	2
Eastern Meadowlark	1	6	5	2
Western Meadowlark	1	6	5	2
Yellow-headed Blackbird	3	8	8	2
Rusty Blackbird	3	8	9	2
Brewer's Blackbird	3,1	8	5	2
Common Grackle	3	5	5,9,7	2
Brown-headed Cowbird	7	8	5,4,1,7	2
Northern Oriole	2	13	1,3	3
Pine Grosbeak	2	7	2,11	4
Purple Finch	2	7	3,2,4	2,1
Red Crossbill	2	7	2,11,3	4,1
White-winged Crossbill	2	7	2,11,3	4,1
Common Redpoll	3	7	5	4
Hoary Redpoll	3	7	5	4
Pine Siskin	2	15	2,3	1,4
American Goldfinch	3,2	7	5,6,4	2
Evening Grosbeak	2	15	3,2,7	1,4
House Sparrow	4	7	7	1

Appendix 2 (continued)

A. Nesting

- 1 Ground
- 2 Canopy or canopy vegetation (tree but not necessarily tree top)
- 3 Subcanopy or shrub
- 4 Cavity, hole or bank
- 5 Ledge or platform
- 6 Cavity - tree roots
- 7 Nest parasite

B. Food

- 1 Aquatic vertebrates, including fish or other aquatic vertebrates
- 2 Birds, small mammals, large insects
- 3 Carrion
- 4 Vegetation such as buds, pine needles, and seeds but excluding species concentrating on seeds or fruits
- 5 Various small vertebrates (including eggs and young), invertebrates, plants, carrion, etc. (e.g., Omnivores)
- 6 Ground invertebrates
- 7 Seeds (plus a smaller amount of fruit by some species)
- 8 Ground invertebrates and seeds
- 9 Ground invertebrates and fruit
- 10 Foliage invertebrates
- 11 Aerial insects - taken while in continuous flight
- 12 Aerial insects - taken in sallies from a perch

Appendix 2 (continued)

- 13 Foliage invertebrates and fruit
- 14 Fruit
- 15 Foliage invertebrates and seeds
- 16 Bark insects
- 17 Nectar and sap
- 18 Aquatic vegetation
- 19 Aquatic invertebrates

C. Habitat

- 1 Deciduous forest
- 2 Coniferous forest
- 3 Mixed deciduous - coniferous forest
- 4 Early successional deciduous - coniferous forest
- 5 Fields and meadows
- 6 Shrub swamp
- 7 Urban
- 8 Open wetlands (e.g., sedge fen, cattail)
- 9 Ponds, lakes, rivers, and streams
- 10 Muskeg
- 11 Lowland coniferous forest

D. Migration

- 1 Permanent resident; populations may be augmented during winter or during summer

Appendix 2 (continued)

-
- 2 Short-distance migrant; generally includes breeders; individuals generally winter south of study areas but most winter north of the tropics
 - 3 Long-distance migrant; generally winter south of the U.S.
 - 4 Winter resident

Appendix 3. Description of habitat types used to classify Michigan study areas.

Appendix 3. Description of habitat types used to classify Michigan study areas.

Habitat Type	Description
Upland Conifer Forest	Upland forest with > 90% conifer species (e.g., pine)
Lowland Conifer Forest	Lowland forest with > 90% conifer species (e.g., black spruce (<u>Picea mariana</u>))
Upland Deciduous Forest	Upland forest with > 90% mixed deciduous species
Maple Forest	Upland deciduous forest with > 90% maple spp.
Lowland Deciduous Forest	Lowland forest with > 90% deciduous species (e.g., black ash (<u>Fraxinus nigra</u>))
Upland Mixed Forest	Upland forest with mixed deciduous and coniferous species
Lowland Mixed Forest	Lowland forest with mixed deciduous and coniferous species
Cedar Forest	Lowland forest with > 90% Northern white cedar (<u>Thuja occidentalis</u>)
Wet Shrub	Alder/willow wetland with no or few trees
Tree Shrub	Alder/willow wetland with trees (e.g., black ash or tamarack (<u>Carix laricina</u>))
New Cut	Logged area < 5 years old
Young Cut Aspen	Logged area with aspen spp. < 3m
Young Cut Mixed	Logged area with mixed species < 3m
Short Aspen	Logged area with aspen spp. > 3m but < 10m
Short Mixed	Logged area with mixed species > 3m but < 10m
Open	Forest opening
Sedge	Wet sedge meadow
Pond	Small pond
Cattail	Wet area with > 90% cattail (<u>Typha</u> spp.)

Appendix 4. Total number of individuals and species observed on control (C) and treatment (T) transects in Michigan during five census periods in 1990. English and scientific names follow AOU (1983).

Appendix 4. Total number of individuals and species observed on control (C) and treatment (T) transects in Michigan during five census periods in 1990. English and scientific names to follow AOU (1983).

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Common Loon <u>Gavia immer</u>	0	1	0	0	0	0	0	0	0	1
Pied-billed Grebe <u>Podilymbus podiceps</u>	0	0	0	1	0	0	0	0	0	0
Canada Goose <u>Branta canadensis</u>	0	1	0	0	0	0	0	0	0	0
Wood Duck <u>Aix sponsa</u>	0	1	0	1	2	0	0	0	0	0
Turkey Vulture <u>Cathartes aura</u>	0	0	0	0	1	0	0	0	0	0
Sharp-shinned Hawk <u>Accipiter striatus</u>	0	0	1	0	0	1	0	2	0	0
Broad-winged Hawk <u>Buteo platypterus</u>	1	3	2	0	0	4	0	2	0	2
Red-tailed Hawk <u>Buteo jamaicensis</u>	0	0	1	0	1	0	0	0	0	0
American Kestrel <u>Falco sparverius</u>	2	0	1	1	1	0	1	1	1	0
Ruffed Grouse <u>Bonasa umbellus</u>	16	11	7	12	1	4	3	5	0	15
Killdeer <u>Charadrius vociferus</u>	1	0	0	0	0	0	0	0	0	0
Common Snipe <u>Gallinago gallinago</u>	0	1	0	0	0	0	0	0	0	0
American Woodcock <u>Scolopax minor</u>	5	1	0	2	4	2	2	4	0	0
Black-billed Cuckoo <u>Coccyzus erythrophthalmus</u>	0	0	0	1	0	0	0	0	0	0

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Yellow-billed Cuckoo <u>Coccyzus americanus</u>	0	0	0	1	0	0	0	0	0	0
Barred Owl <u>Strix varia</u>	0	1	0	0	0	0	0	0	0	0
Ruby-throated Hummingbird <u>Archilochus colubris</u>	0	0	2	2	0	3	1	1	0	0
Belted Kingfisher <u>Caryle alcyon</u>	0	0	1	1	3	1	0	0	0	0
Yellow-bellied Sapsucker <u>Sphyrapicus varius</u>	15	27	3	12	4	17	3	14	4	11
Downy Woodpecker <u>Picoides pubescens</u>	3	2	1	1	3	5	6	1	7	4
Hairy Woodpecker <u>Picoides villosus</u>	4	5	4	3	4	2	4	3	3	5
Black-backed Woodpecker <u>Picoides arcticus</u>	0	0	0	1	2	0	0	2	1	1
Northern Flicker <u>Colaptes auratus</u>	10	10	7	5	24	10	13	6	12	9
Pileated Woodpecker <u>Dryocopus pileatus</u>	1	3	1	2	0	0	0	4	2	4
Eastern Wood-Pewee <u>Contopus virens</u>	1	0	13	16	9	12	12	13	2	5
Yellow-bellied Flycatcher <u>Empidonax flaviventris</u>	1	1	15	6	13	4	0	0	0	1
Alder Flycatcher <u>Empidonax alnorum</u>	1	0	10	7	2	0	0	0	0	0
Least Flycatcher <u>Empidonax minimus</u>	30	28	37	33	3	32	2	4	0	0
Eastern Phoebe <u>Sayornis phoebe</u>	2	0	1	0	0	0	2	0	0	0

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Great Crested Flycatcher <u>Myiarchus crinitus</u>	3	7	5	17	0	8	0	0	0	2
Eastern Kingbird <u>Tyrannus tyrannus</u>	0	0	2	6	0	2	0	5	0	0
Tree Swallow <u>Tachycineta bicolor</u>	1	8	4	0	0	0	0	0	0	0
Gray Jay <u>Perisoreus canadensis</u>	2	7	2	0	9	5	3	4	9	5
Blue Jay <u>Cyanocitta cristata</u>	15	23	17	18	26	14	5	39	73	36
American Crow <u>Corvus brachyrhynchos</u>	1	2	0	0	0	0	0	3	0	1
Common Raven <u>Corvus corax Linnaeus</u>	1	3	2	6	1	0	1	2	2	0
Black-capped Chickadee <u>Parus atricapillus</u>	44	63	18	22	47	44	46	56	66	96
Boreal Chickadee <u>Parus hudsonicus</u>	2	0	0	0	3	0	4	0	4	1
Red-breasted Nuthatch <u>Sitta canadensis</u>	20	25	19	8	12	5	15	13	9	22
White-breasted Nuthatch <u>Sitta carolinensis</u>	5	4	0	1	1	7	1	4	2	11
Brown Creeper <u>Certhia americana</u>	3	16	3	9	2	1	0	1	2	6
House Wren <u>Troglodytes aedon</u>	0	0	0	1	0	1	0	0	1	0
Winter Wren <u>Troglodytes troglodytes</u>	14	23	12	12	17	15	2	8	2	8
Sedge Wren <u>Cistothorus platensis</u>	0	1	1	11	0	6	1	1	1	1

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Golden-crowned Kinglet <u>Regulus satrapa</u>	42	39	30	17	36	32	25	12	24	35
Ruby-crowned Kinglet <u>Regulus calendula</u>	12	11	1	3	5	0	0	9	3	4
Blue-gray Gnatcatcher <u>Polioptila caerulea</u>	0	1	0	0	0	0	0	0	0	0
Eastern Bluebird <u>Sialia sialis</u>	0	0	0	0	1	0	6	0	1	0
Veery <u>Catharus fuscescens</u>	0	1	13	12	6	10	0	1	0	0
Gray-cheeked Thrush <u>Catharus minimus</u>	0	0	0	0	0	0	0	0	1	0
Swainson's Thrush <u>Catharus ustulatus</u>	0	0	0	1	0	0	0	0	0	3
Hermit Thrush <u>Catharus guttatus</u>	32	16	35	28	59	66	14	8	8	14
Wood Thrush <u>Hylocichla mustelina</u>	0	0	0	2	0	4	0	0	0	0
American Robin <u>Turdus migratorius</u>	28	23	7	9	11	21	24	6	7	7
Gray Catbird <u>Dumetella carolinensis</u>	0	1	0	0	1	0	0	0	1	0
Brown Thrasher <u>Toxostoma rufum</u>	4	1	6	0	2	0	0	0	1	0
Cedar Waxwing <u>Bombycilla cedrorum</u>	0	0	17	6	5	2	1	9	3	0
European Starling <u>Sturnus vulgaris</u>	0	0	1	0	0	0	0	0	0	0
Solitary Vireo <u>Vireo solitarius</u>	9	5	5	7	3	0	0	1	0	1

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Yellow-throated Vireo <u>Vireo flavifrons</u>	1	1	0	0	0	0	0	0	0	0
Red-eyed Vireo <u>Vireo olivaceus</u>	3	1	61	77	48	81	24	24	27	51
Golden-winged Warbler <u>Vermivora chrysoptera</u>	6	0	7	5	1	0	0	0	0	0
Tennessee Warbler <u>Vermivora peregrina</u>	0	0	0	0	0	0	0	0	3	2
Nashville Warbler <u>Vermivora ruficapilla</u>	90	79	89	76	72	43	2	2	14	21
Northern Parula <u>Parula americana</u>	1	7	6	10	2	9	0	1	0	1
Yellow Warbler <u>Dendroica petechia</u>	2	0	0	0	0	0	0	0	0	0
Chestnut-sided Warbler <u>Dendroica pensylvanica</u>	12	2	50	31	28	8	0	0	0	0
Magnolia Warbler <u>Dendroica magnolia</u>	0	0	1	1	0	0	0	0	0	1
Cape May Warbler <u>Dendroica tigrina</u>	0	0	2	1	0	0	0	0	2	0
Black-throated Blue Warbler <u>Dendroica virens</u>	0	0	0	0	0	1	0	0	0	0
Yellow-rumped Warbler <u>Dendroica coronata</u>	65	48	10	10	15	23	8	0	2	2
Black-throated Green Warbler <u>Dendroica virens</u>	24	55	39	60	24	48	6	5	4	6
Blackburnian Warbler <u>Dendroica fusca</u>	4	0	9	11	1	2	0	0	0	0
Pine Warbler <u>Dendroica pinus</u>	0	0	0	0	1	0	0	0	0	0

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Palm Warbler <u>Dendroica palmarum</u>	1	2	0	0	0	0	0	0	0	0
Bay-breasted Warbler <u>Dendroica castanea</u>	1	0	0	0	0	0	0	0	0	5
Black-and-white Warbler <u>Mniotilta varia</u>	24	30	14	25	12	7	2	1	6	4
American Redstart <u>Setophaga ruticilla</u>	0	0	0	1	0	0	0	0	0	0
Ovenbird <u>Seiurus aurocapillus</u>	69	55	107	118	64	76	2	2	9	18
Northern Waterthrush <u>Seiurus noveboracensis</u>	0	3	0	3	0	0	0	0	0	0
Connecticut Warbler <u>Oporornis agilis</u>	1	3	0	0	2	0	0	0	0	0
Mourning Warbler <u>Oporornis philadelphia</u>	0	0	20	14	12	9	0	0	1	0
Common Yellowthroat <u>Geothlypis trichas</u>	4	2	4	12	18	18	0	5	6	5
Canada Warbler <u>Wilsonia canadensis</u>	0	0	1	2	1	0	0	0	0	0
Scarlet Tanager <u>Piranga olivacea</u>	0	1	11	4	4	12	0	1	0	1
Rose-breasted Grosbeak <u>Pheucticus ludovicianus</u>	13	15	24	30	5	17	3	0	2	5
Indigo Bunting <u>Passerina cyanea</u>	0	0	9	14	20	24	2	15	0	1
Rufous-sided Towhee <u>Pipilo erythrophthalmus</u>	10	2	2	0	3	3	1	0	0	0
Chipping Sparrow <u>Spizella passerina</u>	10	5	10	5	11	10	27	2	3	0

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Vesper Sparrow <u>Poocetes gramineus</u>	1	0	1	1	0	0	0	0	0	0
Song Sparrow <u>Melospiza melodia</u>	22	3	7	4	12	4	0	0	1	0
Lincoln's Sparrow <u>Melospiza lincolni</u>	0	1	0	0	0	0	0	0	0	0
Swamp Sparrow <u>Melospiza georgianna</u>	7	11	6	9	4	11	0	7	2	6
White-throated Sparrow <u>Zonotrichia albicollis</u>	91	50	50	15	57	28	11	10	23	5
Dark-eyed Junco <u>Junco hyemalis</u>	10	0	5	0	1	0	3	0	0	0
Red-winged Blackbird <u>Agelaius phoeniceus</u>	2	24	0	8	1	9	0	0	0	0
Common Grackle <u>Quiscalus quiscula</u>	3	12	1	2	3	5	0	0	0	0
Brown-headed Cowbird <u>Molothrus ater</u>	4	11	2	6	0	2	0	0	0	0
Northern Oriole <u>Icterus galbula</u>	0	1	0	1	1	0	0	0	0	0
Purple Finch <u>Carpodacus purpureus</u>	9	8	1	7	1	0	0	0	0	0
White-winged Crossbill <u>Loxia leucoptera</u>	2	0	0	3	2	0	0	0	0	0
Pine Siskin <u>Carduelis pinus</u>	1	1	0	0	0	0	0	0	0	0
American Goldfinch <u>Carduelis tristis</u>	3	2	8	4	4	5	5	3	0	0
Evening Grosbeak <u>Coccothraustes vespertinus</u>	4	17	0	0	0	0	0	0	0	0

Appendix 4 (continued)

	<u>May</u>		<u>June</u>		<u>July</u>		<u>August</u>		<u>September</u>	
	T	C	T	C	T	C	T	C	T	C
Unidentified passerine	11	17	13	5	15	19	29	29	32	41
Unidentified woodpecker	5	13	0	1	3	4	1	2	0	3
Total individuals	847	858	877	880	772	818	323	353	389	489
Total species	65	65	66	71	65	54	38	45	43	44

Appendix 5. Presentations, publications, and manuscripts based on work conducted as part of the ELF monitoring program.

Presentations

- Hanowski, J.M., and G.J. Niemi. 1987. Statistical perspectives and experimental design in bird censusing. American Ornithologists Union; San Francisco State University; August 1987.
- Hanowski, J.M., and G.J. Niemi. 1987. Assessing the effects of an extremely low frequency (ELF) antenna system on bird species and communities in northern Wisconsin and Michigan. Lake Superior Biological Conference; University of Minnesota-Duluth; September 1987.
- Blake, J.G., J.M. Hanowski, G.J. Niemi, and P.T. Collins. 1988. Seasonal and annual variation in the influence of time of day on bird censuses. Cooper Ornithological Society, Asilomar, California; March 1988.
- Blake, J.G., G.J. Niemi, and J.M. Hanowski. 1989. Annual variation in bird populations: some consequences of scale of analysis. Cooper Ornithological Society, Moscow, Idaho; June 1989.
- Blake, J.G., G.J. Niemi, and J.M. Hanowski. 1989. Drought and annual variation in bird populations: effects of migratory strategy and breeding habitat. Symposium on Ecology and Conservation of Neotropical Migrant Landbirds, Woods Hole, Massachusetts; December 1989.
- Hanowski, J. M., J. G. Blake, and G. J. Niemi. 1990. Seasonal bird distribution patterns along habitat edges in northern Wisconsin. Lake Superior Biological Conference, Ashland, Wisconsin; September 1990.
- Hanowski, J. M., G. J. Niemi, J. G. Blake, and P. T. Collins. 1990. Effects of extremely low frequency electromagnetic fields on bird species and communities.
- Annual Review of Research on Biological Effects of 50/60 Hz Electric and Magnetic Fields, Denver, Colorado; November 1990.
 - 52nd Midwest Fish and Wildlife Conference, Minneapolis, Minnesota; December 1990.
 - XX Congressus Internationalis Ornithologicus, Christchurch, New Zealand; December 1990.

Publications

Hanowski, J.M., G.J. Niemi, and J.G. Blake. 1990. Statistical perspectives and experimental design in counting birds with line transects. *Condor* 92:328-337.

Blake, J.G., G.J. Niemi, and J.M. Hanowski. Drought and annual variation in bird populations. In J. Hagan and D. W. Johnston, eds., *Ecology and conservation of neotropical landbird migrants*. Smithsonian Institution Press, Washington, DC. In press.

Manuscripts (in review)

Blake, J.G., J.M. Hanowski, G.J. Niemi, A.R. Lima, and P.T. Collins. Hourly variation in transect counts of birds. Submitted to *Journal of Field Ornithology*.

Hanowski, J. M., J. G. Blake, G. J. Niemi, and P. T. Collins. Effects of extremely low frequency electromagnetic fields on breeding and migrating birds. Submitted to *Ecological Applications*.

Hanowski, J.M., J.G. Blake, and G.J. Niemi. Lack of edge effect on forest bird abundance and distribution. Submitted to *Journal of Wildlife Management*.

Manuscripts (in preparation)

Collins, P.T., G.J. Niemi, J.G. Blake, and J.M. Hanowski. Lateral distance distribution patterns for northern forest birds.

I. COVER PAGE

A. SUBCONTRACTOR: MICHIGAN STATE UNIVERSITY
EAST LANSING, MICHIGAN 48824

B. SUBCONTRACT NUMBER: E06595-88-C-007

C. TITLE OF REPORT: ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM
ANNUAL REPORT FOR AQUATIC
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D. REPORTING YEAR: 11/1/89 - 10/31/90

E. REPORT IDENTIFICATION NUMBER: AE-110

II. FRONTISPAGE

- A. Subcontractor: Michigan State University
East Lansing, Michigan 48824
- B. Subcontract Number: E06595-88-C-007
- C. Title of Report: ELF Communications System Ecological
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- D. Reporting Year: 11/1/89 - 10/31/90
- E. Report Identification Number: AE-110
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IV. GLOSSARY AND ACRONYMS

AFDW-biomass - ash-free dry weight of organic matter that accumulates on rock or other substrate surfaces on the stream bottom. This organic matter is produced by algae, bacteria, and fungi and/or by the flocculation and settling of suspended organic matter from the water column.

Alkalinity - a chemical measure of the amount of anions in the water determined by titration with dilute acid; a rough measure of the acid neutralizing capacity of the water derived primarily from the carbonate and bicarbonate ions in it.

ANCOVA - analysis of covariance; a statistical analysis in which treatment means are compared by standardizing for differences in a common covariant (a parameter that varies with parameter in question).

ANOVA - analysis of variance; a statistical procedure for comparing whether treatment means are essentially the same or not; it is essentially an arithmetic process for partitioning a total sum of squares into components associated with recognized sources of variation.

BACI - Before and After, Control and Impact analysis - statistical analysis which compares differences between control and impact sites, both before and after antenna operation by comparing differences in the variance for each site before and after the operation of the antenna (see Stewart-Oaten et al 1986 for details - reference section of element 2).

Backcalculated length - a method for calculating the length of fish at previous age from scales or otholiths. Length is estimated from a body-scale relationship between distance between annuli on scales or otoliths and fish length at capture.

Benthos (Benthic) - organisms that live on or in the river bottom in or on substrates such as sand, gravel, and organic detritus.

Biomass - the weight of a population of organisms, or of some defined portion of it such as an individual or a size class.

Body-scale relationship - an empirically determined relationship between length of fish and the distance between annuli on scales or otoliths; used in backcalculation of length.

Biovolume - a crude estimate of biomass of algal cells where volume is calculated from the shape and size of individual cells using geometric formulae. Individual cell volumes are then multiplied by algal species counts and summed to get total biovolume.

Catch rates - the catch of fish, in numbers or in weight per defined unit of fishing effort.

C.C. - correlation coefficient (r); a measure of the degree to which variables vary together or a measure of the intensity of association.

C-F - collector-filter-feeding aquatic invertebrates; invertebrates that feed by collecting particles of detritus or algae from the water by use of nets or other collecting devices.

C-G - collector-gatherer aquatic invertebrates; invertebrates that feed by collecting detrital particles from substrates in the river.

Chi-square test - statistical test for goodness of fit for observed and expected frequencies.

Chlorophyll *a* - the primary photosynthetic pigment of most plants; in this study, it is extracted using acetone and used as a crude measure of plant productivity or standing crop.

Conductivity - a measure of the ionic strength of the water.

CPUE - the catch of fish, in numbers or in weight per defined unit of fishing effort.

C.V. - coefficient of variation; a quantity of use to the experimenter in evaluating results from different experiments involving the same character but possibly conducted by different persons.

Degree days - daily accumulation of degrees ($^{\circ}$ C) above a pre-set threshold value (in our study the threshold was 2° C).

DeLury method - removal method of population estimation. Population is estimated from the relation of fishing success to cumulative fishing effort. Assumes fish catchability does not change throughout all sampling passes, and the population is significantly reduced with each pass. Three removals were used in this study.

Diatoms - a group of algae that often dominate unpolluted rivers (very few other kinds of algae are present in the Ford River most of the time); they are characterized by having the cells encased in two siliceous covers known as valves.

Discharge (Q) - the amount of water passing a particular point on a river over a given time period, usually expressed in cubic meters per second; it is calculated from measurements of width, depth, and velocity by taking at least 20 verticals of depth, mean velocity, and the width between the verticals across a stream or from depth measurements based on depth(stage)-discharge relationships determined empirically for the river segment being studied.

DO - Dissolved Oxygen; the amount of oxygen dissolved in water.

Electrofishing - method used in fisheries to collect/capture fish. Electric current is applied to the water which temporarily incapacitates the fish so that they can be collected.

Electrofishing efficiency - percent of the total population of fish taken by electrofishing crew.

ELF - Extremely Low Frequency electromagnetic radiation; it is derived primarily from local electric power lines or from the ELF antenna that will be used by the Navy to communicate with submarines at sea.

EPROM - Erasable Programmable Read Only Memory chip; the type of chip used to temporarily store data in the Omnidata data pods used in our ambient monitoring program; these data are transferred by use of an EPROM reader into an Apple computer and summarized.

FCD - Ford Control Downstream - site on Ford River presently used as the control site (see Fig. VII.1).

FCU - Ford Control Upstream - site on Ford River originally considered as a control site. Presently in use as a site for monitoring movement of fish into one of the two primary tributaries of the Ford River above our test and control sites (see Fig. VII.1).

FEX - Ford Experimental - site on Ford River presently used as the primary experimental or test site; it is located where the N-S leg of the ELF antenna crosses the Ford River (see Fig. VIII.1).

FFG - Functional Feeding Groups - aquatic insects species are categorized into feeding groups according to their predominant feeding mode (See Merritt and Cummins, 1984 - reference after element 4).

FS1 - Ford Site 1 - site on Ford River originally used for fish movement studies and for monitoring changes in fish populations in cooperation with the Michigan DNR (see Figure VII.1). Not used presently.

Freidman's test - non-parametric test comparing distributions; the null hypothesis being that the populations within a block are identical against the alternative that at least one treatment comes from populations which have a different location in one direction.

Fyke net - passive trap nets at FCD and FEX. Set in tandem, one capturing upstream migrants the other capturing downstream migrants. Nets block entire width of stream and are very portable and used in areas with unstable substrate.

Grazer - as used in this study; an invertebrate herbivore that feeds on algae on rocks and other substrates on the stream bottom.

Gross Primary Production (GPP) - the total amount of energy fixed by green plants in the process of photosynthesis in a given time period; it is equal to plant respiration plus net primary production.

Growth - incremental increase in mean length and weight. Backcalculation of lengths and body-scale relationship were used to monitor growth in this study.

H' - taxon diversity (after Shannon-Weiner). An information theory index which weights the number of taxa and the apportionment of numbers of individuals among the taxa.

Handling (tagging) mortality - mortality caused by weighing, measuring, tagging, etc. Calculated from recaptured fish found dead in the gear in this study. Probably underestimated.

Hardness - a rough chemical measure of the amount of cations in the water determined by titration.

Holobiotic - an organism that spends its entire life in one environmental medium; e.g., an aquatic beetle, Optioservus sp., whose larval and adult stages are aquatic.

J' - taxon evenness (after Shannon-Weiner). An index which evaluates the apportionment of numbers of individuals within each taxon.

-k/day - processing coefficient. An exponential decay model describing the rate biological material (in our case, leaves) decays per day, $\log_e (\% \text{ remaining}/100)/\text{days}$.

Kruskal-Wallis test - non-parametric statistical test comparing distributions; the null hypothesis being that the populations sampled are continuous and identical, except possibly for location.

Lee's Phenomenon - commonly seen in backcalculated length estimates. In the larger fish, backcalculated lengths at early ages are less than the true average size at that age. Usually due to differential growth or mortality. Reverse Lee's Phenomenon can occur also, especially in non-exploited populations or where predator-prey relationships do not exist or are poorly defined.

Lincoln index - an estimate of population size based on the proportion of marked organisms that are captured in a later sampling effort (see Southwood, 1978 - see references after element 2).

Mann-Whitney U test - non-parametric statistical test of two samples which gives rise to a t-test or ANOVA. Null

hypothesis is that two samples come from populations having the same distribution.

Mark-recapture studies - a method for determining population size or movement of organisms based on recapture of marked individuals.

MDW/IND - mean dry weight (mg.) per individual.

N - Nitrogen when used as follows (otherwise refers to the number of samples taken):

- ammonium-N: ammonium-Nitrogen
- nitrate-N: nitrate-Nitrogen
- nitrite-N: nitrite-Nitrogen
- inorganic-N: inorganic-Nitrogen; the sum of the three N species above.
- organic-N: organic-Nitrogen; total Kjeldahl nitrogen minus ammonium nitrogen.

Naiads - the immature (nymph) stages of insects that undergo incomplete metamorphosis; e.g. dragonfly naiads.

Net Primary Production (NPP) - the amount of energy or carbon that is fixed by the process of photosynthesis that is not used in self maintenance (respiration) by the plant; it supports herbivore or detritivore food chains.

Numerical dominance - the ratio between numbers of individuals from one taxon and the total numbers of individuals found in a sample. The percentage gives the numerical dominance of that taxon.

P - predators; animals that ingest other animals.

PAR - Photosynthetically Active solar Radiation = solar radiation that most plants are able to use in photosynthesis; similar to visual range for humans.

PCA - Principal Components Analysis; a statistical procedure used to ordinate data in relation to environmental variables.

Percent recapture - the ratio between numbers of marked animals recaptured and the total number of animals marked.

Periphyton - algae, bacteria and fungi attached to the substrate, rocks, twigs or any other debris in the

stream. Our studies emphasize periphytic algae attached to bottom substrates.

Phaeophytin a - the breakdown product of chlorophyll a; the ratio of chlorophyll a to phaeophytin a is sometimes used as a very crude estimate of the health of algal populations.

Predators - animals that ingest other animals.

Relative weight (W_r) - weight at length values calculated from fish being studied. Used in comparative analysis of condition against weight at length values calculated from populations in the literature.

RIA - Randomized Intervention Analysis; statistical analysis which compares mean differences between sites before and after antenna impact; a non-parametric equivalent of BACI in which the test statistic is compared to a random distribution of the data set.

S - shredder invertebrates; those that feed on large leaf fragments by shredding holes in this leaf material.

S - taxon richness. The number of taxa in a sample.

Shannon-Wiener diversity - diversity index which uses number of species and abundance within species to compute a values which is comparable between sites and years (see H' above).

Shredder - see S (first definition) above.

Standard weight (W_s) - mean weight at length values calculated from a number of populations from the literature. W_r values are measured against these values to comparatively determine the condition of fish being studied.

TB - total biomass; total weight of all organisms in the taxa being discussed.

TM - Two Mile Creek - one of the two principal tributaries of the Ford River above our two primary study sites; presently used for fish movement studies (see Fig. VII.1).

T-test - statistical test of the difference between two means to analyze variance.

Turbidity - a measure of the light blocking particles suspended in the water.

Univoltine - one generation per year; used to describe aquatic insect life cycles.

Weir - semi-permanent traps used to capture fish. Made of wire mesh held in place with metal rods. Installed at beginning of study season and removed at the end of the season; installation is similar to that described for fyke nets above. Weirs intercept fish moving up or downstream. Fish are captured in removeable weir boxes when these boxes are in place. When boxes are removed, weir is negotiable by all fish.

Wr - relative weight condition factors used in fish studies.

Yearling fish - fish that are one + years old but are not yet sexually mature.

YOY - young of year; fish hatched out earlier in the year.

V. ABSTRACT

The goal of the aquatic ecosystems project is to determine the effects of low-level, long-term, electromagnetic radiation on the biota of streams. This electromagnetic radiation will be derived from the U.S. Navy's extremely low frequency submarine communication system (ELF) located in the upper peninsula of Michigan. The specific ecosystem being studied is the Ford River, a fourth order stream that arises in northern Dickinson and southern Marquette Counties and enters the Michigan portion of Green Bay south of Escanaba, Michigan. Detailed ecological sampling and analyses are being conducted simultaneously at two sites. The control site (FCD) is located on a fourth order section of the Ford River in northern Dickinson County just west of the community of Ralph, Michigan. It is approximately five miles downriver from the test site (FEX) where the N-S leg of the antenna system crosses the river. Engineering projections indicate that the control site will receive 8-10 fold less electromagnetic radiation from the antenna than will the test site after the system is fully operational. These two sites were closely matched in terms of electromagnetic exposure from local electric power distribution lines prior to construction and operation of the antenna. Data collected to date are either preoperational data (June, 1983 to June, 1986), transitional data (July, 1986 through 1989), or fully operational (Oct. 7, 1989-present). Exposure to ELF radiation was restricted to daylight hours at 4-6 amps for several days from July to October, 1986, or at 15 amps for several days from April 28 to November 15, 1987, or at 75 amps for most working days from November 15, 1987 to May 1 1989. Exposure after May 1, 1989 was at 150 amps continuously between 4 pm and 8 am on weekdays and on weekends, and intermittently between 8 am and 4 pm on weekdays. On October 7, 1989 the antenna became fully operational.

The ecological monitoring program consists of four primary components. These include: (1) an extensive program of monitoring chemical and physical environmental data for the two sites; (2) a program to determine ELF effects on the algal communities attached to the rocks on the river bottom; (3) a program to determine ELF effects on the aquatic insects; and (4) a program to determine ELF effects on the fish community with emphasis on fish movements between sites. The two primary sites (test and control, FEX and FCD) are very closely matched both physically and chemically. Data routinely monitored at each site include stream discharge, water and air temperature, photosynthetically active solar radiation (PAR) received above and below the water surface, pH, dissolved oxygen, alkalinity, hardness, turbidity, and nutrients used by the plants such as nitrogen, phosphorus,

and silica. Paired t-tests indicate either that there are no differences between sites for most parameters or that slight differences exist that probably have no effect on the biota. Data collected on the algal community includes chlorophyll *a* standing crop and accrual rates, organic matter standing crop and accrual rate measured as ash free dry weight accumulation on microscope slides, diatom density, diatom individual cell volumes, diatom total biovolume, diatom community diversity and evenness, and data on percent dominance by the major diatom species. No differences in any of these parameters have been detected between the data collected before operation of the antenna and data collected after testing began on the antenna that can be attributed to ELF effects using paired t-tests. A before and after, control and impact statistical procedure (BACI) demonstrated that differences do exist between the before and after (transitional) data for some of these parameters. Correlations with weather variables indicate that these differences are related to differential site responses to weather related variables such as temperature and discharge rather than to ELF effects. This indicates the importance of combining the statistical analysis of the between site relationships for biotic variables with a detailed study of the relationship of those variables with the physical environment in order to determine the potential cause of observed changes in the biotic variables. Studies on the effects of grazing invertebrates on the algal communities have yielded comparable results for the two sites with grazers causing shifts in community composition in some years but not in others.

Data collected for aquatic insect communities in substrate samples at FEX and FCD include structural and functional community parameters as well as growth rates for six target taxa. Movements of one dragonfly, Ophiogomphus colubrinus, at FEX and FCD were compared. Leaf processing rates of fresh and of autumn-abscised tag alder at FEX and FCD were compared, and colonization patterns of aquatic insects colonizing those leaves were analyzed using similar biotic indices as for insects in the substrates. The insects associated with the stream bottom showed distinct seasonal patterns. Coefficient of variation values were highest in the spring and fall transition periods. In the summer seasons, coefficient of variation values were at their lowest levels. Data were treated separately, season by season, using 2-Way ANOVA tests. BACI tests were performed on the seven biotic parameters when year and/or site main effects were significant. BACI tests were significant four times; three times in the fall season and one time in the spring season. ANCOVA tests and multiple linear regression analyses using the physical factors, E.L.F. cumulative ground exposure, discharge, and water temperature showed that most of the variability associated with after E.L.F. activation was attributable to discharge (spring), discharge and water

temperature (summer), and water temperature (fall) rather than to E.L.F. cumulative ground exposure. Growth rates of the taxa analyzed were not associated with E.L.F. activation. Movements of a dragonfly predator were so variable within and between test and control sites that this Element was deleted from future studies. Processing rates of fresh leaves were not significantly different between sites over the years. This was also the case for autumn-abscissed leaves. However, in 1990, the year when E.L.F. was fully operational, differences between sites for each leaf treatment deviated as compared with prior years. Fresh leaves were processed faster at the control site and autumn leaves were processed faster at the experimental site. Future studies will be necessary to determine whether this pattern persists. The variability in biotic parameters for insects colonizing the leaves could be best explained by discharge and/or water temperature differences over the years. Growth rates of four target species of insects were not shown to be affected by E.L.F. activation. A new site, FEX.LINE was added in the summer of 1990 in order to increase the difference in electromagnetic exposure between the test and the control site. We now have three sites: FEX, FEX.LINE, and FCD.

The fisheries portion of the aquatic ecosystems project emphasizes the fish community structure and abundance and brook trout (Salvelinus fontinalis) growth, condition and mobility. Much of the data are obtained using 1/2 inch mesh fyke nets and 1/2 inch hardware cloth weirs. Catch statistics for all species caught by this gear are kept and used to generate data on community composition and abundance as well as data on age, length, growth, and relative condition of individual species. Fourteen species were collected at the test site (FEX) in 1990 while eighteen species were collected at the control site (FCD). Overall, the species composition and diversity were similar at the two sites with the only changes seen in the seldom caught species. Growth and condition factors were calculated for several of the more common species and compared to literature values. Length-weight regression analysis and relative weight values were used in brook trout condition analysis. Most species in the Ford River grow slower than the average calculated from populations in the literature. Brook trout movement varied in intensity and magnitude over all years of the study due to changes in population abundance. Brook trout movements peaked in every year as temperatures exceeded their optimum for growth (16° C) and this timing was variable over all years of the study. Pre- and post-movement population estimates obtained at least 1 mile downstream of the study sites have shown that brook trout density decreases significantly after the peak movement occurs. At this time no effect of the ELF antenna operation has been detected on 1) species diversity, 2) catch by number or biomass, 3) mean daily brook trout movement rates, or 4) brook trout length-

at-radius regressions. However, behavioral observations and certain recapture results tentatively suggest that brook trout may not move upstream under the fully operational antenna.

Overall, we have detected no changes in the aquatic community that we can relate statistically with confidence to operation of the ELF antenna. We monitor a wide variety of population and community level parameters for the algal, insect and fish communities. Many of these have low enough coefficients of variation between the control and test sites to allow us to detect relatively subtle (20 to 30 %) differences should such differences occur.

VI. SUMMARY

This research project is directed at determining the effects of low-level, long-term, electromagnetic fields (ELF) on natural stream ecosystems and their associated plant and animal life. Detailed ecological sampling and analyses are being conducted simultaneously at two sites: (1) a control site, FCD, and (2) an experimental site, FEX, at the corridor of the ELF antenna. These sites have been studied since 1983 with additional sites monitored for studies of fish movements. The N-S leg of the ELF antenna crosses the FEX site and was tested at 4-6 amps for several hours on several days from May to October, 1986; at 15 amps during part of several days between April 28 and November 15, 1987, at 75 amps for most working days during 1988 and at 150 amps during most working days in 1989 and has been operated at full power since October 7, 1989. The analyses reported here includes data from the four year transition period and one year of full antenna operation.

Element 1- Conduct Ambient Monitoring Program

Data for all chemical and physical parameters demonstrated that the experimental and control sites were very well matched. For the majority of the parameters, there were no significant differences between sites. When significant differences did occur between the chemical constituents, they usually involved slight increases in a downstream direction. This trend of slight increase from the upstream site to the downstream site for alkalinity, hardness, nitrate, and organic nitrogen may be related to an expected accumulation of dissolved load in a downstream direction or to local land use differences between sites. Whatever the cause, the differences were small and probably would not lead to significant inter-site differences in productivity. We conducted experiments in 1987 to determine the impact of N and P inputs on the algal community. Both had to increase before significant changes in the algal community occurred. Clearly, no such shift in N and P has occurred.

Dissolved oxygen was only slightly below saturation at both sites but was slightly but significantly higher at FEX

than it was at FCD. This is consistent with all previous years except 1988.

Chloride also was slightly but significantly higher at FEX than it was at FCD. This difference might reflect a slight amount of road salt influence from Highway M-95 at Channing, MI that is diluted in a downstream direction. This difference between the two sites did not occur in 1988. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored. The differences that did occur were slight and should have little impact on site productivity.

Element 2- Monitoring of Species Composition, Numbers, Diversity, Biomass Production, Cell Volume, and Chlorophyll a/Phaeophytin a Production for Periphyton.

1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year-to-year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t-tests for 1989-90 data showed a significant difference between our control (FCD) and experimental sites (FEX), although there were no differences for all data collected since 1983. "Before" (6/83-4/86) and "after" (5/86-9/90), control (FCD) and impact (FEX) (BACI) and Randomized Intervention Analysis (RIA) indicate that the between site relationship in chlorophyll a has changed since May 1989 when the testing of the antenna began. The significant positive correlations between water temperature and chlorophyll a, the importance of water temperature as a predictor of chlorophyll a in stepwise regression models, and the increasing water temperatures during the drought periods in the spring and summer in 1986, 87, 88, 89, and 90 lead us to believe that this change is related to weather variables and not to ELF exposure. This conclusion is supported by analysis of covariance (ANCOVA) of the after data with ELF exposures included as a covariant. ANCOVA analysis do not suggest that ELF exposures are correlated with the observed inter-site differences.

2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year-to-year variability similar to chlorophyll a. These parameters have been consistently characterized by showing no significant differences between sites since 1983, although organic matter accrual at FEX was higher than FCD for 1989-90. BACI analyses and RIA also showed that no difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. Stepwise regression analysis indicate that water temperature is the most important predictor of organic matter standing crop. Organic matter standing crop was correlated with water temperature (positively) and dissolved oxygen (negatively).

3. Diatom Cell Density

Diatom cell density continued to be characterized by no statistical difference between sites, regardless of length of data set compared according to paired t-tests. However, BACI analyses and RIA indicated that data collected before May 86 were significantly different from data collected after May 86. The increased density after May 86 may be related to the low discharges and high temperatures during May and early summer in each of these years. Density was highest in May in all five years. Silica concentrations and water temperature appeared in the stepwise regression analysis as the most reliable predictors of diatom density. The importance of weather was suggested by the significant positive correlation with water temperature.

4. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences according to paired t-tests. BACI analysis and RIA detected no significant changes in the inter-site relationship for biovolume. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density. Stepwise regression analysis indicates that water temperature and soluble reactive phosphorus concentrations are the most consistent predictors of cell volume, while there were no consistent predictors of total biovolume. Average cell volume was negatively correlated ($p < 0.05$) with water temperature and total biovolume was not correlated with any of the physical/chemical variables.

5. Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1990 or for all data collected to

date according to paired t-tests. Annual trends showed a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. In 1990, we calculated percent abundance for all species of diatoms and presented data for those species that achieved dominance greater than 10 % for any season. Two species, Achnanthes minutissima and Cocconeis placentula were found to dominate during the 1990 summer period. Three species achieved dominance during the winter of 1989. Synedra was a dominant winter species, but represented a smaller proportion of the community than it had been during winter 1986-87. BACI and RIA analyses were presented for four dominant and two non-dominant species of diatoms, and showed that few differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the BACI and RIA analyses. Because of the pattern of year to year differences and ANCOVA results, we suggest that these changes may be related to factors other than ELF effects.

6. Effects of Environmental Variables on the Periphyton Community

Stepwise multiple regression analysis was conducted for each biological parameter on the physical/chemical variables. In many cases, the regression models agreed with the results of the correlation matrix, yet a large amount of variance was left unexplained. In some cases, the regression models pointed out relationships that did not show up in the correlation matrix (for instance, silica appeared consistently in the models for density and diversity, yet, neither was correlated with silica). The stepwise regression models and correlation matrix proved useful in identifying possible causes for the patterns observed for our biological parameters and are essential for separating weather effects from possible ELF effects.

7. Photosynthesis-Respiration Studies

Net primary production, respiration, and gross primary production of the community on rock surfaces did not differ greatly between sites. RIA and BACI analyses indicated that there have been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data.

Element 3- Effects of Insect Grazer Populations on Periphyton Communities.

Grazing macroinvertebrates can change the composition of the diatom community at densities equal to or greater than

densities found in the Ford River. Specifically, Glossoma nigrum, a grazing caddisfly, caused a shift in dominance within the diatom community in 1985 and 1986 with Cocconeis decreasing in abundance and Achnanthes increasing in abundance as grazing pressure increased. Such shifts in community structure occurred at both FEX and FCD despite no significant changes in community based parameters such as diversity, chlorophyll a and organic matter biomass accumulation expressed as ash free dry weight. Results from 1985 were somewhat different from results from 1986. In 1986, the trend towards decreased abundance of Cocconeis and increased abundance of Achnanthes occurred at both sites but was not as significant as in 1985. In 1987, there was no measurable impact of grazers on any aspect of the periphyton community with the possible exception of shifts in dominance of a couple of minor taxa at FEX. In 1988 and 1989, there was a grazer impact on the dominance of Achnanthes but this impact resulted in a decrease in dominance (opposite the results of 1985 and 86). Between year differences in the impact of grazers on the diatom communities in our streamside channels may be due to the initial densities of the diatoms on the colonized tiles used in the experiment and/or to silt decreasing the ability of the grazer to utilize the algae in the organic matrix on the tiles. Regardless of the reasons for the year to year variability, such variability limits the usefulness of these studies in detection of E.L.F. effects on the stream biota. Thus, we propose to eliminate this element from the study in the future and increase our efforts for Element 2.

Element 4 - Species Richness and Biomass of Stream Insects from Artificial Substrates in Riffles

Coefficient of variation values for structural and functional community parameters were lowest during the summer season each year (June - August) and were highest during the transitional periods of spring (April, May) and fall (September - November) seasons. In the spring, both dramatic changes in water temperature and potentials for high discharges interact with life cycle changes of the insects. In the fall, dramatic drops in water temperatures and fall rains also interact with life cycle changes of the insects. Therefore, data analyses were separated by season. The summer, more stable period, should be the season where any E.L.F. effects could be best detected. Two-Way ANOVAS showed significant year and/or site differences for many biotic parameters, with the summer season showing the fewest significant differences. Only in the summer months were there no significant year by site interactions (except for numbers of individuals, which is the most 'coarse-grained' biotic parameter).

B.A.C.I. tests were performed for variables where there were significant year or year by site differences. Those tests showed significant before versus after differences once in the spring (numbers of individuals) and three times in the fall (H', J', S). Results were never significant for the summer data analyzed, which included H', J', S, numbers of individuals, total insect mass, and predator/prey ratios.

Both discharge and water temperatures were significantly correlated with insect mass and with periphyton density. ANCOVA analyses showed that discharge varied with insect mass. During the spring, mass of insects at FEX were more negatively impacted by discharge than was insect mass at FCD. There were significant differences between site means during the summer and fall because FEX almost always supported a higher mass of insects than FCD.

Multiple linear regression tests were performed with years, E.L.F. cumulative ground exposure, mean discharge, and cumulative degree days as the independent variables. In the spring, discharge accounted for more of the variation in S, numbers of individuals and mean insect mass than any other physical variable. In the summer, both discharge and/or cumulative degree days accounted for most of the variation in H', J', S, numbers of individuals and total insect mass. In the fall, cumulative degree days accounted for most of the variation at FEX. Multiple R^2 values were low for most of the biotic parameters at FCD in the fall. Only one significant relationship was found then; between discharge and numbers of individuals.

Changes in mean dry weight/individual (MDW/IND) values for three mayflies, one beetle, two caddisflies, and the chironomid assemblage were presented. Thus far, one species, Paraleptophlebia mollis has been analyzed using chronological as well as physiological time (cumulative degree days) as the independent variables. There was no relationship between E.L.F. activation and changes in MDW/IND values for this species.

An additional site was added to the study in June of 1990: FEX.LINE. This site, downstream of FEX, has higher E.L.F. fields impinging it and data from that site will be compared both with the FEX site and the reference site, FCD, in future reports.

Element 5 - Movements of Ophiogomphus colubrinus, a Dragonfly Predator

(This element was deleted after 1989, but a first draft of the results appears in this report.)

Movement patterns of Q. colubrinus were followed by marking and recapturing animals at FEX and FCD from 1985 through 1989. Recapture success was very high, averaging approximately 50%. This species moved only in a downstream direction and it moved relatively short distances. Nine 24 hr and eleven 48 hr recapture series were performed. There were no consistent differences between the sites with respect to distances travelled, even through E.L.F. lines were activated in 1986 and were increased in amperage and duration from that time until the system went into full operation in the fall of 1989.

Element 6 - Leaf Litter Processing

Each year, fresh leaves were processed faster than were autumn leaves at each site when all years were averaged together. There were no site differences for fresh leaves and no site differences for autumn leaves. A new site was added; namely, FEX.LINE. The intensity of ELF fields are higher there than at the FEX site. Fresh and autumn leaves were placed there in 1990. Leaf processing rates were analyzed for all sites from the beginning of the study through 1990. In 1990, the year when E.L.F. was in full operation, fresh leaves were processed much more slowly at FEX relative to FCD. Thus, there were strong deviations between sites that cannot be accounted for by techniques or by an unusual fall. 1991 should be an important year in determining whether the 1990 results will be repeated. The addition of the new site below the E.L.F. antenna should be especially helpful.

Insects collected from leaves in 1990 are yet to be fully analyzed, and so insect data for 1990 are not available for this report. The lowest coefficient of variation (C.V.) values for structural and functional community parameters of the insect community on leaves occurred after the leaves had been in the river approximately four weeks. Data from that period of incubation was used in the analyses. Multiple regression analyses, using years, cumulative degree days, and mean discharge values showed that most of the variation in H' was accounted for by cumulative degree days and by mean discharge values, with little being accounted for by years alone. All three non-orthogonal physical variables explained much of the variation in processing rates, insect taxon richness, numbers of individuals, and total insect mass, adjusted for leaf mass. In no case did years alone explain most of the variation. B.A.C.I. tests could not be performed on these data, as there is only one mean value for any given year of processing rates and for any collection data. Further, the samples are non-independent, given the

fact that we are looking at the continuum of processing patterns.

ANCOVAS showed that growth rates (MDW/IND values) for two species of mayflies and one species of stonefly, for the most part, were not significantly different between sites. In only one case were sizes of individuals of Ephemerella invaria on autumn leaves different between FEX and FCD after E.L.F. activation. In 1986 and in 1989, size classes were lower at FEX than at FCD. This difference only occurred for the last collection date (There are six collection dates). Data from the 1990 and 1991 seasons at the two sites and at the new site should reveal whether this pattern occurred by chance or whether the individuals of this species, when found on autumn leaves, grow more slowly at the FEX site.

Two appendices appear at the end of this Element: A draft of a manuscript on the effects of condensed tannins on leaf processing rates and a paper written by Ms. Jennelle Marcereau, my field assistant for the summer, who did an independent project on preferences of leaf material under differing periods of incubation by Pteronarcys sp.

Element 7 - Fish Community Composition and Abundance

1. Species Composition

Fourteen species from four orders and nine families were collected at FEX in 1990. This represented a net decrease of one order, one family and four species from previous years. Eighteen species from eleven families and six orders were collected at FCD in 1990 with an decrease of three species from previous years. Overall, the species composition was similar at the two sites with the only changes seen in rare species.

2. Species Abundance

Numerically and by biomass, the catch was dominated by five species. Numerically, common shiners and creek chubs made up over 50% of the catch at both sites. Burbot and creek chub catch was the least variable, and brook trout, white sucker and common shiner catches were most variable. By biomass, white suckers and brook trout were the dominant species at FEX making up over 70% of the catch. At FCD, common shiners and white suckers comprised nearly 70% of the catch. Brook trout and white sucker catch in biomass was the most variable. Catch in biomass was more variable from year to year than catch in number. Overall, the fish species composition was similar from site to site and from

year to year. BACI analyses indicated that there were no significant differences between FCD and FEX in either the numeric or biomass catch when the pre-operational (1983-1985) and transitional (1986-1989) periods were compared.

Shannon-Weaver species diversity index decreased at both sites in 1990 from previous values. Index values have been decreasing linearly at both sites from 1983 to 1990. Covariance analysis indicates that the rate of decrease has been similar at both sites. BACI analysis suggests that there has been no demonstrable effect of the ELF antenna on species diversity.

3. Catch Statistics

Catch rates (catch per day) were variable for all species and were seasonally dependent. At FEX, catch rates for common shiners, burbot, and white suckers were about average. Brook trout and creek chub catches decreased. Brook trout continued a negative trend in catch rate at FCD. Common shiner catch was extremely high at FCD while creek chub and white sucker catch was average to slightly below average when compared to previous years. Brook trout, burbot and white suckers all demonstrated similar catch rates at both sites and the differences can be attributed to increased habitat heterogeneity at FCD. BACI analysis indicated no difference in the mean daily catch between FEX and FCD when the pre-operational (1983-1985) and transitional (1986-1989) periods were compared.

The mean length of most species in 1990 showed no consistent year to year trends at either FCD or FEX, and brook trout, creek chubs and white suckers at FCD were significantly larger than their FEX counterparts.

4. Fish Community Mobility

Most non-salmonid fish species with adequate sample sizes demonstrated site to site movement with most species showing a non-marking site recapture rate of 20%. Recapture percentages for 1989 were high, similar to 1983 through 1985. Site to site movements were lower in 1986, 1987, 1988 and 1990 due to significant discharge or population size changes in these years.

5. Individual Species Analyses

Age, growth and condition factor analysis using common shiners, creek chubs and white suckers was initiated as a section of this element in 1986 with the premise that these factors are good indicators of fish stress. Growth analysis using scales indicated that common shiners and creek chubs show better than average growth when compared to values in

the literature. White suckers and northern pike both displayed poor growth when compared to literature values. Fish condition was examined using relative condition factors. Standard weight formulas were derived for common shiners, creek chubs and white suckers from literature data. Common shiner condition was above the species average in each year. Creek chubs and white suckers demonstrated below species average condition ($Wr = 87-92$). Creek chub condition factors declined from 1983-1987 and then increased slightly in 1988 through 1990. Common shiner condition showed a cyclic trend from 1983 - 1986, then maintained a lower condition above the species mean for 1986 - 1988 and 1990. The 1989 condition factor for common shiners was very high. White sucker condition declined from 1983 through 1986 then improved from 1987 through 1990, however, all values were below the species mean.

6. Fixed Gear Calibration

This study is designed to determine a functional relationship between fixed gear catch and actual fish densities. Net and weir catches can then be used to more accurately determine fish densities in the Ford River. DeLury estimates showed that fish densities and biomass declines from upstream sites to downstream sites. Also pre-movement (Spring) populations and biomass are higher than post-movement (Summer) estimates at all sites.

Element 8 - Brook Trout Movement

1. Movement Patterns and Rates

Brook trout catches peaked in late spring-early summer at all sites. The peak occurred in June in 1984, 1987, 1988 and 1989 and in July in 1985 and 1990 with the movement in an upstream direction. Peak catches 1984, 1985, 1987 and 1988 were not seen in 1986, 1989, or 1990. Brook trout movement appeared to be initiated by mean daily water temperatures exceeding the optimal growth temperature (16°C). Movement rates are probably controlled by how quickly temperatures increase past optimal in spring. Low groundwater discharge and river flow volumes also may create thermal barriers to movement. Ground water recharge through spring snowmelt and precipitation are also important variables. Brook trout ($>190\text{ mm}$) move from FEX and FCD upstream toward the TM site based on a total of 754 tagged and branded fish. In all years, TM was chosen over FCU on the basis of the mean temperature being closer to optimal growth temperature. Recapture rates were consistent from 1984 to 1985 with no movement found 1986 and little in 1987, 1988 and 1990. Movement was observed in 1989 although not at 1984-1985 levels. Movement rates were found to range

between 0.67 to 6.7 km/day. Rates from FEX to TM were similar between 1984, 1985, 1987 and 1989 with no catches between these sites in 1986, 1988, and 1990. Brook trout movement rates were greater in 1989 than 1984 and 1985 from FCD to TM with no movement detected in 1986 and 1988 and little in 1987 and 1990.

No differences in either mean daily movement rate or number of days between tagging and recapture were detected when the pre-operational and transitional periods were compared. Chi-squared analysis indicates that a greater percentage of brook trout moved upstream past the antenna during the pre-operational (1983-1985) period than did so during the transitional period (1986-1989). A suspected increase in the density of beaver dams from 1984 to 1989, coupled with the low water during these years, confounds the interpretation of the chi-squared test and precludes attributing the difference to the operation of the ELF antenna. Lack of any brook trout recaptures at a fyke net established upstream of the antenna and observations of the behavior of one radio-tagged brook trout, tentatively suggest that brook trout may not migrate upstream past the fully operational ELF antenna.

2. Population Analysis

Michigan Department of Natural Resources conducted four electrofishing surveys at two sites on the Ford River. The brook trout density at FS1 in June 1985 was 269 ± 47.5 per ha with biomass of 2.35 kg/ha. Most of these fish were YOY and yearling fish with very low densities of adult fish. Trout densities at FCD ranged from 60.7 fish/ha (biomass = 1.28 kg/ha) at pre-movement to 0 fish during the summer post-movement period. These densities are very low when compared to literature values and are probably indicative of the variable conditions of the Ford River. These data also indicate that a large percentage of the population moves out of the lower river (FCD site) in the Spring movement period.

ELF calibration studies determined the brook trout densities range from 0.0 fish/ha at FCD to 405.7 fish/ha at TM and that biomass ranges from 0.0 kg/ha at FCD to 14.7 kg/ha at TM. Overall values are below Michigan averages and show the recruitment is low at the sites sampled (except TM).

3. Brook Trout Age, Growth and Condition

Age and growth analysis using scales indicated that the brook trout in the Ford River exhibit average or better growth when compared to literature values. BACI analysis suggests that brook trout captured at FCD and FEX did not differ in length-at-radius when pre-operational (1983-1985) and transitional (1986-1989) periods were compared. However, BACI analysis did suggest a possible difference

($\alpha = 0.10$) when the slopes of weight-at-length regressions from pre-operational and transitional periods were compared. During the pre-operational period slopes of the weight-at-length regression for FEX were greater than those at FCD; during the transitional period, the opposite was true. Brook trout length at age 1 was approximately 90 mm, at age 2 was approximately 188 mm and at age 3 was approximately 285 mm. Brook trout condition was examined using relative weight condition factors (W_r) and regression analysis. A standard weight formula was calculated from 45 literature populations for use in this analysis. Ford River brook trout demonstrated average to below average condition when compared to the species average (W_r 89 - 104). Condition factors declined from 1983 to 1986 and improved in 1987 to 1990. Statistical analysis of this data is in progress and will be reported in the next report.

VII. PROJECT RATIONALE AND APPROACH

Our research plan is directed at determining the effects of extremely low-level, long term electromagnetic fields (ELF) and gradients produced by the ELF Communications Systems on aquatic plant and animal life. The integrated approach we have taken is to combine the major interrelated and interactive components of aquatic systems (i.e., periphytic algae, aquatic insects, and fish) and to monitor sensitive life history events and community processes critical to the basic structure and function of stream ecosystems. These include: periphyton and stream invertebrate colonization, migration, diversity, trophic level changes in density and biomass, as well as primary productivity; organic matter processing by macroinvertebrates; dynamics of fish population growth, reproduction, and survival; fish behavior including movement patterns of homing and migration. Since many of these processes and events are mutually dependent on one another and interactions are complex, we feel that a holistic approach with a multi-disciplinary effort is imperative.

Our research plan represents an integrated study of stream ecosystems involving three aquatic components for monitoring the potential effects of ELF. These components are: (1) periphytic algae; 2) aquatic insects; and 3) fish. The design incorporates studies of ecosystem properties with studies of behavior and biology of individual species so that any effects of ELF can be quantified at the population, community and ecosystem levels.

We selected stream ecosystems as representative aquatic ecosystems rather than lakes or marshes because; (1) upstream-downstream paired plots on the same system provide less variability than between lake comparisons; (2) migratory behavior is more likely to be important in stream organisms; and (3) our expertise and interests are oriented toward stream ecology.

The effects of ELF on stream ecosystems will be tested using a paired plot design of selected sections of the chosen stream, the Ford River. Plots were selected to afford one area of study away from the antenna corridor for use as a control site (FCD), and another area directly under the antenna cable for use as the experimental site (FEX) (Fig. VII.1). These two stream sections constitute our paired plot design. We have intensively studied and sampled the river at these sites since June of 1983, when the final site selections were made. We also monitor fish movement using the other sites indicated on Fig. VII.1 (FCU, and TM).

Study Area, Dickinson Co., Michigan

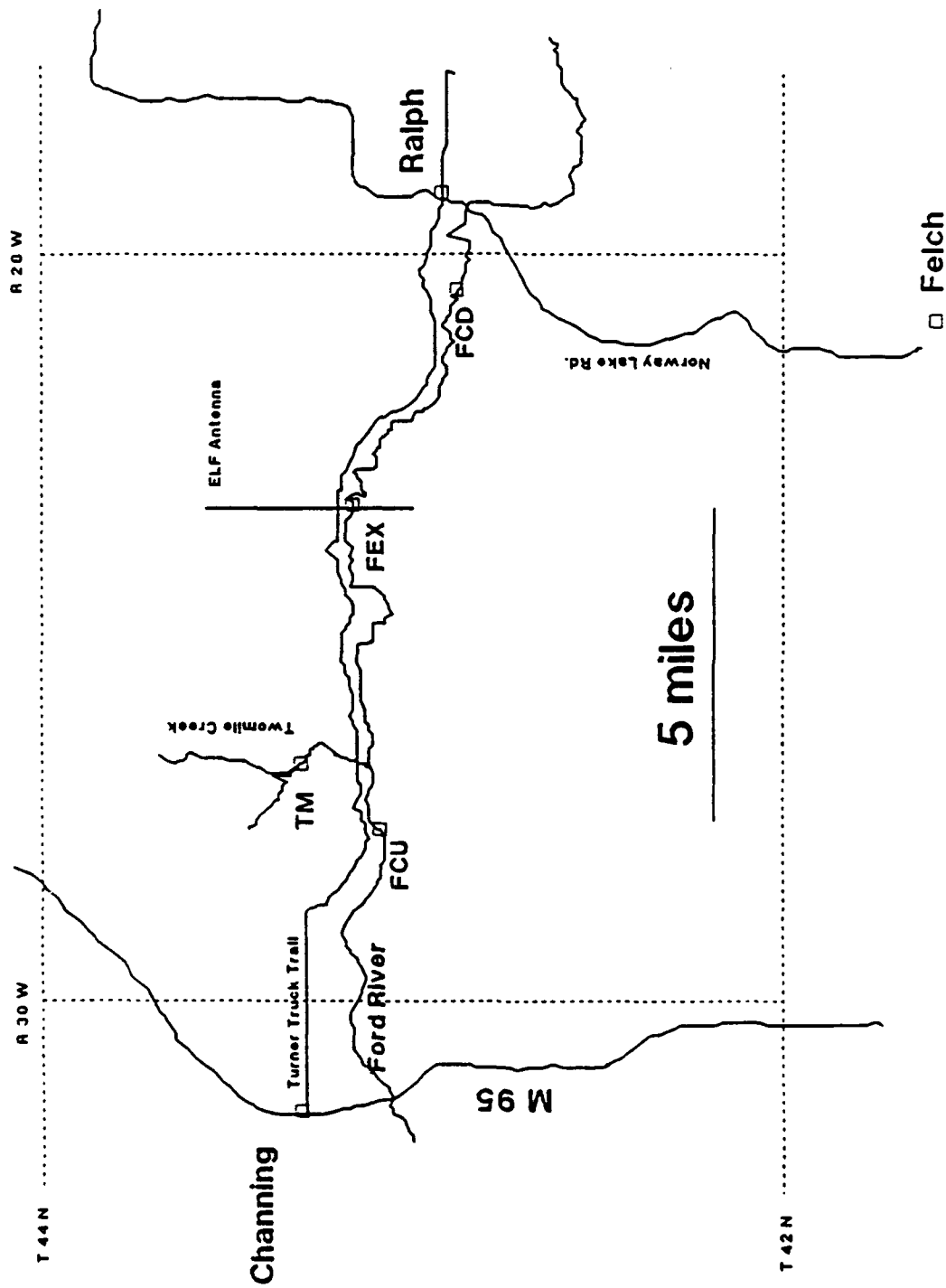


Figure VII.1 ELF Research Sites on the Ford River, Dickinson County, Michigan.

For the two primary sites, we are continuously monitoring stream velocity and water depth so the discharge can be calculated. Water temperatures, dissolved oxygen, pH, and solar radiation at the surface and at the stream bottom are also being continuously monitored. We also sample all other chemical parameters required in the RFP.

The data generated from this research should; (1) determine whether the ELF Communications System affects aquatic plant and animal life in stream systems; and (2) contribute to a better understanding of stream processes which will help clarify a number of important aspects of current conceptual models of stream ecosystem structure and function.

VIII. PRESENTATIONS AND PUBLICATIONS FOR 1989-1990

- Burton, T. M., M. P. Oemke, and J. Molloy. 1989. The effects of N and P additions on the algal communities in a hardwater and a softwater stream in northern Michigan. 24th Congress, Societas Internationalis Limnologiae. August 11-18, Munich, Germany. (Paper in press in Verh. Internat. Verein. Limnol. 24: to be published in 1990).
- Burton, T. M., M. P. Oemke, and J. Molloy. 1990. Effects of grazing by the Trichopteran, Glossosoma nigrior, on diatom community composition in the Ford River, Michigan. 11th International Symposium on Living and Fossil Diatoms, August 12-17, San Francisco, CA. (To be published in Symposium Proceedings in Mem. Calif. Acad. Sci.).
- Burton, T. M., M. P. Oemke, and J. Molloy. 1990. The effects of stream order and alkalinity on the composition of diatom communities in two northern Michigan river systems. 11th International Symposium on Living and Fossil Diatoms, August 12-17, San Francisco, CA. (To be published in Symposium Proceedings in Mem. Calif. Acad. Sci.).
- Marod, S. M., G. E. Whalon, and W. W. Taylor. 1989. Brook trout movement due to thermal stress in the Ford River, Dickinson County, Michigan. Annual Meeting, Michigan Academy of Sciences, March 17, Grand Rapids, MI.
- Marod, S. M. and W. W. Taylor. 1989. Temperature initiated brook trout movements in the Ford River, Dickinson County, Michigan. 51st Midwest Fish and Wildlife Conference, December 3-6, Springfield, IL.
- Mullen, D. M. and T. M. Burton. 1990. Electromagnetic field effects on a riverine ecosystem in northern Michigan. U.S. Department of Energy Annual Review of Research on Biological Effects of 50/60 Hz Electrical and Magnetic Fields, November, Denver, CO.
- Stout, R. J. 1990. Invited Seminar, Leaf input dynamics across latitudinal gradients, October, Department of Botany, University of Florida, Gainesville.
- Stout, R. J. 1990. Invited Seminar, Role of condensed tannins in leaf processing in streams, November, Department of Entomology, Michigan State University, East Lansing.

IX. OVERALL OBJECTIVES AND SPECIFIC TASK OBJECTIVES

OVERALL OBJECTIVE

Our major objective in this study is to determine the effects of low level, long term electromagnetic fields and gradients produced by the ELF Communication System on aquatic plant and animal life in streams. The study will incorporate studies of ecosystem properties with studies of behavior and biology of individual species so that any effects of ELF will be quantified at the population, community and ecosystem level.

SPECIFIC TASK OBJECTIVES

A. Periphytic Algal Studies

The objectives of the periphytic algal studies are:

- (1) to quantify any changes in species diversity, algal density, and chlorophyll *a* that might occur as a result of ELF electromagnetic fields;
- (2) to quantify any changes in primary productivity that might occur as a result of ELF; and
- (3) to monitor algal cell volume and chlorophyll *a* to phaeophytin *a* ratio, thereby providing an index to physiological stress of periphytic algal cells that might occur as a result of ELF electromagnetic fields.

B. Aquatic Insect Studies

The objectives of the studies of aquatic insects are:

- (1) to quantify any changes in organic matter processing rates that occur as a result of ELF;
- (2) to quantify changes in species richness, individual abundances, and species diversity of the aquatic insect communities associated with leaf pack and inorganic stream bottom substrates;
- (3) to quantify trophic, behavioral, and community level changes in selected species of aquatic insects from an array of functional feeding groups (grazers, collectors, etc.).

C. Fish Studies

The objectives of the studies of the fish are:

- (1) to quantify any changes in the seasonal movement patterns and abundance of the mobile fish community that occur as a result of ELF;

- (2) to quantify any changes in the rate of brook trout movement through the ELF corridor that occur as a result of ELF electromagnetic fields.

X. PROGRESS BY WORK ELEMENT

Element 1 - Conduct Ambient Monitoring Program

Changes from workplan - None.

Objectives

The objectives of this work element are: (1) to provide the background data on physical and chemical parameters needed to correlate observations on biological community dynamics with environmental parameters, and (2) to monitor stream chemistry to determine whether or not observed changes in community structure are related to water quality changes rather than potential ELF radiation induced changes.

Rationale

The chemical and physical factors selected for study are known or suspected to be important factors that may control or influence growth, community structure, or community dynamics of periphyton, insects, and fish. Correlating these variables with biological data may ultimately be useful in predicting the effects of these environmental parameters on the biotic community. Thus, they may be useful in separation of background environmental variability from effects induced by extremely low frequency electromagnetic radiation (ELF). Even though many of these variables may not presently correlate with biological data, unexpected large shifts could lead to dramatic changes in the biotic community. Thus, a second goal of the monitoring program is to document the presence or absence of shifts in chemical or physical variables that could occur if some perturbation such as an unexpected discharge of a pollutant were to occur. The physical and chemical parameters being monitored include the major plant nutrients because of their potential impact on trophic level dynamics (e.g. the various species of nitrogen and phosphorus as well as silica since diatoms dominate benthic algal production) or parameters that are known to influence insects and fish (e.g. turbidity, dissolved oxygen, discharge and current velocity, water temperature, etc.). Many of the parameters were originally specified in the request for proposal and offer general indices to site productivity or water quality (e.g. specific conductance, alkalinity, hardness, chloride, etc.). Some of the original parameters have been eliminated. These include total dissolved solids and suspended solids. Neither correlated well with biological

parameters. Further, an index to total dissolved solids can be derived from correlations of this parameter with specific conductance, alkalinity, and hardness, while turbidity provides an index to suspended solids (see correlations reported in the 1988 annual report).

The goal of this annual report will be to present data on all parameters collected since 1983 at our current monitoring sites (the experimental site, FEX, and the control site, FCD) and to document trends and variability in each parameter. We also present statistical comparisons between the two sites in order to document the fact that the two sites do not differ significantly for most of these parameters.

Materials and Methods

Ambient monitoring stations were installed at the experimental site (FEX) and at the control site (FCD) in July, 1983 and were operated until the last week of October. Each year since 1983, these stations were installed in mid-April and were operated through the last week of October. This period represented the period from snow melt in spring until the time of some ice and snow deposition in autumn. After late October, problems were encountered with equipment maintenance and the stations were removed and stored for the winter.

The ambient monitoring equipment automatically logged on Omnidata data pods (model DP 211) the following parameters:

(1) Photosynthetically active solar radiation (PAR) was measured in a clearing on the stream bank and represented above water solar radiation. PAR was also measured under the water surface, 15 cm above the stream bottom in a riffle to pool transition area and represented below water solar radiation. These measurements were taken using Li-Cor Model LI-192SB underwater quantum sensors. Data were taken at both FEX and FCD through 1986, but measurements were deleted at FCD in 1987 due to failure of one of the data pods. This pod was repaired and has worked well since 1988. However, the above water solar probe at FEX failed for 1990. Because of the loss of the FCD pod in 1987, all correlations involving solar radiation in our analysis use the above water solar radiation at FEX. Since it is impossible to place the solar probes at the location of the periphyton samplers (these samplers are moved frequently to maintain a match in depth and velocity between the sites), the above water solar probes at both sites have been placed in the most unshaded area available. This provides a daily measure of light intensity available to the area which should correlate with the daily intensity at the periphyton samplers. To be consistent, and since there is no data for FCD in 1987, we have opted to use the FEX solar data as

representative of the entire area including FCD. For 1990, the above water solar radiation at FCD was converted (using a conversion factor for between site differences generated from the 1989 data at both sites) into FEX values and used in the correlational analysis. The above water solar probe for FEX will be repaired for the 1991 field season.

(2) Dissolved oxygen was monitored using L. G. Nestor Model 8500 portable dissolved oxygen meters with general purpose submersible probes. These meters started to deteriorate in performance in 1987 after five years in the field. We had difficulty maintaining the meters and probes in operating condition especially at FCD. We had these meters repaired during the 1987-88 winter period and ordered new probes. We obtained reliable data for both sites for 1988. The dissolved oxygen meter at FCD was submerged in a flood event during mid-June of 1989. As there were insufficient funds at the time to replace it, the dissolved oxygen data used for this report comes from the twice weekly samples taken in the field at both sites. A new D.O. meter was ordered for the 1990 season, however, it was placed on backorder, and we did not receive it until the end of the field season. The 28 day mean dissolved oxygen at FEX using this field data is not significantly different (paired-t = -0.117, P = 0.913) than the 28 day means calculated using the ambient monitoring equipment at that site. Thus, we feel that there is no serious loss of data resulting from the temporary loss of the meter. Since the ambient monitoring equipment provides more detailed data (every 30 minutes throughout the season) than the manual field sampling, we are replacing the D.O. meter before the start of the 1991 field season.

(3) pH was measured using the Altex (Beckman) Monitor II System with specially built long term, gel-filled submersible pH probes from Fisher Scientific. These meters have given us problems in the past. The meters were repaired over the winter of 1987-88 and new probes were ordered. We think that much of our past problems were associated with using the submersed probes for too long a period of time. These probes only have a submersed expected life of 3 or 4 months according to the chemist at Fisher Scientific. By changing the probes as needed over the summer, we were able to obtain consistent data from 1988 through 1990.

(4) Air and water temperature were monitored using thermistors which are corrected (when necessary) for instrument errors using correction factors generated twice a week from measurements taken with hand held thermometers simultaneously with the measurements taken with the thermistors.

Water depth was monitored using Stevens Type F strip chart recorders. These depth data were used to calculate

discharge using a stage height-discharge relationship developed for each of the two sites on the Ford River. Stage (water level) - discharge relationships were determined for each station using Teledyne Gurley pygmy or Price-type current meters using the velocity area technique (Gregory and Walling 1973, p. 129) with at least 20 verticals per cross-section. At least 15 of these determinations have been made at various stage heights each season to insure that the relationship has not changed from previous years. The extremely low flow associated with the drought conditions in 1988 led to some adjustments of the stage-discharge relationship for the low discharge end of the regression for both sites. Discharge values were highly predictable from stage height data using calculated regressions with R^2 values greater than 0.96 for FEX and 0.97 for FCD.

All automatically acquired data were checked and calibrated at least twice per week. Thus, even if the meters became inoperable, we still had at least two determinations per week for each parameter. For example, the field pH meters were calibrated twice per week with pH 7 and 10 buffers, and field pH meters were checked against an Orion Model 701 specific ion and pH meter in the laboratory at these same times twice each week. Dissolved oxygen meters were calibrated using the azide modification of the Winkler procedure (APHA 1980). Air and water temperature were recorded twice per week using hand-held thermometers, and depth was recorded from the manual staff gauges at each site.

Data from the data pods were transferred from the EPROM chips in the data pods to diskettes using an Omnidata Model 217 reader and an Apple II plus computer. Data, accumulated daily at 30 minute intervals, were read and summarized every two weeks throughout the April to October period. These data are summarized for the 28 day intervals used for periphyton sampling in this report. Daily summary data were supplied to each task investigator (periphyton, insects, fish tasks) as computer printouts.

In addition to the manual determinations of pH, dissolved oxygen, water and air temperature as described above, samples were taken once per week for determination of turbidity, alkalinity, hardness, and specific conductance. These samples were chilled on ice, returned to the field laboratory, and the above parameters were determined within three hours of collection. Twice per week, samples were taken and frozen for later determination of total phosphorus, soluble reactive phosphorus (samples filtered within three hours of collection), nitrate-N, nitrite-N, ammonium-N, organic-N (total Kjeldahl N minus ammonium),

chloride, and dissolved silicate-Si (Si samples were refrigerated instead of being frozen since freezing can cause interference with this procedure). The N, P, Si, and Cl samples were analyzed during the winter months after preparation of the annual report. Thus, there is a one year lag time in reporting these data. During winter months, samples were taken at one month intervals for all of the parameters discussed above through the winter of 1986-87. This interval was decreased to once every other month in 1987-88 and once every 6 weeks in 1988-90 since the expense of taking the samples is prohibitive given the minimal amount of biological data collected during the winter months.

All chemical analyses followed procedures outlined in Standard Methods (APHA 1980) or approved techniques of the U.S. Environmental Protection Agency (U.S. EPA 1979).

Stream velocity was also recorded for the periphyton samplers (see Element 2) using the Gurley pygmy meters about once per week. These data were used to adjust the positions of the periphyton samplers in the stream so that samplers at each site were exposed to comparable flow regimes. These velocity measurements will be presented in Element 2 of this report.

Statistical comparisons included paired t-tests between the two sites for each parameter, correlations between the two sites and correlations between the chemical and physical parameters. Unless otherwise indicated, we accepted as significant $p < 0.05$.

This year for the first time, the ELF exposure rates at each site could be calculated from antenna operation time and intensity data provided by IITRI. These data were combined with on site measurements of exposure at each intensity (also provided by IITRI) as follows:

1. The total hours of operation for each antenna element (NS, EW1, EW2) or combination of elements (EW or B) were summed for each day and multiplied by 60 to determine total minutes of operation.
2. This was then multiplied by the site specific exposure (mV/min) determined for each amperage used and for each antenna element (provided by IITRI).
3. The total mV experienced from each antenna element for a day were summed to give the total mV experienced at each site for every day

of operation as follows:

$$E = EW1a + EW2b + EWc + NSd + Be$$

where:

- *E = total exposure (mv) at a site for a day
- EW1 = total time (min) that the East West Leg 1 element of the antenna was operated on that day
- EW2 = total time (min) that the EW2 element of the antenna was operated on that day
- EW = total time (min) that the EW element (both EW1 and EW2 elements) of the antenna was operated on that day
- NS = total time (min) that the North South element of the antenna was operated on that day
- B = total time (min) that the whole (Both the EW and NS elements) of the antenna was operated on that day
- a = site specific exposure rate while only the EW1 element was operating
- b = site specific exposure rate while only the EW2 element was operating
- c = site specific exposure rate while both the EW1 and EW2 elements were operating
- d = site specific exposure rate while only the NS element was operating
- e = site specific exposure rate while the whole antenna was operating
- * the calculations for each day use the exposure rates at each site that have been determined for the specific amperage that the antenna was operating at on that day

The following steps were taken in order to make these calculations possible:

1. The on-site measurements made in May 1990 were used for all 150 amp calculations.
2. Since there were no measurements taken at 5C1-5 (FCD periphyton, P/R, grazer, insects and leafpack site) until 1988, the values from 5C1-1 (the FCD ambient monitoring site) were used for 5C1-5 prior to 1988. These values were approximately equal for the 2 sites when they were both measured in 1988, 1989 and 1990.
3. Since we only have measurements for the NS

and EW elements in 1988 and for B (both) elements in 1989, and the antenna operated in all three modes over those 2 years, B in 1988 was estimated to be 1/2 of B in 1989 (operations were conducted at 75 amps in 1988 and at 150 amps in 1989) and NS and EW in 1989 were estimated to be twice NS and EW in 1988. This was done on the advice of IITRI.

These data were only available through 1989 and all analyses involving these data reported here are limited to data collected before 1990. Steps are currently underway to update the exposure data.

Results and Discussion

A. Field Chemistry

The dissolved oxygen (DO) data for 1990 (Table 1.1) corroborated the highly predictable pattern observed at both sites for all previous years of the project with winter highs and summer lows (Fig. 1.1). In general, winter values were 11 mg/L or higher and summer values never dropped below 7 mg/L (Fig. 1.1). Since cold water contains more dissolved oxygen at saturation than does warm water, one would expect this type of pattern if the water in the river is near saturation throughout the year. The Ford River was typically 5-15 % undersaturated at each site. DO showed high negative correlations with temperature at each site ($r = -0.91$ and -0.94 at FCD and FEX respectively, $p < 0.01$ at both sites). There was a significant ($p < 0.01$) correlation ($r = 0.94$) in dissolved oxygen values between the two sites for 1990 (Table 1.2) as illustrated by Fig 1.1 and Table 1.1. We also reported this high degree of correlation for all data collected prior to 1990 ($r = 0.99$) (Table 1.3). In 1990, there were significant differences between the two sites (Table 1.2) with FEX being consistently higher than FCD. Differences between the two sites are generally quite small (Fig. 1.1) with values at each site well above DO levels of 6.0 mg/L needed for maintenance of trout populations in good condition (Mckee and Wolf 1963).

The 1990 pH data for the two sites followed the previous pattern of summer highs and winter lows (Fig. 1.2, Table 1.1) probably related to higher levels of primary production in the summer (see Element 2) coupled with lower stream discharge, and higher values for alkalinity (pH is significantly ($p < 0.01$) correlated with these parameters). The most highly correlated parameters with pH were water temperature with $r = 0.70$ and discharge with $r = -0.78$. The pH values at the two sites were significantly correlated

Table 1.1 pH and Dissolved Oxygen (mg/L) for the Ford River.
Values are Means $\pm$ S.E., N in Parentheses.

Date	pH		Dissolved Oxygen	
	Experimental(FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
10/2/89	8.00 $\pm$ 0.01 (3)	7.80 $\pm$ 0.05 (12)	9.85 $\pm$ 0.27 (9)	9.71 $\pm$ 0.25 (9)
10/30/89	8.09 $\pm$ 0.01 (6)	8.10 $\pm$ 0.01 (6)	11.43 $\pm$ 0.36 (9)	11.15 $\pm$ 0.37 (9)
12/11/89	7.98 $\pm$ 0 (2)	7.98 $\pm$ 0 (2)	10.68 $\pm$ 0 (2)	10.10 $\pm$ 0 (2)
1/22/90	7.83 $\pm$ 0 (2)	7.83 $\pm$ 0 (2)	11.50 $\pm$ 0 (2)	10.55 $\pm$ 0 (2)
3/3/90	7.85 $\pm$ 0 (2)	7.80 $\pm$ 0 (2)	12.08 $\pm$ 0 (2)	10.93 $\pm$ 0 (2)
4/16/90	7.85 $\pm$ 0 (2)	7.85 $\pm$ 0 (2)	12.50 $\pm$ 0 (2)	11.45 $\pm$ 0 (2)
5/14/90	7.87 $\pm$ 0.04 (9)	7.88 $\pm$ 0.03 (9)	11.16 $\pm$ 0.38 (9)	10.84 $\pm$ 0.38 (9)
6/11/90	7.98 $\pm$ 0.01 (22)	7.87 $\pm$ 0.02 (26)	10.24 $\pm$ 0.16 (8)	9.86 $\pm$ 0.16 (8)
7/9/90	7.95 $\pm$ 0.02 (24)	7.93 $\pm$ 0.02 (26)	8.72 $\pm$ 0.20 (9)	8.51 $\pm$ 0.09 (9)
8/6/90	8.07 $\pm$ 0.02 (14)	8.06 $\pm$ 0.01 (20)	9.07 $\pm$ 0.17 (9)	8.89 $\pm$ 0.09 (9)
9/4/90	8.07 $\pm$ 0.02 (11)	8.00 $\pm$ 0.03 (6)	9.01 $\pm$ 0.11 (8)	9.16 $\pm$ 0.13 (9)

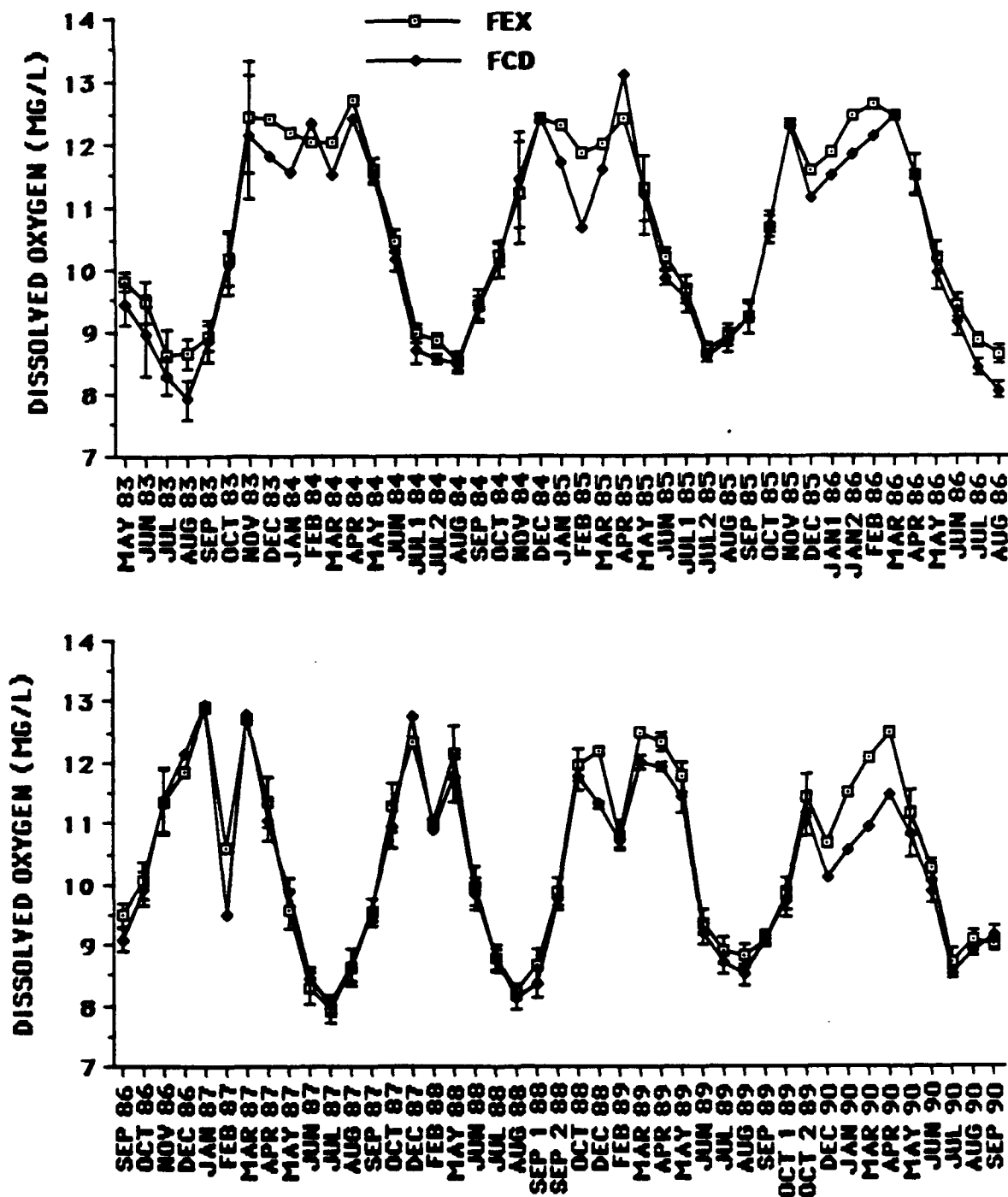


FIGURE 1.1 MEAN DISSOLVED OXYGEN LEVELS (± 1 SE) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

Table 1.2 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for water chemical constituents and ambient parameters for 1989-1990.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Conductivity	10	1.190	NS	0.62	P<0.05
Hardness	10	- 3.150	P=0.05	0.99	P<0.01
Alkalinity	10	- 1.381	NS	0.92	P<0.01
Turbidity	10	- 2.193	NS	0.88	P<0.01
pH	10	2.003	NS	0.79	P<0.01
Dissolved Oxygen	10	3.666	P=0.01	0.94	P<0.01
Water Temperature	10	1.962	NS	1.00	P<0.01

Table 1.3 Results of Paired t-tests and correlations between Experimental (FEX) and control (FCD) sites for water chemical constituents and ambient parameters from June 1983 to September 1990.

Parameter	df	Paired t-value	Significance	Correlation Coefficient	Significance
Conductivity	85	0.026	NS	0.81	P<0.01
Hardness	85	-4.178	P<0.01	0.98	P<0.01
Alkalinity	85	-2.404	P<0.05	0.97	P<0.01
Turbidity	84	-2.147	P<0.05	0.73	P<0.01
pH	79	1.040	NS	0.29	P<0.01
Dissolved Oxygen	84	6.552	P<0.01	0.97	P<0.01
Water Temperature	84	3.463	P<0.01	1.00	P<0.01

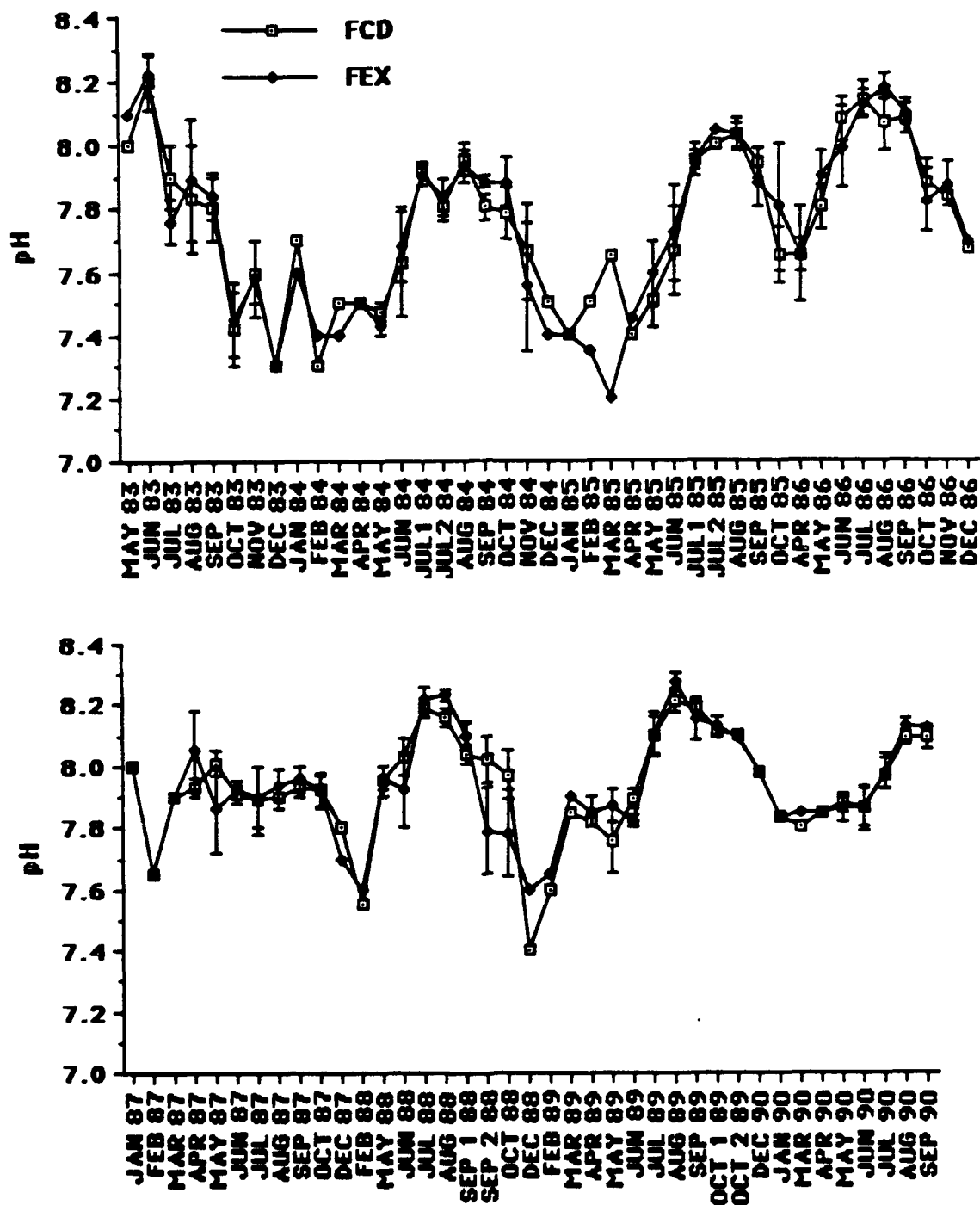


FIGURE 1.2 MEAN pH LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

with each other in 1990, and there were no significant differences between sites (Table 1.2) as was true for all data collected over the course of the study (Table 1.3). Automatically acquired data for the two sites for 1990 were consistent in quality unlike the inconsistent data collected in 1986 and 1987. The changes in procedure described in the methods section resulted in this consistent data in 1988 through 1990.

Alkalinity and hardness followed similar trends for the two sites (Table 1.4, Figs. 1.3, 1.4) with high values occurring during times of low flows and low values occurring during times of high flows (Fig. 1.5, 1.6). Both parameters showed strong negative correlations with discharge ($r > -0.80$) and were significantly ($p < 0.01$) positively correlated with specific conductance ($r = 0.70$ or greater). As expected, hardness and alkalinity were highly correlated with each other ($r = 0.95$, $p < 0.01$) at both sites, and it would be feasible to drop one of these two analyses from our sampling program. If we elect to drop one of these two in the future, we will drop hardness. Alkalinity at FCD was highly correlated with alkalinity at FEX both in 1990 ($r = 0.92$, $p < 0.01$) and when all data since 1983 were included ($r = 0.97$, $p < 0.01$). There was no significant difference between the sites for 1990 (Table 1.2); however, there was a significant difference between the sites (FCD > FEX) when the whole data set was examined (Table 1.3). Hardness was just as highly correlated between the sites, but there was a significant difference between the sites for both 1990 and the entire data set (Table 1.2, Table 1.3). Hardness at FCD was slightly, but significantly, greater than at FEX. The slight but significant increases in hardness and alkalinity for the entire data set from the upstream site to the downstream site may be related to an expected increase in cations and anions associated with accumulation of ions in a river in a downstream direction.

Conductivity (Fig. 1.7, Table 1.5) followed the same seasonal pattern as did alkalinity (Fig. 1.3) and hardness (Fig. 1.4), with high conductivities occurring in months with low discharge and lower conductivities occurring in the months with high discharge (conductivity correlates negatively with discharge ($r > -0.75$, $P < 0.01$)). Conductivity values at FEX were significantly ($p < 0.05$) correlated ($r = 0.62$) with conductivity values at FCD during 1990 (Table 1.2) and for all data collected since 1983 ($r = 0.81$) (Table 1.3). There were no significant differences between sites (Table 1.2).

Turbidity (Table 1.5, Fig. 1.8) remained relatively low reflecting the excellent water quality of the Ford River. Turbidity at FEX was highly correlated with turbidity at

Table 1.4 Alkalinity and Hardness (mg CaCO₃/L) for the Ford River.
Values are Means $\pm$ S.E., N in Parentheses.

Date	Alkalinity		Hardness	
	Experimental (FEX)	Control (FCD)	Experimental (FCX)	Control (FCD)
10/2/89	167 $\pm$ 2 (5)	164 $\pm$ 3 (5)	184 $\pm$ 1 (5)	182 $\pm$ 3 (5)
10/30/89	158 $\pm$ 4 (4)	160 $\pm$ 4 (4)	177 $\pm$ 4 (4)	179 $\pm$ 4 (4)
12/11/89	154 $\pm$ 0 (2)	156 $\pm$ 0 (2)	177 $\pm$ 0 (2)	179 $\pm$ 0 (2)
1/22/90	159 $\pm$ 0 (2)	157 $\pm$ 0 (2)	189 $\pm$ 0 (2)	192 $\pm$ 0 (2)
3/4/90	141 $\pm$ 0 (2)	159 $\pm$ 0 (2)	189 $\pm$ 0 (2)	196 $\pm$ 0 (2)
4/16/90	115 $\pm$ 0 (2)	141 $\pm$ 0 (2)	163 $\pm$ 0 (2)	175 $\pm$ 0 (2)
5/14/90	86 $\pm$ 20 (5)	105 $\pm$ 7 (5)	126 $\pm$ 6 (5)	132 $\pm$ 8 (5)
6/11/90	96 $\pm$ 9 (5)	87 $\pm$ 21 (5)	121 $\pm$ 9 (5)	126 $\pm$ 9 (5)
7/9/90	121 $\pm$ 10 (5)	123 $\pm$ 10 (5)	145 $\pm$ 10 (5)	149 $\pm$ 9 (5)
8/6/90	156 $\pm$ 4 (5)	155 $\pm$ 4 (5)	177 $\pm$ 3 (5)	178 $\pm$ 3 (5)
9/4/90	162 $\pm$ 2 (5)	159 $\pm$ 2 (5)	181 $\pm$ 2 (5)	181 $\pm$ 2 (5)

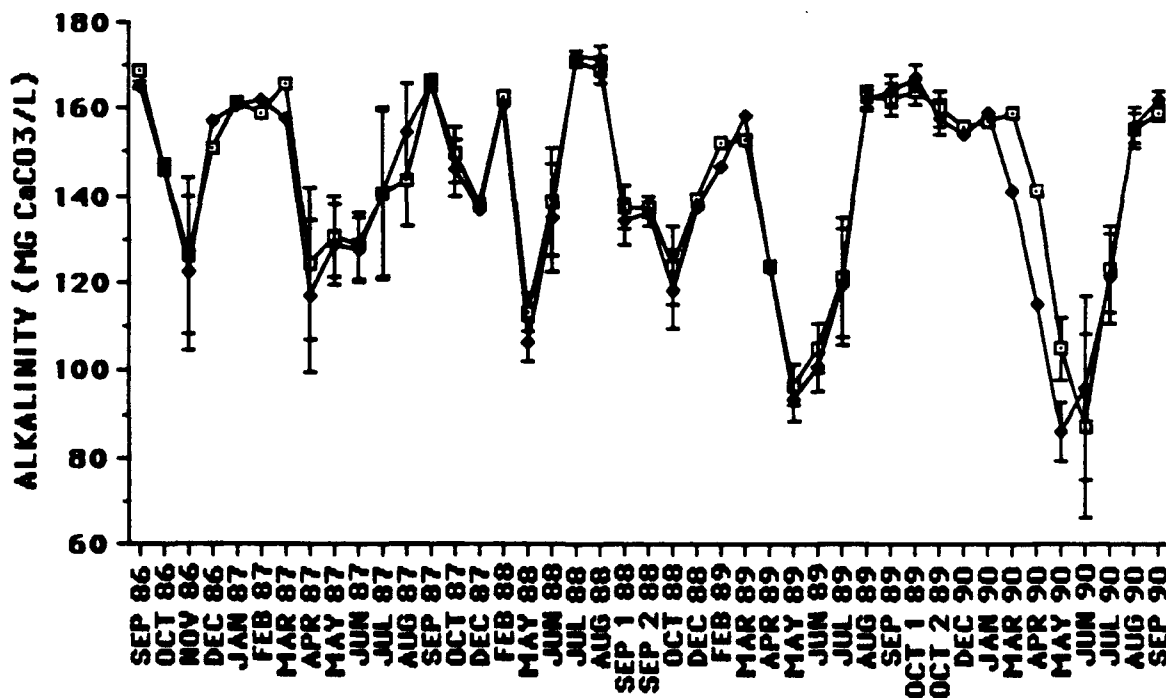
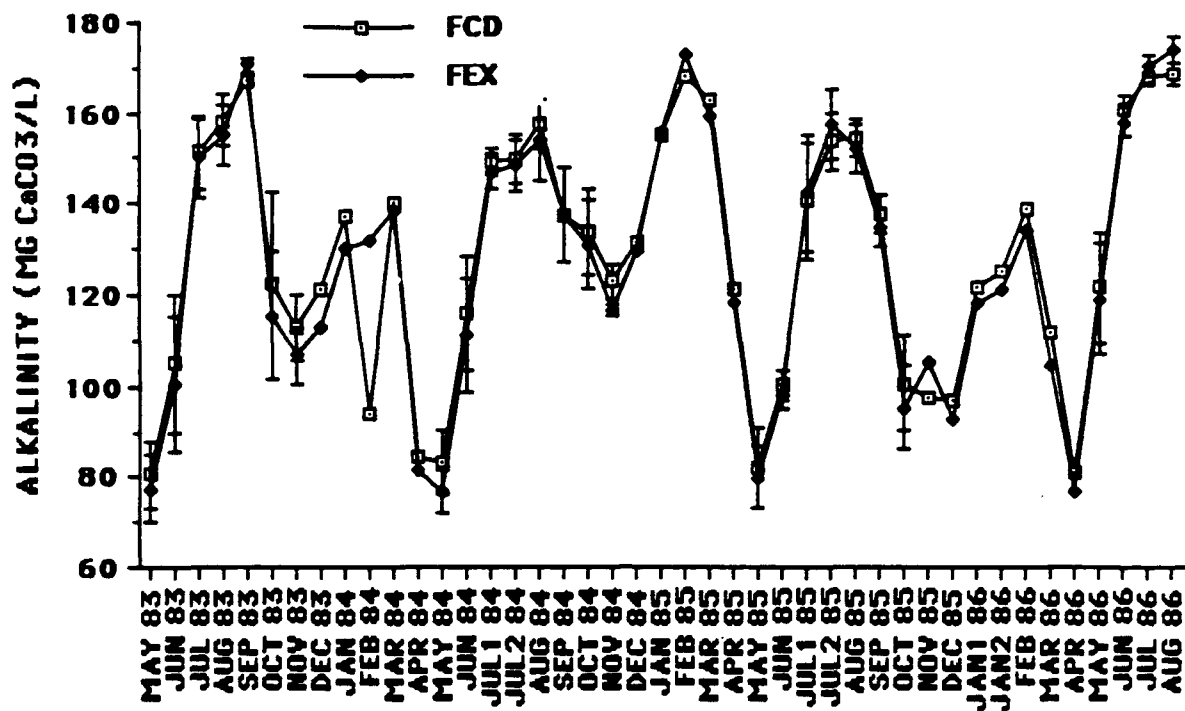


FIGURE 1.3 MEAN ALKALINITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

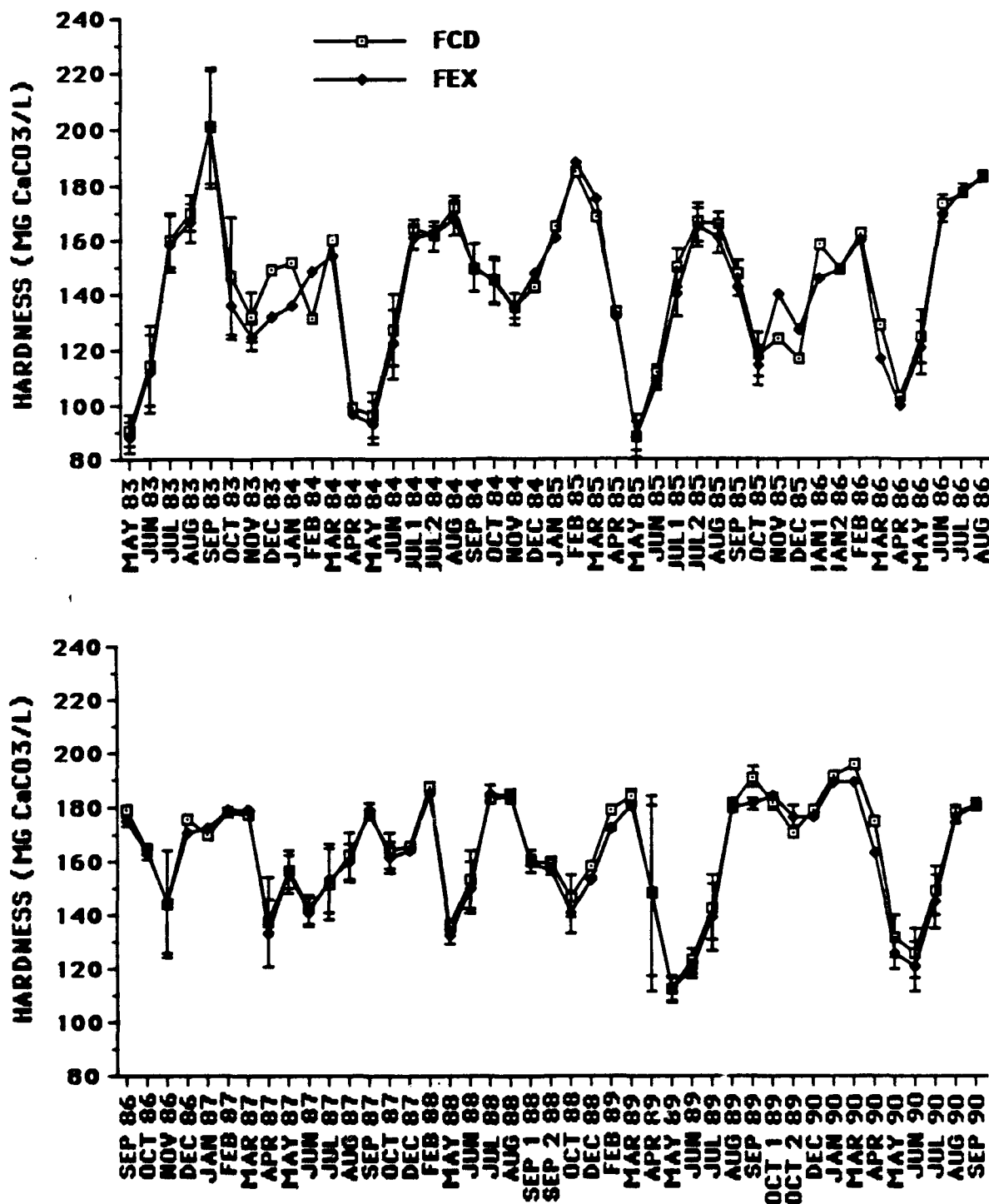


FIGURE 1.4 MEAN HARDNESS LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

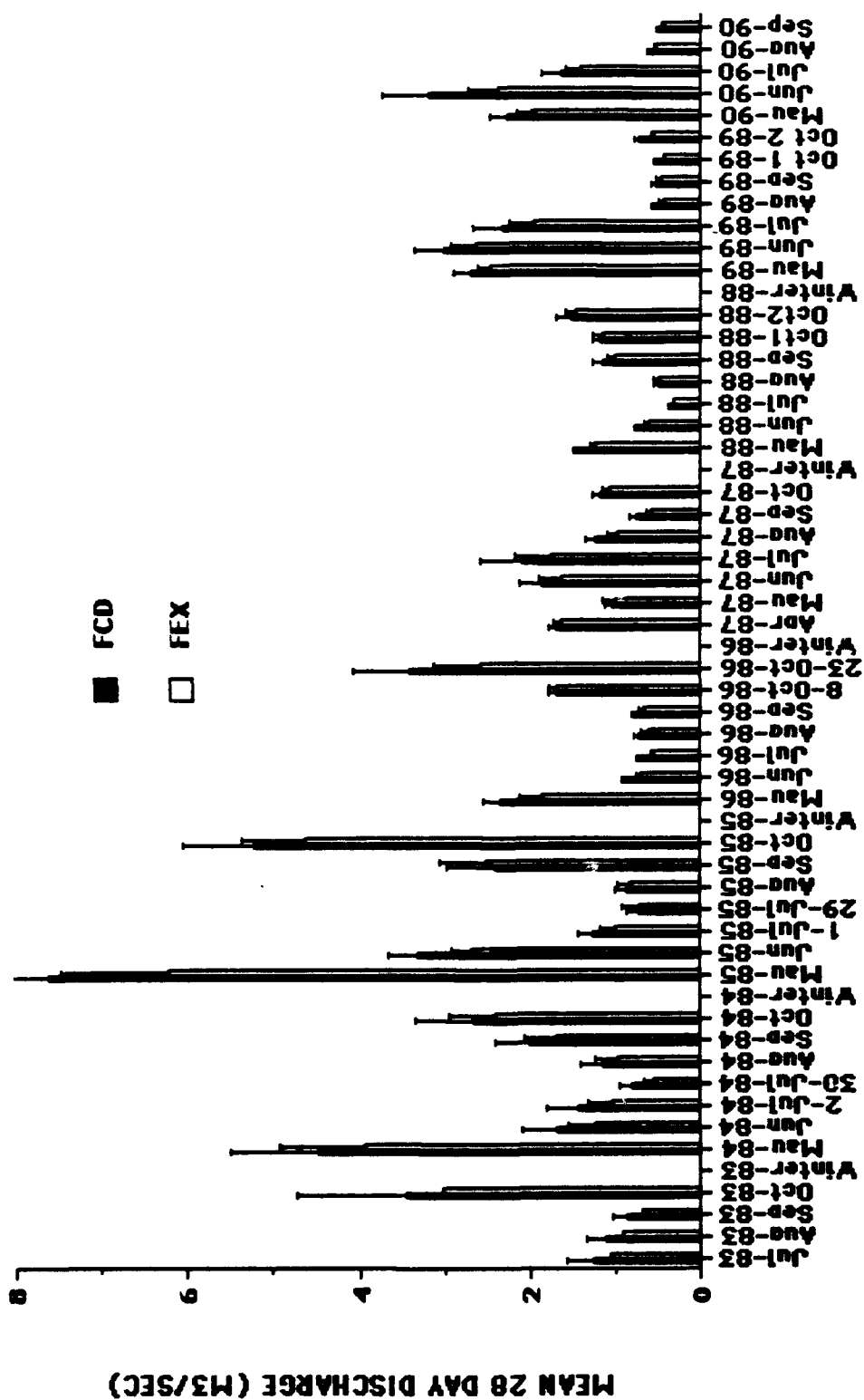


FIGURE 1.5 MEAN DISCHARGE LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

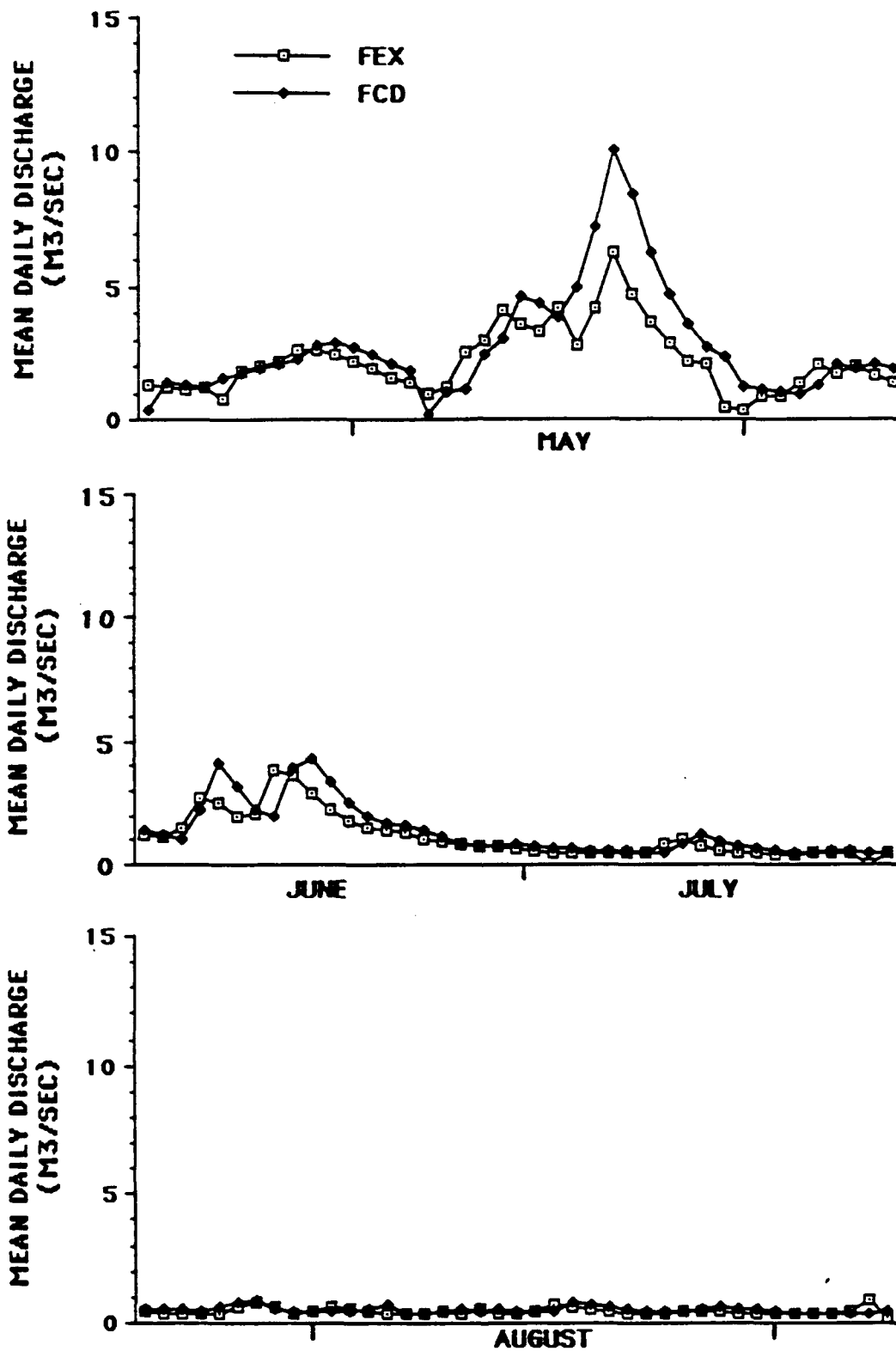


FIGURE 1.6 DAILY DISCHARGE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1990.

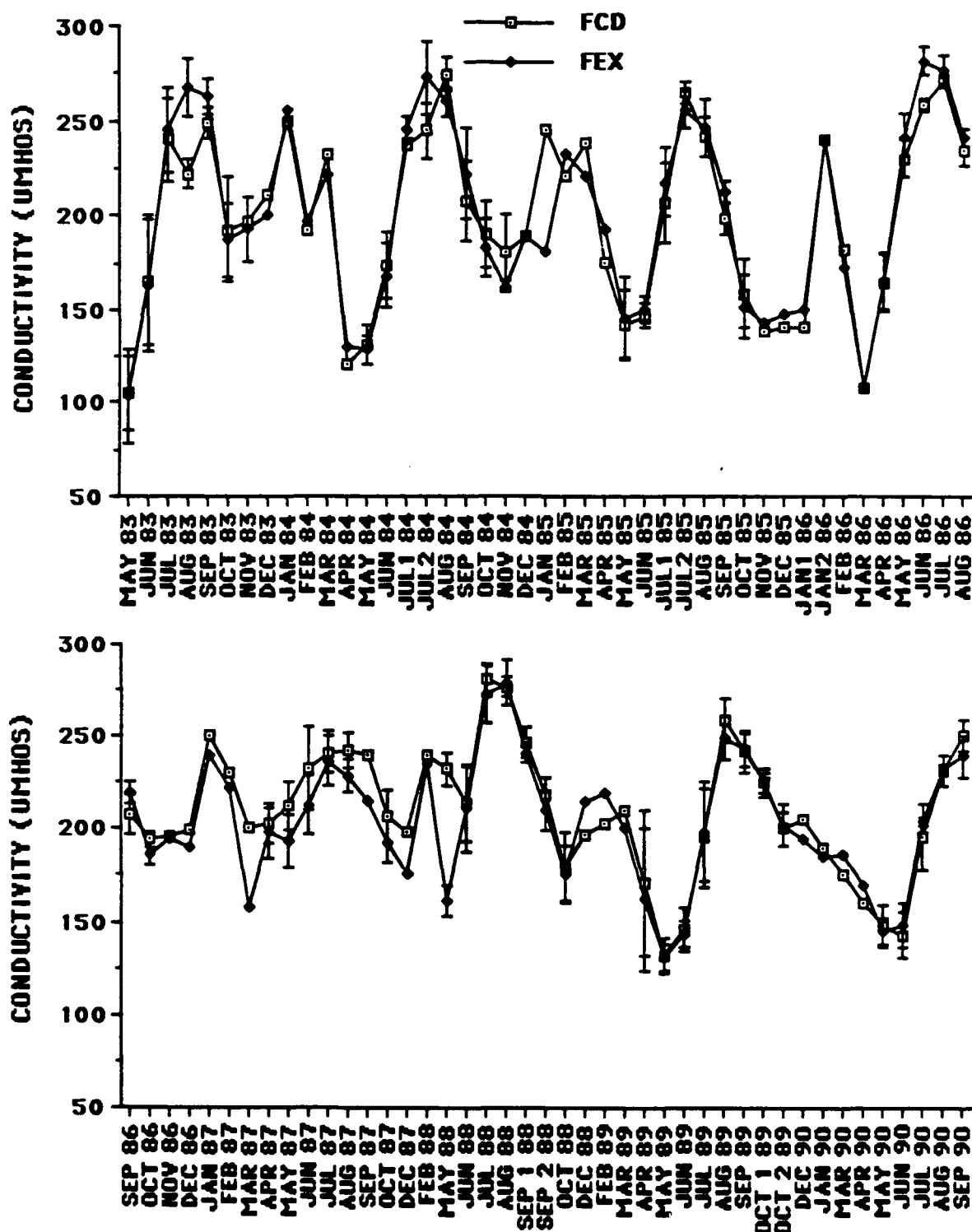


FIGURE 1.7 MEAN CONDUCTIVITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

Table 1.5 Conductivity ($\mu\text{mhos/cm}$) and Turbidity (NTU 's) for the Ford River.
Values are Means $\pm$ S.E. , N in parentheses.

Date	Conductivity			Turbidity		
	Experimental (FEX)	Control	(FCD)	Experimental (FEX)	Control (FCD)	
10/2/89	225 $\pm$ 5 (5)	225 $\pm$ 8 (5)		1.3 $\pm$ 0.1 (5)	1.2 $\pm$ 0.1 (5)	
10/30/89	202 $\pm$ 11 (4)	200 $\pm$ 9 (4)		1.1 $\pm$ 0.1 (4)	1.4 $\pm$ 0.1 (4)	
12/11/89	194 $\pm$ 0 (2)	205 $\pm$ 0 (2)		1.1 $\pm$ 0.0 (2)	1.3 $\pm$ 0.0 (2)	
1/22/90	185 $\pm$ 0 (2)	190 $\pm$ 0 (2)		1.2 $\pm$ 0.0 (2)	1.2 $\pm$ 0.0 (2)	
3/4/90	186 $\pm$ 0 (2)	175 $\pm$ 0 (2)		1.5 $\pm$ 0.0 (2)	1.6 $\pm$ 0.0 (2)	
4/16/90	170 $\pm$ 0 (2)	160 $\pm$ 0 (2)		1.5 $\pm$ 0.0 (2)	1.5 $\pm$ 0.0 (2)	
5/14/90	145 $\pm$ 7 (5)	148 $\pm$ 11 (5)		0.7 $\pm$ 0.1 (5)	0.9 $\pm$ 0.1 (5)	
6/11/90	148 $\pm$ 12 (5)	143 $\pm$ 13 (5)		0.8 $\pm$ 0.2 (5)	1.0 $\pm$ 0.2 (5)	
7/9/90	204 $\pm$ 21 (5)	196 $\pm$ 18 (5)		0.9 $\pm$ 0.1 (5)	1.1 $\pm$ 0.1 (5)	
8/6/90	232 $\pm$ 3 (5)	231 $\pm$ 8 (5)		1.4 $\pm$ 0.3 (5)	1.3 $\pm$ 0.1 (5)	
9/4/90	239 $\pm$ 11 (5)	250 $\pm$ 8 (5)		1.4 $\pm$ 0.1 (5)	1.4 $\pm$ 0.1 (5)	

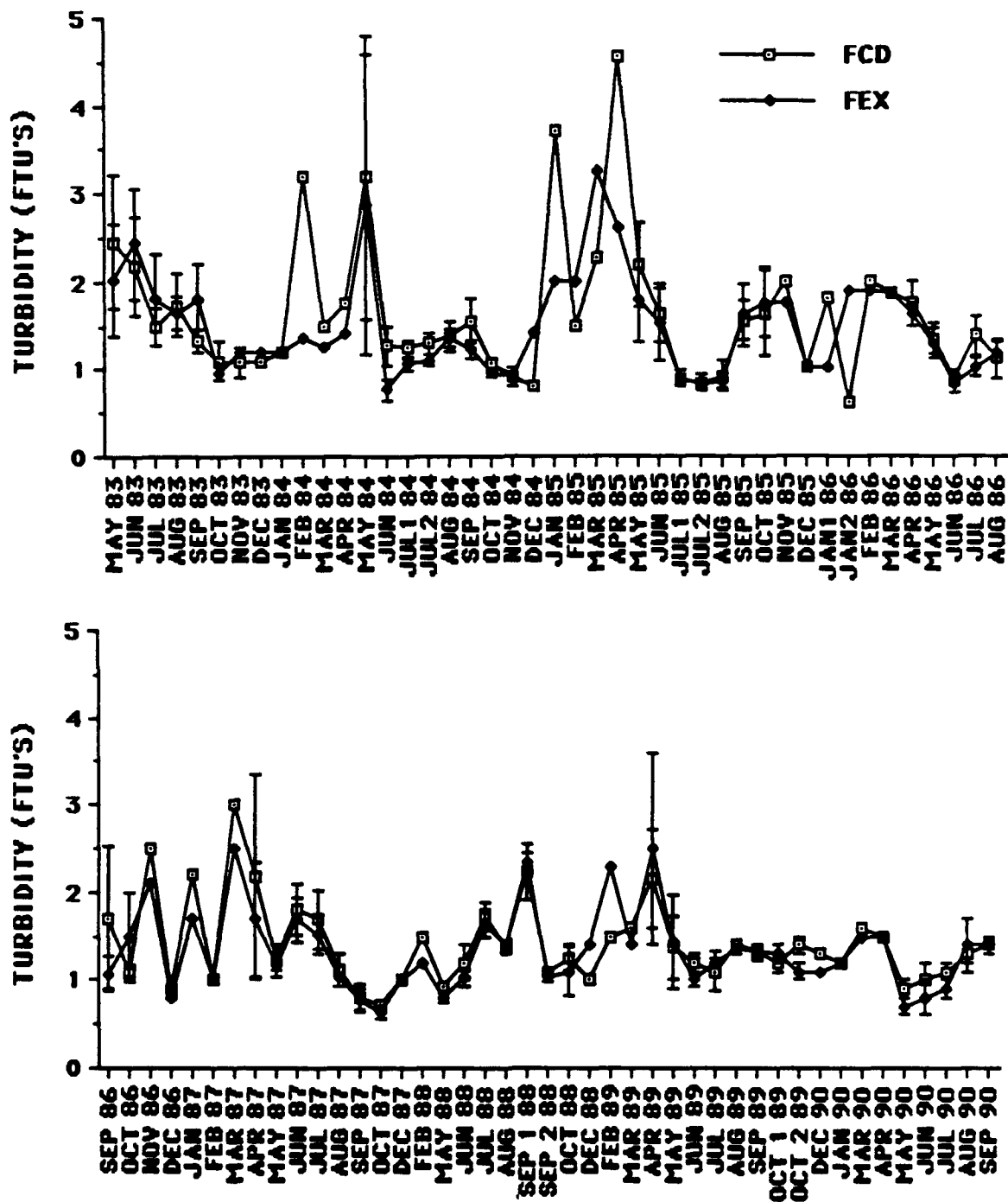


FIGURE 1.8 MEAN TURBIDITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

FCD. There were no significant differences between the two sites for 1990 (Table 1.2); although, when the whole data set is examined, FCD was significantly higher than FEX (Table 1.3). Turbidity generally increases with discharge, and as a result, tends to increase in a downstream direction (Gregory and Walling 1973). This fact may explain the difference in turbidity detected between the two sites. The actual difference between the two sites was quite small (Fig. 1.8). Turbidity correlated positively with discharge ($r = 0.55$, $p < 0.01$) which also increased in the downstream direction.

The annual cycle of spring and fall high discharges has changed over the past few years (Fig. 1.5). Due to the trend towards drier years, the discharge has generally been lower than it was in the first few years of the study. In addition, the peak discharge for 1989 and 1990 occurred in June (Fig. 1.6) and the late summer discharge values were some of the lowest recorded during this study. In general, FCD had a slightly higher discharge than did FEX, (a trend expected in a stream in a downstream direction as water enters the channel from groundwater seepage and/or overland flow along the channel).

B. Nutrient Chemistry

Nutrient chemistry samples are frozen and analyzed during the following winter. Thus, data in this annual report do not include data for 1990.

Trends in total phosphorus prior to 1987 were not obvious because of the high variability of this constituent (Fig. 1.9), although values appeared to be somewhat higher in the winter, spring, and summer in 1986 at FEX than they were in previous years. The data for 1987 through 1988 (Table 1.6, Fig. 1.9) were characterized by somewhat less variance between sites than had previously been the case. We have no explanation for this decrease in variance. Concentrations of total phosphorus declined to the lowest levels to date during 1989. In fact, these concentrations approached levels characteristic of soluble reactive phosphorus (SRP) and were even slightly lower than SRP for several dates (Table 1.6). SRP should always be less than Total P, since Total P includes SRP plus the organic forms of P. Thus, we suspect that the digestion solutions were not properly formulated for some or all of the total N and P analyses conducted on the 1989 samples. Total P and organic N (Total N minus inorganic N) analyses for 1989 will be eliminated from the data base in the future and will not be used in final correlation analyses, stepwise regressions, etc.

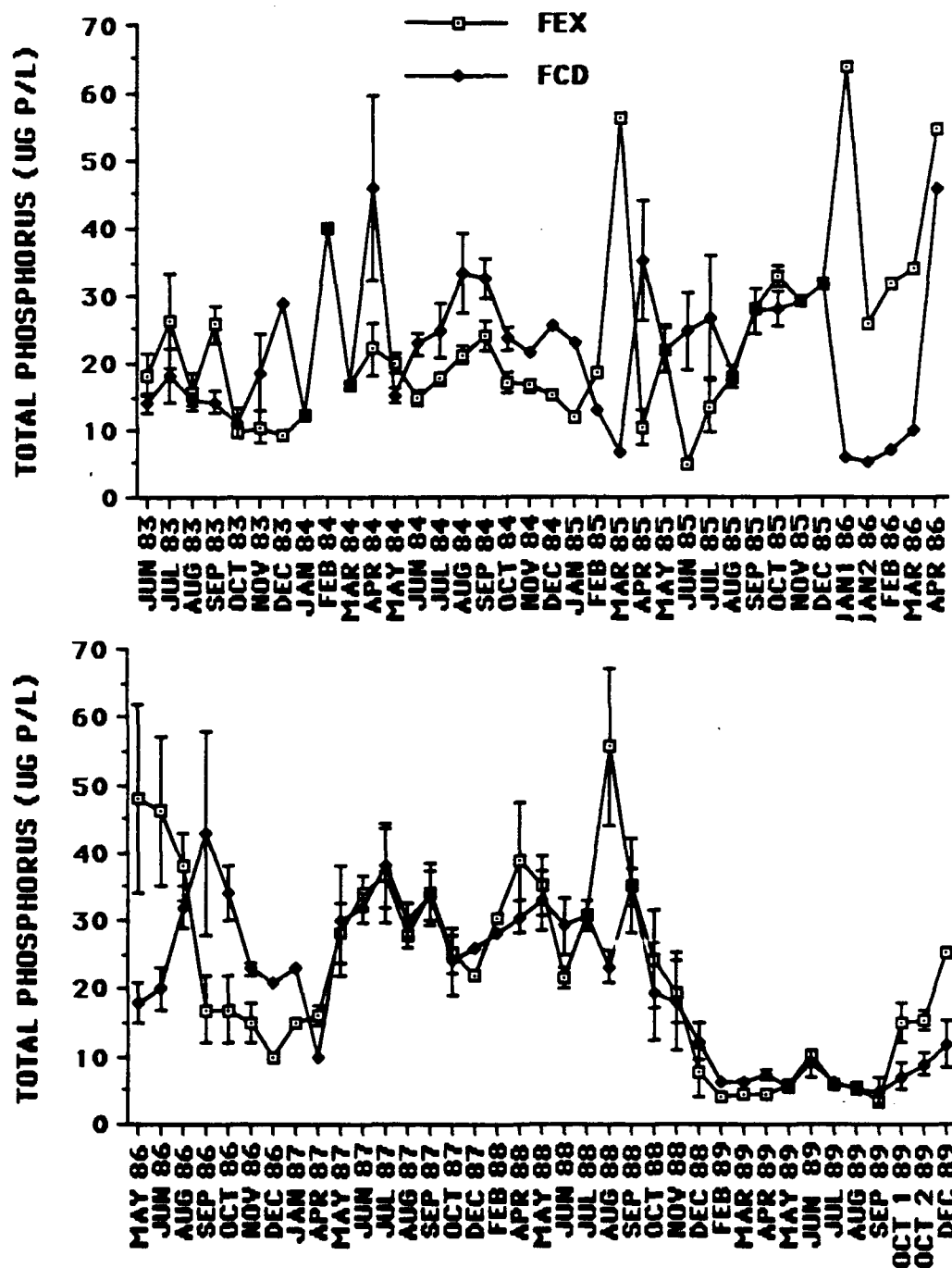


FIGURE 1.9 MEAN TOTAL PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 1.6 Soluble Reactive Phosphorus ($\mu\text{g P/L}$) and Total Phosphorus ($\mu\text{g/L}$) for the Ford River for 1989. Values are Means $\pm$ S.E., N in Parentheses.

DATE	Soluble Reactive Phosphorus		Total Phosphorus	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
2/11/89	6.2	(1) 6.35	(1) 3.85	(1) 6.15
3/20/89	5.74 $\pm$ 0.46	(2) 8.87 $\pm$ 2.52	(2) 4.24 $\pm$ 0.39	(2) 6.35 $\pm$ 0.20
4/17/89	6.49 $\pm$ 1.21	(2) 9.48 $\pm$ 1.91	(2) 4.24 $\pm$ 0.39	(2) 7.31 $\pm$ 0.77
5/15/89	7.37 $\pm$ 0.81	(8) 7.30 $\pm$ 0.98	(8) 6.01 $\pm$ 0.65	(8) 5.39 $\pm$ 0.68
6/12/89	5.90 $\pm$ 0.73	(8) 5.56 $\pm$ 0.58	(8) 10.33 $\pm$ 0.29	(8) 8.99 $\pm$ 1.86
7/10/89	6.91 $\pm$ 1.00	(9) 6.03 $\pm$ 0.69	(9) 5.86 $\pm$ 0.27	(9) 6.11 $\pm$ 0.46
8/7/89	2.86 $\pm$ 0.20	(8) 2.88 $\pm$ 0.20	(8) 5.34 $\pm$ 0.29	(8) 5.15 $\pm$ 0.69
9/5/89	3.38 $\pm$ 0.21	(8) 3.31 $\pm$ 0.16	(8) 3.22 $\pm$ 0.58	(8) 4.86 $\pm$ 1.94
10/2/89	4.05 $\pm$ 0.15	(8) 4.43 $\pm$ 0.41	(8) 15.09 $\pm$ 2.92	(8) 6.99 $\pm$ 2.02
10/30/89	4.28 $\pm$ 0.45	(9) 3.89 $\pm$ 0.19	(9) 15.30 $\pm$ 1.51	(9) 8.97 $\pm$ 1.53
12/11/89	4.85 $\pm$ 0.84	(2) 4.15 $\pm$ 0.28	(2) 25.26	(1) 11.9 $\pm$ 3.64

The concentrations of total P in the Ford River were characteristic of values for the eastern U.S. prior to 1989 reflecting land use that is 50 to 90 % forest (Omernik 1977 placed Michigan in the eastern U.S. region). Land use in the Ford River watershed is dominated by short rotation forestry with Populus tremuloides (quaking aspen) being the predominant forest species. Total P at FEX was significantly correlated with total P at FCD in 1989 (Table 1.7), but these correlations should be discounted because of the questionable 1989 data base. There were no significant differences between the two sites from 1983 through 1989 (Table 1.8). Total P was not strongly correlated with any of the chemical and physical parameters monitored, however, it was negatively correlated with silica ($r = -0.36$ at FCD and -0.28 at FEX, $p < 0.05$). These correlations, though not very robust, are reasonable since total P is primarily associated with particulates which are usually directly correlated with discharge while Si is usually inversely correlated with discharge.

Soluble reactive phosphorus (SRP) consistently stayed below $10 \mu\text{g P/L}$ except at FCD in late 1986 (Fig. 1.10, Table 1.6). There did appear to be an increase at FCD in 1986 that did not occur at FEX (Fig. 1.10), but this apparent trend towards increased P at the control site did not continue past 1986. In fact, there have been no significant differences in SRP between FCD and FEX since 1986, and SRP at FCD was highly correlated with SRP at FEX (Table 1.7). Overall, from 1983 through 1989 there is no significant difference between FEX and FCD, and the 2 sites correlate well (Table 1.8). As with total phosphorus, soluble reactive phosphorus seems to be more consistent between the sites in the last 3 years than in the earlier years of the study. The decrease in total phosphorus observed in 1989 was not reflected in the concentrations of soluble reactive phosphorus. SRP is strongly correlated with chloride ($r = 0.66$ at FCD and 0.41 at FEX, $p < 0.01$). The SRP values for FEX and FCD (Fig. 1.10, Table 1.6) were characteristic of values for land that is 50 to 90 % forested according to Omernik (1977).

Nitrate-N, nitrite-N, and ammonium-N values were usually comparable at both FEX and FCD (Figs. 1.11, 1.12, 1.13, Table 1.9). Nitrate-N values were very similar between the sites (Fig. 1.11, Table 1.8) with the exception that there was a divergence in nitrate-N values between the two sites in 1985 (Fig. 1.11), but nitrate-N was comparable for other time periods. One possibility for this difference is that leaching occurred from a small area of forest just upstream of FCD that was clearcut in 1985. This forest practice is known to lead to high nitrate losses in the first year or so after cutting for some northern hardwoods forests similar to

Table 1.7 Results of Paired t-tests and Correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemistry parameters for 1988-1989.

Parameter	df	Paired t-value	Significance	Correlation Coefficient	Significance
Organic Nitrogen	9	0.537	NS	0.86	P<0.01
Inorganic Nitrogen	9	-0.392	NS	0.87	P<0.01
Ammonium-N	9	-0.786	NS	0.45	NS
Nitrate -N	9	0.841	NS	0.98	P<0.01
Nitrite -N	9	1.819	NS	0.94	P<0.01
Total Phosphorus	9	-1.633	NS	0.91	P<0.01
Soluble Reactive Phosphorus	9	-1.098	NS	0.84	P<0.01
Silicate	9	-1.163	NS	0.97	P<0.01
Chloride	9	4.463	P<0.01	0.65	P<0.05

Table 1.8 Results of Paired t-tests and correlations between Experimental (FEX) and Control(FCD) sites for nutrient chemistry parameters from June 1983 to September 1989.

Parameter	df	paired t-value	Significance	Correlation Coefficient	Significance
Organic Nitrogen	74	-2.807	P<0.01	0.75	P<0.01
Inorganic Nitrogen	74	-1.747	NS	0.80	P<0.01
Ammonium-N	74	0.180	NS	0.29	P<0.01
Nitrite- N	74	2.282	P<0.05	0.73	P<0.01
Nitrate- N	74	-1.777	NS	0.83	P<0.01
Total Phosphorus	74	0.833	NS	0.29	P=0.01
Soluble Reactive Phosphorus	74	-1.808	NS	0.76	P<0.01
Silicate	76	0.754	NS	0.92	P<0.01
Chloride	74	3.827	P<0.01	0.90	P<0.01

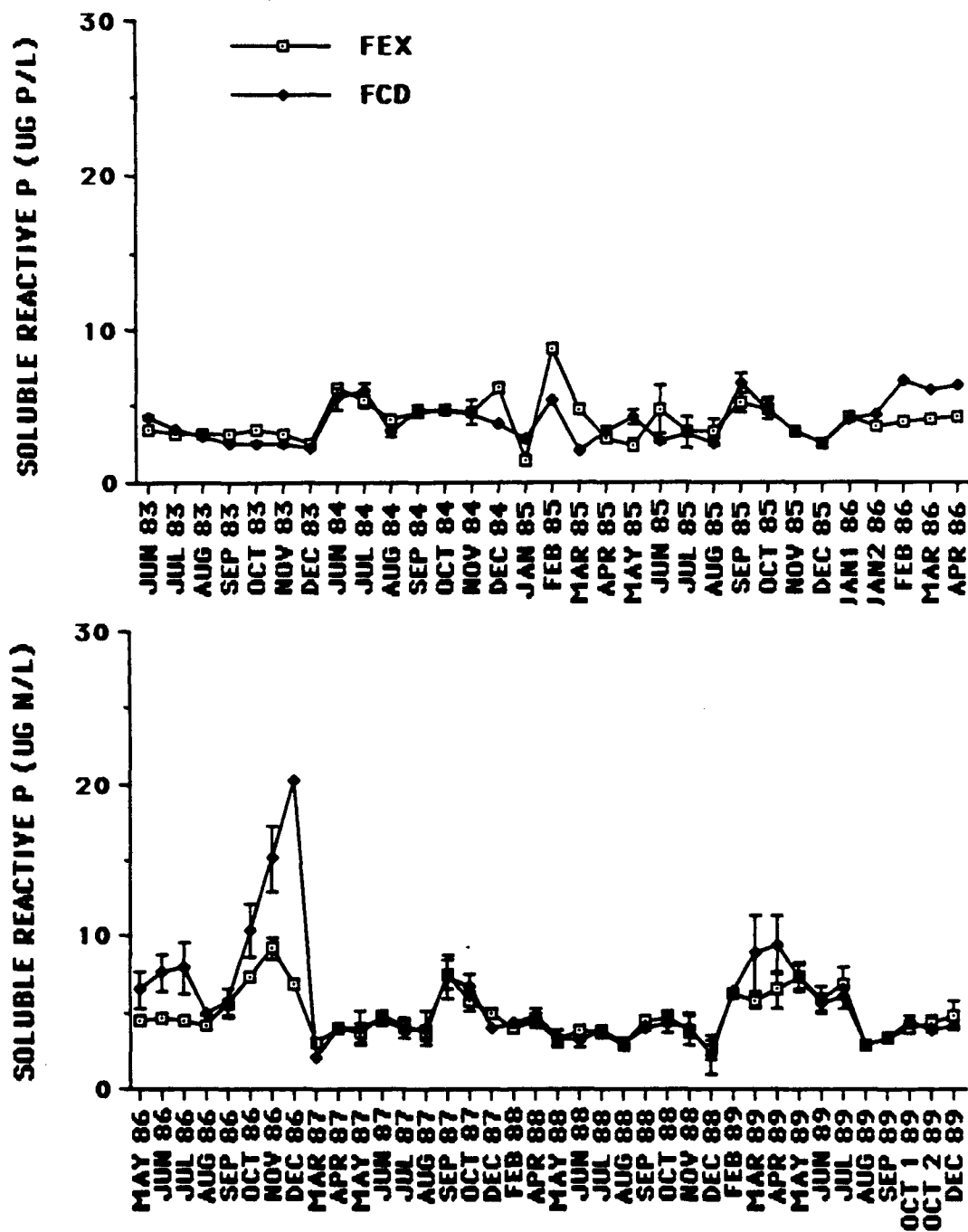


FIGURE 1.10 MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

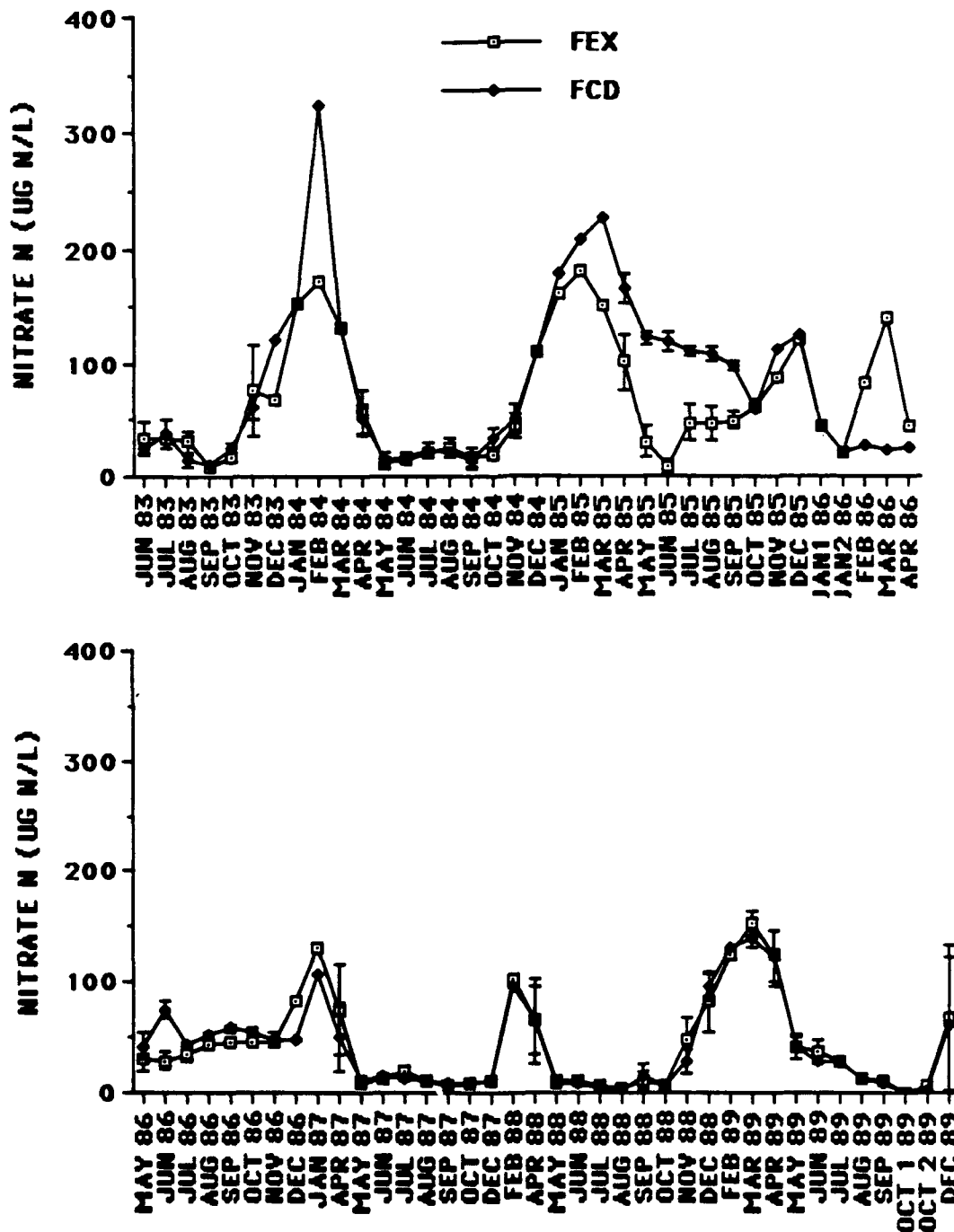


FIGURE 1.11 MEAN NITRATE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

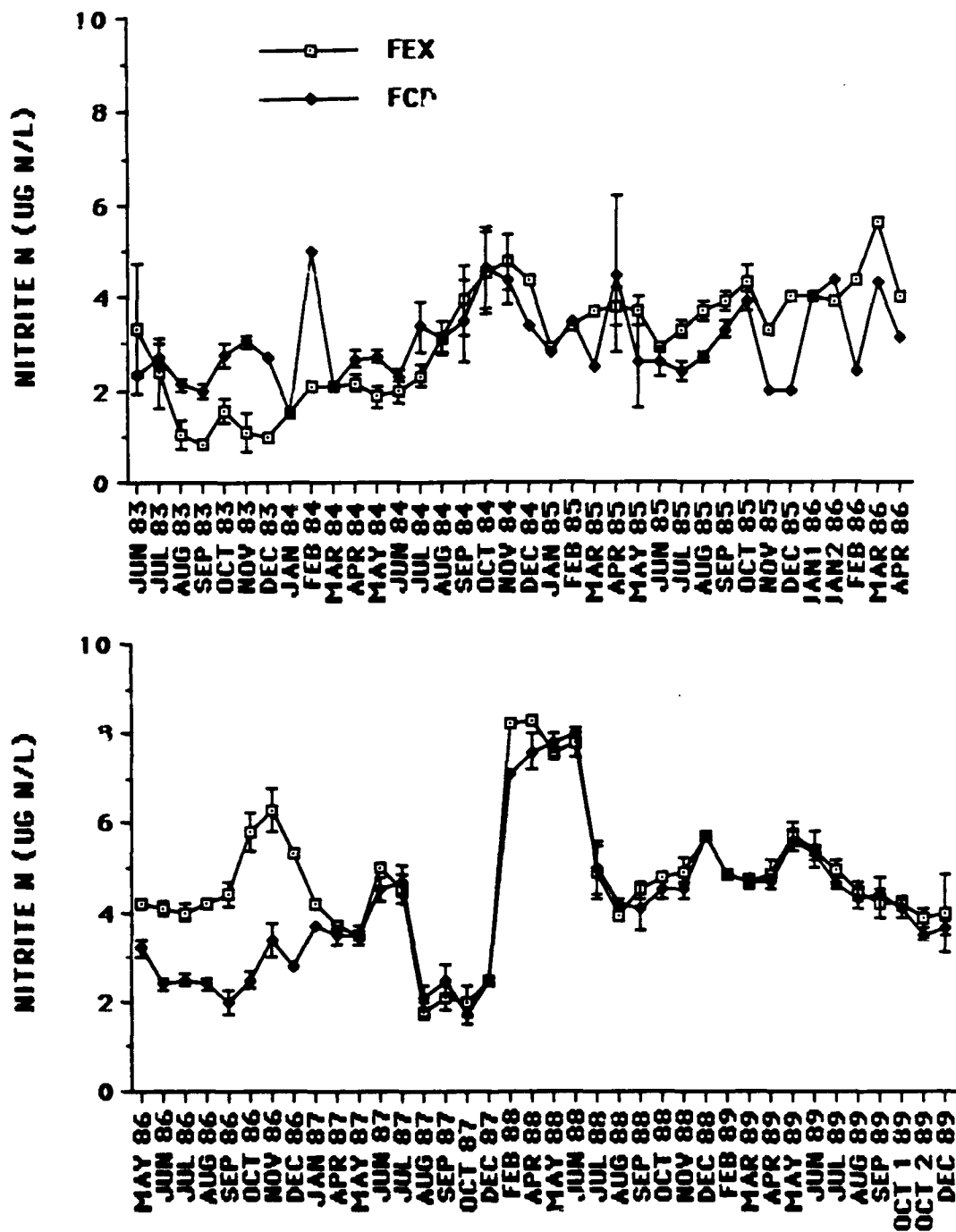


FIGURE 1.12 MEAN NITRITE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

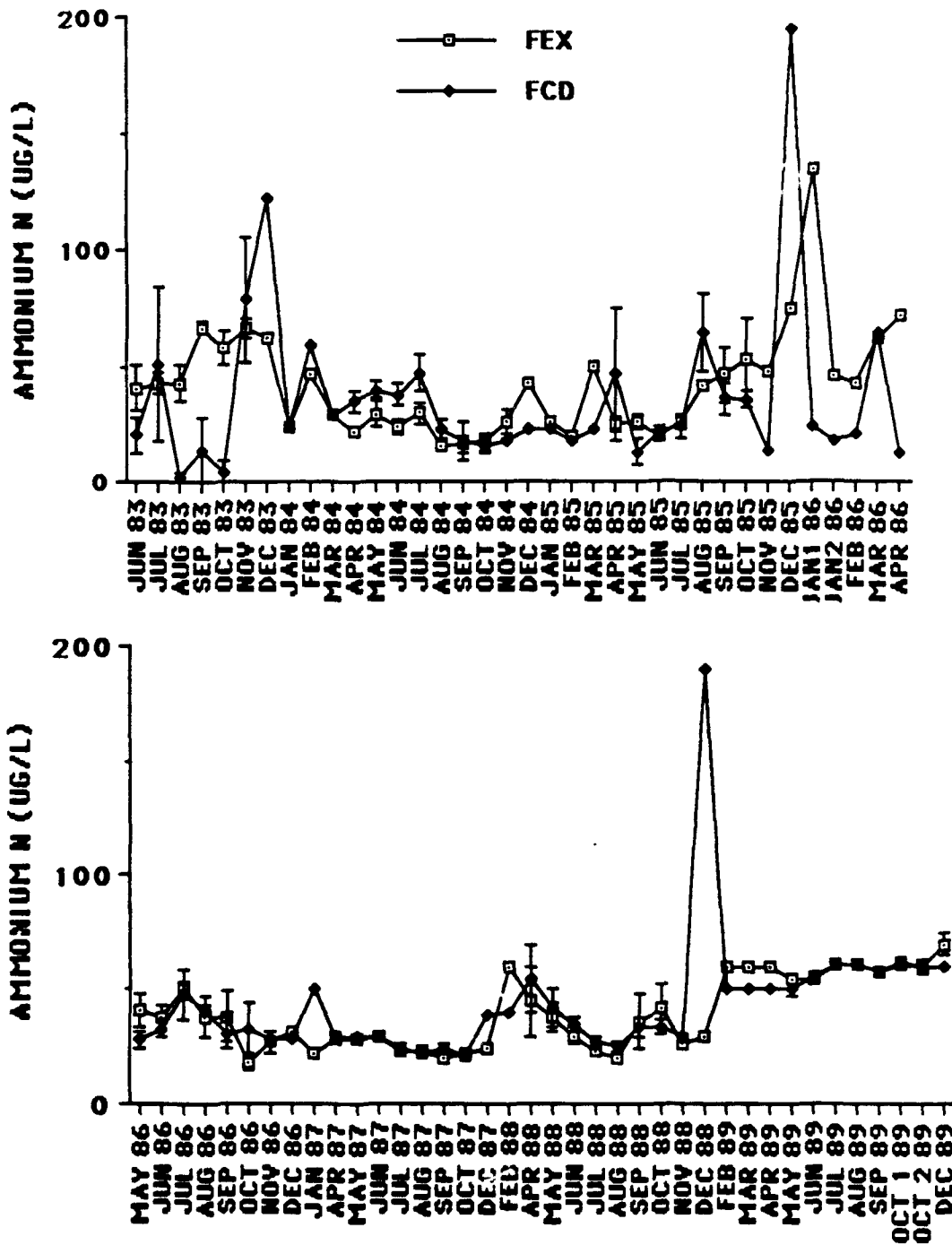


FIGURE 1.13 MEAN AMMONIUM CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 1.9 Ammonium ($\mu\text{g N/L}$), Nitrate-N ($\mu\text{g N/L}$) and Nitrite-N ($\mu\text{g N/L}$) for the Ford River for 1989. Values are Means $\pm$ S.E., N in parentheses.

Date	Ammonium -N	Nitrate -N	Nitrite-N
Experimental Site (FEX)			
2/11/89	60.00	124.17	4.83
3/20/89	60.00	153.34 $\pm$ 11.17	4.66 $\pm$ 0.17
4/17/89	60.00	123.67 $\pm$ 22.84	4.83 $\pm$ 0.34
5/15/89	55.00 $\pm$ 1.89	40.86 $\pm$ 10.43	5.76 $\pm$ 0.28
6/12/89	55.00 $\pm$ 1.89	38.00 $\pm$ 9.24	5.38 $\pm$ 0.40
7/10/89	61.11 $\pm$ 2.00	27.95 $\pm$ 2.93	4.94 $\pm$ 0.24
8/7/89	61.25 $\pm$ 1.25	13.92 $\pm$ 1.36	4.45 $\pm$ 0.22
9/5/89	57.50 $\pm$ 1.64	10.30 $\pm$ 2.56	4.20 $\pm$ 0.33
10/2/89	62.22 $\pm$ 1.45	0.60 $\pm$ 0.26	4.20 $\pm$ 0.16
10/30/89	56.67 $\pm$ 3.33	6.93 $\pm$ 0.36	3.89 $\pm$ 0.21
12/11/89	70.00 $\pm$ 50	67.94 $\pm$ 65.25	3.99 $\pm$ 0.85
Control Site (FCD)			
2/11/89	50.00	131.17	4.83
3/20/89	50.00	138.84 $\pm$ 7.67	4.66 $\pm$ 0.17
4/17/89	50.00	121.34 $\pm$ 25.17	4.66 $\pm$ 0.17
5/15/89	50.00 $\pm$ 2.67	41.65 $\pm$ 10.82	5.59 $\pm$ 0.23
6/12/89	56.25 $\pm$ 1.83	29.29 $\pm$ 2.61	5.34 $\pm$ 0.17
7/10/89	61.00 $\pm$ 2.00	28.02 $\pm$ 2.53	4.65 $\pm$ 0.15
8/7/89	61.25 $\pm$ 1.25	13.55 $\pm$ 1.61	4.32 $\pm$ 0.22
9/5/89	57.80 $\pm$ 1.64	9.21 $\pm$ 2.09	4.41 $\pm$ 0.35
10/2/89	61.11 $\pm$ 2.00	0.64 $\pm$ 0.38	4.08 $\pm$ 0.21
10/30/89	58.89 $\pm$ 2.61	2.17 $\pm$ 1.45	3.52 $\pm$ 0.12
12/11/89	60.00	61.1 $\pm$ 60.8	3.65 $\pm$ 0.17

the forests along the Ford River (Bormann and Likens 1979, Vitousek et al. 1982). Despite this difference in 1985, there were no significant between site differences in nitrate-N for the whole data set (Table 1.8) or for the 1989 data set (Table 1.7), and nitrate concentrations at the two sites were highly correlated. Nitrite-N concentrations at the two sites in 1989 were not significantly different (Table 1.7) and were strongly correlated. There is a significant difference between the two sites when the whole (1983 - 1989) data set is examined (Table 1.8). This appears to be related to the high intersite variability prior to 1987 (Fig. 1.12). Ammonium-N concentrations are not significantly different between the sites (Fig. 1.13) for either the 1989 data set (Table 1.7) or the entire data set (Table 1.8). The between site correlation is weak ($r = 0.29$, $p = 0.01$, Table 1.8) for the entire data set and not significant ($r = 0.45$, Table 1.7) for the 1989 data set. This lack of correlation is probably due to the relatively low inter-month variation, especially in 1989.

The patterns for inorganic-N and nitrate-N (Figs. 1.11 and 1.14, Table 1.10) generally follow the pattern of mid-summer lows and winter highs described for nitrate for northern hardwood forests by Bormann and Likens (1979). These values are characteristic of values for streams in the eastern U. S. that are 50 to 90 % forested (Omernik 1977). Inorganic-N values were not significantly different between the two sites in 1989 (Table 1.7) or for the entire data set (Table 1.8). Concentrations of inorganic-N at FEX were significantly correlated to concentrations at FCD (Tables 1.7 and 1.8). Inorganic-N and nitrate-N (the major component of inorganic nitrogen) both correlate positively with dissolved oxygen ($r = 0.68$ and 0.70 respectively, $p < 0.01$) and negatively with water temperature ($r = -0.74$ and -0.76 respectively, $p < 0.01$) reflecting the pattern of winter highs and summer lows.

Organic nitrogen at FEX was significantly different from organic-N at FCD prior to 1987, but these differences have disappeared since 1987 (Fig. 1.15, Table 1.10). The 1989 data are questionable as explained for total P above and will not be used in future statistical analyses. As was true for inorganic-N, total P, and SRP values, organic-N values were characteristic of streams draining areas of the eastern U. S. that are 50 to 90 % forested (Omernik 1977).

There were no significant differences for silicate-Si between FEX and FCD (Tables 1.7, 1.8, 1.11, Fig. 1.16), and concentrations at FEX were significantly related to concentrations at FCD (Table 1.7). Concentrations were relatively constant throughout the year at about 7 to 9 mg Si/L, although periods of dilution did occur during high

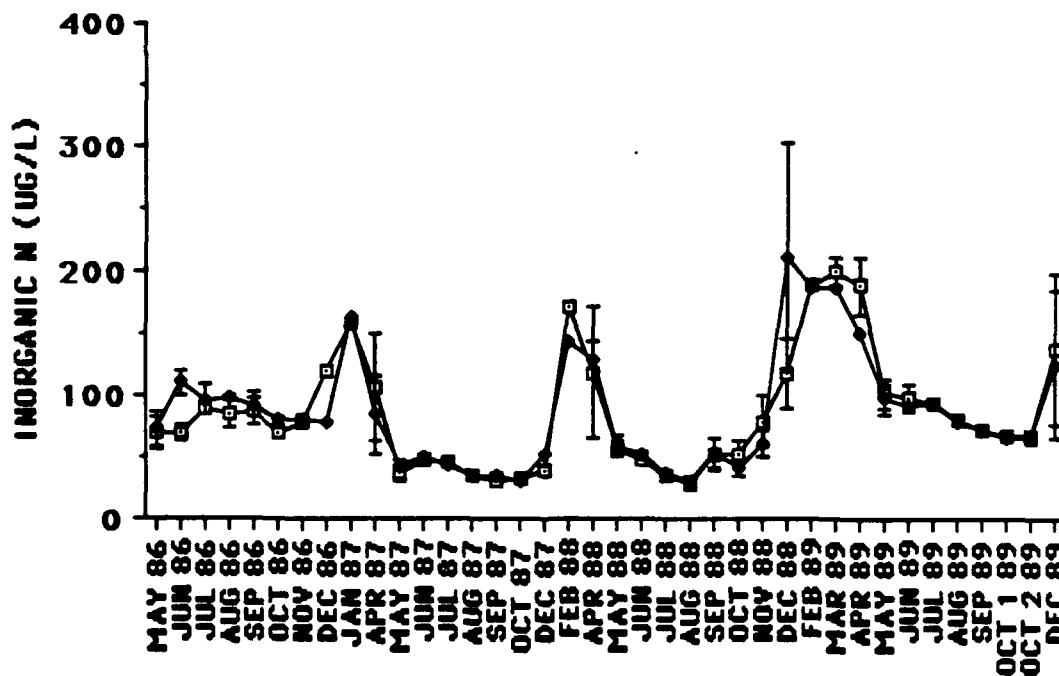
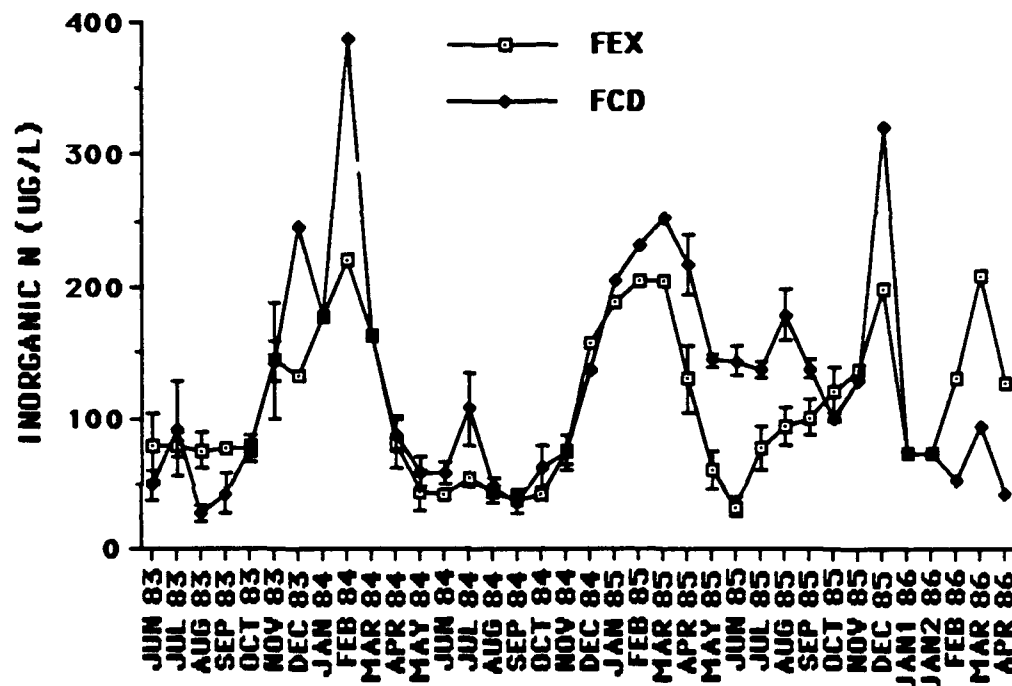


FIGURE 1.14 MEAN INORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 1.10 Organic-N ($\mu\text{g N/L}$) and Inorganic-N ($\mu\text{g N/L}$) for the Ford River for 1989.
Values are Means $\pm$ S. E., N in parentheses.

Date	Organic Nitrogen		(FCD)	Inorganic Nitrogen	
	Experimental (FEX)	Control		Experimental (FEX)	Control (FCD)
2/11/89	311.00	(1)	*	(1)	189.00 (1) 186.00 (1)
3/20/89	50.00 $\pm$ 261.00	(2)	*		200.00 $\pm$ 11.00 (2) 186.00 (1)
4/17/89	*		*		188.50 $\pm$ 22.50 (2) 151.00 (1)
5/15/89	112.92 $\pm$ 60.49	(8)	*	(8)	101.63 $\pm$ 11.65 (8) 97.25 $\pm$ 12.19 (8)
6/12/89	442.88 $\pm$ 94.53	(8)	481.63 $\pm$ 98.69	(8)	98.38 $\pm$ 9.34 (8) 90.88 $\pm$ 3.41 (8)
7/10/89	679.33 $\pm$ 46.62	(9)	651.78 $\pm$ 113.04	(9)	94.00 $\pm$ 2.37 (9) 93.76 $\pm$ 2.28 (9)
8/7/89	450.38 $\pm$ 62.80	(8)	649.63 $\pm$ 121.09	(8)	79.63 $\pm$ 1.85 (8) 79.13 $\pm$ 2.36 (8)
9/5/89	296.75 $\pm$ 102.37	(8)	393.88 $\pm$ 85.20	(8)	72.00 $\pm$ 3.02 (8) 71.13 $\pm$ 3.38 (8)
10/2/89	182.96 $\pm$ 48.42	(9)	351.94 $\pm$ 69.66	(9)	67.01 $\pm$ 1.43 (9) 65.83 $\pm$ 1.92 (9)
10/30/89	464.17 $\pm$ 45.33	(9)	595.50 $\pm$ 48.28	(9)	67.50 $\pm$ 4.03 (9) 64.58 $\pm$ 3.13 (9)
12/11/89	423.08 $\pm$ 66.09	(2)	715.25 $\pm$ 30.25	(2)	136.92 $\pm$ 61.09 (2) 124.75 $\pm$ 60.25 (2)

* Concentration of Organic Nitrogen too low to detect

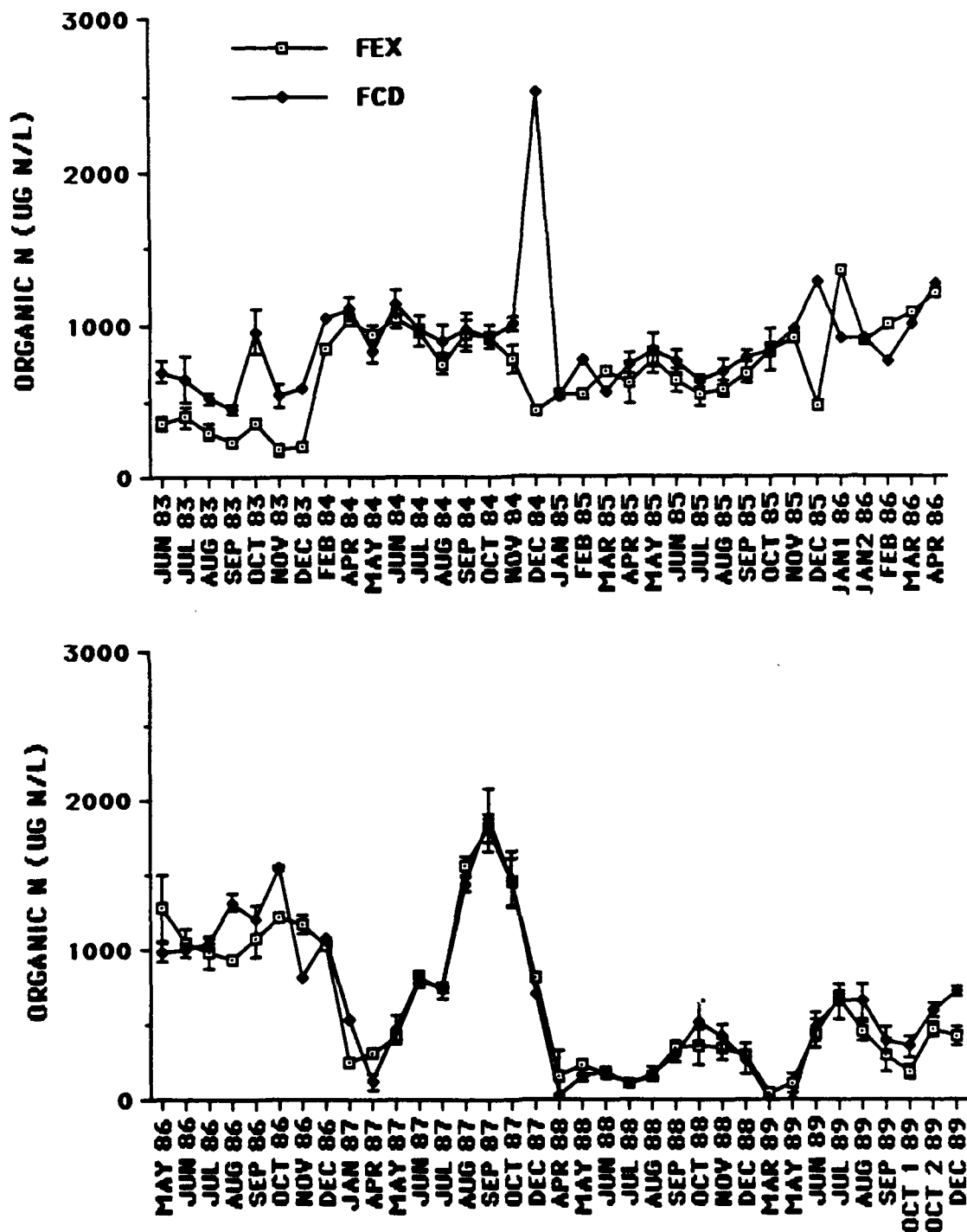


FIGURE 1.15 MEAN ORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 1.11 Dissolved Silica (mg Si/L) and Chloride (mg Cl/L) for the Ford River for 1989.
Values are Means $\pm$ S. E., N in Parentheses.

Date	Silica		Chloride	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
2/11/89	9.47 (1)	9.24 (1)	3.11 (1)	2.73 (1)
3/20/89	9.34 $\pm$ 0.14 (2)	9.18 $\pm$ 0.06 (2)	3.39 $\pm$ 0.28 (2)	2.89 $\pm$ 0.16 (2)
4/17/89	6.77 $\pm$ 2.44 (2)	7.44 $\pm$ 1.68 (2)	3.36 $\pm$ 0.32 (2)	2.89 $\pm$ 0.16 (2)
5/15/89	3.49 $\pm$ 0.23 (8)	3.60 $\pm$ 0.46 (8)	3.27 $\pm$ 0.28 (8)	3.40 $\pm$ 0.36 (8)
6/12/89	4.32 $\pm$ 0.44 (8)	4.66 $\pm$ 0.22 (8)	3.47 $\pm$ 0.68 (7)	3.23 $\pm$ 0.59 (7)
7/10/89	6.09 $\pm$ 0.20 (9)	6.23 $\pm$ 0.18 (9)	2.76 $\pm$ 0.13 (8)	2.51 $\pm$ 0.15 (8)
8/7/89	7.27 $\pm$ 0.26 (8)	6.91 $\pm$ 0.13 (8)	2.92 $\pm$ 0.35 (8)	2.91 $\pm$ 0.62 (8)
9/5/89	5.64 $\pm$ 1.07 (8)	6.98 $\pm$ 0.11 (8)	3.56 $\pm$ 0.29 (8)	3.03 $\pm$ 0.31 (8)
10/2/89	6.89 $\pm$ 0.90 (9)	5.27 $\pm$ 1.11 (9)	4.21 $\pm$ 0.23 (9)	3.52 $\pm$ 0.24 (9)
10/30/89	8.07 $\pm$ 0.42 (9)	7.96 $\pm$ 0.26 (9)	5.19 $\pm$ 0.66 (9)	4.28 $\pm$ 0.69 (9)
12/11/89	8.79 $\pm$ 0.77 (2)	8.30 $\pm$ 0.72 (2)	6.75 $\pm$ 2.84 (2)	6.39 $\pm$ 2.68 (2)

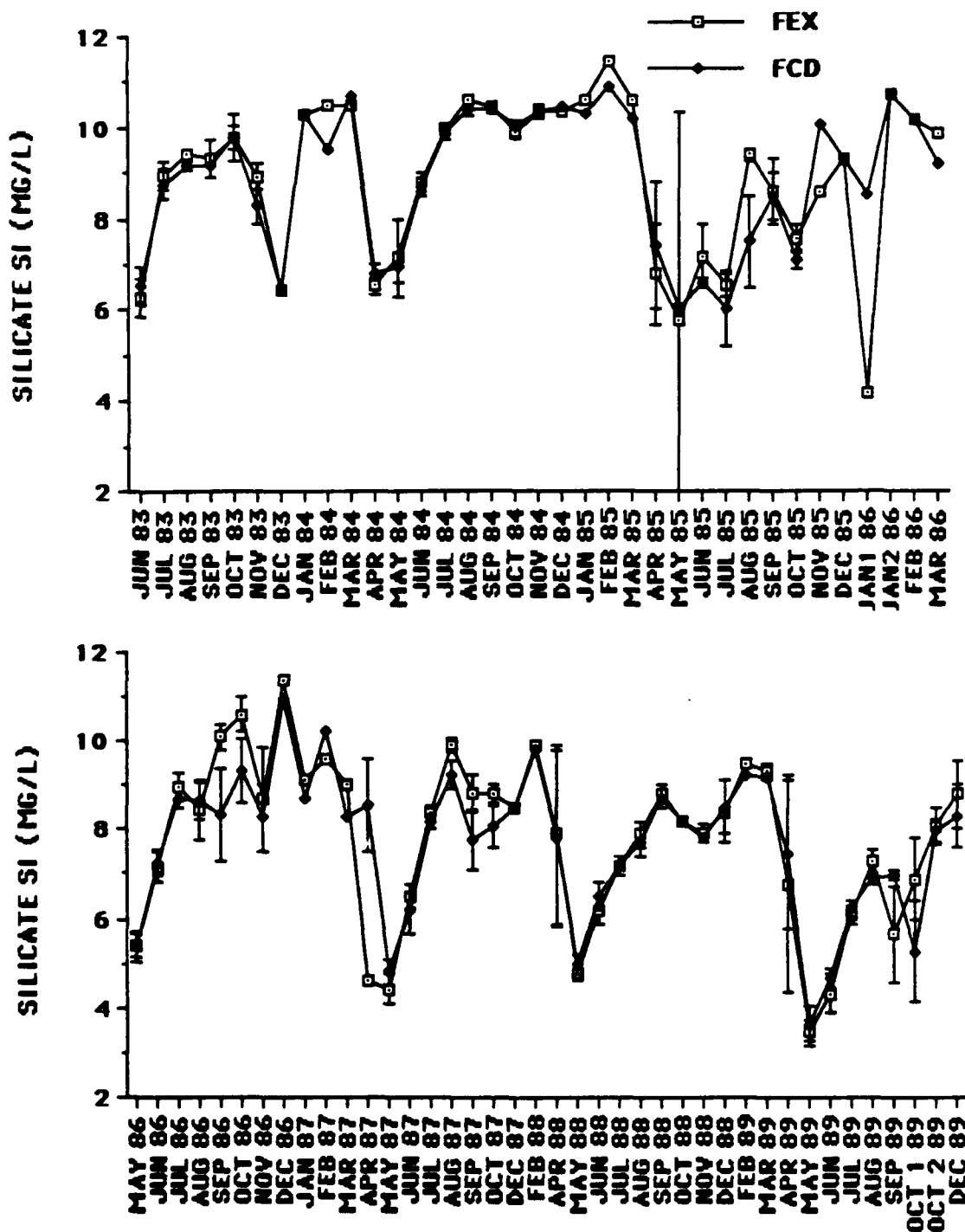


FIGURE 1.16 MEAN SILICATE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

flows in April or May each year and during other periods of high discharge (Fig. 1.16, 1.5, 1.6). Silica is correlated with hardness ($r = 0.49$, $p < 0.01$) and alkalinity ($r = 0.50$, $p < 0.01$), probably reflecting the negative correlation of all three with discharge.

Chloride at FEX was significantly different from chloride at FCD in 1989 (and in all previous years except 1987) (Table 1.7, 1.8, 1.11, Fig. 1.17). Values for the two sites were significantly correlated in 1989 (Table 1.7), as they had been in previous years. Concentrations of Cl appeared to be larger at the upstream site (FEX) in 1984, 1985, 1986, 1988 and 1989 than they were at the downstream site (FCD) (Fig 1.17). This gradient may have reflected the fact that some of the chloride inputs were from road salting near Channing, MI with dilution of these inputs in a downstream direction. Chloride concentrations increased in 1986 but since 1987 have dropped back to values typical of the time period from 1983 through 1985. The reasons for this increase in 1986 followed by a decrease are unknown. However, these values are not much higher than one would expect from rainwater and are certainly much lower than any concentration known to cause problems for fish or other aquatic organisms (McKee and Wolf 1963).

C. Physical and Meteorological Parameters

The primary physical parameters monitored include air and water temperature, above and below water photosynthetically active radiation (PAR), and stream discharge. These data are automatically logged at 30 minute intervals from mid-April through the end of October. Almost no data are available from the winter months.

Solar radiation (PAR) was highly variable using the 30 minute interval data. An integrating instrument would have provided more useful data but was not included in our original equipment list. Our 28 day summaries have been calculated as an average of the 30 minute PAR values for the period from 1000 to 1400 hours daily (Fig. 1.18). These data from the experimental site (FEX) are characteristic of data from both sites. Prior to 1990, we have a good record of PAR value at FEX, but there is a gap in above water PAR data at FCD. The above water PAR data for FEX has been taken in an open area next to the river that is shaded only during early morning and late afternoon hours. FEX data are used in correlational analyses for both sites. One would expect some variation from site to site based on differential cloudiness from one site to the next, but these differences should not be great. This approach results in data for each 28 day period for open, unshaded portions of the river. These data should be correlated with actual

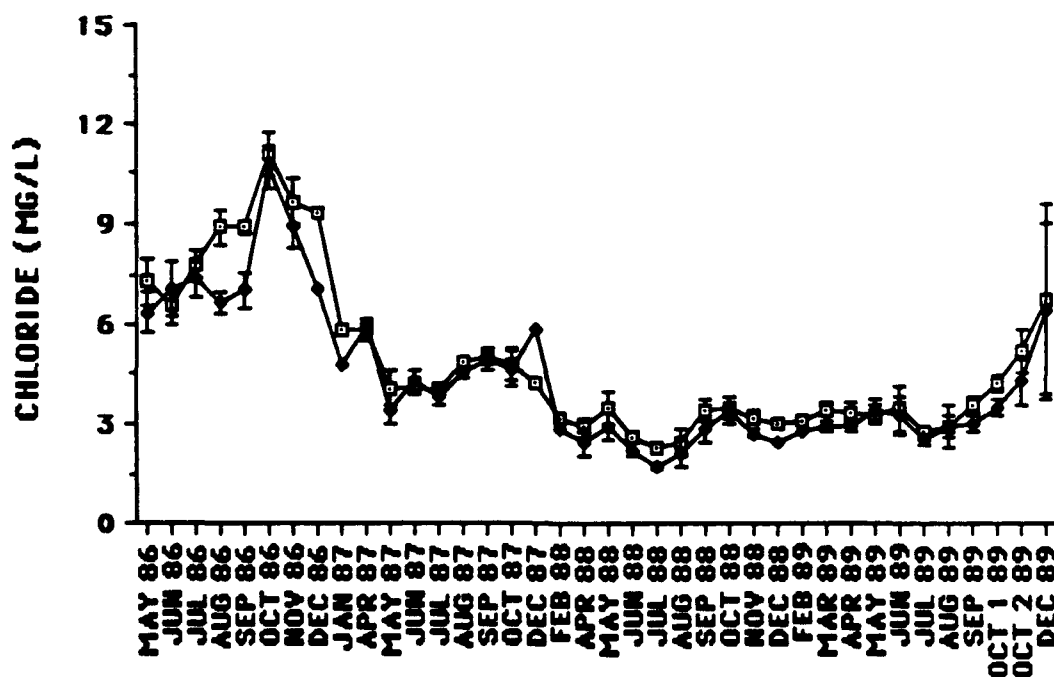
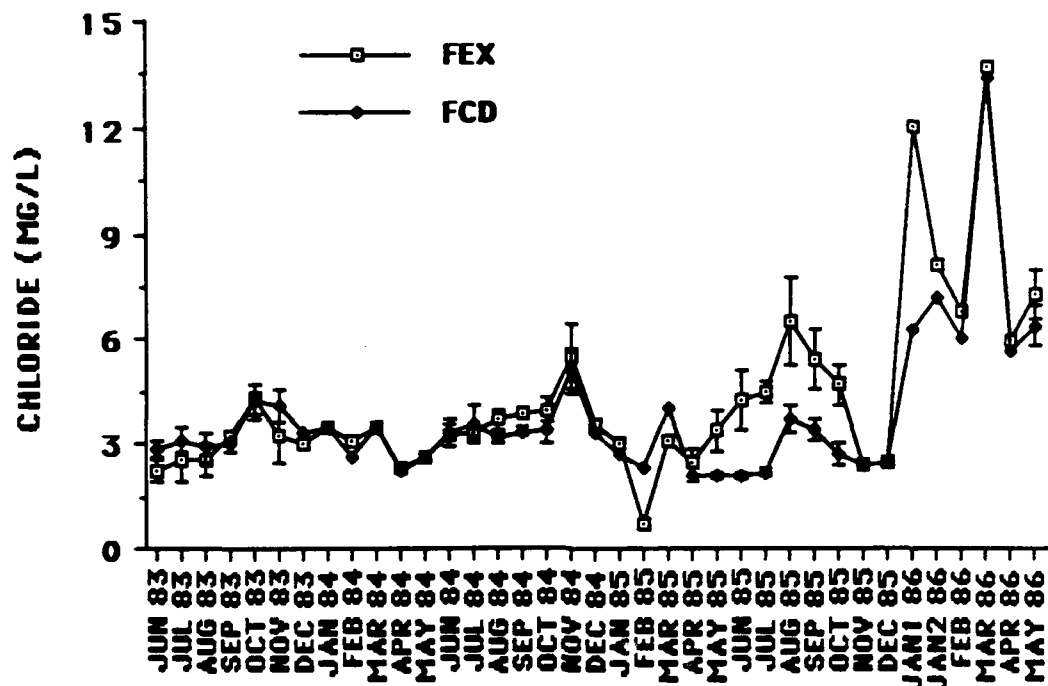


FIGURE 1.17 MEAN CHLORIDE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

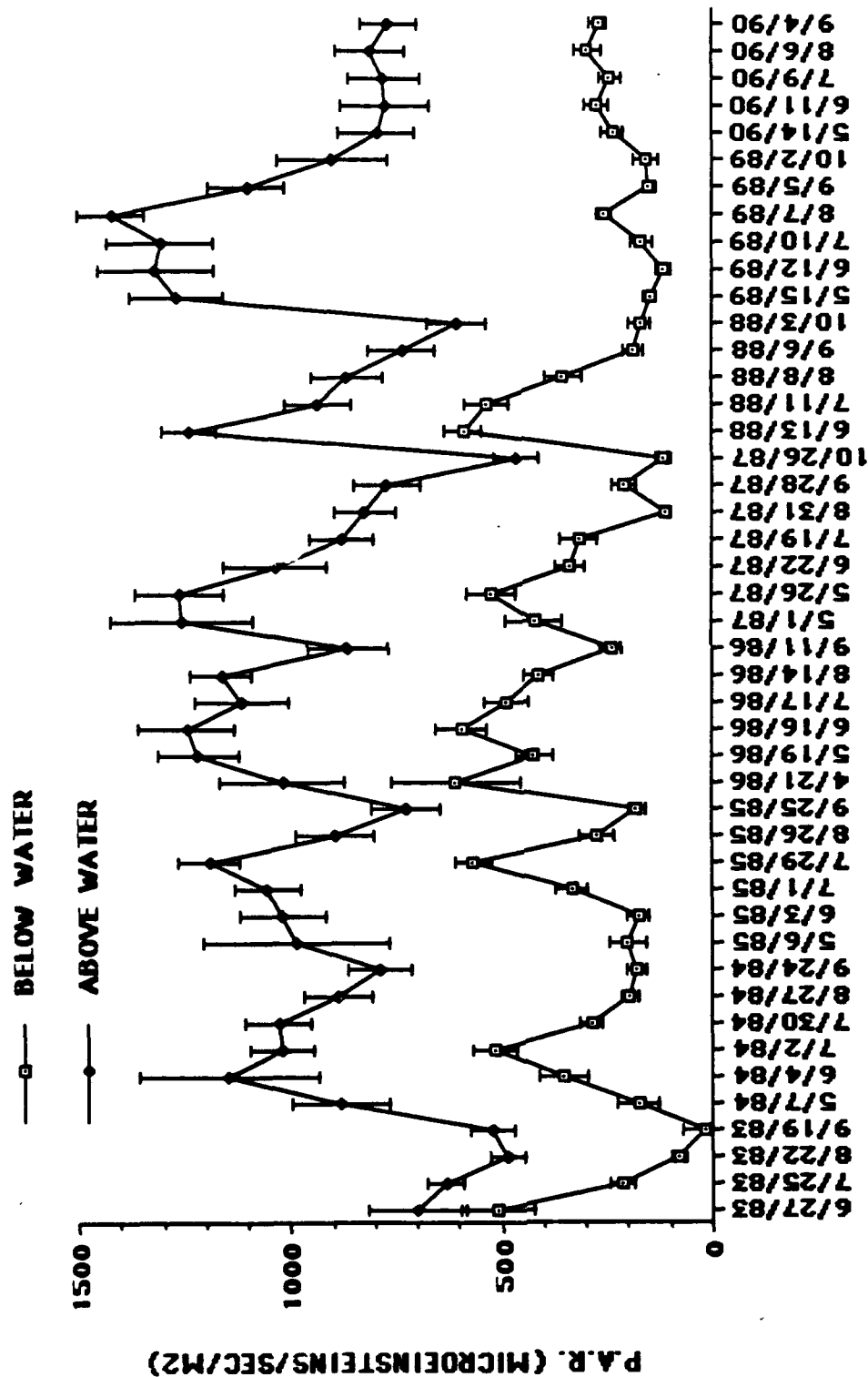


FIGURE 1.18 MEAN SOLAR RADIATION (+S.E.) BETWEEN 10:00 AND 14:00 FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) SITE, 1983-1990. DATA FOR 1990 ABOVE HAVE BEEN CONVERTED BASED ON FCD DATA (SEE TEXT FOR THE DETAILS).

solar inputs at the river surface above the periphyton samplers but certainly do not represent actual exposure data. The samplers are in open areas but are shaded by the banks and vegetation at certain times of the day. While we carefully try to match the extent of shading at both sites, we have no actual measurement of solar input just above the sampler. As mentioned in the methods, due to a broken solar probe at FEX in 1990, an FCD to FEX conversion factor of 0.723 (generated from the 1989 data at both sites (Fig. 1.19)) was used to calculate the above water solar radiation at FEX for 1990. This conversion value reflects the fact that the probe at FEX is in a more shaded site. Underwater solar radiation (Figs. 1.18, 1.19) is also monitored at a central unshaded point in the river and not immediately adjacent to the periphyton samplers. As for above water solar, it should be correlated with actual exposure but is certainly not actual exposure data. This placement reflects the need to have the probes next to the automatic recording devices and results in data that are less useful for correlation analyses than actual input data would be.

Air and water temperature have been monitored since 1983 and are available as needed. The water temperatures for 1990 were typical (Fig. 1.20) of data from past years (Fig. 1.21) for the growing season with temperatures rising rapidly from at or near zero under ice to 5 to 10° C before our monitoring stations are installed in April. Temperature continued to rise through mid-June to about 20° C where it remained through August (Fig. 1.20). As in previous years temperatures began to cool in mid-August and cooled to about 12° C by the end of our reporting season in September. In previous years, this cooling continued to an average temperature of 6-8° C by the end of October for the 28 day exposure periods for the benthic algae (Fig. 1.21). On subsequent monthly sampling trips from November through April, stream temperatures were at or near zero. The average temperature data for the 28 day exposure periods for the benthic algal samples illustrate that average summer temperatures have been less than 20° C for every summer except 1983 and 1988 with 1988 attaining the highest average temperatures since the start of the study (Fig. 1.21). The temperatures experienced in 1990 were lower than those of 1988 but still reflected the trend of low flows (Fig. 1.5) and high temperatures of the past few years.

Stream discharge data have already been presented for the 28 day benthic algal exposure periods (Fig. 1.5) and for mean daily values for 1989 (Fig. 1.6). However, the first three years of these data were calculated from actual discharge measurements taken with current meters once or twice per week. Initially, data were logged on Omnidatapods

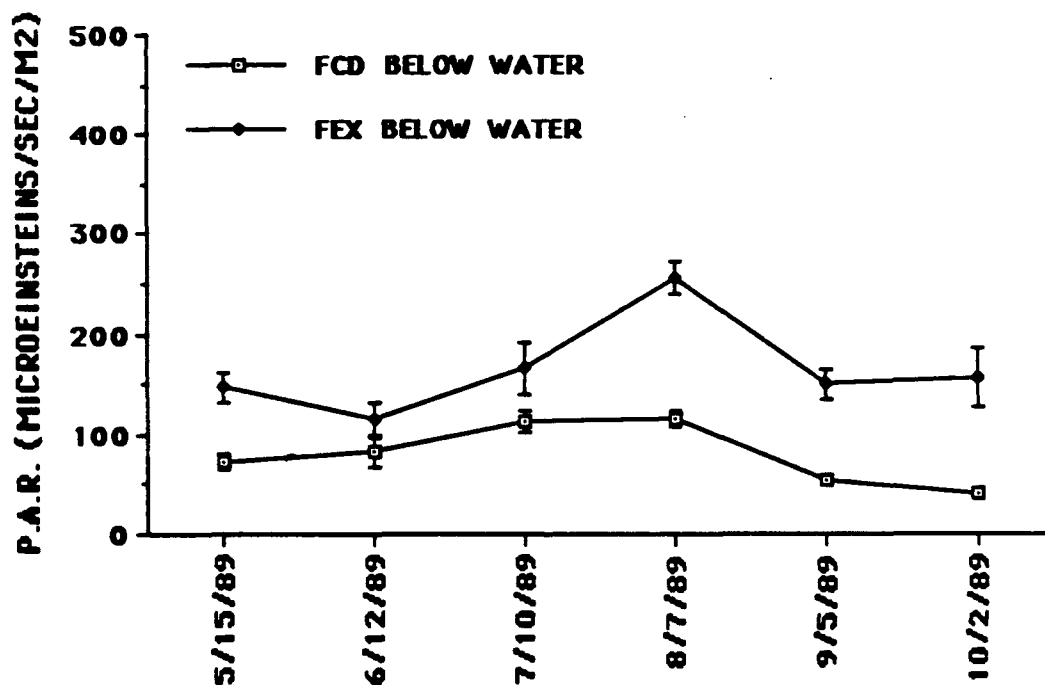
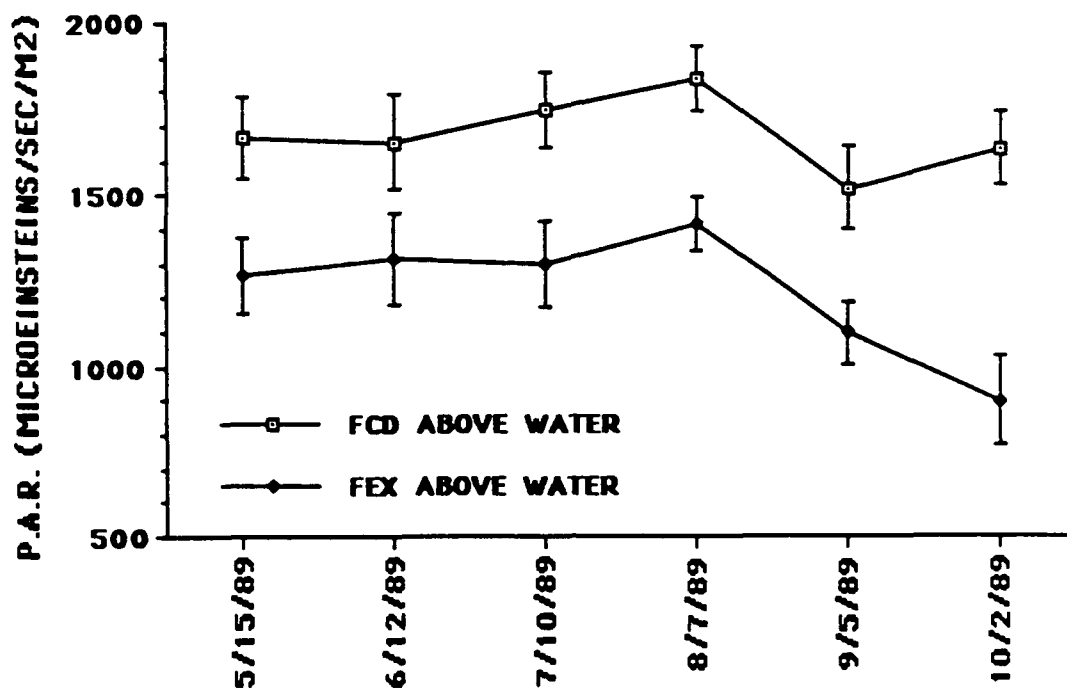


FIGURE 1.19 MEAN SOLAR RADIATION (+S.E.) BETWEEN 10:00 AND 14:00 FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1989.

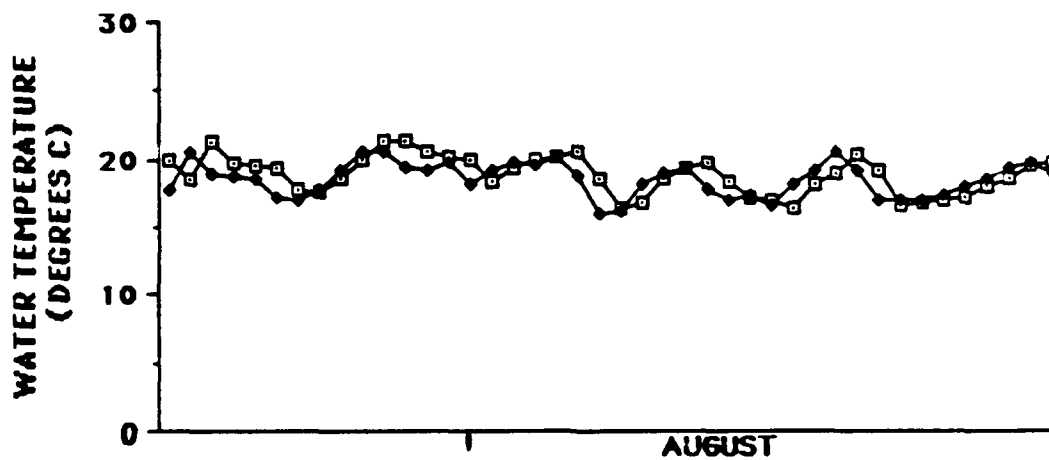
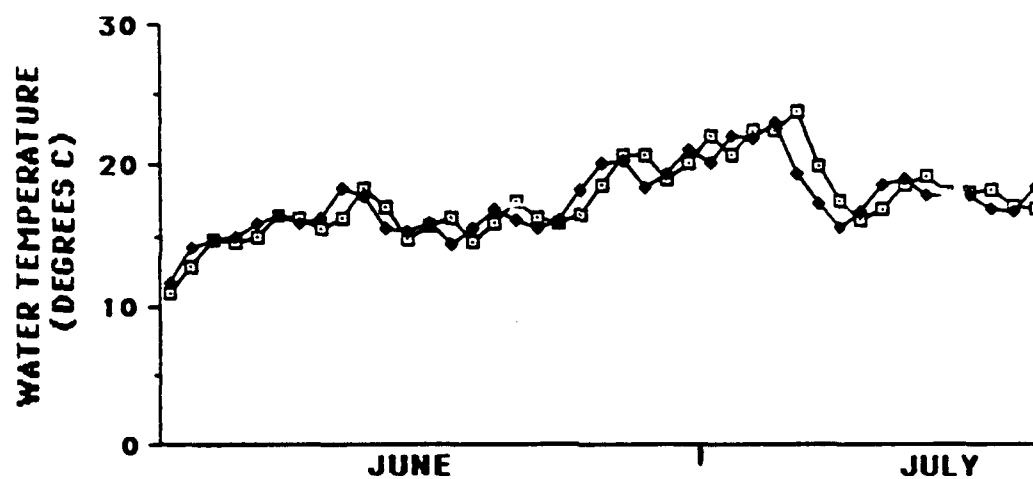
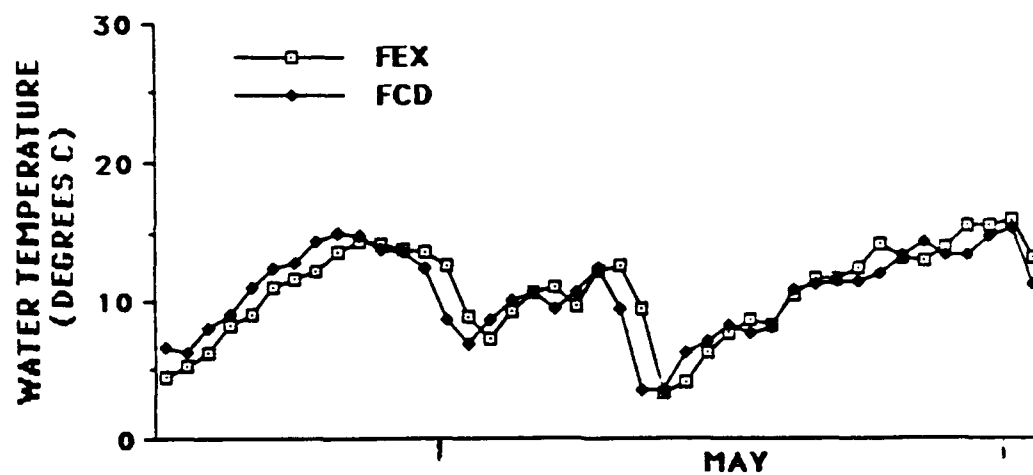


FIGURE 1.20 DAILY WATER TEMPERATURE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1990.

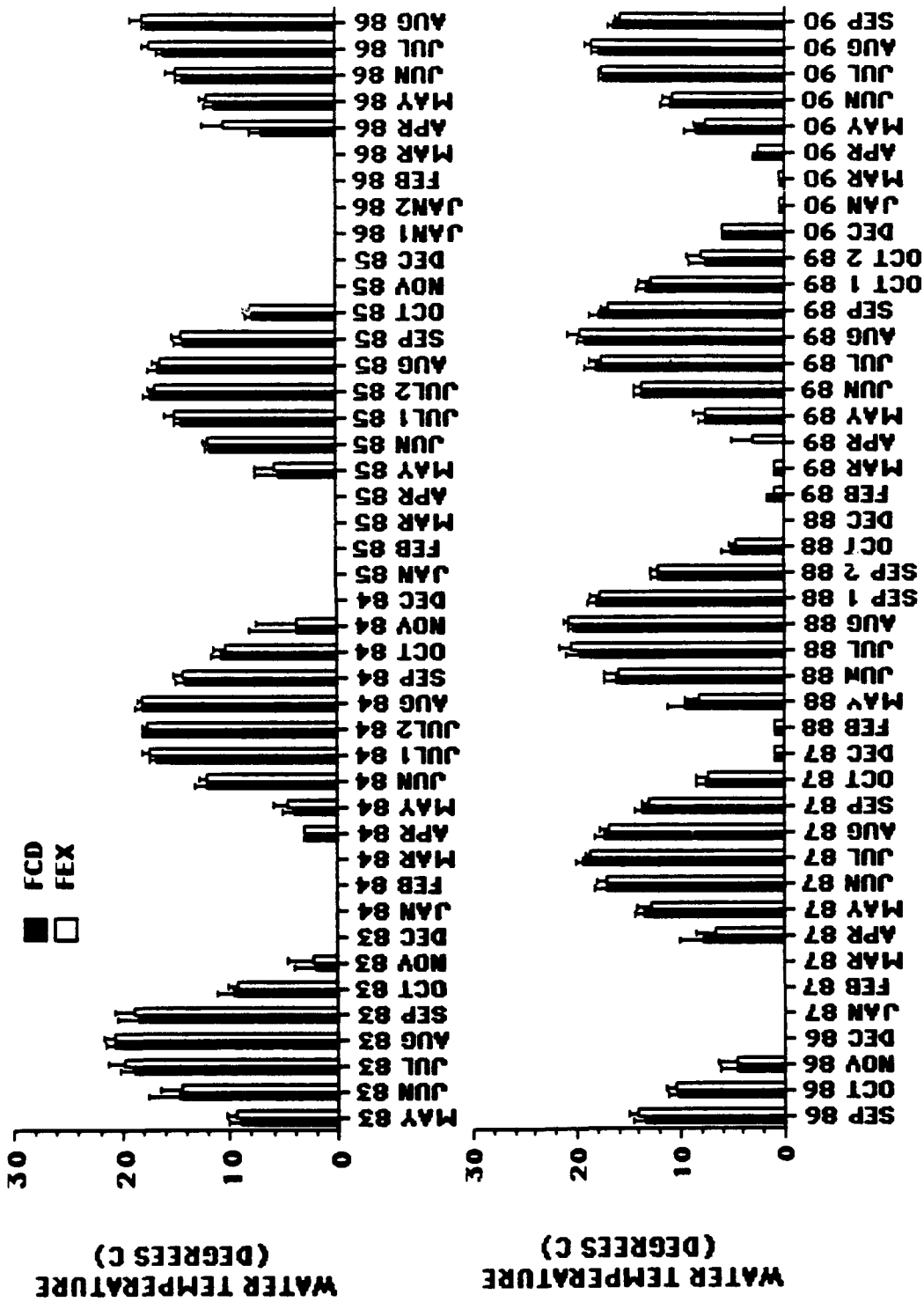


FIGURE 1.21 MEAN WATER TEMPERATURE (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

using modified Stevens Type F recorders. These data had to be converted to discharge using two regressions. The first related electrical output from the recorders to the datapods to actual water depth. The second related water depth to discharge using a standard depth-discharge regression. The first of these regressions changed any time the float line was set to a different position on the float wheel. Thus, retrieval and conversion of these data proved to be quite a chore. We have not yet completed this task. In 1986, this system was abandoned and the simple but effective strip chart recorder has been used since. Data on mean daily flows are currently available for all years since 1986.

We have used data from the National Weather Service's nearest stations at Crystal Falls and/or Iron Mountain to calculate the time that has lapsed between the time of removal from the river of each set of the 28 day benthic algal samples and the time since the last major precipitation event. Our hypothesis that scour of algal biomass from the slides during large storms was having a major impact on some of the parameters measured for the periphyton task was not supported by the data. Since Crystal Falls, MI data may not be precise for the Ford River watershed, we have collected supplemental rainfall data for each site for the last four summers (Fig. 1.22). We are currently summarizing this data for future correlations and entry into multiple regression models.

ELF exposures at the two sites were very low until June of 1989 (Fig. 1.23) when testing of the antenna at 150 amps started. These data ($\log_{10}$ transformed) were used as the covariate in analysis of covariance to directly test for ELF effects on the biota. Results of these analyses are reported in subsequent elements of the report.

D. Summary

Data for all chemical and physical parameters demonstrated that the experimental and control sites were very well matched. For the majority of the parameters, there were no significant differences between sites. When significant differences did occur between the chemical constituents, they usually involved slight increases in a downstream direction. This trend of slight increase from the upstream site to the downstream site for alkalinity, hardness, nitrate, and organic nitrogen may be related to an expected accumulation of dissolved load in a downstream direction or to local land use differences between sites. Whatever the cause, the differences were small and probably would not lead to significant inter-site differences in productivity. We conducted experiments in 1987 to determine the impact of N and P inputs on the algal community. Both

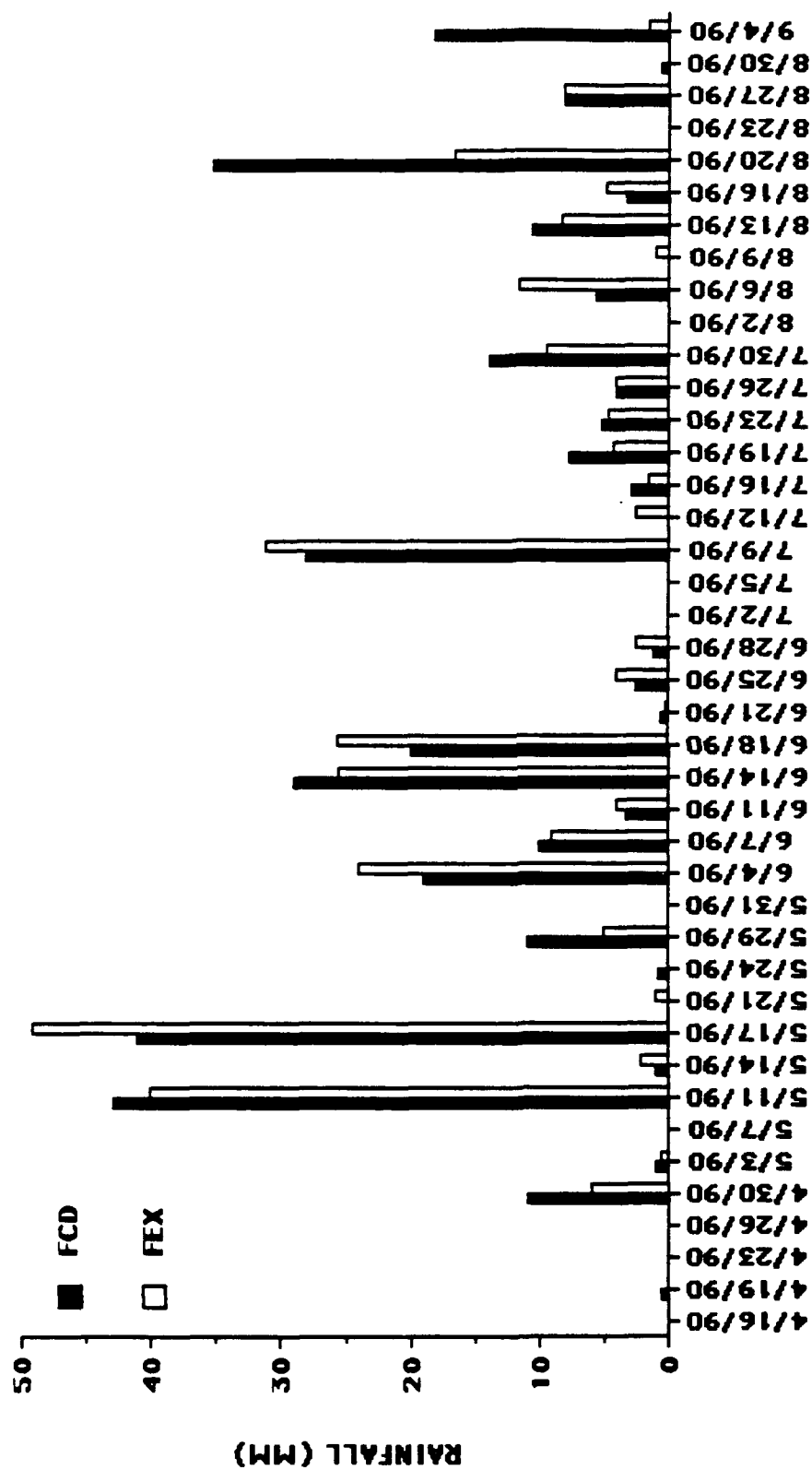


FIGURE 1.22 DAILY RAINFALL AMOUNTS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1990.

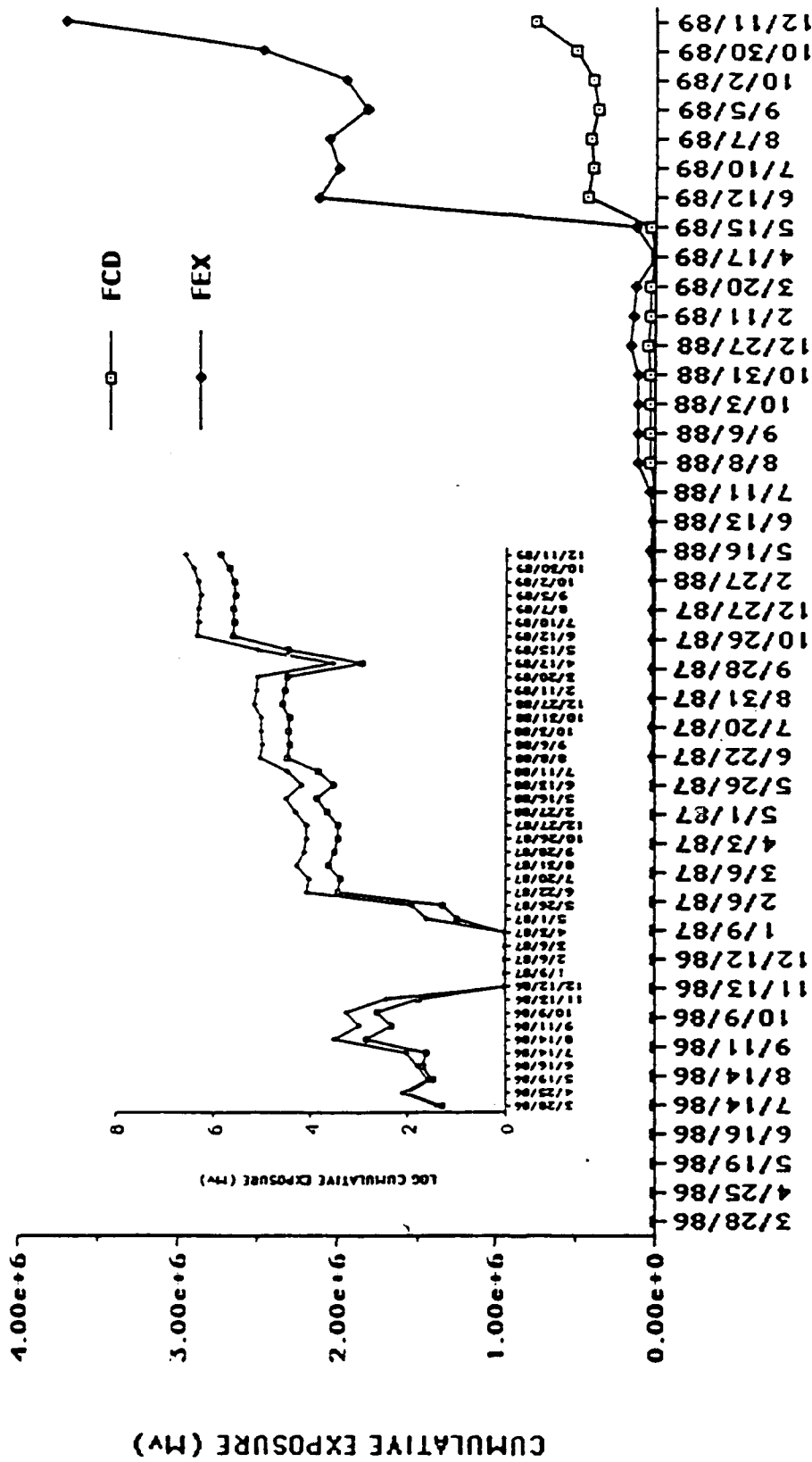


FIGURE 1.23 28-DAY CUMULATIVE EXPOSURE DATA FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990. THE INSET SHOWS THE LOG 10 TRANSFORMATION OF THE EXPOSURE DATA AND MAGNITUDE OF THE DIFFERENCE BETWEEN SITES.

had to increase before significant changes in the algal community occurred. Clearly, no such shift in N and P has occurred.

Dissolved oxygen was only slightly below saturation at both sites but was slightly but significantly higher at FEX than it was at FCD. This is consistent with all previous years except 1988.

Chloride also was slightly but significantly higher at FEX than it was at FCD. This difference might reflect a slight amount of road salt influence from Highway M-95 at Channing, MI that is diluted in a downstream direction. This difference between the two sites did not occur in 1988. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored. The differences that did occur were slight and should have little impact on site productivity.

E. References

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Element 2 - Monitoring of Species Composition Numbers, Diversity, Organic Matter Accrual Rates and Standing Crop, Cell Volume, and Chlorophyll a Accrual Rates and Standing Crop for Periphyton.

Changes from workplan - The winter sampling schedule for the biological parameters was changed from monthly (28 days) to bimonthly sample collection in October 1987 resulting in three winter data sets. This routine was changed to once every 6 weeks for the winters of 1988-89 and 1989-90 to provide an additional winter data set. This additional data set proved necessary because of our current approach of analyzing the data on both an annual and summer/winter basis.

Another change this year is the elimination of the chlorophyll a to phaeophytin a ratio from this report. It was reported in the past as an indicator of the physiological health of the algal community. The high variabilities encountered in this index make its usefulness in detection of ELF effects questionable.

We also added two new monitoring sites for this element in May, 1990 to increase the magnitude of the difference in ELF exposure between our control (FCD) and experimental (FEX) sites (See Fig. VII.1 for site locales). The ELF exposure rate at FEX under full antenna power is 61 mV/m resulting in an exposure that is only 5.0 times greater than the exposure rate of 12.3 mV/m at FCD. This difference is below the desired 10 fold difference in exposure rate called for at the beginning of this study. Two new sites (FCD-N and FEX-N, corresponding to IITRI designations 5C1-7 and 5T2-7 respectively) were added on May 15, 1990. The exposures of 7.9mV/m at FCD-N and 85mV/m at FEX-N result in a 10.8 fold difference in exposure between the two sites ($FEX-N/FCD-N = 10.8$). FCD-N is about 130 m downstream of FCD and FEX-N is about 40 m downstream of FEX (about 10 m downstream of the point where the antenna crosses the river.

In order to maintain continuity in the data base for making before and after comparisons, we continued to collect data from the original sites at FCD and FEX. We will continue to collect data from the original sites as well as from the two new sites until the end of the study. The use

of the original sites and the new sites together will allow us to compare results along a gradient of exposures to ELF electromagnetic radiation ranging from background to an intermediate 5 fold increase in ELF exposure and to a high of a 10.8 fold increase in ELF exposure within 10 m of the antenna crossing. To date, we have too few sample points from the new sites to allow statistical analysis, but these sites will be included in all future reports. The additional person hours required to monitor all four sites will be available because of the proposed elimination of the study of periphyton-grazer interactions in Element 3.

Objectives

The objectives of the periphytic algal studies are:

- (1) to monitor any changes in chlorophyll a and organic matter accrual rates and standing crops as a result of ELF electromagnetic fields,
- (2) to determine algal cell volumes as an index of physiological stress in periphytic algal cells that might occur as a result of ELF electromagnetic fields.
- (3) to quantify any changes in species diversity, species composition, species evenness, and cell density that occur as a result of ELF electromagnetic fields, and,
- (4) to quantify any changes in primary productivity that might occur as a result of ELF electromagnetic fields.

Rationale

Structural Community Indices: Shifts in community composition of the attached algae provide a sensitive measure of changes in water quality (e. g. APHA 1980, Blum 1956, Patrick 1966, 1978). Introduction of pollutants and/or increases in amounts of toxins, nutrients, or other pollutants often results in changes in abundances of particular algal species and/or to the absence or reduction in numbers of individuals of sensitive species or to large increases in numbers of individuals of tolerant species or to replacement of some of the species currently in the community with different species. These changes usually result in changes in species evenness (the number and distribution of individuals within the community) and richness (number of species within the community) leading to

changes in species diversity (the information index that is a composite measure of richness and evenness) of the attached algal community. Since diatoms comprise more than 90 % of the attached algal community in the Ford River, our hypothesis is that shifts in the species composition of the attached diatom community will be a sensitive indicator of any effects of ELF electromagnetic radiation on the algal community. Thus, we are using the Shannon-Wiener species diversity index, an evenness index, and measurements of species percent dominance for between site comparisons of attached diatom communities to detect subtle shifts in species composition that may occur as a result of ELF radiation. The diatom community which develops on exposed glass slides may consist of as many as 50-70 species on a single slide out of an estimated species pool for the Ford River of over 350 species. Changes in species abundance, species diversity, and species evenness of this community provide sensitive and statistically measurable parameters against which to measure seasonal variation, site variation, yearly variation and potential ELF effects.

In addition to studying the species composition of the attached diatoms, we are examining the relatively simple parameter of overall cell density. This directly determined density measure represents the numerical end product of species succession and abundance or dominance shifts by individual species in the attached algae community, and also includes the effects of physical environmental factors. The use of cell density, which is affected by both biological and physical factors, may reveal changes due to ELF effects. This single parameter is also a very important correlate with other estimates of production, such as chlorophyll *a*, or organic matter accrual. This labor intensive direct counting procedure is the yardstick against which other production estimates are often compared and should help separate potential ELF induced effects from other biological or physical influences.

Functional Community Indices: Measurement of the amounts of chlorophyll *a*, the primary photosynthetic pigment used by all algae, provides both quantitative and qualitative comparisons between sites. The quantity of chlorophyll *a* present can be directly measured through the intensity of its fluorescence and can be correlated with cell density and individual average cell volume to indicate the relative or qualitative physiological state of the algal community. Subtle effects of ELF electromagnetic fields on the photosynthetic pigment may result in a general physiological weakening of individual cells. This weakening may decrease both the total quantity of chlorophyll *a* present, as well as reduce the amount of oxygen generated through photosynthesis. The photosynthetic rate of the attached

algae is monitored at both sites throughout the summer. This is a labor intensive task and is only feasible during the summer months when the entire field crew is at the research site.

This multiple approach of methodologies couples direct determinations of quantities of pigments present with direct measurements of oxygen levels produced by that pigment. Thus, these parameters allow statistical comparisons of production between sites throughout the year. Utilizing several different approaches allows us to continue analyses at times when we must rely on single approaches due to weather or labor constraints. For example, measuring chlorophyll *a* and organic matter accrual directly during winter provide estimates of production when the more detailed production studies of photosynthetic rates are not feasible.

In 1986 and 1987, we investigated a new statistical procedure defined by Stewart-Oaten *et al* (1986) to determine the suitability of this technique for analyses of the kinds of structural community indices that we were examining on the Ford River. The analysis, referred to as the BACI test, was demonstrated in the 1986 annual report to illustrate the technique and to see if it would be useful for significance testing on single species population abundances. In 1987, we continued our investigations into the use of the BACI analysis for functional indices, particularly chlorophyll *a* and AFDW-biomass. We used the method in 1988 to examine seasonal variations of each of the biological parameters from 1983 to 1988. In 1989 we continued the BACI analysis by adding the 1988-89 data to the previous comparisons and expanded the analysis to include: accrual rates, photosynthesis/respiration studies and abundances of rare algal species. This analysis has proved to be quite informative and is continued for 1990. This year we have introduced Randomized Intervention Analysis (RIA) as an additional means of analyzing biological and diatom abundance data. In addition, we continued stepwise multiple regressions of our physical/chemical parameters on our biological parameters.

Our rationale has been to provide multiple data sets taken independently to be used in determinations of structural and functional indices, incorporating several methodologies in order to detect and separate any "real" differences as a result of ELF electromagnetic radiation from either background variability or errors associated with a reliance on a single method of data collection or analysis.

Materials and Methods

Plexiglass slide racks were designed to hold 8 or 10 standard 7.6 x 2.5 cm glass slides in a vertical placement oriented facing the current in the river. These slide racks were fastened to bricks and placed in riffle habitats at the control (FCD, FCD-N) and experimental sites (FEX, FEX-N). Slides were removed after 14 days for chlorophyll *a* and AFDW-organic matter accrual rates and after 28 days (62 or 63 days during winter 1987 and 42 days during the winters of 1988 and 1989) for species composition and cell count determinations, chlorophyll *a*, and AFDW-organic matter standing crop determinations. Ten slides per site were used for each determination, except that this number was increased to 25 during the winters starting in 1987.

For species composition, cell counts, and cell volume determinations, 5 slides were removed on each sampling period from each habitat. Three slides were air dried and the other two were placed in a mixture of 6 parts water, 3 parts 95% ethanol and 1 part formalin (6:3:1 solution). These numbers were doubled during winter sampling starting in 1987. The air dried slides were later scraped in the lab with razor blades to remove the diatoms for further specimen cleaning and slide preparation. The slides preserved in the 6:3:1 solution will be used to determine species composition of non-diatom algae should this prove necessary. Preliminary comparisons have indicated that non-diatom algae comprise a minor component of the algal community in the Ford River. Thus, we have chosen to emphasize studies of diatoms.

Slides were prepared for specimen identification by cleaning the diatoms removed from the exposed glass slides in concentrated hydrogen peroxide (30%) followed by further oxidation of the cellular contents with the addition of small amounts of potassium dichromate (Van der Weff 1955). The cleaned diatoms were then rinsed with distilled water and settled in graduated cylinders. The final volume of concentrate containing the cleaned diatom frustules was then measured and 1 ml subsamples pipetted onto 22 mm² coverslips, until an adequate counting density was achieved. The coverslips were air dried and permanently mounted on glass slides using Hyrax medium.

Counting to determine diatom density calculations, and species determinations was done at 1250X magnification on a Zeiss microscope equipped with phase contrast illumination and an oil immersion 100X Neofluar phase objective with numerical aperture of 1.30. Transects were taken moving across the coverslip until approximately 500 frustules were counted. Estimates of diatom densities were then calculated from these quantitative samples via the equation:

(Valves Counted) (Area Coverslip) (Volume Concentrate)
 Cells m^2 = 2 (Area Transect) (Volume Subsample) (Area Sampled)

Diatom species composition was recorded for each slide counted for determination of species richness, diversity (H') using the Shannon-Wiener formula (Southwood 1978; chosen for its more universal use and acceptance than other more obscure diversity indices), species evenness (J') (Pielou 1969, p.233), and dominance. Cell volume measurements were taken by measuring lengths, widths and depths and recording shapes of dominant diatoms for calculation of cell volume based on geometric formulae or combinations of various geometric volumes.

Analyses for chlorophyll *a* followed the fluorometric determination described in Method 1003C in Standard Methods (APHA 1980). All samples were analyzed within a month of collection. Initial analyses suggested no differences in these parameters whether or not the samples were ground first with a tissue homogenizer to facilitate cellular rupture. Therefore, this step was eliminated. Slides were collected, frozen for at least 24 hours to promote cell rupture, and then pigments extracted in 90% buffered acetone. Chlorophyll *a* was then determined following procedures outlined in Standard Methods (APHA 1980).

Organic matter biomass determinations were conducted following procedures 1003D for productivity estimates in Standard Methods (APHA 1980). While using the gain in ash-free dry weight per unit area as a measure of net bacterial and algal production (APHA 1980), we recognize that determining rates of primary production from a temporal series of biomass measurements results in minimal estimates of net production. The losses that may occur from excretion of organic compounds, respiration, mortality, decomposition, emigration, or grazing are certainly not included in determining this production estimate (Wetzel 1975). Likewise, accumulations of organic matter from physical processes such as flocculation or settling of dissolved and particulate organic matter are also possible (Lock et al. 1984). The accrual of organic matter biomass is a combination of processes involving dynamics of both colonization and production as well as physical processes. Results from our study of the colonization component on biomass accrual should increase the accuracy of these production estimates. Rather than list results as production, however, we will refer to them as organic matter accrual rates or AFDW-biomass accrual rates.

Statistical comparisons between sites emphasize the paired t-test, as recommended by one of our reviewers in past annual reports. Single year data for October, 1989

through September, 1990 and results for yearly and seven year paired t-tests on all parameters measured will be presented in this report. Additionally, emphasis has been placed on the analysis of biological parameters using the BACI and RIA techniques. Previous methods for analysis of "before" and "after" ELF effects as presented in earlier annual reports included the 3-way analysis of variance. The variables included a year, site and month effect for the selected parameter. While this analysis may prove to be the most statistically robust of several analyses available, they all may suffer from lack of true replication (Hulbert 1984). Because of such considerations and to expand our methods, we have analyzed our biological data according to the BACI method presented by Stewart-Oaten et al (1986) and the RIA method presented by Carpenter et al (1989).

The BACI design determines whether the difference between simultaneously collected samples of a given parameter at Impact (FEX) and Control (FCD) sites has changed significantly with antenna operation. The mean of the "before" differences between sites is compared to the mean of the "after" differences between sites by using an unpaired t-test. If the magnitude of the difference between the control and impact sites changes significantly ($p < 0.05$) after impact, there may be a significant antenna impact. The procedure assumes that the following criteria are met: (1) the measures of the parameters at any time are independent of the measures of those parameters at any other time, and (2) the differences between the control and impact sites of the "before" period are additive. The first criterion was met by the sampling regime used in our study. The parameters we examined were measured independently for each period. The second condition was satisfied by transforming the data, if necessary (Steel and Torrie 1986). If regression of the differences versus the average at both sites for the raw or transformed data produced a slope that was not significantly different from zero (Tukey's Test for Additivity), the differences were additive. The differences for each period were then compared with an unpaired two-tailed t-test.

Using the BACI analysis, we can examine seasonal variations of chlorophyll *a* and AFDW-biomass standing crop and production, cell volume, biovolume, cell density, species diversity, evenness, and diatom abundance. Seasons for this analysis consisted of a Summer (May to October) and a Winter (November to April) period, with all seasons prior to Summer, 1986 representing the "before" period. The "after" period commenced July 22, 1986 at FEX with an average 4 amp ELF exposure for variable time periods during the day over 31 consecutive days. During 1987, the site at FEX received 15 amps for variable time periods during

daylight hours from May 22 through August 31, 1987. The experimental site was exposed to 75 amps for variable time periods throughout most of 1988 and 150 amps from May 1, 1989 to October 7, 1989. Since October 7, 1989 the antenna has been operated full time and at full power. Using the BACI design we ran pooled comparisons on all the biological data except diatom abundance; i.e. all sampling dates from June, 1983 to April, 1986 as the "before" period and all dates from May, 1986 to September, 1990 as the "after" period. For each biological parameter, seasonal pooled comparisons were run; i.e. Summers (or Winters) 1983, 1984, 1985 as the "before" period and Summers (Winters) 1986, 1987, 1988, 1989 and 1990 as the "after" period. Additionally, individual seasons of the "before" period for each parameter were compared to other "before" seasons to determine whether any differences occurred prior to impact. Each of the "before" seasons were then individually compared to each of the "after" seasons to see whether significant differences occurred as a result of ELF exposure. The results of all BACI analyses are in Appendices A and B with summary tables included in the body of this element.

This year we have included randomized intervention analysis (RIA) as a non-parametric alternative to the BACI technique (Carpenter et al 1989). The RIA design, like BACI, is based on replicated sampling over time, before and after a manipulation, at control (FCD) and experimental (FEX) sites. A mean difference between FCD and FEX is calculated from both the "before" and "after" data sets. The absolute value of the difference between these means represents the test statistic. Random permutations of the time series of inter-site differences provides an estimate of the distribution of the test statistic. In effect, we have replaced BACI's unpaired t-test with a randomized error distribution taken from our own data sets. The proportion of randomly created differences between means that are greater than the observed difference between means, determines whether a significant change has occurred between sites after antenna operation. As with the BACI technique, a significant finding does not indicate that an antenna impact has taken place, but rather that some non-random change between sites has occurred.

By using a randomly created error distribution, the RIA design eliminates problems of non-normality and heterogeneous variances associated with the BACI technique. Carpenter et al (1989) does note that RIA may be affected by autocorrelations in the data. Our sampling regime of independent paired observations over time eliminates this autocorrelation problem. Another limitation of RIA as demonstrated by Carpenter et al (1989) is the lack of test sensitivity with sample sizes of less than 40. Presently,

we have analyzed all the biological, gross primary production and diatom species abundance data using RIA. The same protocol of using total and pooled seasonal "before" and "after" data used with BACI has been followed for RIA. However, we were not able to make year-to-year comparisons using RIA, due to small (2-17 observations) sample sizes (Tables 2.6, 2.11, Appendices A and B).

RIA calculations were performed using the RIAPUB program obtained from Dr. Stephen R. Carpenter of the Center for Limnology, University of Wisconsin-Madison. The program, written in Fortran, is interactive in nature and is applicable for most studies of this type. Results from our analysis of biological and diatom abundance data using both the BACI and RIA designs will be presented at the 1991 Midwest Pollution Control Biologists Meeting in Chicago, Illinois.

We also calculated the Minimum Detectable Differences (Zar, 1984 pg. 153) for each of our biological parameters. This tells us the magnitude of ELF induced change in any of these parameters that we will be able to identify statistically given the present level of variance and sample size for each parameter. This year we have included the results from a large correlation matrix in order to examine the relationship between our biological parameters and the physical/chemical variables. Also, in order to explore those relationships further, we conducted stepwise multiple regression analysis (p to enter = 0.05 and p to remove = 0.10) for each biological parameter before and after the antenna was turned on, using all the physical/chemical parameters monitored, plus a variable to signify site. Regressions were run for the entire data set (1983-1990) using all variables except discharge, and on the total summer data set with all the variables including discharge (discharge data is only available for the summer months).

In order to directly assess the effects of ELF exposure on the biological parameters, we have used analysis of covariance (ANCOVA) with the ELF exposure data, presented in element 1, as the covariate in this analysis. ANCOVA, as calculated in this study, is a means of standardizing the values of each parameter at the two sites for the intersite differences in the covariate, ELF exposure, and then comparing the standardized values between sites. This should allow us to determine if inter-site differences in any of our biological parameters are caused by ELF exposure. As an example, we compared the species diversity of the two sites (using a paired t-test) before the antenna was turned on and found no significant difference. The same comparison using data from the period after testing began on the antenna detects a significant difference between the sites.

We use ANCOVA to test the hypothesis that this change in the inter-site relationship is caused by ELF exposures. To do this, ANCOVA was conducted on the after data set. The result of the ANCOVA was a significant inter-site difference in species diversity. Since the ANCOVA results do not differ from the results of the paired t-test on the same data set, we conclude that the change in the inter-site relationship indicated by the before and after paired t-tests is not due to the covariate, ELF exposure.

While we increase the degree of statistical analyses performed, as well as the complexity of the analyses with each report as more data become available, a large inherent variability still remains between our biological field samples collected at one point in time. For example, chlorophyll *a* determinations had coefficients of variation (C.V.'s) that averaged 32% in 84-85, 42% in 85-86, 37% in 86-87, 34% in 87-88, 38% in 1988-89 and 30% in 89-90. AFDW-biomass had C.V.'s that averaged 40% in 84-85, 64% in 85-86, 45% in 86-87, 48% in 87-88 and 36% in 88-89 and 89-90. C.V.'s for diatom cell density averaged 38% in 84-85, 39% in 85-86, 33% in 86-87, 45% in 87-88, 9% in 88-89 and 18% in 89-90 (these lower C.V.'s since 1988 probably resulted from increasing the number of valves counted per slide from 300 to 500 as a means of effectively lowering the variation). All three important biological parameters showed average C.V.'s possibly too high to detect subtle differences due to ELF effects if comparisons are made at one point in time or for a single random sample period only. The individual C.V.'s of many of our monthly samples often fell below the 20% rejection level commonly used in benthic studies (Cummins 1975), in spite of the wide range in C.V. values observed over the course of a year. At times when the C.V.'s were low, statistical comparisons between sites provided a sample size sufficient to be 95% certain of detecting a 40% difference in means between the two sites at the 0.05 significance level (Sokal and Rohlf 1969). Coefficients of variation tended to be lower during low flow periods in summer and more variable during the higher waters seen in spring and fall periods. Thus, statistical comparisons in future reports will emphasize these time periods to be able to detect small differences between single time period comparisons. Our main efforts have been to use tests rigorous enough to detect differences using larger samples over time. We expect overall trends to be examined through the BACI and RIA techniques.

Derived measurements of species diversity or species evenness calculated from the field samples were characterized by much lower C.V.'s. C.V.'s for species diversity ranged from 1% to 27% for individual samples and averaged 10% in 85-86, 10% in 86-87, 6% in 87-88, 1% in 88-

89 and 2% in 89-90 . For species evenness C.V.'s averaged 7% in 85-86, 6% in 86-87, 4% in 87-88, 5% in 88-89 and 2% in 89-90. Again, the improvement in C.V.'s since 1988 reflects the increase in the number of valves counted per slide from 300 to 500 at that time. The derived measurements based on the actual density counts clearly all fit the criterion of C.V.'s being lower than 20 % and offer sensitive parameters that can be used to detect ELF effects.

Results and Discussion

A. Colonization Patterns

In previous annual reports (AE-020, AE-031 and AE-045 for 1982-83, 1983-84, and 1984-85), we summarized data on colonization patterns for periphyton for the Ford River. These data demonstrated that for determining rates of productivity and organic matter accumulation, a 14 day period was best during the active growing season (mid-April to mid-September). This 14 day period coincided with rapid increases in chlorophyll *a*, phaeophytin *a*, and accrual of organic matter. Selecting this early period minimizes losses due to sloughing that increase as the periphyton community "matures" or approaches its maximum sustainable density on the slides (Burton and King 1983). This period of maximum daily increase in organic matter and chlorophyll *a* is often used as a measure of net production (APHA 1980; Burton and King 1983). Since the daily increases are less rapid during the cold weather, we used the 28 day period for estimates of daily productivity or accrual rate during the winter months from 1983 - 1986, a 56 day period for the winter of 1987 and a 42 day period for all winters since 1987, and the 14 day period from April through October for all summers.

After 14-21 days during exposure periods without major flood events, the periphyton community composition was shown to change slowly through time (Oemke and Burton 1986), and qualitatively approximated the mature community on natural substrates in the stream. Thus, standing crop estimates of chlorophyll *a*, organic matter, and all community composition parameters (cell density, species diversity, species evenness, and species dominance) are based on a 28 day exposure period throughout the year. All data from 1983-1990, excluding the winters since 1987, were based on this 28 day exposure period and sampling regime. During the winter of 1987-88, winter samples were taken at 56 day intervals. Since 1988-89, winter samples have been taken at 42 day intervals. As reported in the 1982-83 annual report (AE-20) and in Oemke and Burton (1986), differences between

a slow flowing pool habitat, and the more rapidly flowing riffle habitat were either slight or insignificant as exposure length increased. Thus, all samples are presently collected from riffle areas only.

Data on these colonization dynamics were published in Hydrobiologia (Oemke and Burton 1986), and presented as an appendix in the annual report for 1986-87 (AE-071).

B. Patterns for Chlorophyll a

Chlorophyll a standing crop data for October 1989 through September 1990 followed annual patterns of summer peaks and winter lows (Fig. 2.1, Table 2.1). Annual patterns have indicated that chlorophyll a peaks during the summer months of July or August, although in 1989 and 1990 the highest chlorophyll a standing crops have occurred in May. The chlorophyll a levels over the last few summers are higher than recorded prior to 1987 and are probably associated with the higher temperatures and lower flows experienced over the past few years. Most measures of algal standing crop (density, chlorophyll a, AFDW-organic matter accrual) as well as species composition appear to have increased as a consequence of the very dry weather in May and early summer for the past five years (with the exception of June 1989). Another consistent pattern for chlorophyll a has been that standing crop has been low in winter (Fig. 2.1). As reported earlier, winter 1986-87 was characterized as being moderate in severity, with substantially warmer temperatures, resulting in less ice cover for the Ford River. The levels of pigment observed for 1986-87 winter were much greater than those observed in any other winter (Fig. 2.1).

The period of highest variability has generally been the periods from late March through June. This period sometimes contains secondary peaks in standing crop production, e.g. April 1984, May 1986, 1989 and 1990 (Fig. 2.1). This secondary peak seems to be associated with dry spring seasons with low flows and relatively warm temperatures following snow melt runoff events. Stepwise multiple regression models indicate that water temperature is the most consistent predictor of chlorophyll a standing crop at both sites (Table 2.2). This is consistent with the results of the correlation matrix. Chlorophyll a correlates negatively with: discharge ($r = -0.46$ at FCD and FEX), inorganic nitrogen ($r = -0.43$ and -0.41), nitrate ($r = -0.45$ and -0.40) and dissolved oxygen ($r = -0.40$ and -0.46) and chlorophyll a correlates positively with: air temperature ($r = 0.67$ and 0.57) and water temperature ($r = 0.45$ and 0.54) (all p 's < 0.01).

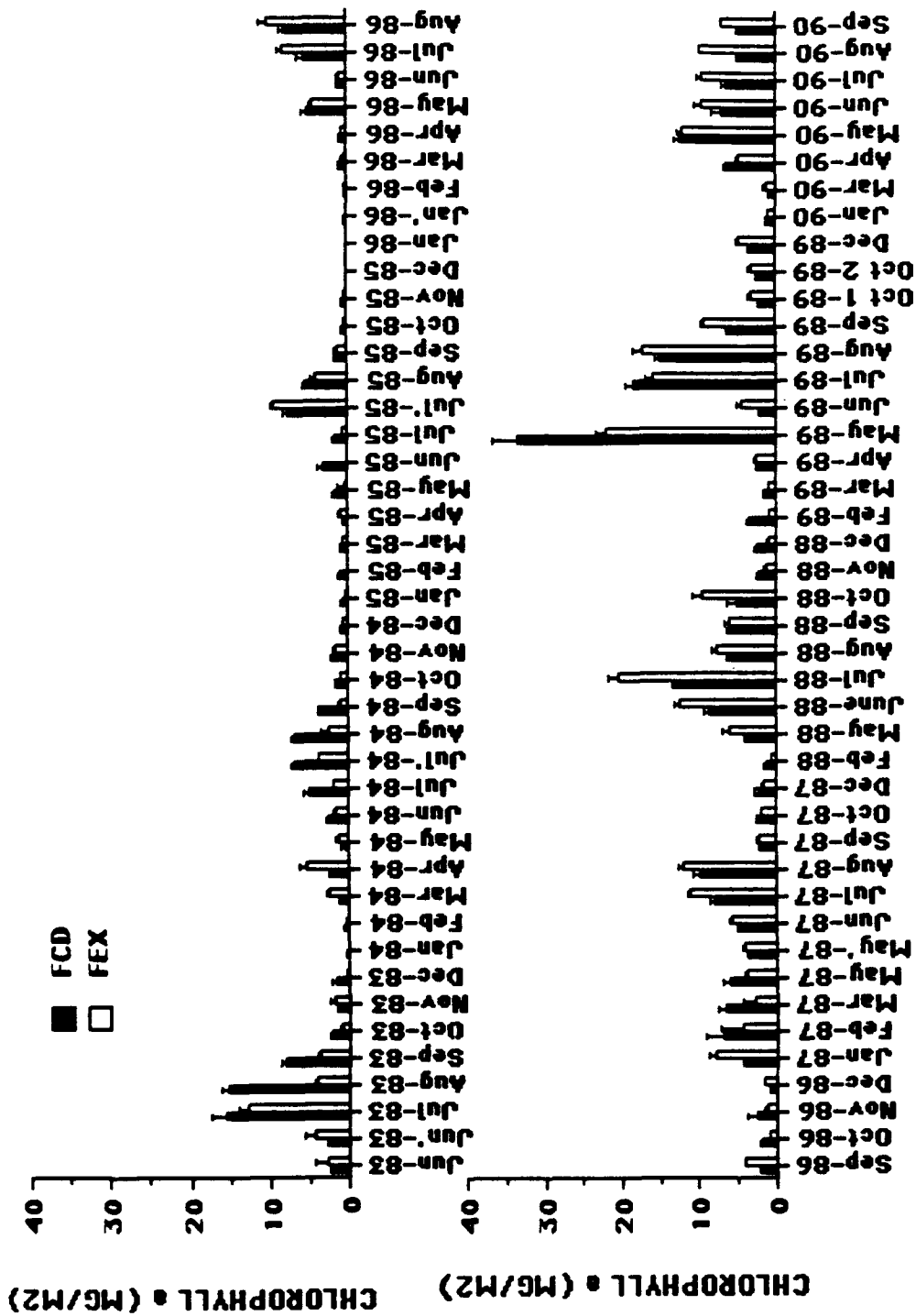


FIGURE 2.1 CHLOROPHYLL a STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1990.

Table 2.1 Chlorophyll a (mg/m²) from slides exposed for 28 days in the Ford River. Values are Means $\pm$ S.E, N in Parentheses.

Date out	Experimental (FEX)	Control (FCD)
10/2/89	3.15 $\pm$ 0.34 (10)	1.99 $\pm$ 0.20 (10)
10/30/89	3.20 $\pm$ 0.41 (10)	2.35 $\pm$ 0.17 (10)
12/11/89	4.72 $\pm$ 0.31 (25)	3.16 $\pm$ 0.23 (25)
1/22/90	0.87 $\pm$ 0.08 (25)	1.19 $\pm$ 0.14 (25)
3/3/90	1.37 $\pm$ 0.06 (25)	1.02 $\pm$ 0.06 (26)
4/16/90	4.69 $\pm$ 0.31 (25)	6.35 $\pm$ 0.42 (25)
5/14/90	12.07 $\pm$ 0.77 (9)	12.42 $\pm$ 0.61 (9)
6/11/90	9.52 $\pm$ 1.05 (10)	6.87 $\pm$ 1.27 (10)
7/9/90	9.68 $\pm$ 0.56 (10)	6.32 $\pm$ 0.76 (10)
8/6/90	9.77 $\pm$ 0.23 (10)	4.80 $\pm$ 0.43 (10)
9/4/90	6.88 $\pm$ 0.23 (10)	4.70 $\pm$ 0.27 (10)

Table 2.2 Results of stepwise multiple regression analysis for each biological parameter (total and summer data) on selected physical/chemical variables (A = alkalinity, Am = ammonia, C = conductivity, Cl = chloride, D = discharge, IN = inorganic nitrogen, Na = nitrate, ON = organic nitrogen, Si = silica, SRP = soluble reactive phosphorus, ST = Site, T = water temperature, TP = total phosphorus and Tu = turbidity).

Parameter	Data	Season	Model	R ²	Major factor	% contribution of major factor
Chlorophyll A	Before	total	$Y = 0.29T + 0.034A - 1.50ST - 2.14$	0.49	T	82
	summer		$Y = 1.09T - 1.91ST + 1.25D - 11.23$	0.56	T	79
	After	total	$Y = 0.53T - 0.07A - 0.13TP + 12.71$	0.33	T	62
	summer		$Y = -1.09Cl + 12.2$	0.14	Cl	100
AFDW	Before	total	$Y = 2.17C + 33.83T - 92.21$	0.55	T	95
	summer		$Y = 52.56T + 13.93TP - 175.15$	0.44	T	82
	After	total	$Y = 45.96T - 6.95A + 70.31Cl + 1155.26$	0.35	T	68
	summer		No model fit			
Density	Before	total	$Y = 0.686T + 2.845$	0.34	T	100
	summer		$Y = 3.163T - 0.439A + 26.701$	0.37	A	62
	After	total	$Y = -1.62A - 26.39Si - 2.94TP + 571.73$	0.46	Si	69
	summer		$Y = -1.6A - 25.37Si - 3.24TP + 574.04$	0.43	Si	72
Evenness	Before	total	$Y = -0.009T - 0.001Na + 0.843$	0.21	T	71
	summer		$Y = -0.04T - 0.006A - 0.03SRP + 0.02S_2 + 0.39$	0.64	A	43
	After	total	$Y = 0.002A - 0.02Cl + 0.02SRP + 0.37$	0.21	Cl	37
	summer		$Y = 0.003Am - 0.001IN + 0.043Si - 0.066ST + 0.47$	0.37	Si	41
Cell Volume	Before	total	$Y = -26.86T + 696.8$	0.46	T	100
	summer		$Y = -38.65SRP + 439.2$	0.10	SRP	100
	After	total	$Y = -60.3T + 248.4Cl - 170.4SRP + 983.7$	0.35	T, SRP	40
	summer		$Y = 33.88Cl + 41.67SRP - 53.29$	0.40	SRP	90
Biovolume	Before	total	$Y = -1.23ST + 4.78$	0.12	ST	100
	summer		$Y = 0.47T - 0.06A - 0.91ST + 6.00$	0.30	T	43
	After	total	no model fit			
	summer		$Y = 0.29SRP - 2.88Si + 24.74$	0.17	Si	65
Diversity	Before	total	$Y = -0.53T - 0.46Tu - 0.001ON + 0.101Si + 4.23$	0.33	Si	30
	summer		no model fit			
	After	total	$Y = 0.003C + 0.013Am - 0.007IN + 0.084SRP + 0.13Si + 0.26$	0.40	C	25
	summer		$Y = 0.02Am + 0.22Si - 0.33ST + 0.77$	0.45	Am	44

The annual comparison for 89-90 between sites showed a significant difference using a paired t-test for chlorophyll *a* levels (Table 2.3) with FEX being consistently higher than FCD. Chlorophyll *a* levels between sites were highly correlated in 1990 ($r = 0.87$, Table 2.3) just as they were for the entire study period (Table 2.4). We have also computed the minimum detectable differences for each of our biological parameters (Table 2.5). The minimum detectable difference is the percent different the 2 sites must be in order for us to be able to detect it at our standard significance level of 0.05. This was done according to the method provided in Zar (1984, pg. 153) on the entire data sets and on the summer and winter data sets. The 62% needed for the winter data set highlights the variability found in our winter data for chlorophyll *a* and all other biological parameters.

Results of BACI comparisons of 7.5 year $\log(x+1)$ transformed chlorophyll *a* data (Table 2.6 and appendix A, Table A-1) indicated that a significant difference ($p < 0.01$) occurred when "before" (6/83-4/86) and "after" (5/86-9/90) means were compared with an unpaired t-test ($df = 84$, t -value = 2.989). When broken down on a seasonal basis, the significance was the result of a significant difference between 83-85/86-90 summer regressions (Table 2.6). Summer by summer comparisons showed that these differences primarily arose from differences between the summer of 83, 84, and 85 and the summers of 87, 88 and 90. The significant difference probably reflected the unusually high chlorophyll *a* levels observed during the low flow, hot summers of recent years. These results were corroborated by randomized intervention analysis (Table 2.6), although RIA does not allow the year by year comparisons that were made in the BACI analysis. Analysis of covariance with the ELF exposures at each site as the covariate was used to test the hypothesis that the change in the inter-site relationship in chlorophyll *a* standing crop is caused by the operation of the ELF antenna (Table 2.7). Before antenna operations began in 1986 there was a significant difference between the sites for chlorophyll *a*. There was not a significant inter-site difference after antenna operations began in 1986. The ANCOVA result from analysis of the after data set indicates that this change in the inter-site relationship is not attributable to ELF exposure. Due to the strong correlation between chlorophyll *a* and water temperature, the importance of water temperature in the stepwise regression models for chlorophyll *a*, and the recent warming trend evidenced by the drought of 1987 and 1988, we feel that the difference in the inter-site relationship, detected by both BACI and RIA, is due to a differential site response by the

Table 2.3 Paired t-test and Correlations between the Experimental(FEX) and Control (FCD) sites for Biological parameters for 1989-1990.

Parameter	df	Paired t-value	Significance	Correlation Coefficient	Significance
Chlorophyll a	10	-2.356	P < 0.05	0.868	P < 0.01
AFDW	8	-1.566	NS	0.416	NS
Chlorophyll a daily accrual	10	-1.694	NS	0.957	P < 0.01
AFDW daily accrual	9	-2.281	P < 0.05	0.867	P < 0.01
Species Diversity	10	1.247	NS	0.901	P < 0.01
Species Evenness	10	1.173	NS	0.929	P < 0.01
Cell density	10	-0.747	NS	0.773	P < 0.01
Cell volume	10	-0.483	NS	0.830	P < 0.01
Biovolume	10	-0.139	NS	0.497	NS

Table 2.4 Paired t-test and correlations between the Experimental (FEX) and Control (FCD) sites for Periphyton parameters for 1983-1990.

Parameter	df	Paired t-value	Significance	Correlation Coefficient	Significance
Total Chlorophyll a	85	0.488	NS	0.851	P < 0.01
AFDW	83	- 1.629	NS	0.704	P < 0.01
Chlorophyll a daily accrual	89	- 1.695	NS	0.832	P < 0.01
AFDW daily accrual	88	- 0.953	NS	0.608	P < 0.01
Diversity	84	1.939	NS	0.702	P < 0.01
Evenness	84	1.513	NS	0.790	P < 0.01
Cell density	84	- 1.577	NS	0.896	P < 0.01
Cell volume	84	0.690	NS	0.957	P < 0.01
Biovolume	84	- 1.288	NS	0.703	P < 0.01

Table 2.5 Minimum detectable differences for major biological parameters using paired T-tests. Values were computed the complete data set and for summer and winter data sets. Values are % detectable change (at $P < 0.05$)

Parameter	Total	Summer	Winter
Chlorophyll a	29.1	33.5	62.0
Organic matter (AFDW)	22.5	26.3	49.1
Evenness	5.1	6.3	7.2
Cell volume	24.6	23.7	23.2
Biovolume	53.1	59.2	104.2
Density	48.4	51.1	139.1
Diversity	7.4	8.6	11.9
Chlorophyll a Accrual	32.1	37.0	49.8
AFDW Accrual	27.1	29.7	60.8

Table 2.5 Summary of BACI and RIA Comparisons for Chlorophyll *a* and AFDW-Biomass between Control (FCD) and Experimental (FEX) Sites for 1983-1990. N in parentheses for BACI and RIA, respectively.

Parameter	Comparison	BACI Signif. ($p < 0.05$)	RIA Signif. ($p < 0.05$)
Chlorophyll <i>a</i>	6/83-4/86 vs. 5/86-9/90 (84) (84)	$p < 0.01$	$p < 0.05$
	Summer 83-85 vs. 86-90 (49) (51)	$p = 0.06$	$p < 0.01$
	S 83/88 (9)	$p < 0.05$	
	S 83/90 (9)	$p < 0.05$	
	S 84/87 (11)	$p < 0.05$	
	S 84/88 (10)	$p < 0.05$	
	S 84/90 (10)	$p < 0.01$	
	S 85/87 (11)	$p < 0.05$	
	S 85/88 (10)	$p < 0.01$	
	S 85/90 (10)	$p < 0.01$	
	Winter 83-85 vs. 86-89 (33) (33)	NS	NS
Chlor. <i>a</i> Daily Accrual	6/83-4/86 vs. 5/86-9/90 (86) (86)	$p < 0.01$	$p = 0.18$
	Summer 83-85 vs. 86-90 (51) (53)	$p < 0.01$	$p = 0.14$
	S 83/88 (17)	$p < 0.05$	
	S 84/89 (11)	$p < 0.01$	
	S 85/89 (11)	$p < 0.01$	
	S 85/90 (8)	$p < 0.05$	
	S 86/89 (11)	$p < 0.05$	
	Winter 83-85 vs. 86-89 (33) (35)	NS	NS
AFDW-Biomass	6/83-4/86 vs. 5/86-9/90 (83) (83)	NS	NS
	Summer 83-85 vs. 86-90 (48) (50)	$p < 0.01$	$p < 0.01$
	Winter 83-85 vs. 86-89 (33) (33)	NS	NS
AFDW-Biomass Daily Accrual	6/83-4/86 vs. 5/86-9/90 (88) (86)	NS	NS
	Summer 83-85 vs. 86-90 (52) (53)	NS	NS
	Winter 83-85 vs. 86-89 (34) (35)	NS	NS

Table 2.7 Analysis of covariance results for biological parameters using cumulative exposures at each site as the covariate. Analysis based on data from 1986 - 1989.

Parameter	Between site t tests		ANCOVA
	Before	After	
Chlorophyll <u>a</u>	P < 0.05	NS	NS
Organic matter standing crop	NS	NS	NS
Evenness	NS	P < 0.01	P < 0.05
Diversity	NS	P < 0.01	P < 0.05
Cell volume	P < 0.05	NS	NS
Biovolume	NS	NS	NS
Density	NS	NS	NS

algal communities at the two sites to the increase in water temperatures observed in recent years. However, more data from both sites under full antenna operations is needed before any conclusions can be drawn.

Daily chlorophyll *a* accrual rates followed the same pattern as did standing crop with mid-summer peaks and winter lows (Fig. 2.2, Table 2.8). Daily rates peaked in July, consistent with the pattern observed in the last three years. The daily accrual rates were very similar between FEX and FCD, and there were no significant differences between the sites in 1989-90 (Table 2.3). Differences were found to be significant between sites in the report for 1983-84, analyzing only a single year's data by paired *t*-tests. Since then, greater care has been taken to place slides in similar habitats with respect to current velocity, shading, and depth. Subsequent reports have shown no significant site differences in the last five years. The minimum detectable difference for chlorophyll *a* accrual (Table 2.5) of 32.1% is similar to that for chlorophyll *a* standing crop.

BACI analysis of the chlorophyll *a* accrual rates indicate that there is a difference in the between site relationship "before" impact (6/83-4/86) and that relationship "after" impact (5/86-9/90) (Table 2.6, A-2). This is due to differences between the summers of 1983 and 1988, 1985 and 1990, and the summers of 1984, 1985 (before years) and 1989 (an after year). RTA fails to pick up the differences detected in the BACI analysis (Table 2.6). However, it does produce low (though not significant) *p* values. Once again, this change in the inter-site relationship may be related to weather differences between these years.

C. Patterns of Organic Matter Accumulation

Organic matter measured as accumulation of ash free dry weight (AFDW) on glass slides generally followed the same trends in 1989-1990 as did chlorophyll *a* (Figs. 2.1, 2.3). The organic matter standing crop did not quite reach the levels reported in the previous summers, perhaps resulting from a return to pre-drought temperatures in 1990 (Table 2.9). The pattern for the colder winter months was essentially the same for 1989-90 as for the previous winter periods.

Paired *t*-tests between sites for AFDW-organic matter accumulation showed no significant differences for 1989-1990 data (Table 2.3) or for all the data taken since 1983 (Table 2.4). Correlations between both sites (Table 2.3) showed a

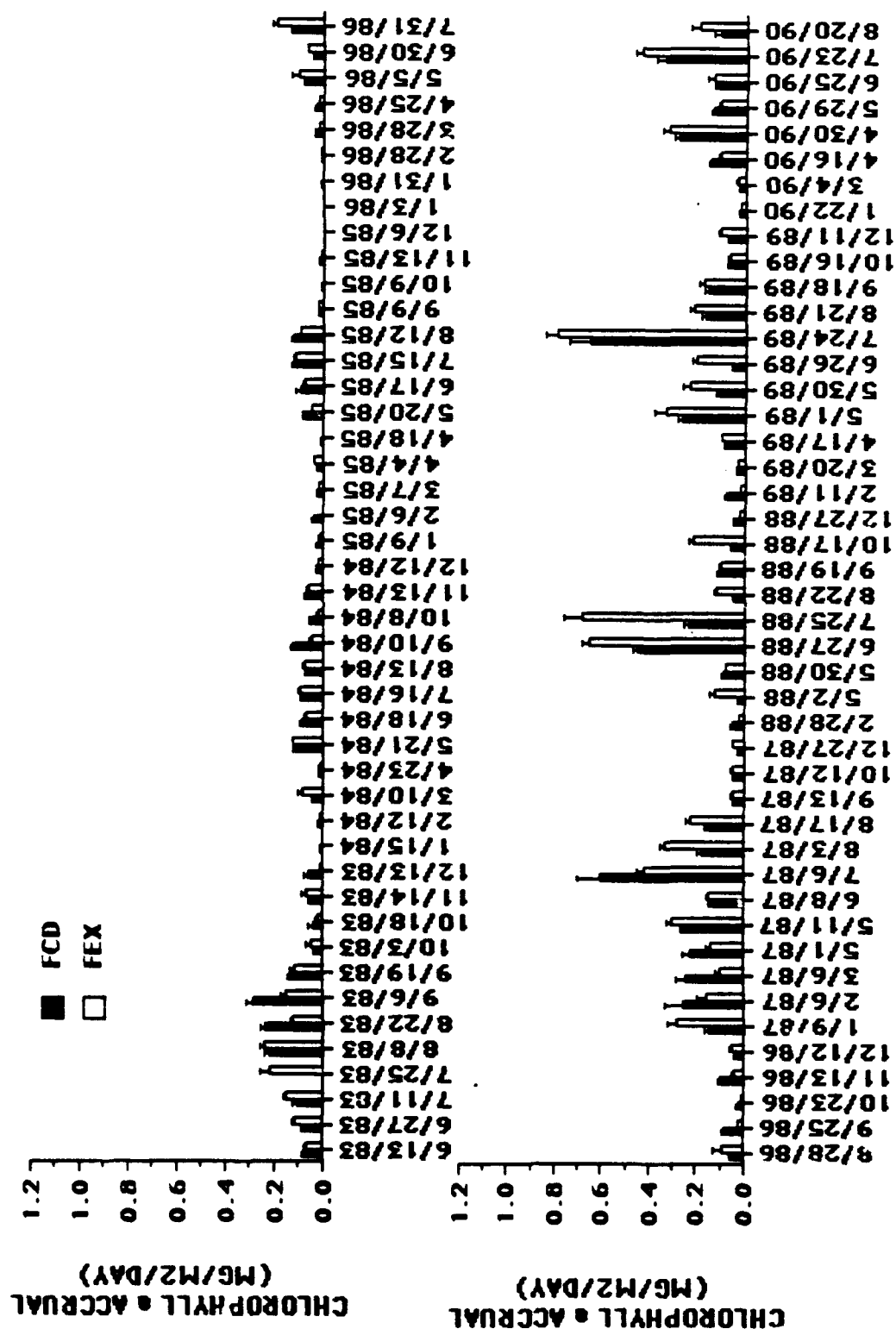


FIGURE 2.2 ACCRUAL RATES OF CHLOROPHYLL • FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1990.

Table 2.8 Ash Free Dry Weight Biomass (mg/m²) from slides exposed for 28 days in the Ford River. Values are Means $\pm$ S.E., N in parentheses.

Date out	Experimental (FEX)	Control (FCD)
10/2/89	1081 $\pm$ 166 (9)	1400 $\pm$ 184 (10)
10/30/89	1288 $\pm$ 87 (10)	837 $\pm$ 87 (10)
12/11/89	618 $\pm$ 45 (25)	592 $\pm$ 95 (25)
1/22/90	477 $\pm$ 38 (25)	252 $\pm$ 40 (25)
3/3/90	595 $\pm$ 61 (25)	246 $\pm$ 12 (24)
4/16/90	498 $\pm$ 29 (25)	736 $\pm$ 65 (23)
5/14/90	*	1445 $\pm$ 94 (9)
6/11/90	1368 $\pm$ 96 (28)	461 $\pm$ 50 (10)
7/9/90	*	673 $\pm$ 79 (8)
8/6/90	781 $\pm$ 54 (10)	549 $\pm$ 26 (10)
9/4/90	797 $\pm$ 62 (10)	672 $\pm$ 37 (10)

* Data lost

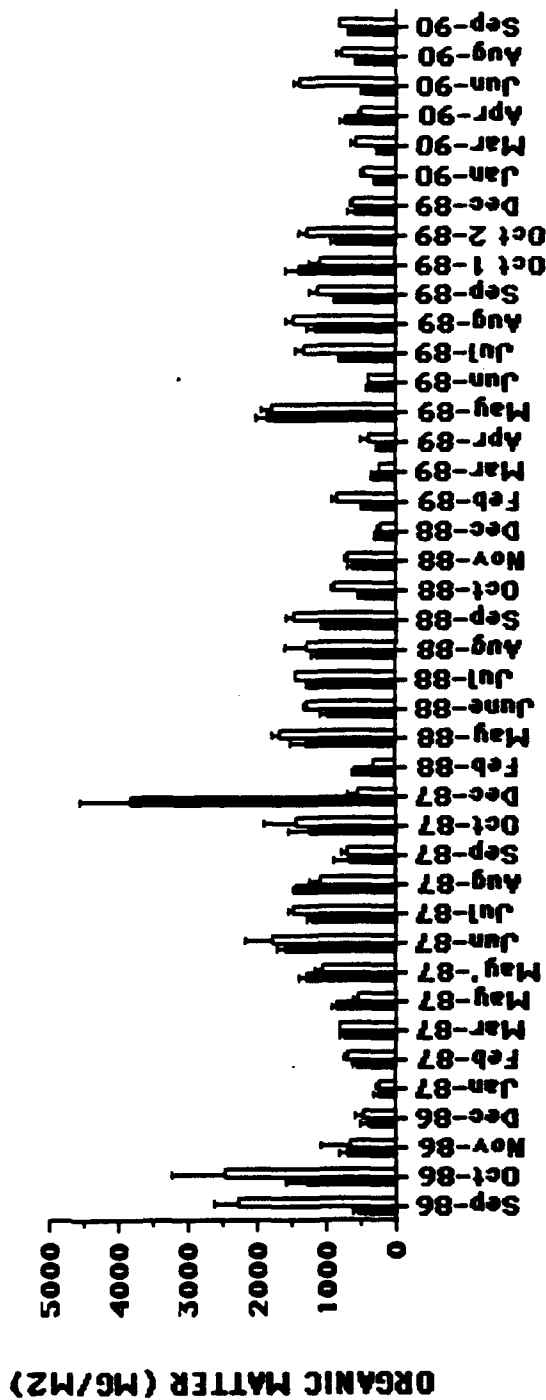
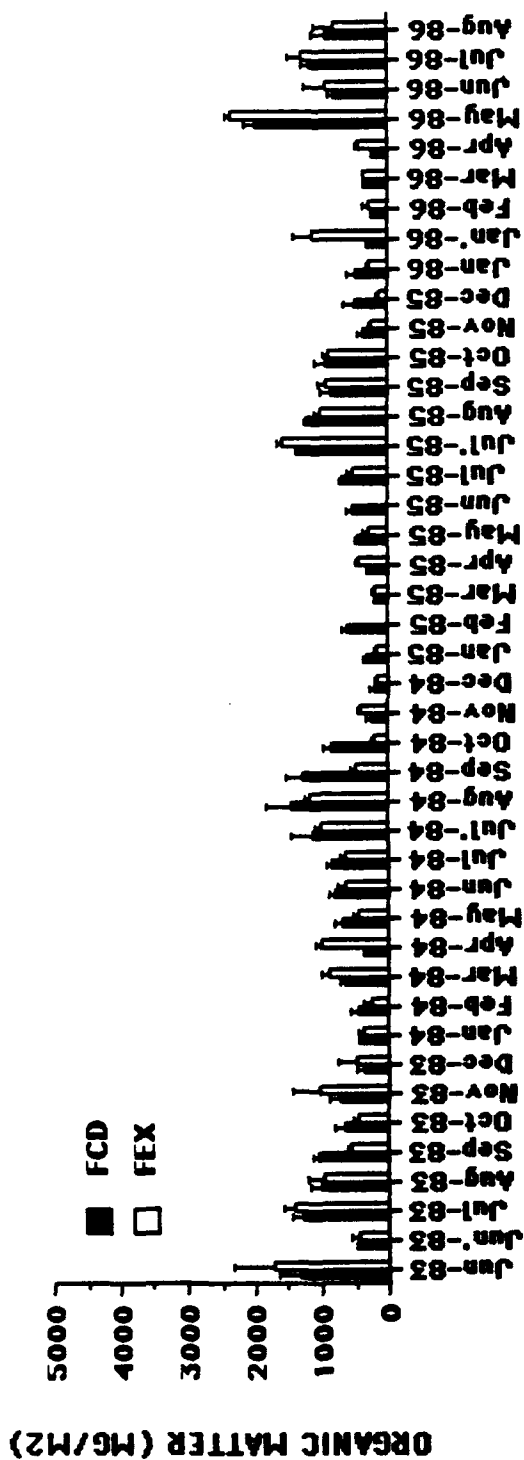


FIGURE 2.3 ORGANIC MATTER STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1990.

Table 2.9 Daily accrual rates of chlorophyll *a* (mg/m²/d) and AFDW-Biomass (mg/m²/d) for Control (FCD) and Experimental (FEX) sites on the Ford River. Values are Means $\pm$ S.E., N in parentheses.

Date	Chlorophyll <i>a</i>		ADFW-Biomass	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
9/18/89	0.179 $\pm$ 0.015 (10)	0.157 $\pm$ 0.020 (10)	38 $\pm$ 4 (10)	24 $\pm$ 3 (10)
10/16/89	0.073 $\pm$ 0.004 (10)	0.068 $\pm$ 0.009 (10)	36 $\pm$ 3 (10)	37 $\pm$ 2 (10)
12/11/89	0.112 $\pm$ 0.007 (25)	0.075 $\pm$ 0.006 (25)	15 $\pm$ 1 (25)	14 $\pm$ 2 (25)
1/22/90	0.021 $\pm$ 0.002 (25)	0.028 $\pm$ 0.003 (25)	11 $\pm$ 1 (25)	6 $\pm$ 1 (25)
3/3/90	0.034 $\pm$ 0.001 (24)	0.025 $\pm$ 0.002 (26)	15 $\pm$ 1 (25)	6 $\pm$ 1 (24)
4/16/90	0.107 $\pm$ 0.007 (25)	0.148 $\pm$ 0.010 (25)	11 $\pm$ 1 (25)	17 $\pm$ 2 (23)
4/30/90	0.324 $\pm$ 0.024 (10)	0.280 $\pm$ 0.023 (10)	33 $\pm$ 2 (10)	23 $\pm$ 3 (10)
5/29/90	0.108 $\pm$ 0.002 (10)	0.135 $\pm$ 0.008 (10)	19 $\pm$ 2 (15)	17 $\pm$ 3 (15)
6/25/90	0.140 $\pm$ 0.027 (10)	0.125 $\pm$ 0.016 (10)	11 $\pm$ 1 (14)	14 $\pm$ 2 (10)
7/23/90	0.437 $\pm$ 0.036 (10)	0.340 $\pm$ 0.042 (10)	52 $\pm$ 1 (10)	33 $\pm$ 2 (10)
8/20/90	0.192 $\pm$ 0.046 (10)	0.110 $\pm$ 0.023 (10)	40 $\pm$ 3 (10)	33 $\pm$ 2 (10)

non-significant correlation ($r = 0.42$) in 1990, although the correlation was significant for the entire data set (Table 2.4). BACI analyses were conducted on AFDW-organic matter standing crop data (Table 2.6, A-3). The overall 7.5 year pooled comparison for AFDW mean differences for the 1983-86 "before" and 1986-90 "after" was found to be non-significant, although there was a significant difference (echoed by RIA) in the before and after summer data. However, none of the individual year-to-year comparisons were significant. Therefore, we place little significance on the summer result. The minimum detectable difference for AFDW-organic matter is 22.5% for the entire data set, 26% for the summer data set and 49.1% for the winter data set (Table 2.5). The high winter value is due to the high variability in our winter data sets. The two sites tend to experience different winter conditions, i.e. FEX tends to freeze over quicker than FCD and often will be frozen over while FCD remains open.

Stepwise multiple regression models generated for AFDW-organic matter at both sites for both the total and summer data sets indicated that water temperature was the most important predictor of organic matter standing crop (Table 2.2). Between site t-tests on the "before" and the "after" data indicated that the between site relationship in organic matter standing crop was not altered when testing of the antenna began in 1986 (Table 2.7) (reflecting the results from BACI and RIA).

Organic matter accrual rates (Table 2.8 and Fig. 2.4) followed a pattern of winter lows and summer highs similar to the pattern followed by organic matter standing crop. The accrual rates for the two sites were significantly different in 1989-90, even though there was a high degree of correlation between sites ($r = 0.87$) (Table 2.3). Overall, there was no significant difference in organic matter accrual rates between the two sites, and the data were highly correlated between sites (Table 2.4). The minimum detectable difference for organic matter accrual was 27.1% (Table 2.5), similar to the value for organic matter standing crop. BACI analysis on AFDW-organic matter accrual (Table 2.6, A-4) indicated that (as with AFDW accumulation) there were no differences in the between site relationship "before" and "after" testing began on the antenna in May of 1986, a result corroborated by randomized intervention analysis (Table 2.6).

D. Patterns of Diatom Cell Density

Diatom cell density reached its lowest level during the winter for each of the years studied at each site (Fig. 2.5). Typically, the lowest values occurred in January or

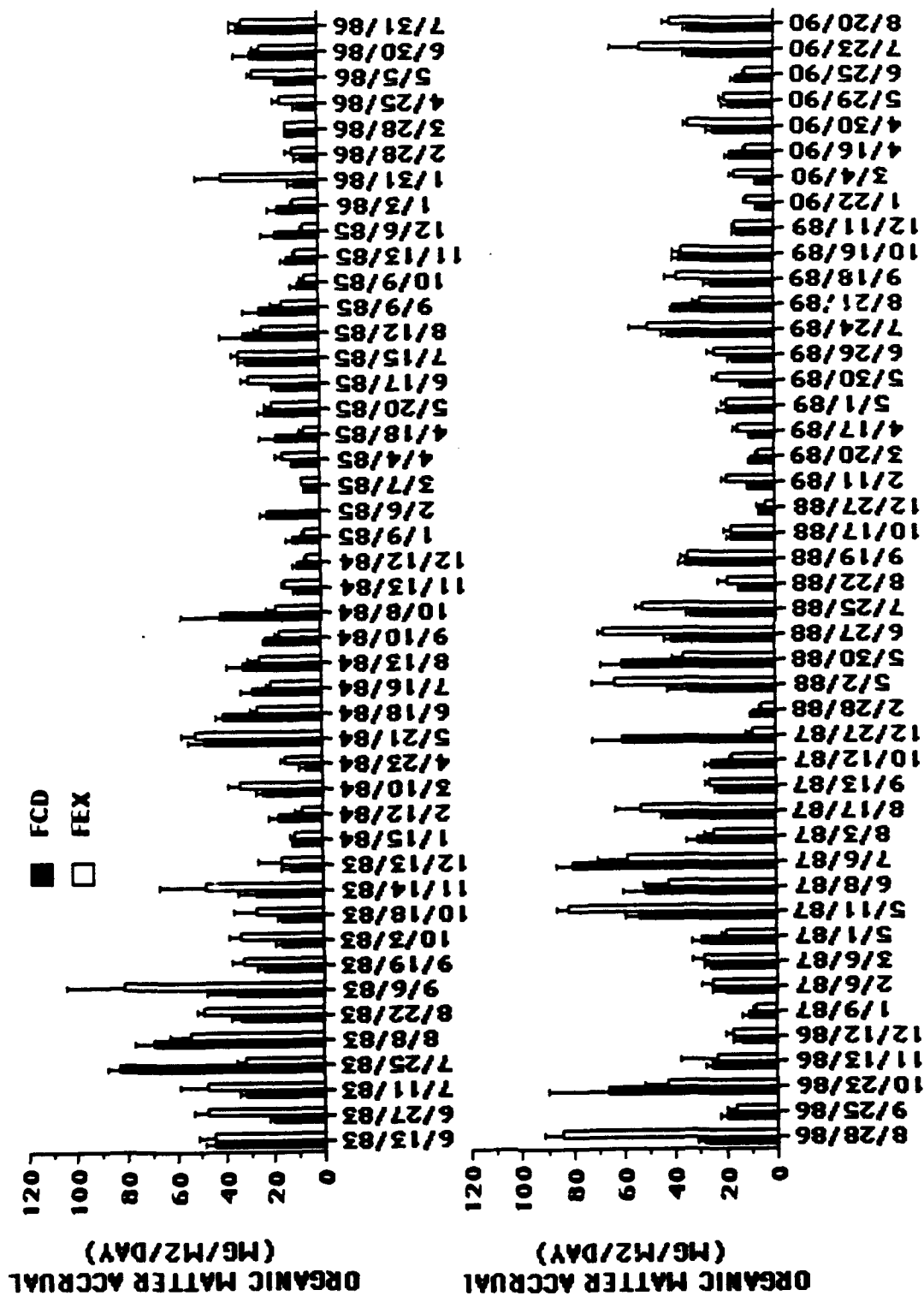


FIGURE 2.4 ACCRUAL RATES OF ORGANIC BIOMASS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1990.

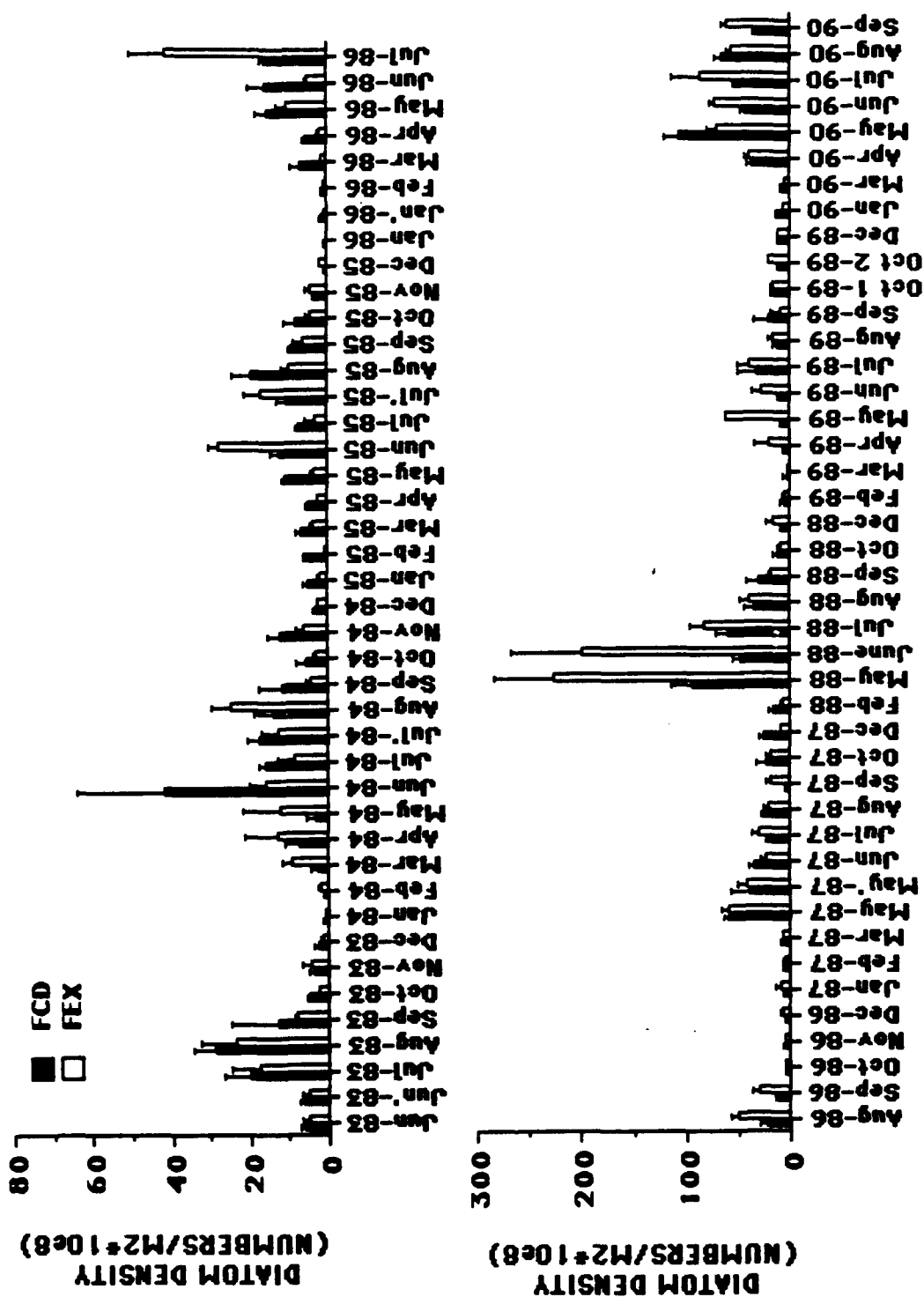


FIGURE 2.5 DIATOM CELL DENSITIES FOR THE FORD RIVER, 1983-1990.

February when the Ford River was ice covered with limited light penetration and with water temperatures near 0°C. The winter season from late October until April was characterized by diminished levels of diatom density. Actual values ranged from 10^7 to 10^8 cells/m². The peak values for diatom cell density occurred at less predictable intervals (Fig. 2.5). The highest monthly densities of cells were reported in August 1983, June 1984, June 1985, May 1986, May 1987, May 1988 and 1989 and May - July of 90 (Fig. 2.5). Thus, the highest cell densities measured were found to occur anytime within a four month spring-summer period. The duration of continued high cell densities also varied by year (Fig. 2.5); sometimes continuing throughout the summer and at other times restricted to only one or two months of very high densities, e.g., May 1986. In 1990, densities remained high throughout the summer (Fig. 2.5). It appears that the most predictable pattern was for lowest cell densities in the winter and for greatest densities in the spring and/or summer (Fig. 2.5, Table 2.10).

The stepwise multiple regression models for cell density were all highly significant (Table 2.2). Silica and water temperature appeared to be important predictors of diatom density. Interestingly, cell density did not correlate with silica, although it is correlated with water temperature ($r = 0.31$ at FCD and 0.36 at FEX, $P < 0.01$). As silica is a major constituent of the diatom test, a major diatom bloom can reduce silica levels in rivers. If diatom are having such an effect in the Ford River, one might expect silica concentrations to be low during the periods of rapid increases in diatom biomass such as happens in the spring (Fig. 1.16) or during periods of peak diatom biomass in the summer (Si is high during summer low flow periods). A more reasonable explanation of the observed pattern in Si is that the pattern results from increased dilution of silica by snow melt in the spring followed by increases to peak levels during summer low flow periods when all stream water is of base flow origin. Thus, the stepwise regression suggesting that Si and temperature are good predictors of diatom cell density may simply reflect a more basic pattern of high density levels during the low flow, warm temperature periods in the summer and low density levels during cooler periods of winter and spring when weathering rates are slow and dilution by snow melt and surface runoff is high.

Paired t-tests showed that site differences in cell densities were not significant for 1989-90 (Table 2.3) or for all the data collected since 1983 (Table 2.4). Cell density at FEX was also closely correlated with cell density at FCD (Tables 2.3, 2.4). BACI results from the overall 7.5 year cell density data, however, showed a significant difference between "before" (6/83-4/86) and "after" (5/86-

Table 2.10 Cell Density (Cells/m² x 10⁸) and Biovolume (cubic microns/m² x 10¹¹)
for Experimental (FEX) and Control (FCD) sites for 1989-90.
Values are Means $\pm$ S.E.

Date	N	Experimental (FEX)		Control (FCD)	
		Density	Biovolume	Density	Biovolume
10/2/89	3	16.37 $\pm$ 1.08	9.80 $\pm$ 0.27	16.06 $\pm$ 1.22	8.42 $\pm$ 0.56
10/30/89	3	20.30 $\pm$ 0.11	6.52 $\pm$ 0.28	10.61 $\pm$ 1.78	4.62 $\pm$ 0.56
12/11/89	6	10.41 $\pm$ 0.36	15.49 $\pm$ 0.69	9.62 $\pm$ 0.66	7.55 $\pm$ 0.48
1/22/90	6	6.71 $\pm$ 0.71	5.08 $\pm$ 0.57	12.70 $\pm$ 0.64	14.18 $\pm$ 1.30
3/4/90	6	4.04 $\pm$ 0.75	2.86 $\pm$ 0.25	8.13 $\pm$ 0.39	5.85 $\pm$ 0.38
4/16/90	6	37.54 $\pm$ 4.34	15.60 $\pm$ 1.81	37.00 $\pm$ 3.28	11.35 $\pm$ 0.67
5/14/90	3	69.94 $\pm$ 8.61	16.81 $\pm$ 2.44	105.82 $\pm$ 14.37	27.90 $\pm$ 3.83
6/11/90	3	72.96 $\pm$ 4.32	13.49 $\pm$ 0.95	42.41 $\pm$ 3.85	7.33 $\pm$ 0.66
7/9/90	2	85.78 $\pm$ 26.59	21.00 $\pm$ 5.56	52.90 $\pm$ 4.96	17.37 $\pm$ 1.92
8/6/90	3	56.83 $\pm$ 3.17	15.26 $\pm$ 1.19	64.30 $\pm$ 6.96	21.39 $\pm$ 3.15
9/4/90	3	61.74 $\pm$ 3.26	13.78 $\pm$ 1.32	32.82 $\pm$ 4.22	7.60 $\pm$ 0.82

9/89) periods (Table 2.6, A-5). Further analysis suggested that the summer variations were responsible for this significant result. The between site relationship for cell density for the summer of 1983 was different than it was for the summers of 1988 and 1990. This difference was also detected by RIA, although not quite at the significant level (Table 2.11). As there is no pattern in these results to suggest either ELF or weather effects (83 is the only before year that is different than the after years, and the summer of 83 was a warm summer as was the summer of 88) we offer no explanation for these results. Cell density is highly variable between the sites (Fig. 2.5) resulting in a rather large (approximately 50%) minimum detectable difference (Table 2.5).

E. Patterns in Individual Cell Volume and Total Biovolume

Individual cell volumes for the 7.5 year period (Fig. 2.6) were characterized by a trend towards larger volumes of diatoms in the periphyton occurring during the colder, winter months of November through March and smaller diatoms occurring during the summer months. The 1987-88 cell volume data did not follow this pattern however. Following the dramatic rise in mean cell volume during the winter of 1986-87 associated with dominance by Synedra and Diatoma, values dropped off during the spring-summer and remained low over the winters of 1987-88 and 1988-89 (Fig. 2.7, Table 2.12). The cell volume for the winter of 1989-90 returned to the levels seen before 1986-87.

A paired t-test showed that mean cell volume was not significantly different between sites (Table 2.3) for either 1989-90 or all data collected since 1983 (Table 2.4). Mean cell volume at FEX was not significantly correlated with mean cell volume at FCD for either 1990 or the entire data set (Tables 2.3, 2.4). BACI and RIA comparisons of cell volume showed that "before" data were not different from "after" data either on an overall basis or for any summer or winter season comparisons (Table 2.11). However, since the "before" data was not additive for most of these comparisons (Appendix A, Table A-6), the t-test cannot be considered valid (Stewart-Oaten 1986). Although cell volume is fairly variable between years (Fig. 2.6), it remains fairly consistent between sites resulting in a relatively low (approximately 25%) minimum detectable difference (Table 2.5).

Cell volume was negatively correlated with water temperature ($r = -0.44$ at FCD and -0.41 at FEX, $p < 0.01$). Both water temperature and soluble reactive phosphorus

Table 2.11 Summary of BACI and RIA Comparisons for Density, Volume, Biovolume, Diversity and Evenness between Control (FCD) and Experimental (FEX) Sites for 1983-1990. N in parentheses for BACI and RIA, respectively.

Parameter	Comparison	BACI Signif. (p < 0.05)	RIA Signif. (p < 0.05)
Cell Density	6/83-4/86 vs. 5/86-9/90 (83) (85)	p < 0.01	p = 0.06
	Summer 83-85 vs. 86-90 (48) (51)	p < 0.01	p = 0.18
	S 83/88 (9)	p < 0.05	
	S 83/90 (9)	p < 0.05	
	Winter 83-85 vs. 86-89 (33) (34)	NS	NS
Cell Volume	6/83-4/86 vs. 5/86-9/90 (83) (85)	NS	NS
	Summer 83-85 vs. 86-90 (48) (51)	NS	NS
	Winter 83-85 vs. 86-89 (33) (34)	NS	NS
Biovolume	6/83-4/86 vs. 5/86-9/90 (83) (85)	p < 0.05	p = 0.09
	Summer 83-85 vs. 86-90 (48) (51)	NS	NS
	Winter 83-85 vs. 86-89 (33) (34)	NS	NS
Species Diversity	6/83-4/86 vs. 5/86-9/90 (83) (85)	p < 0.05	p < 0.05
	Summer 83-85 vs. 86-90 (48) (51)	NS	NS
	Winter 83-85 vs. 86-89 (33) (34)	NS	NS
Species Evenness	6/83-4/86 vs. 5/86-9/90 (83) (85)	p < 0.01	p < 0.01
	Summer 83-85 vs. 86-90 (48) (51)	p < 0.05	p < 0.05
	S 83/87 (10)	p < 0.05	
	S 85/87 (11)	p < 0.05	
	Winter 83-85 vs. 86-89 (33) (34)	p < 0.05	p < 0.05
Gross Primary Production	7/84-8/85 vs. 6/86-8/90 (54) (56)	NS	NS

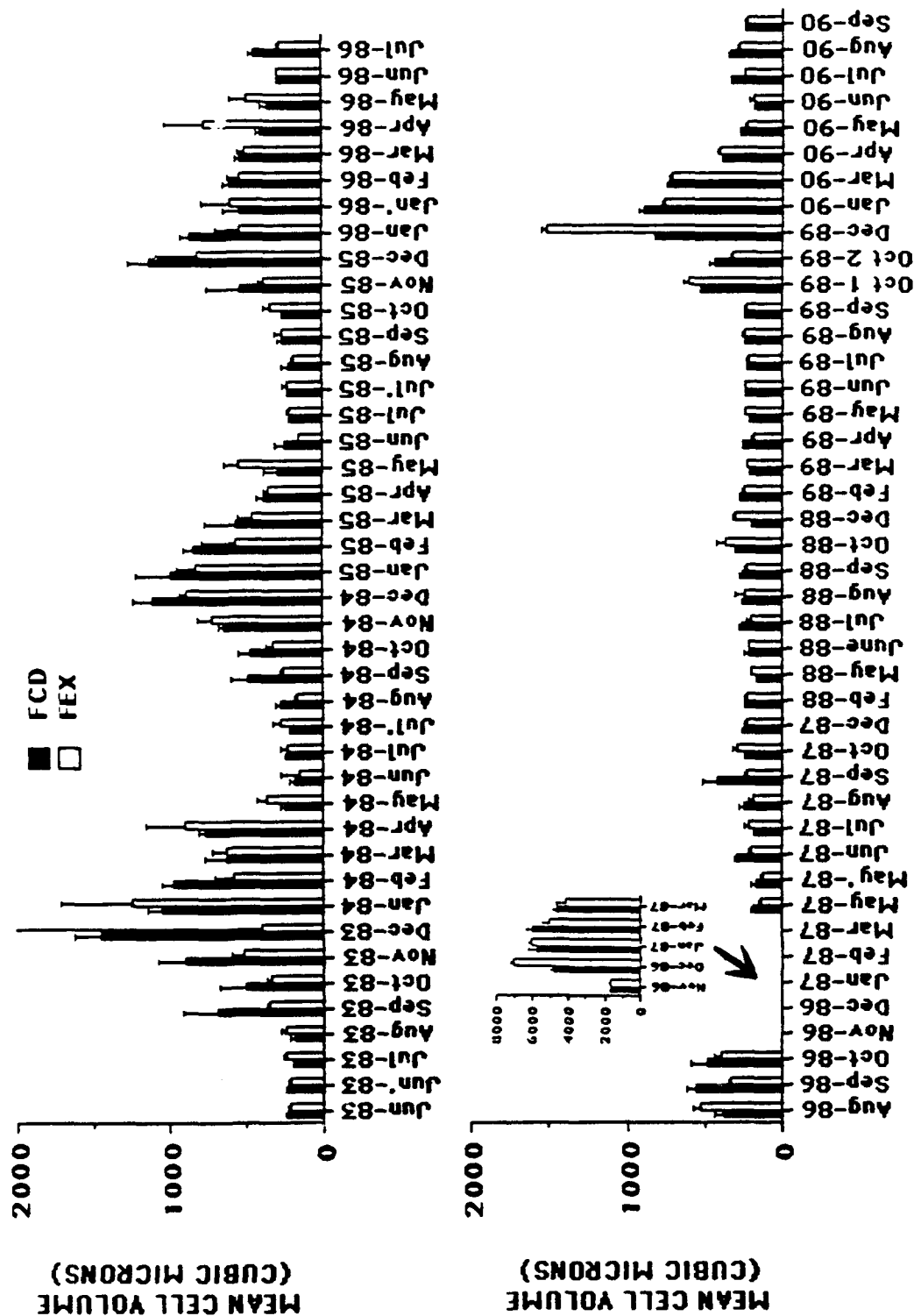


FIGURE 2.6 INDIVIDUAL CELL SIZES FOR THE FORD RIVER, 1983-1990.

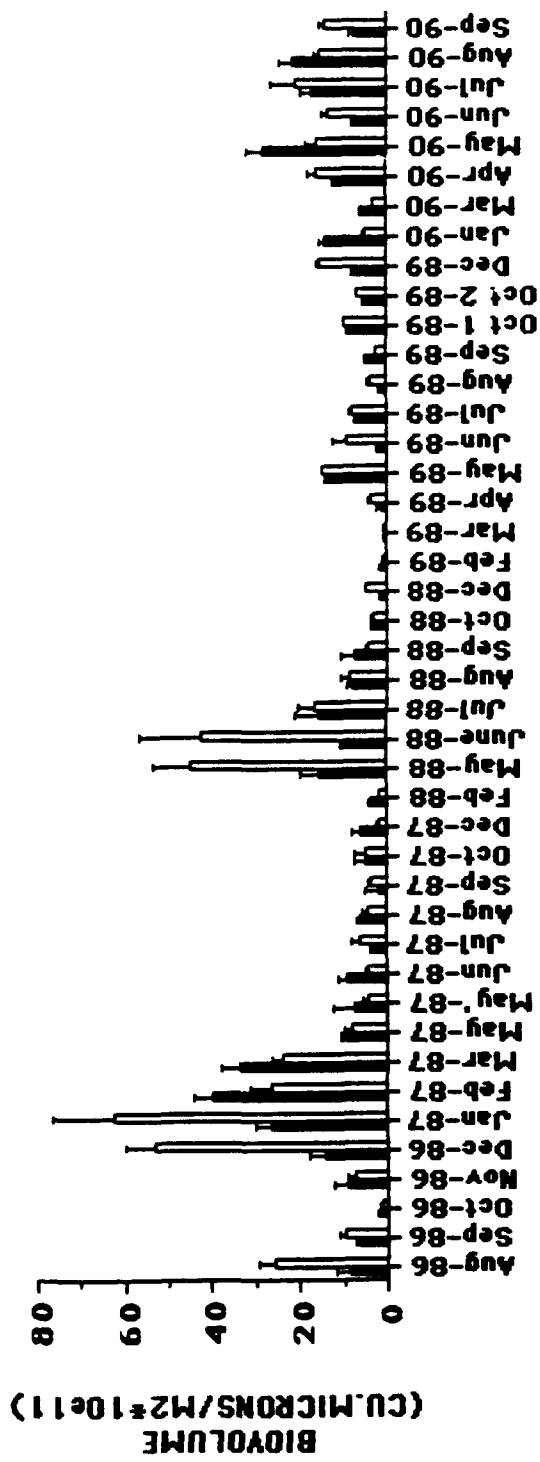
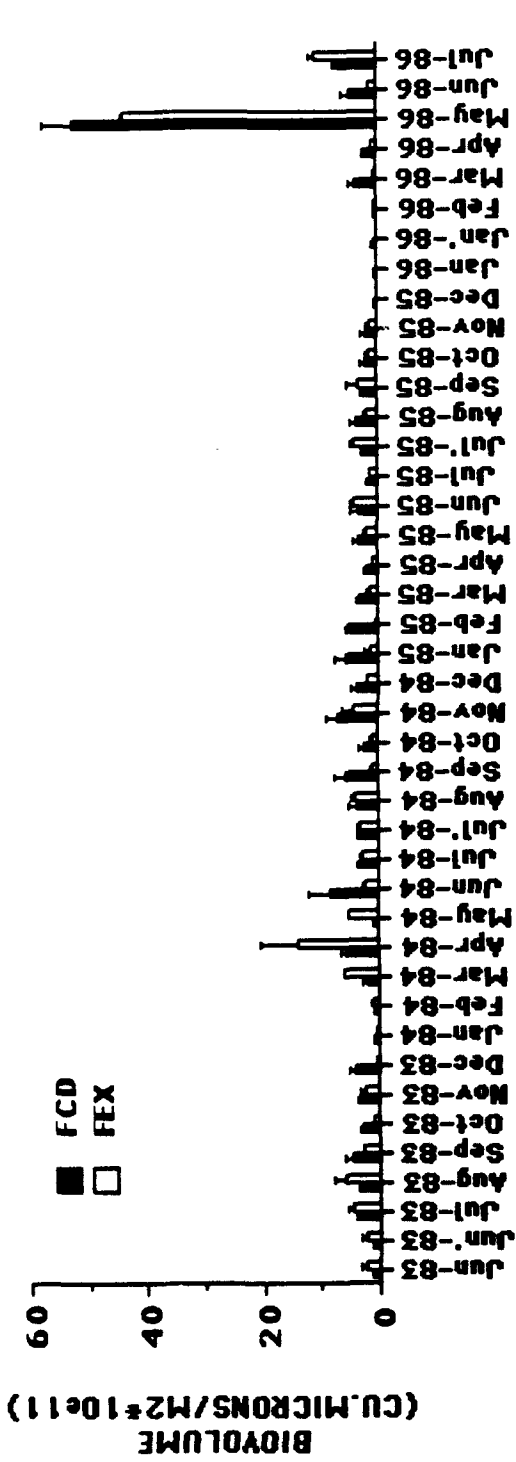


FIGURE 2.7 DIATOM BIOVOLUME FOR THE FORD RIVER, 1983-1990.

Table 2.12 Average individual Diatom Cell Volume (cubic microns) for Experimental (FEX) and Control (FCD) sites for 1989-90. Values are means $\pm$ S.E.

Date	N	Experimental (FEX)	Control (FCD)
10/2/89	3	601.5 $\pm$ 24.87	525.5 $\pm$ 5.03
10/30/89	3	321.3 $\pm$ 13.58	440.9 $\pm$ 17.99
12/11/89	6	1449.1 $\pm$ 27.51	789.6 $\pm$ 28.87
1/22/90	6	755.1 $\pm$ 13.72	893.9 $\pm$ 29.98
3/4/90	6	707.2 $\pm$ 17.51	717.2 $\pm$ 16.25
4/16/90	6	412.4 $\pm$ 10.45	382.7 $\pm$ 5.76
5/14/90	3	229.6 $\pm$ 7.49	264.1 $\pm$ 9.02
6/11/90	3	187.5 $\pm$ 22.70	172.8 $\pm$ 1.32
7/9/90	2	243.6 $\pm$ 3.80	328.5 $\pm$ 1.55
8/6/90	3	268.2 $\pm$ 10.02	326.8 $\pm$ 15.08
9/4/90	3	222.9 $\pm$ 17.18	232.8 $\pm$ 10.90

appeared to be consistent predictors of cell volume in the stepwise multiple regression models (Table 2.2).

Total biovolume for 1990 was highest in May (Fig. 2.7, Table 2.10). The biovolume levels for 1990 remained high, maintaining the trend of the past few years. Both density (Fig. 2.5) and biovolume (Fig. 2.7) have been characterized by substantially larger spring-summer peak values since May 1986, apparently as a result of the very dry months of May since that time. The large biovolume peak observed during the 1986-87 winter has not been repeated consistently due to the absence of the large species, Synedra ulna. The presence of Synedra again during winter 1989-90 produced a peak in biovolume, although not of the same magnitude as that seen during winter 1986-87 (Fig. 2.7).

A comparison of total biovolume between sites with the paired t-test showed that biovolume at FEX was not significantly different ($p < 0.05$) from biovolume at FCD either for the 1989-90 data (Table 2.3) or for all data collected since 1983 (Table 2.4). Biovolume at FEX was significantly ($p < 0.05$) correlated with biovolume at FCD in 1989-90 (Table 2.3), but not for all the data collected since 1983 (Table 2.4). BACI comparisons of biovolume showed that there was a significant difference in the between site relationship "before" and "after" May 1986 (Table 2.11, A-7). However, none of the season by season comparisons were significant, and the RIA result for this data was not significant, indicating that whatever small change in the inter-site relationship for biovolume that BACI detected is probably not important. The high variability in between site differences (Fig. 2.7) accounted for the high minimum detectable difference in biovolume (Table 2.5).

The stepwise multiple regression models (Table 2.2) explained only a small portion of the variance and none of the chemical/physical parameters appeared to be important predictors of total biovolume.

F. Patterns of Species Diversity and Species Evenness

The pattern in the Shannon Wiener diversity index (H') and the evenness index (J') over the entire period from 1983 to 1990 (Figs. 2.8, 2.9, Table 2.13) was similar, with evenness and diversity appearing to track each other during most seasons. In general, the pattern for both indices was that greatest values occurred in the winter months and

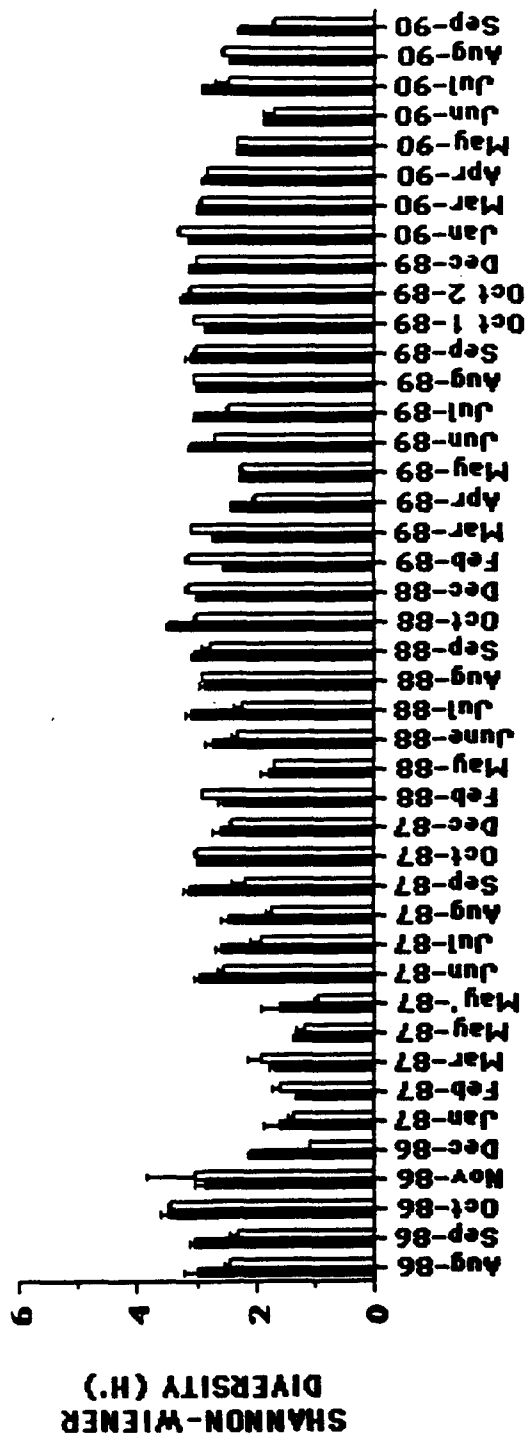
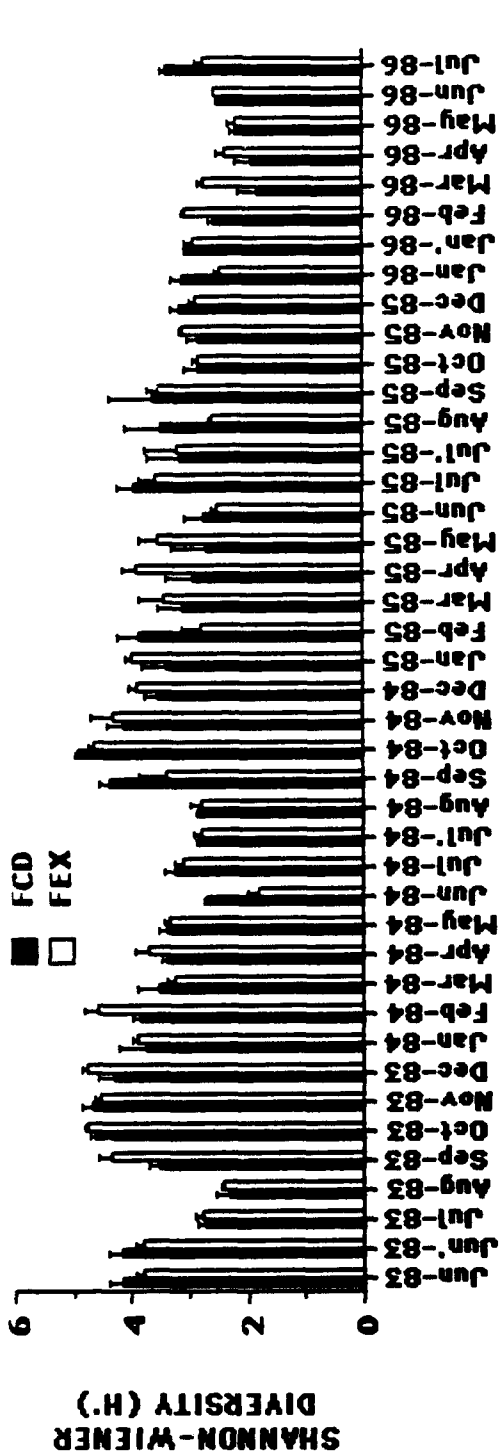


FIGURE 2.8 DIATOM SPECIES DIVERSITY FOR THE FORD RIVER, 1983-1990.

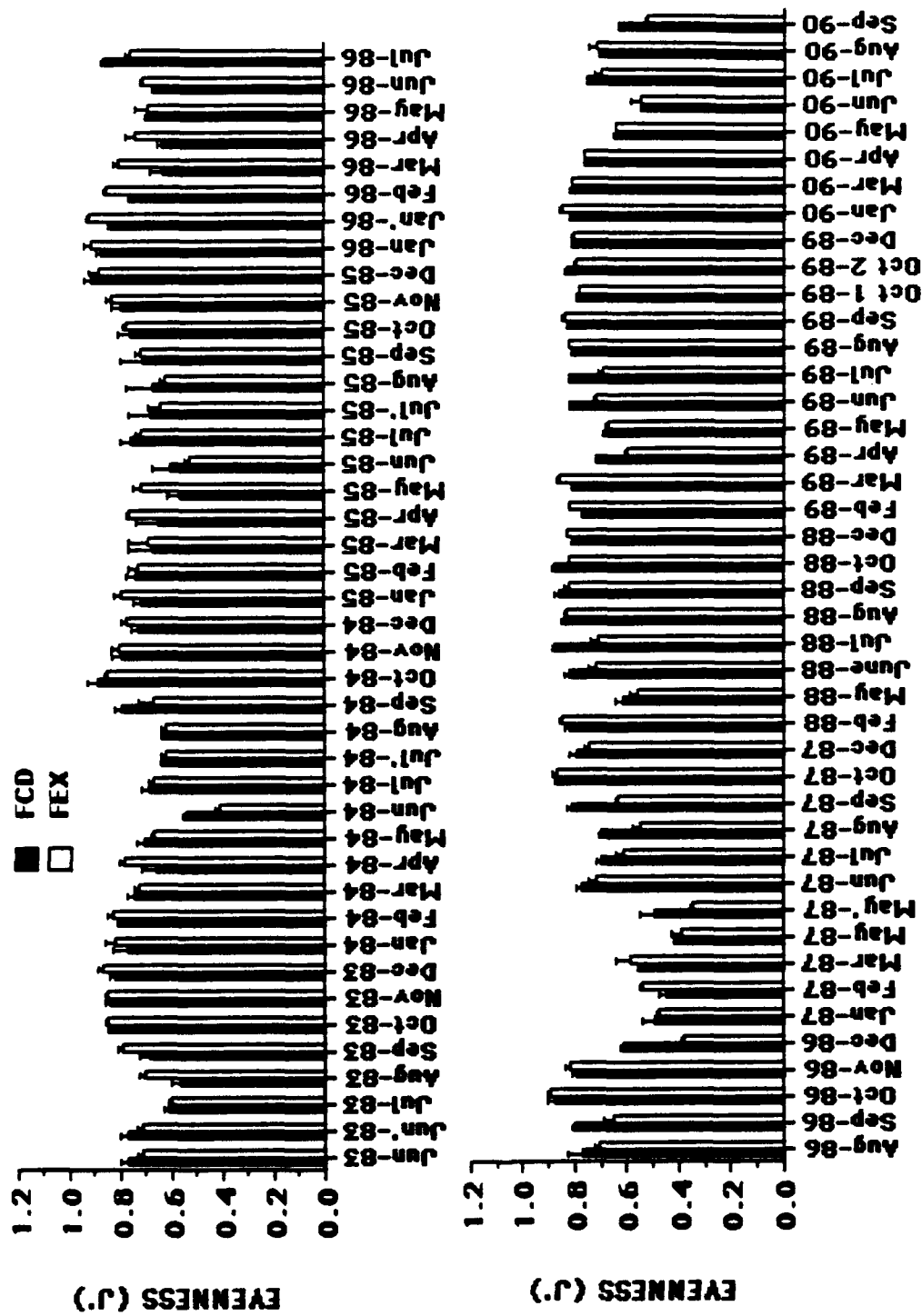


FIGURE 2.9 DIATOM SPECIES EVENNESS FOR THE FORD RIVER, 1983-1990.

Table 2.13 Species Diversity (H') and Evenness (J ') for Experimental (FEX) and Control (FCD) sites for 1990. Values are Mean $\pm$ S.E.

Date	N	Experimental (FEX)		Control (FCD)	
		Diversity	Evenness	Diversity	Evenness
10/2/89	3	3.009 $\pm$ 0.025	0.783 $\pm$ 0.006	2.838 $\pm$ 0.017	0.788 $\pm$ 0.003
10/30/89	3	3.057 $\pm$ 0.055	0.794 $\pm$ 0.012	3.205 $\pm$ 0.024	0.831 $\pm$ 0.005
12/11/89	6	2.970 $\pm$ 0.028	0.798 $\pm$ 0.005	3.092 $\pm$ 0.010	0.807 $\pm$ 0.003
1/22/90	6	3.268 $\pm$ 0.017	0.848 $\pm$ 0.006	3.086 $\pm$ 0.020	0.809 $\pm$ 0.005
3/4/90	6	2.896 $\pm$ 0.018	0.813 $\pm$ 0.002	2.971 $\pm$ 0.020	0.815 $\pm$ 0.004
4/16/90	6	2.808 $\pm$ 0.009	0.757 $\pm$ 0.005	2.861 $\pm$ 0.024	0.761 $\pm$ 0.004
5/14/90	3	2.286 $\pm$ 0.021	0.635 $\pm$ 0.006	2.238 $\pm$ 0.047	0.644 $\pm$ 0.013
6/11/90	3	1.674 $\pm$ 0.190	0.549 $\pm$ 0.040	1.817 $\pm$ 0.026	0.538 $\pm$ 0.010
7/9/90	2	2.447 $\pm$ 0.212	0.700 $\pm$ 0.022	2.867 $\pm$ 0.022	0.749 $\pm$ 0.006
8/6/90	3	2.547 $\pm$ 0.024	0.720 $\pm$ 0.024	2.400 $\pm$ 0.022	0.700 $\pm$ 0.005
9/4/90	3	1.678 $\pm$ 0.027	0.519 $\pm$ 0.008	2.251 $\pm$ 0.036	0.634 $\pm$ 0.002

lowest values in the summer months. This pattern continued for the 1989-1990 period.

The pattern of winter highs and summer lows for diversity and evenness corresponded with predictable patterns in species abundance. During the summers from 1983 to 1989, only Achnanthes minutissima and Cocconeis placentula ever achieved dominance greater than 10 % of the individuals in the community (Fig. 2.10, Table 2.14). Typically, Achnanthes was the most dominant species present in May and June, but decreased in abundance and was replaced by Cocconeis as the most dominant species in July and August. Achnanthes then increased in dominance again in September and October as the abundance of Cocconeis declined. This general pattern continued during the summer of 1990, although abundance did not increase until August (Fig. 2.11, 2.12). This general pattern was based on total numbers of diatoms present. Since Cocconeis is more than 1.5 times larger than Achnanthes, the pattern of July-August dominance by Cocconeis is actually under-represented by data based on counts. From examination of shards of the actual sample slide under the scanning electron microscope, it appears that Cocconeis totally dominates the substrate surface with Achnanthes cells interspersed in spaces between the almost continuous covering of the microscope slide by Cocconeis. Thus, calculation of % dominance based on biovolume might be a better way of assessing dominance and is a calculation we hope to include in future reports.

The abundance data from the summer of 1989 was different from data collected for previous summers in that Fragilaria vaucheriae achieved greater than 10 % dominance along with Achnanthes minutissima and Cocconeis placentula. This unusual dominance pattern for Fragilaria can be explained by its unusually high abundance (40 % dominance) during the month of May, 1989. During 1990, Fragilaria abundance appeared to follow the more typical pattern seen from 1983-1988 (Fig. 2.13).

The winter diatom flora has been much more variable than the summer flora. Achnanthes has been a dominant component of the flora most years, as well as Fragilaria vaucheriae and Gomphonema olivaceum (Table 2.14). The winter of 1989-90 generally followed this dominance pattern, with the exception of Gomphonema, which did not reach its usual abundance levels (Fig. 2.10, Fig. 2.14). Synedra ulna did reach abundance levels of approximately 11% during the winter of 1989-90, accounting for the observed peaks in cell volume and biovolume. Synedra was also a dominant species during the unusually warm winter of 1986-87, when it reached

Table 2.14 Dominant Diatom Species at Experimental (FEX) and Control (FCD) Sites, 1983-1990.

Seasons	<i>Achnanthes minutissima</i>	<i>Cocconeis placentula</i>	<i>Diatoma tenue</i>	<i>Fragilaria vaucheriae</i>	<i>Gomphonema intricatum</i>	<i>Gomphonema olivaceum</i>	<i>Meridion circulare</i>	<i>Navicula cryptocephala</i>	<i>Synedra ulna</i>
Summer									
83	●	●							
84	●	●							
85	●	●							
86	●	●							
87	●	●							
88	●	●							
89	●	●		●					
90	●	●							
Winter									
83	●			●		●	●		
84	●			●		●			
85	●			●		●	●		
86	●		●	●		●			●
87	●			●	●	●		●	
88	●			●		●			
89	●			●					●

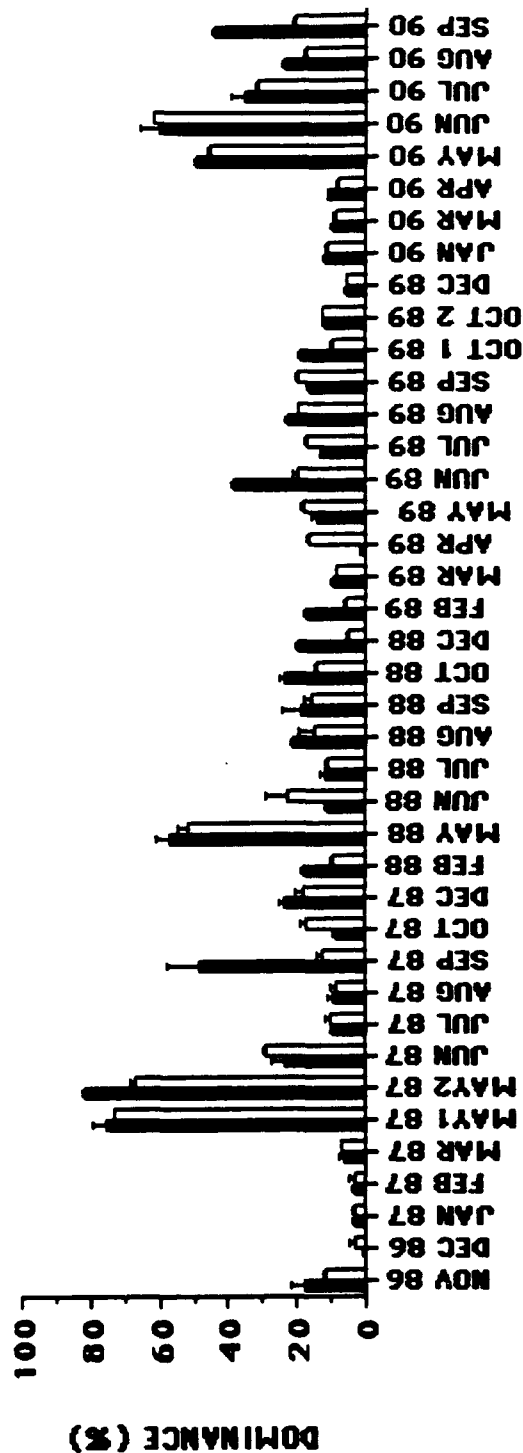
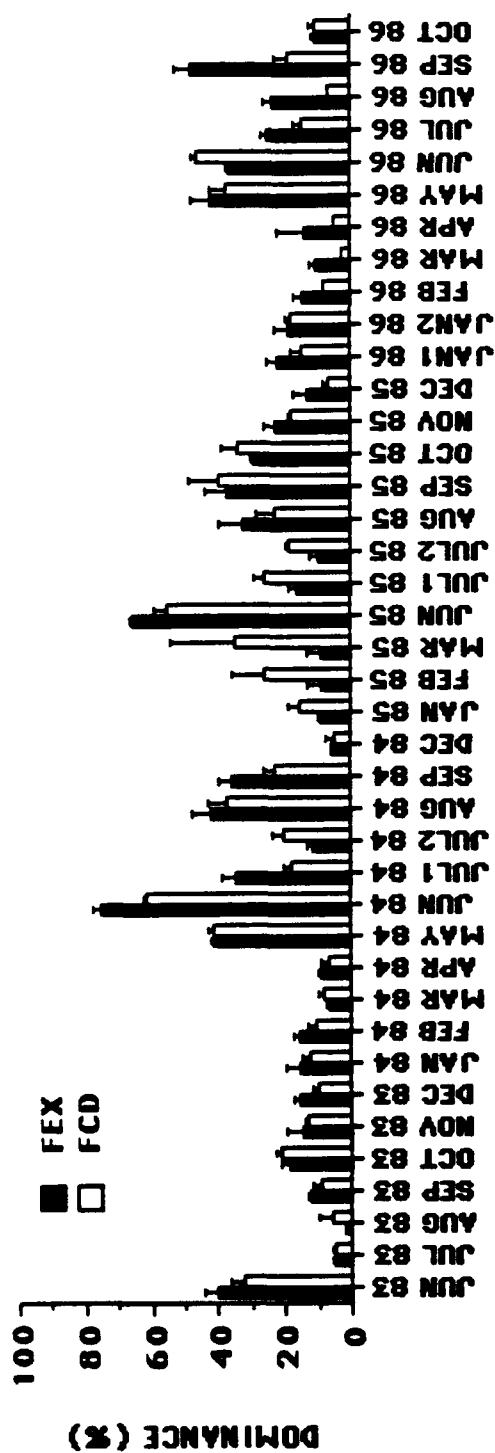


FIGURE 2.11 *Achnanthes minutissima* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

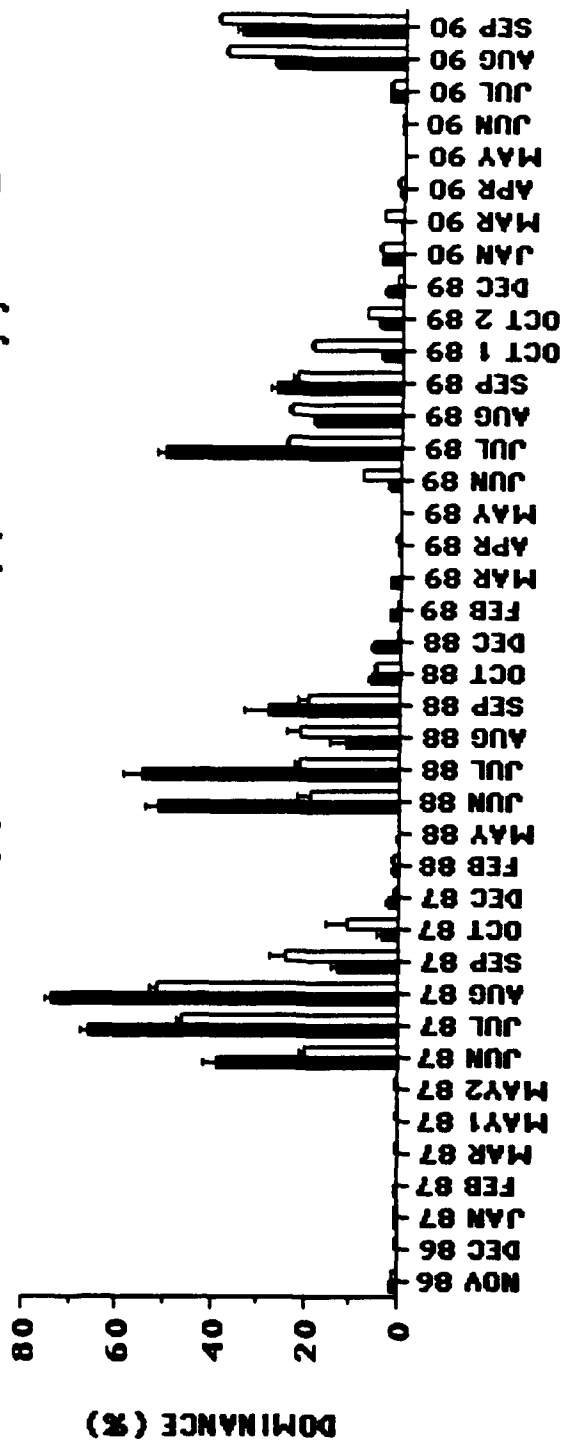
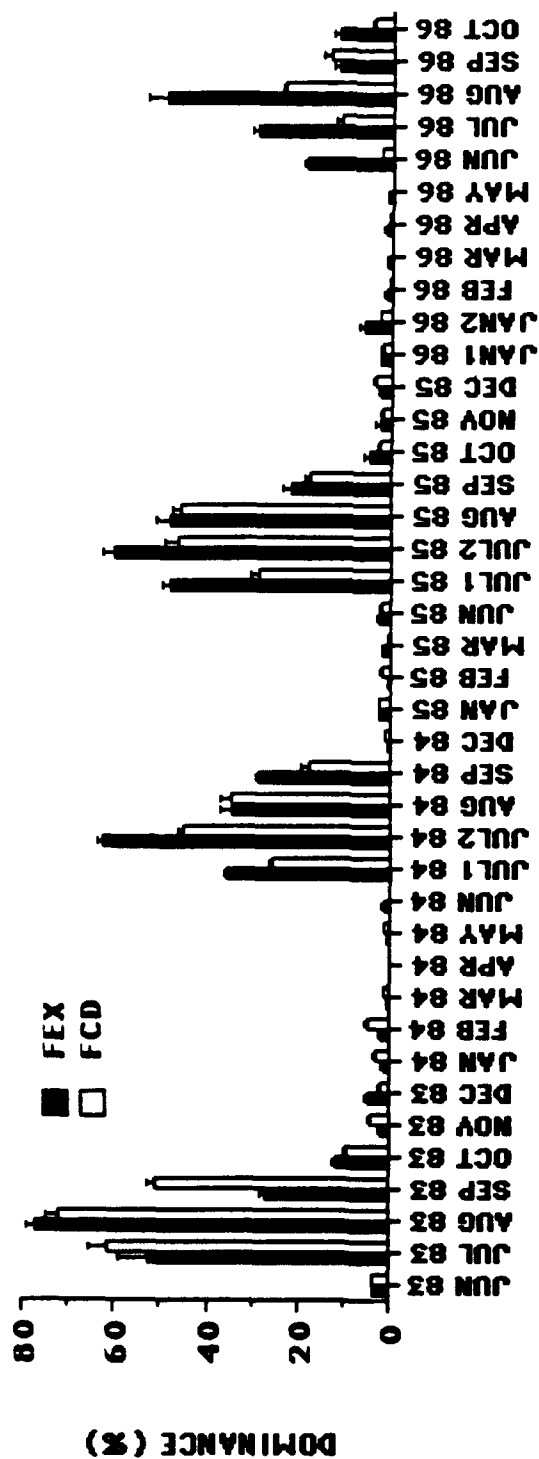


FIGURE 2.12 *Coccioneis placentula* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

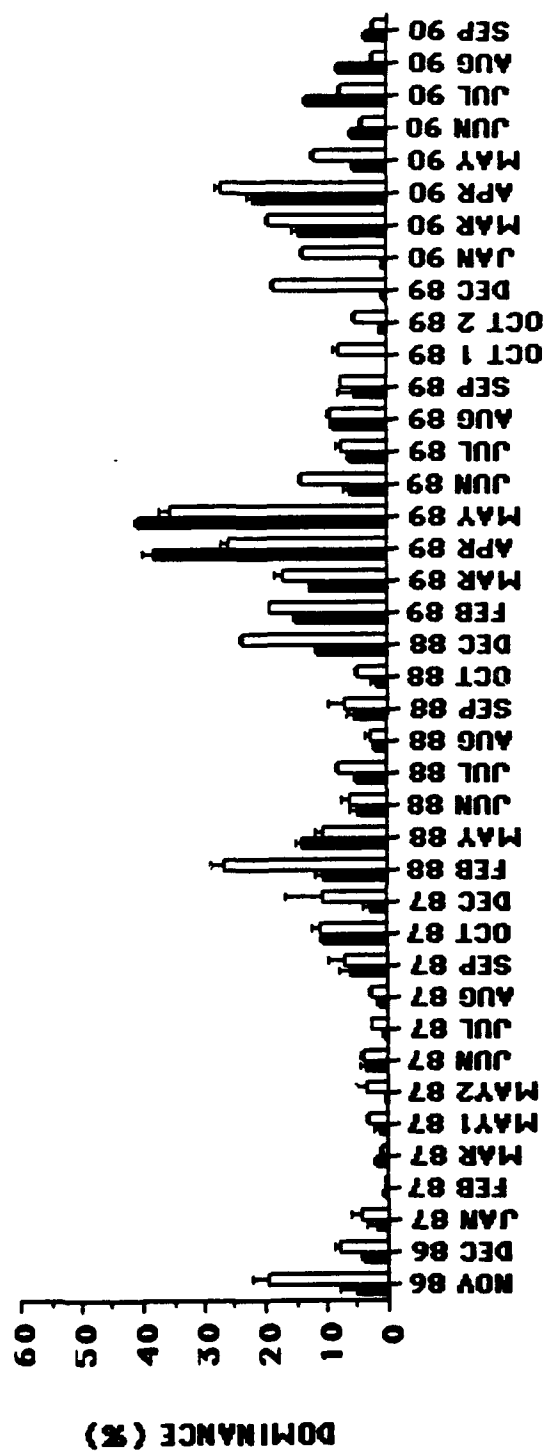
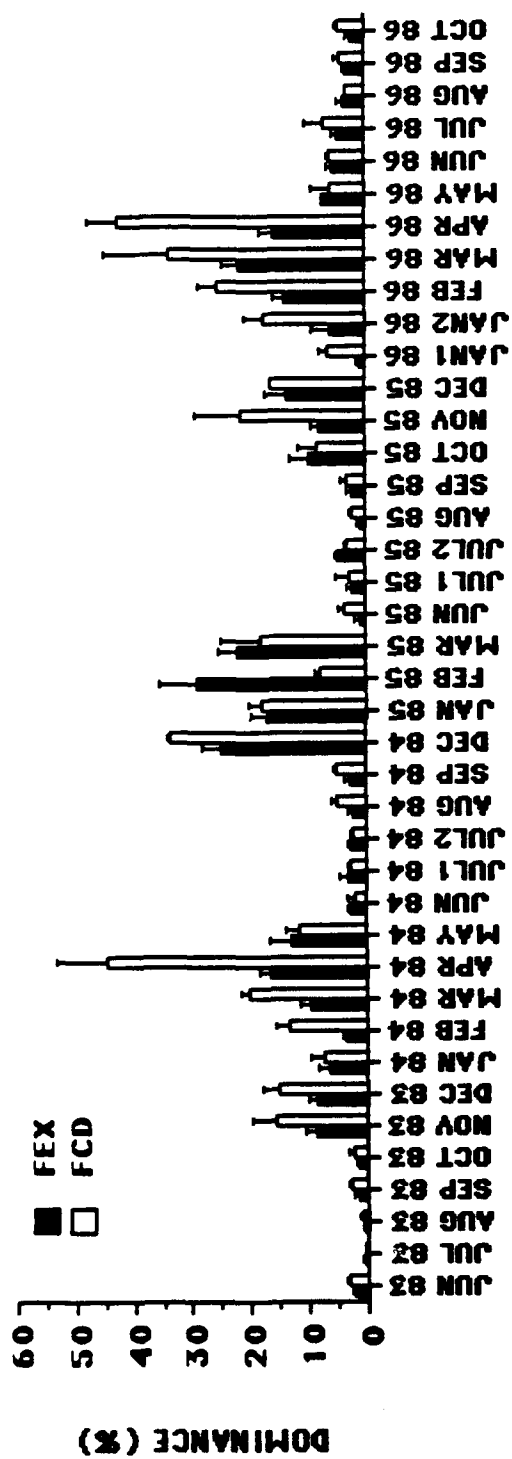


FIGURE 2.13 *Fragilaria vaucheriae* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

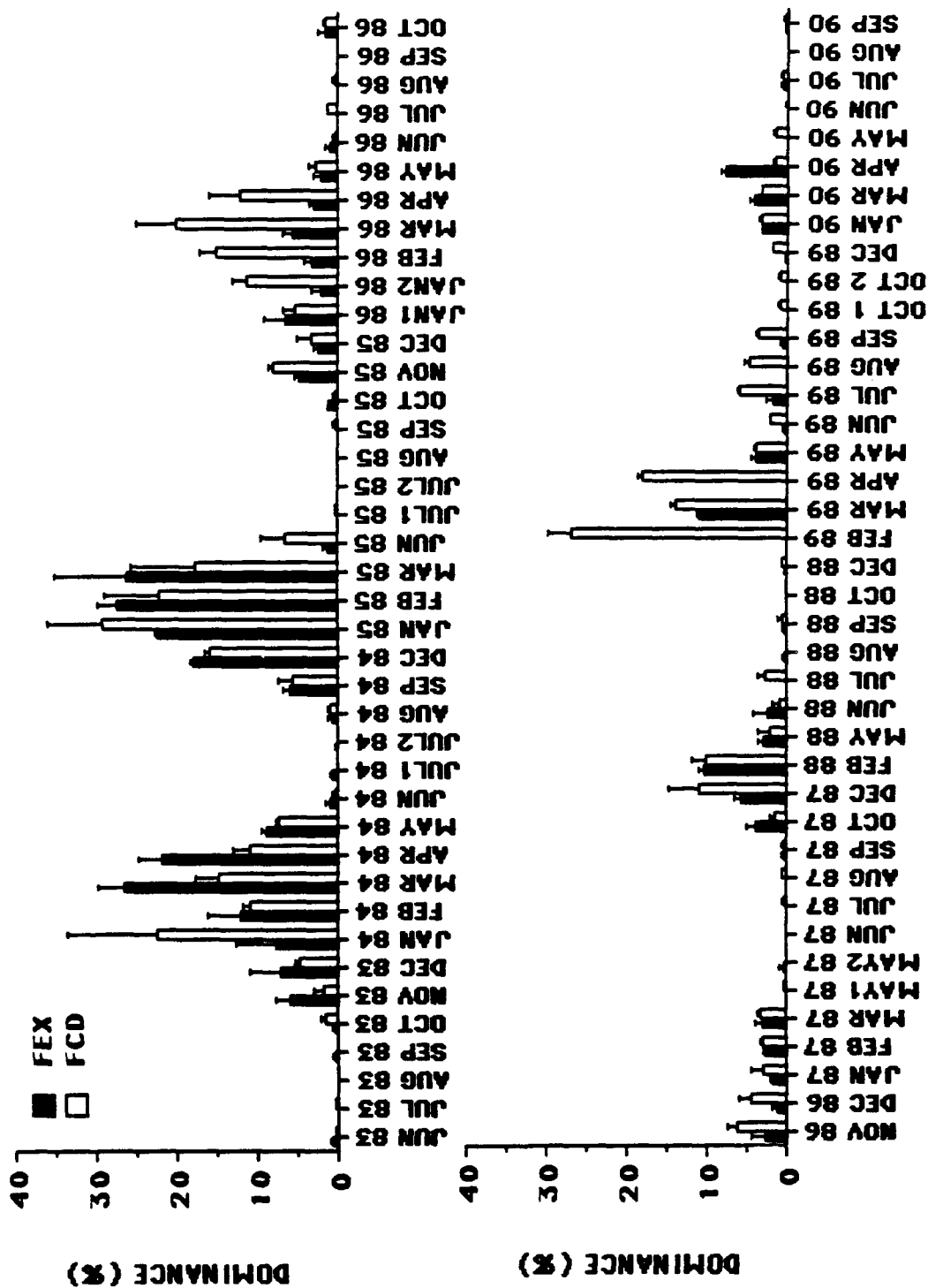


FIGURE 2.14 Gomphonema olivaceum PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

abundance levels of 51% (Fig. 2.15). The variable winter species abundance pattern observed during 1989 resulted in typical patterns of high diversity and evenness seen in previous winters.

Non-dominant (< 10% of total community composition) species such as Achnanthes lanceolata, Cocconeis pediculus, Cymbella minuta, Fragilaria construens and Synedra ulna have also responded in a predictable manner throughout the seven year period (Figs. 2.16, 2.17, 2.18, 2.19, 2.15). These species can also be divided into species that achieve greatest dominance in winter or summer. Species that are most abundant in summer include only Cocconeis pediculus (Fig. 2.17) and Cymbella minuta (Fig. 2.18). There are three winter abundant species: Achnanthes lanceolata, Fragilaria construens and Synedra ulna (Figs. 2.16, 2.19, 2.15). The combination of more dominant forms in the winter as well as the preponderance of minor species with peak abundance in the winter leads to the observed pattern in diversity and evenness of winter highs and summer lows (Figs. 2.8, 2.9).

We have quantified the changes in diatom abundance over time by analyzing dominant species present in winter and summer and several non-dominant species with the BACI technique (Table 2.15, Appendix B). Differences between the control and impact sites were calculated using the arcsin square root of the mean transformation suggested by Steel and Torrie (1960) for proportional data. There have been no significant changes in the inter-site relationships since testing of the ELF antenna began in the summer of 1986 for any of the dominant summer (Achnanthes, Cocconeis) or winter species (Achnanthes, Fragilaria, Gomphonema) when the entire seasonal 83-85 "before" data were compared to the 86-90 "after" data (Table 2.15). Results from unpaired t-tests for the two dominant summer species and three dominant winter species indicated that there were no significant differences between means for any of the "before" years and any of the years after testing began in 1986. Regressions run on the winter species indicated that some "before" and "after" data were not additive (Tables B-3, B-4, B-5). The small number of available data points for several years probably increased the chance for finding significant regressions. Seasonal pooled BACI comparisons of mean differences for the typically non-dominant species Cymbella minuta and Synedra ulna were not significant (Table 2.15). Also, no year-to-year comparisons for the summer species Cymbella or the winter species Synedra were found to be significant ($p < 0.05$).

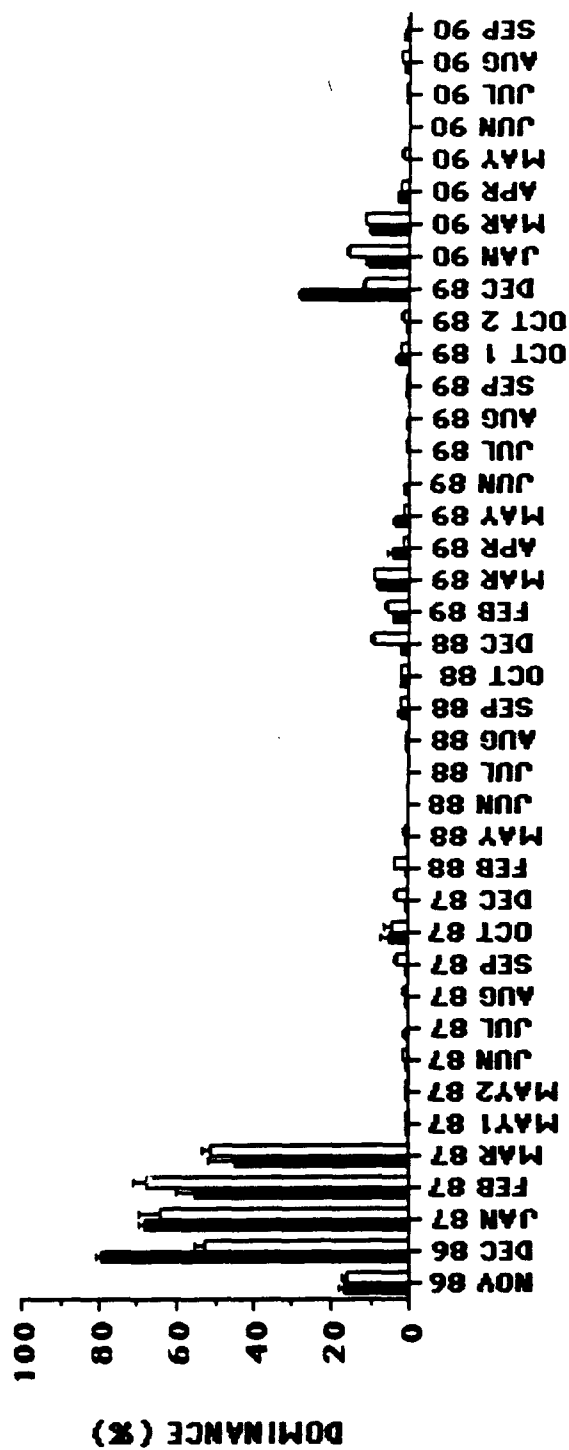
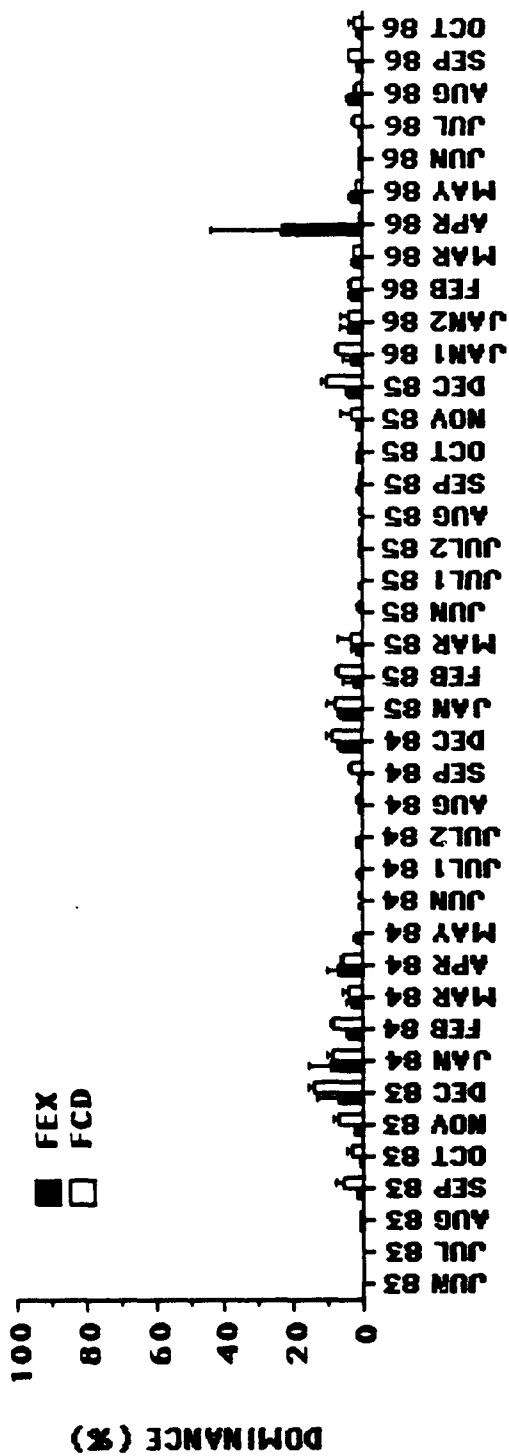


FIGURE 2.15 *Synedra ulna* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

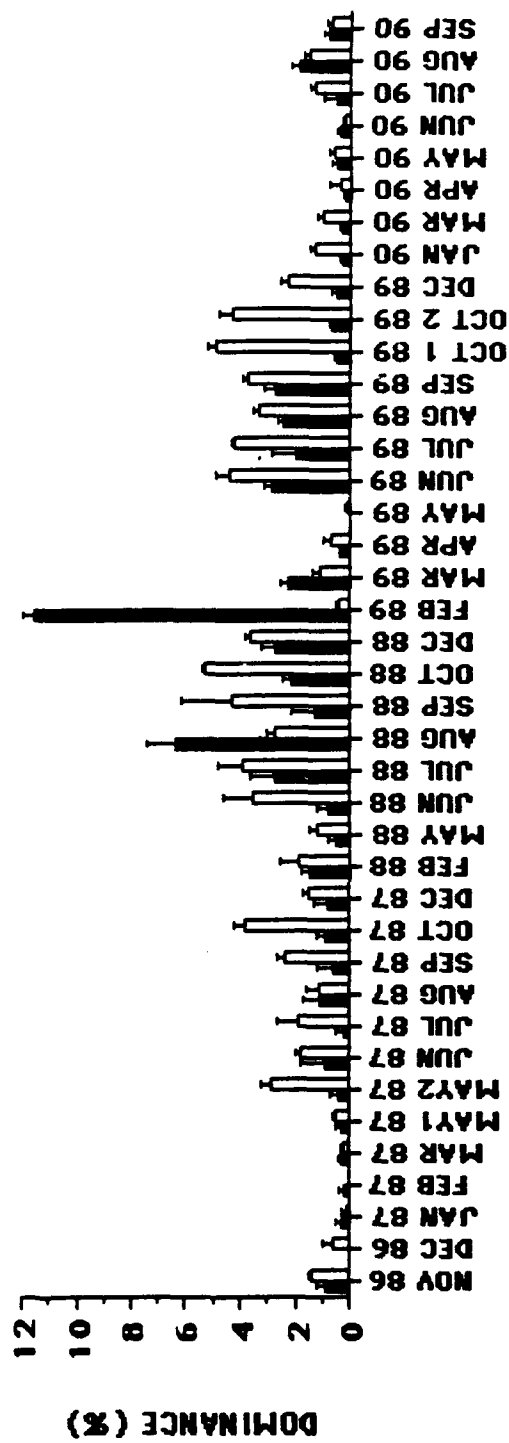
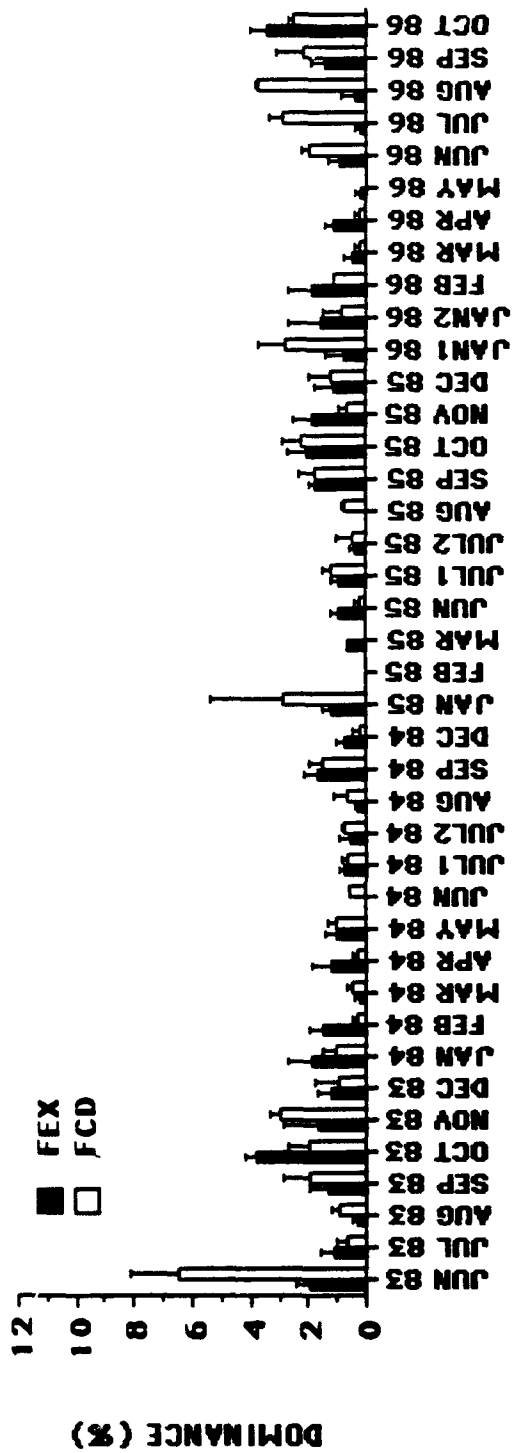


FIGURE 2.16 *Achmanthes lanceolata* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

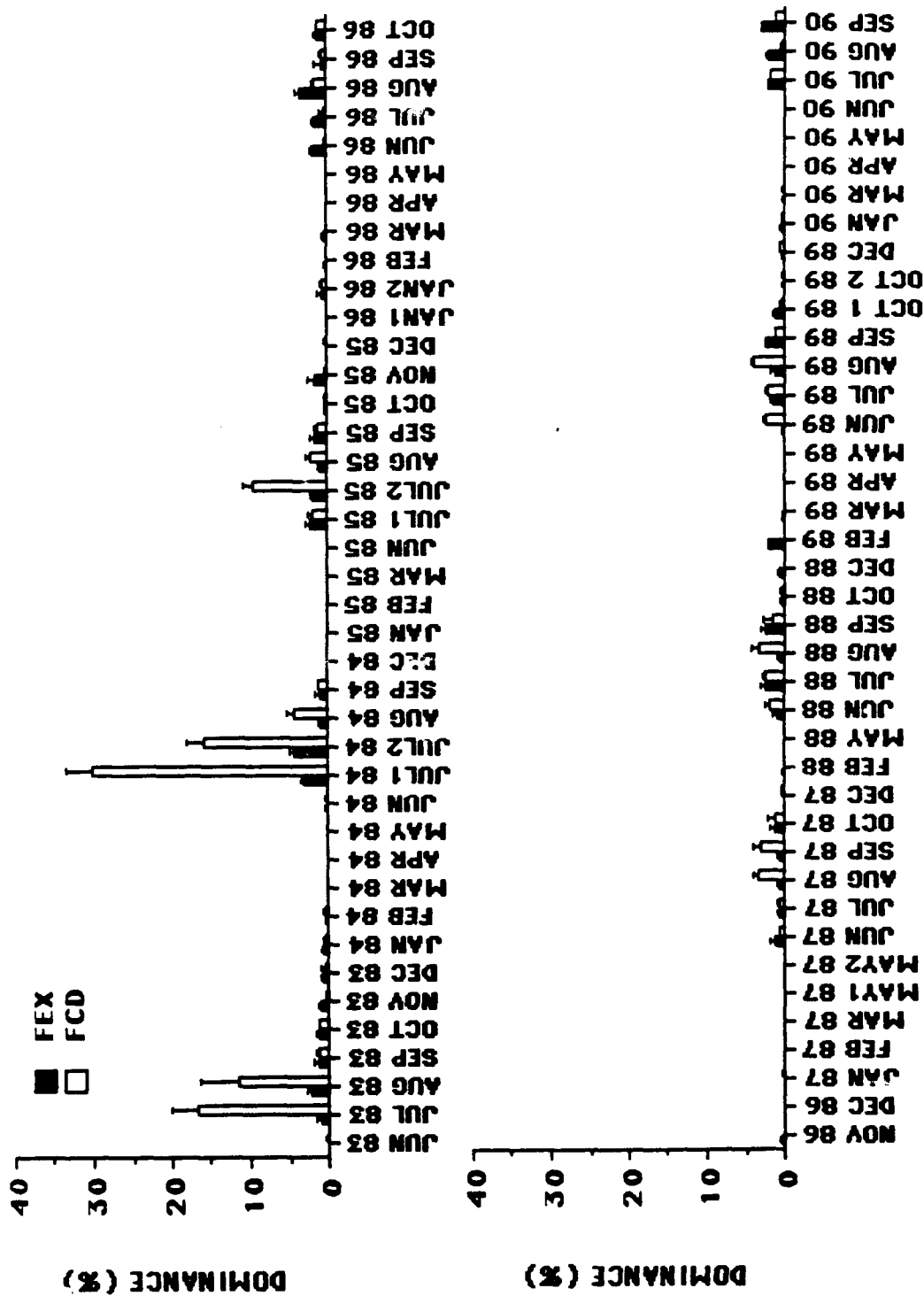


FIGURE 2.17 *Cocconeis pediculus* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

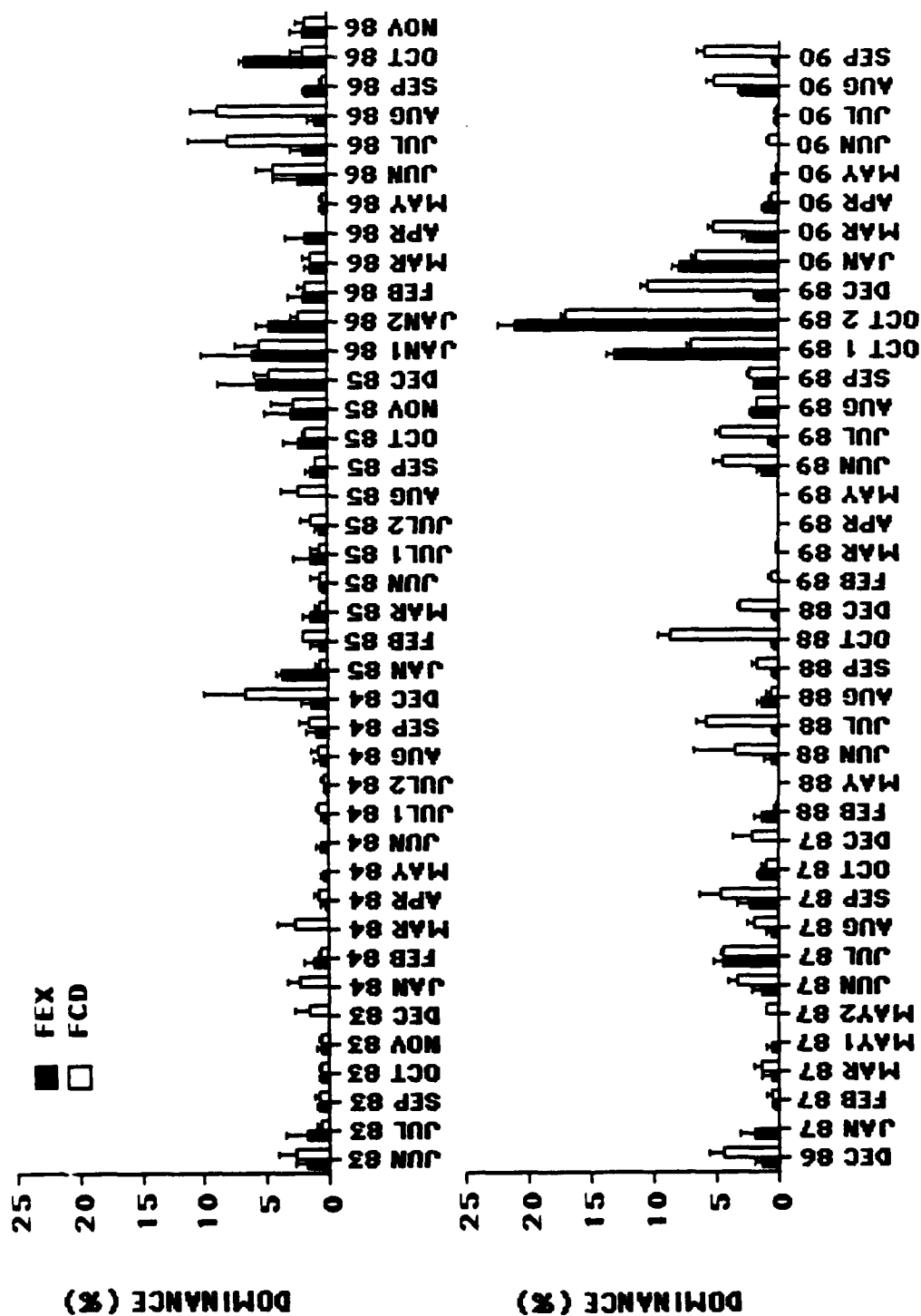


FIGURE 2.19 *Fragilaria conspersa* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1990.

Table 2.15 Summary of Diatom Abundance BACI and RIA Comparisons between Control (FCD) and Experimental (FEX) Sites for 1983-1990. N in parentheses for BACI and RIA, respectively.

Species	Comparison	BACI Signif. (p < 0.05)	RIA Signif. (p < 0.05)
<u>Summer</u>			
Achnanthes minutissima	Summer 83-85 vs. 86-90 (45) (46)	NS	NS
Cocconeis placentula	Summer 83-85 vs. 86-90 (45) (46)	NS	NS
Cymbella minuta	Summer 83-85 vs. 86-90 (44) (45)	NS	NS
<u>Winter</u>			
Achnanthes minutissima	Winter 83-85 vs. 86-89 (31) (33)	NS	NS
Fragilaria vaucheriae	Winter 83-85 vs. 86-89 (31) (33)	NS	NS
Gomphonema olivaceum	Winter 83-85 vs. 86-89 (31) (33)	NS	NS
Synedra ulna	Winter 83-85 vs. 86-89 (31) (33)	NS	NS

This year we have expanded our diatom abundance analyses to include RIA, as well as BACI. RIA seasonal comparisons of abundance data for the five dominant species indicated no significant differences in the between site relationship "before" and "after" antenna operation. No significant differences were found for RIA analysis of the non-dominant species of Cymbella and Synedra (Table 2.15). In all comparisons, results determined via RIA reflected results obtained by the BACI technique.

In an attempt to detect even more subtle changes in diatom abundances due to ELF exposure, we have run BACI analyses for dominant species that demonstrated obvious peaks in abundance during particular months of the year. For example, Achnanthes minutissima becomes very abundant during the months of May and June each year (Fig. 2.11). By pooling all the May and June data for the years 1983-85 as the "before" period and all the May and June data for 1986-90 as the "after", we can more closely examine mean differences between sites. We found no overall significant differences between mean percent dominance data for the four species analyzed using BACI (Table 2.16). Monthly species RIA comparisons cannot be run at this point in time, since we have insufficient numbers of observations for accurate RIA analysis. With the addition of several more years of data, the analysis of these species using both the BACI and RIA methods may prove to be sensitive indicators of potential ELF effects.

Comparisons of diversity and evenness between sites through paired t-tests indicated no significant differences in diversity or evenness between sites for 1989-90 (Table 2.3), or for the entire data set from 1983-1990 (Table 2.4). Correlation coefficients of 0.90 for diversity and 0.93 for evenness indicated the close relationship of these parameters between the two sites for 1989-90 (Table 2.3). These relationships remained highly correlated when data from 1983-1990 were considered (Table 2.4).

Both evenness and diversity exhibit low minimum detectable differences, 5.1% and 7.4%, respectively, indicating their potential value in detecting ELF effects (Table 2.5). Stepwise multiple regression analysis of evenness indicated that temperature and chloride were important predictors for entire "before" and "after" data sets (Table 2.2). When only summer data were considered, alkalinity and silica were fair predictors for evenness. Stepwise multiple regression models for species diversity included silica for all "before" data and conductivity for all "after" data as useful predictors. No model could be fitted for diversity for "before" summer data (Table 2.6). Diversity was significantly ($p < 0.01$) positively correlated

Table 2.16 Results of Monthly BACI Comparisons of Dominant Diatom Species (1983-1990).

Species	Comparison	Tukey's Test for Additivity				t - test					
		BEFORE	Sig. p<0.05	DF	AFTER	Sig. p<0.05	DF	Unpaired t-value	Probability (two-tailed) p<0.05		
Achnanthes minutissima	May & Jun 83-85/ May & Jun 86-90	3	0.276	NS	9	0.132	NS	12	-1.190	0.257	NS
Cocconeis placentula	Jul & Aug 83-85/ Jul & Aug 86-90	7	0.719	NS	9	0.110	NS	16	-0.677	0.508	NS
Fragilaria vaucheriae	Feb, Mar, Apr 84-86/ Feb, Mar, Apr 87-89	7	0.479	NS	7	0.803	NS	14	0.992	0.338	NS
Gomphonema olivaceum	Feb & Mar 84-86/ Feb & Mar 87-89	5	0.050	NS	5	0.709	NS	10	0.694	0.504	NS

with above water solar radiation at FEX ($r=0.48$) and FCD ($r=0.53$). The correlation matrix did not reveal any strong correlations between evenness and physical/chemical variables at either site.

Results of BACI comparisons for diversity and evenness demonstrated significant changes in the inter-site relationship for the pooled "before" (6/83-4/86) and "after" (5/86-9/90) data (Tables 2.11, A-8, A-9). Seasonal pooled comparisons for diversity were not significant. The only year-to-year comparison that was significant was the comparison of the summer of 83 to the summer of 87. Evenness differed from diversity in the fact that significant differences in the between site relationship occurred for both summer and winter data (Tables 2.11, A-9). Summer year-to-year comparisons of evenness resulted not only in the difference between the summer of 83 and 87 that had been true for diversity, but also in a significant difference between the summer of 85 and 87. No significant differences among year-to-year comparisons existed for evenness winter data, even though the winter pooled comparison of mean evenness differences was significant. This difference in the pooled winter data is most likely related to the fact that the 1985 transformed data, which failed Tukey's test for additivity, was included in the overall comparison. Evenness and diversity data analyzed using RIA reflected the results of the BACI analysis (Table 2.11).

Results from analysis of covariance using cumulative exposure demonstrated no ELF effects on either evenness or diversity (Table 2.7). The fact that there were no differences in the summer 1989 and 1990 data (years of maximum ELF exposure to date) and any other year, along with results of the ANCOVA, suggest that the observed differences in evenness and diversity result from some factor other than ELF. We suspect that the observed differences in diversity and evenness may be due to a change in diatom counters, which occurred with the May 1987 sample set. The trend toward a decrease in diversity, as well as an increase in evenness could have been caused by a bias against rarer species by the new diatom expert.

G. Effects of Environmental Variables on the Periphyton Community

Stepwise multiple regressions conducted on the total data set and the summer data set for each biological parameter failed to explain much of the variance in many of the cases. They did, however, identify some strong relationships between some of the physical/chemical parameters and the biological parameters.

The entire set of data on physical, chemical, and biological parameters collected since 1983 was separated by site and entered for calculation of correlation coefficients. These relationships were discussed throughout the report and used to guide variable selection for the stepwise multiple regression analysis conducted this year. Other approaches have been used in the past and will be included in future reports. A brief synopsis of some of these approaches is included here.

The multiple regressions calculated for the June 1983 to June 1985 data sets for each site were presented in the annual reports for 1984-85 and for 1985-86 and were not repeated for 1986-87 or 1987-88. Likewise, variable transformations were performed in 1985-86 to determine the linearity of variable relationships. These will not be repeated for this report but may be useful when the factor analyses are more thoroughly investigated. Our conclusion from the 1985-86 report that "an overall correlation matrix appeared to be as robust using untransformed data as any transformation attempted" was one reason for the determination of correlation coefficients on our entire data set for 1983 through 1990.

We have tried correlation matrices on transformed and untransformed data in the past and have also tried multiple and stepwise regressions. The correlation matrix on untransformed data seems to yield as much information as any of the other approaches. However, other approaches such as stepwise regression analysis, multifactor analysis of variance and multiple regression analysis are also useful and will be included in future analysis.

H. Photosynthesis-Respiration Studies

A separate study was undertaken to evaluate primary production and community respiration using short term changes in dissolved oxygen concentrations during the summer period of intense algal growth. The dissolved gas procedures are advantageous because estimates of net primary production, gross primary production, and community respiration may be obtained with one technique (Bott *et al.* 1979). Rocks from the stream bed were placed inside each of six plexiglass chambers occupying 1/3 to 1/4 of the total chamber volume of 3-4 L. Three light and three dark chambers were run simultaneously on each date. Recirculated water was continuously recycled through the chambers using submersible pumps. Each test lasted from 0.5-2.0 hours between 1000 and 1300 hours of each test day in 1984. One

site was tested during one week, and the second was tested during the following week in 1984. Even though 1984 results indicated no significant difference (t-test) between sites for net production, respiration, or gross production, the relatively large standard deviations led us to change procedures concerning exposure durations and site selection for 1985. Since 1985, production and respiration studies at FCD and FEX have been conducted on the same day with the test at each site lasting one hour. Tests were begun at one site at 1000 hours and completed at the other site by 1400 hours. Each site was tested first on alternate weeks.

The assumptions made for the purposes of production calculations considered algal periphyton to occupy only the upper half of each rock. Chlorophyll *a*, extracted from rocks covered by attached periphyton, was measured for each chamber with a fluorimeter. Surface area was determined by wrapping each rock in aluminum foil, straightening the foil, and determining the area of foil using a leaf area meter (LI-COR). Hourly production and respiration rates were estimated (Table 2.17) from dissolved oxygen, chlorophyll *a*, and rock surface area measurements.

We agree with reviewers from past years that production and respiration studies should be done for as many seasons of the year as possible. However, these procedures are labor intensive (ca. 40-50 hours per determination or 400 to 500 hours for the 10 runs per summer) and can only be done with present level of funding during times when student technicians are available (June 15 through September 1). Thus, these determinations will be done in this period only unless additional funds are forthcoming for studies during other seasons. We also agree that ^{14}C studies would be better than just monitoring changes in dissolved oxygen. Again, lack of equipment and funding to purchase such equipment precludes this as well.

Gross and net primary production and respiration were similar between the control (FCD) and experimental (FEX) sites for 1990 with the exception of the 7/6 and 7/10 dates (Table 2.17). We have analyzed gross primary production rates from 1984 to 1990 with the BACI and RIA technique (Tables 2.11, A-10). There was no significant difference in the between site relationship for either the pooled "before" and "after" data, or any year-to-year comparison using BACI. RIA also demonstrated no significant difference in pooled "before" or "after" data. We will compare results between sites using paired t-tests for each year for the final report.

I. BACI and RIA Comparisons of Biological and

Table 2.17 Hourly Production and Respiration Rates for Rock Substrate of the Ford River.

Date	NET PRIMARY PRODUCTION			RESPIRATION*			GROSS PRIMARY PRODUCTION**	
	mgO ₂ /m ²	mg Chl a/m ²	mg O ₂ /mg Chl a	mgO ₂ /m ²	mg Chl a/m ²	mg O ₂ /mg Chl a	mgO ₂ /m ²	mg Chl a
FORD CONTROL SITE (FCD)								
6/26/90	48.89 ± 8.69	37.53 ± 4.24	1.35 ± 0.30	61.84 ± 13.46	48.70 ± 4.56	1.25 ± 0.17	110.73	2.60
7/6/90	74.54 ± 18.52	16.08 ± 5.83	7.27 ± 4.11	53.03 ± 10.88	27.69 ± 6.72	2.19 ± 0.03	127.57	9.46
7/10/90	154.05 ± 17.12	21.72 ± 7.08	8.81 ± 2.68	5.91 ± 2.96	17.43 ± 2.31	0.38 ± 0.20	159.96	9.19
7/12/90	67.46 ± 5.65	38.75 ± 3.93	1.75 ± 0.05	64.06 ± 13.01	35.21 ± 6.88	1.92 ± 0.38	131.53	3.67
7/24/90	24.63 ± 6.59	14.84 ± 1.48	1.80 ± 0.69	49.64 ± 4.23	16.95 ± 0.89	2.97 ± 0.38	74.27	4.76
7/31/90	49.53 ± 6.03	22.55 ± 3.86	2.34 ± 0.48	62.81 ± 5.43	27.35 ± 1.21	2.29 ± 0.10	112.34	4.62
8/2/90	46.29 ± 6.06	11.33 ± 2.71	4.39 ± 0.89	29.43 ± 5.01	25.05 ± 4.03	1.20 ± 0.14	75.72	5.59
8/7/90	28.27 ± 14.17	31.57 ± 8.44	0.93 ± 0.56	27.46 ± 1.45	18.01 ± 2.68	1.59 ± 0.21	55.72	2.52
8/21/90	11.16 ± 3.59	18.68 ± 2.01	0.62 ± 0.21	67.93 ± 7.02	17.41 ± 1.82	3.95 ± 0.40	79.09	4.57
8/30/90	22.38 ± 5.79	14.10 ± 2.24	1.81 ± 0.77	34.94 ± 4.35	11.77 ± 3.05	3.52 ± 1.19	57.32	5.33
Ave ± S.E.	52.72 ± 12.94	22.72 ± 3.13	3.11 ± 0.89	45.70 ± 2.24	24.58 ± 3.46	2.13 ± 0.35	98.42 ± 11.09	5.23 ± 0.76
FORD EXPERIMENTAL SITE (FEX)								
6/26/90	96.50 ± 35.48	35.88 ± 6.28	2.50 ± 0.63	33.60 ± 4.96	27.08 ± 0.12	1.42 ± 0.00	130.09	3.92
7/6/90	110.23 ± 5.99	6.08 ± 2.45	35.79 ± 22.90	28.64 ± 3.51	8.66 ± 4.2	9.53 ± 6.86	138.88	45.32
7/10/90	48.04 ± 13.76	3.75 ± 1.62	15.09 ± 2.66	97.61 ± 6.83	13.71 ± 2.35	7.86 ± 2.16	145.66	22.95
7/12/90	39.04 ± 23.44	29.51 ± 2.81	1.43 ± 0.93	118.21 ± 10.59	20.94 ± 2.08	5.70 ± 0.49	157.25	7.12
7/24/90	25.76 ± 5.94	15.25 ± 0.95	1.72 ± 0.43	73.07 ± 10.00	18.98 ± 3.44	4.31 ± 1.26	98.83	6.02
7/31/90	49.32 ± 7.74	13.47 ± 4.74	4.87 ± 1.72	30.98 ± 2.30	17.93 ± 4.73	1.94 ± 0.43	80.30	6.41
8/2/90	39.94 ± 5.72	23.33 ± 4.39	1.81 ± 0.40	50.90 ± 15.51	14.40 ± 0.92	3.53 ± 0.90	90.05	5.33
8/7/90	25.68 ± 5.30	10.36 ± 3.46	2.82 ± 0.55	43.58 ± 6.11	17.08 ± 6.57	4.67 ± 2.84	69.26	7.49
8/21/90	32.85 ± 13.91	12.35 ± 1.37	2.61 ± 0.97	25.26 ± 6.49	14.52 ± 2.44	1.76 ± 0.37	58.11	4.37
8/30/90	55.69 ± 10.53	15.41 ± 1.40	3.55 ± 0.45	27.50 ± 7.41	22.55 ± 2.39	1.19 ± 0.21	83.19	4.75
Ave ± S.E.	52.30 ± 9.11	16.54 ± 3.21	7.22 ± 3.42	52.93 ± 10.33	17.58 ± 1.64	4.19 ± 0.90	105.24 ± 11.03	11.41 ± 4.16

* = Gross Respiration of Entire Microbial Community (Bacteria and Algae)

** = Total Metabolism = Respiration + Net Primary Production

Diatom Abundance Data

Results obtained using the RIA method generally reflected those from BACI (Tables 2.6, 2.11, 2.15). Similar probability levels were found for AFDW-biomass, AFDW-biomass accrual, cell volume, diversity, evenness, gross primary production and seasonal diatom abundance data. While probability levels did not agree precisely between methods for parameters such as chlorophyll *a*, chlorophyll *a* accrual, cell density and biovolume, the *p* values were usually within a few percentage points of one another. Overall, we feel that RIA offers a means of increasing the statistical rigor of this portion of the study.

For those parameters where significant differences did occur using both BACI and RIA, a closer look is required to determine whether ELF electromagnetic radiation or some other factor has caused the observed differences. As discussed previously, significant differences found in either BACI or RIA do not imply that ELF has caused the change, nor do these tests reveal at what point in time the change occurred. Ecological and procedural considerations must be examined as well as ELF effects. Bayesian statistics have been suggested by Carpenter (1990) and Reckhow (1990) as a means to quantitatively compare alternative hypotheses or models. This technique may offer a quantitative explanation for our observed changes in parameters such as chlorophyll *a*, diversity and evenness, and will be investigated as to its appropriateness for this study and included in future reports if appropriate.

J. Summary

1. Chlorophyll *a*

Annual patterns for chlorophyll *a* standing crop and accrual were characterized by large year-to-year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired *t*-tests for 1989-90 data showed a significant difference between our control (FCD) and experimental sites (FEX), although there were no differences for all data collected since 1983. "Before" (6/83-4/86) and "after" (5/86-9/90), control (FCD) and impact (FEX) (BACI) and Randomized Intervention Analysis (RIA) indicate that the between site relationship in chlorophyll *a* has changed since May 1989 when the testing of the antenna began. The significant positive correlations between water temperature and chlorophyll *a*, the importance of water temperature as a predictor of chlorophyll *a* in stepwise regression models, and the increasing water

temperatures during the drought periods in the spring and summer in 1986, 87, 88, 89, and 90 lead us to believe that this change is related to weather variables and not to ELF exposure. This conclusion is supported by analysis of covariance (ANCOVA) of the after data with ELF exposures included as a covariant. ANCOVA analysis do not suggest that ELF exposures are correlated with the observed inter-site differences.

2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year-to-year variability similar to chlorophyll *a*. These parameters have been consistently characterized by showing no significant differences between sites since 1983, although organic matter accrual at FEX was higher than FCD for 1989-90. BACI analyses and RIA also showed that no difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. Stepwise regression analysis indicate that water temperature is the most important predictor of organic matter standing crop. Organic matter standing crop was correlated with water temperature (positively) and dissolved oxygen (negatively).

3. Diatom Cell Density

Diatom cell density continued to be characterized by no statistical difference between sites, regardless of length of data set compared according to paired t-tests. However, BACI analyses and RIA indicated that data collected before May 86 were significantly different from data collected after May 86. The increased density after May 86 may be related to the low discharges and high temperatures during May and early summer in each of these years. Density was highest in May in all five years. Silica concentrations and water temperature appeared in the stepwise regression analysis as the most reliable predictors of diatom density. The importance of weather was suggested by the significant positive correlation with water temperature.

4. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences according to paired t-tests. BACI analysis and RIA detected no significant changes in the inter-site relationship for biovolume. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times

density. Stepwise regression analysis indicates that water temperature and soluble reactive phosphorus concentrations are the most consistent predictors of cell volume, while there were no consistent predictors of total biovolume. Average cell volume was negatively correlated ($p < 0.05$) with water temperature and total biovolume was not correlated with any of the physical/chemical variables.

5. Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1990 or for all data collected to date according to paired t-tests. Annual trends showed a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. In 1990, we calculated percent abundance for all species of diatoms and presented data for those species that achieved dominance greater than 10 % for any season. Two species, Achnanthes minutissima and Cocconeis placentula were found to dominate during the 1990 summer period. Three species achieved dominance during the winter of 1989. Synedra was a dominant winter species, but represented a smaller proportion of the community than it had been during winter 1986-87. BACI and RIA analyses were presented for four dominant and two non-dominant species of diatoms and showed that few differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the BACI and RIA analyses. Because of the pattern of year to year differences and ANCOVA results, we suggest that these changes may be related to factors other than ELF effects.

6. Effects of Environmental Variables on the Periphyton Community

Stepwise multiple regression analysis was conducted for each biological parameter on the physical/chemical variables. In many cases, the regression models agreed with the results of the correlation matrix, yet a large amount of variance was left unexplained. In some cases, the regression models pointed out relationships that did not show up in the correlation matrix (for instance, silica appeared consistently in the models for density and diversity, yet neither was correlated with silica). The stepwise regression models and correlation matrix proved useful in identifying possible causes for the patterns observed for our biological parameters and are essential for separating weather effects from possible ELF effects.

7. Photosynthesis-Respiration Studies

Net primary production, respiration, and gross primary production of the community on rock surfaces did not differ greatly between sites. RIA and BACI analyses indicated that there have been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data.

K. References

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APPENDIX A:

BACI Analyses for Biological Parameters

Table A-1. Results of Summer BACI Comparisons of Chlorophyll a between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*			Sig. p < 0.05	DF	AFiER Prob.	Sig. p < 0.05	t - test*		
		BEFORE Prob.	Sig. p < 0.05	DF					Unpaired t-value	Probability (two-tailed), p < 0.05	Sig.
6/83-4/86 //	38	0.244	NS	46	0.034	S	84	2.989	0.004	S	
5/86-9/90											
S 83-85/86-90	19	0.455	NS	30	0.570	NS	49	1.958	0.0560	NS	
S 83/84	5	0.526	NS	6	0.056	NS	11	0.361	0.725	NS	
S 83/85	5	0.526	NS	6	0.266	NS	11	-0.074	0.943	NS	
S 83/86	5	0.526	NS	5	0.252	NS	10	-1.495	0.166	NS	
S 83/87	5	0.526	NS	5	0.085	NS	10	-1.753	0.110	NS	
S 83/88	5	0.526	NS	4	0.395	NS	9	-2.285	0.048	S	
S 83/89	5	0.526	NS	4	0.014	S	9	1.436	0.185	NS	
S 83/90	5	0.526	NS	4	0.141	NS	9	2.357	0.043	S	
S 84/85	6	0.056	NS	6	0.266	NS	12	-0.662	0.521	NS	
S 84/86	6	0.056	NS	5	0.252	NS	11	-2.141	0.056	NS	
S 84/87	6	0.056	NS	5	0.085	NS	11	-2.516	0.029	S	
S 84/88	6	0.056	NS	4	0.395	NS	10	-3.090	0.011	S	
S 84/89	6	0.056	NS	4	0.014	S	10	2.025	0.070	NS	
S 84/90	6	0.056	NS	4	0.141	NS	10	3.144	0.010	S	
S 85/86	6	0.266	NS	5	0.252	NS	11	-1.962	0.076	NS	
S 85/87	6	0.266	NS	5	0.085	NS	11	-2.599	0.025	S	
S 85/88	6	0.266	NS	4	0.395	NS	10	-3.546	0.005	S	
S 85/89	6	0.266	NS	4	0.014	S	10	1.879	0.090	NS	
S 85/90	6	0.266	NS	4	0.141	NS	10	3.514	0.006	S	
S 86/87	5	0.252	NS	5	0.085	NS	10	-0.120	0.907	NS	
S 86/88	5	0.252	NS	4	0.395	NS	9	-1.209	0.258	NS	
S 86/89	5	0.252	NS	4	0.014	S	9	0.143	0.889	NS	
S 86/90	5	0.252	NS	4	0.141	NS	9	1.339	0.213	NS	

Table A-1. Results of Summer BACI Comparisons Cont.

Comparison; (Bef/Aft, Bef/Bef, or Aft/Aft)	Tukey's Test for Additivity*				t - test*				
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed); p < 0.05	Sig.
S 87/88	0.085	NS	4	0.395	NS	9	-1.929	0.086	NS
S 87/89	0.085	NS	4	0.014	S	10	0.454	0.659	NS
S 87/90	0.085	NS	4	0.141	NS	9	1.881	0.093	NS
S 88/89	0.395	NS	4	0.014	S	10	-0.574	0.579	NS
S 88/90	0.395	NS	4	0.141	NS	10	0.587	0.57	NS
S 89/90	0.014	S	4	0.141	NS	10	0.909	0.385	NS

*Data was log (x+1) transformed

Table A-1. Results of Winter BACI Comparisons of Chlorophyll *a* between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*			t-test*		
		BEFORE Prob.	Sig. p < 0.05	AFTER Prob.	Sig. p < 0.05	Unpaired t-value	Probability (two-tailed): p < 0.05
W 83-85/86-89	18	0.020	S	0.825	NS	-1.172	0.250
W 83/84	5	0.086	NS	0.679	NS	0.814	0.434
W 83/85	5	0.086	NS	0.012	S	0.792	0.445
W 83/86	5	0.086	NS	0.821	NS	0.783	0.452
W 83/87	5	0.086	NS	-	-	1.142	0.297
W 83/88	5	0.086	NS	0.898	NS	-1.373	0.207
W 83/89	5	0.086	NS	0.917	NS	-0.108	0.916
W 84/85	5	0.679	NS	0.012	S	-0.285	0.781
W 84/86	5	0.679	NS	0.821	NS	0.214	0.835
W 84/87	5	0.679	NS	-	-	1.852	0.114
W 84/88	5	0.679	NS	0.898	NS	-1.281	0.236
W 84/89	5	0.679	NS	0.917	NS	1.081	0.311
W 85/86	6	0.012	S	0.821	NS	0.367	0.720
W 85/87	6	0.012	S	-	-	3.188	0.015
W 85/88	6	0.012	S	0.898	NS	-1.643	0.135
W 85/89	6	0.012	S	0.917	NS	1.134	0.286
W 86/87	5	0.821	NS	-	-	0.572	0.588
W 86/88	5	0.821	NS	0.898	NS	-0.715	0.498
W 86/89	5	0.821	NS	0.917	NS	0.726	0.489
W 87/88	1	-	-	0.898	NS	0.035	0.974
W 87/89	1	-	-	0.917	NS	2.075	0.107
W 88/89	3	0.898	NS	0.917	NS	1.599	0.161

*Data was log (x+1) transformed

Table A-2. Results of Summer BACI Comparisons of Chlorophyll a Accrual between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison	DF	Tukey's Test for Additivity*				t-test*		
		BEFORE	Sig.	AFTER	Sig.	Unpaired	Probability	Sig.
	DF	Prob.	p < 0.05	DF	p < 0.05	t-value	(two-tailed)	p < 0.05
6/83-4/86 //	39	0.063	NS	47	0.011	86	0.008	S
5/86-9/90	20	0.186	NS	31	0.067	51	0.003	S
S 83-85/86-90	8	0.238	NS	5	0.525	13	0.200	NS
S 83/84	8	0.238	NS	5	0.287	13	0.075	NS
S 83/85	8	0.238	NS	5	0.079	13	-1.026	NS
S 83/86	8	0.238	NS	7	0.350	15	-0.565	NS
S 83/87	8	0.238	NS	9	0.020	17	-2.478	S
S 83/88	8	0.238	NS	6	0.670	14	-2.980	S
S 83/89	8	0.238	NS	3	0.383	11	-1.496	NS
S 83/90	5	0.525	NS	5	0.287	10	0.252	NS
S 84/85	5	0.525	NS	5	0.079	10	1.586	NS
S 84/86	5	0.525	NS	7	0.350	12	0.699	NS
S 84/87	5	0.525	NS	9	0.020	14	2.112	NS
S 84/88	5	0.525	NS	6	0.670	11	-3.745	S
S 84/89	5	0.525	NS	3	0.383	8	-2.248	NS
S 84/90	5	0.287	NS	5	0.079	10	1.638	NS
S 85/86	5	0.287	NS	7	0.350	12	0.623	NS
S 85/87	5	0.287	NS	9	0.020	14	2.070	NS
S 85/88	5	0.287	NS	6	0.670	11	-3.945	S
S 85/89	5	0.287	NS	3	0.383	8	-2.484	S
S 85/90	5	0.079	NS	7	0.350	12	-0.263	NS
S 86/87	5	0.079	NS	9	0.020	14	1.380	NS
S 86/88	5	0.079	NS	6	0.670	11	-2.051	NS
S 86/89	5	0.079	NS	3	0.383	8	-0.736	NS
S 86/90								

Table A-2. Results of Summer BACI Comparisons of Chlorophyll a Accrual Cont.

Comparison	Tukey's Test for Additivity*				t - test*		
	BEFORE	AFTER		Sig.	Unpaired	Probability	Sig.
	DF	Prob.	p < 0.05	DF	t-value	(two-tailed)	p < 0.05
S 87/88	7	0.350	NS	9	1.618	0.125	NS
S 87/89	7	0.350	NS	6	-1.800	0.095	NS
S 87/90	7	0.350	NS	3	-0.705	0.499	NS
S 88/89	9	0.020	S	6	0.655	0.525	NS
S 88/90	9	0.020	S	3	0.987	0.349	NS
S 89/90	6	0.670	NS	3	1.022	0.333	NS

*Data was $\log(x+1)$ transformed

Table A-2. Results of Winter BACI Comparisons of Chlorophyll a Accrual between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison	Tukey's Test for Additivity*						t - test*				
	BEFORE		Sig. p < 0.05	DF	AFTER		Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed)	Sig. p < 0.05
	Prob.	Prob.			Prob.	Prob.					
W 83-85/86-89	18	0.196	NS	15	0.692	NS	33	0.556	0.582	NS	
W 83/84	5	0.267	NS	5	0.869	NS	10	0.371	0.719	NS	
W 83/85	5	0.267	NS	6	0.003	S	11	0.728	0.482	NS	
W 83/86	5	0.267	NS	4	0.973	NS	9	-2.302	0.047	S	
W 83/87	5	0.267	NS	1	-	-	6	-0.521	0.621	NS	
W 83/88	5	0.267	NS	3	0.448	NS	8	-1.103	0.302	NS	
W 83/89	5	0.267	NS	4	0.550	NS	9	-0.367	0.722	NS	
W 84/85	5	0.869	NS	6	0.003	S	11	0.283	0.783	NS	
W 84/86	5	0.869	NS	4	0.973	NS	9	0.466	0.653	NS	
W 84/87	5	0.869	NS	1	-	-	6	0.173	0.868	NS	
W 84/88	5	0.869	NS	3	0.448	NS	8	1.347	0.215	NS	
W 84/89	5	0.869	NS	4	0.550	NS	9	-0.911	0.386	NS	
W 85/86	6	0.003	S	4	0.973	NS	10	-2.740	0.021	S	
W 85/87	6	0.003	S	1	-	-	7	-1.320	0.228	NS	
W 85/88	6	0.003	S	3	0.448	NS	9	-1.387	0.199	NS	
W 85/89	6	0.003	S	4	0.550	NS	10	-1.118	0.29	NS	
W 86/87	4	0.973	NS	1	-	-	5	1.133	0.309	NS	
W 86/88	4	0.973	NS	3	0.448	NS	7	0.021	0.984	NS	
W 86/89	4	0.973	NS	4	0.550	NS	8	-0.669	0.522	NS	
W 87/88	1	-	-	3	0.448	NS	4	-0.538	0.619	NS	
W 87/89	1	-	-	4	0.550	NS	5	-0.538	0.614	NS	
W 88/89	3	0.448	NS	4	0.550	NS	7	-1.426	0.197	NS	

*Data was log(x+1) transformed

Table A-3. Results of Summer BACI Comparisons of AFDW-Biomass between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE Prob.	Sig. $p < 0.05$	DF	AFTER Prob.	Sig. $p < 0.05$	Unpaired t-value	Probability (two-tailed; $p < 0.05$)
6/83-4/86 //	38	0.350	NS	45	0.708	NS	1.534	0.129
5/86-9/90	38							NS
S 83-85/86-90	19	0.027	S	29	0.152	NS	3.322	0.002
S 83/84	5	0.296	NS	6	0.071	NS	1.699	0.117
S 83/85	5	0.296	NS	6	0.314	NS	-0.620	0.548
S 83/86	5	0.296	NS	5	0.760	NS	-1.871	0.091
S 83/87	5	0.296	NS	5	0.931	NS	-0.098	0.924
S 83/88	5	0.296	NS	4	0.861	NS	-2.225	0.053
S 83/89	5	0.296	NS	4	0.889	NS	1.711	0.121
S 83/90	5	0.296	NS	3	0.180	NS	0.102	0.922
S 84/85	6	0.071	NS	6	0.314	NS	-2.402	0.033
S 84/86	6	0.071	NS	5	0.760	NS	-3.100	0.010
S 84/87	6	0.071	NS	5	0.931	NS	-1.871	0.088
S 84/88	6	0.071	NS	4	0.861	NS	-3.358	0.007
S 84/89	6	0.071	NS	4	0.889	NS	2.983	0.014
S 84/90	6	0.071	NS	3	0.180	NS	1.276	0.234
S 85/86	6	0.314	NS	5	0.760	NS	-1.661	0.125
S 85/87	6	0.314	NS	5	0.931	NS	0.580	0.573
S 85/88	6	0.314	NS	4	0.861	NS	-1.900	0.087
S 85/89	6	0.314	NS	4	0.889	NS	1.337	0.211
S 85/90	6	0.314	NS	3	0.180	NS	-0.274	0.790
S 86/87	5	0.760	NS	5	0.931	NS	1.899	0.087
S 86/88	5	0.760	NS	4	0.861	NS	0.590	0.570
S 86/89	5	0.760	NS	4	0.889	NS	-0.714	0.493
S 86/90	5	0.760	NS	3	0.180	NS	-1.234	0.252

Table A-3. Results of Summer BACI Comparisons Cont.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*			t-test*		
		BEFORE Prob.	Sig. $p < 0.05$	AFTER Prob.	Unpaired t-value	Probability (two-tailed), $p < 0.05$	Sig.
S 87/88	5	0.931	NS	0.761	-2.597	0.029	S
S 87/89	5	0.931	NS	0.889	1.737	0.113	NS
S 87/90	5	0.931	NS	0.180	-0.341	0.742	NS
S 88/89	4	0.761	NS	0.889	-0.647	0.532	NS
S 88/90	4	0.761	NS	0.180	-1.440	0.184	NS
S 89/90	4	0.889	NS	0.180	-0.909	0.387	NS

*Data was $\log(x+1)$ transformed

Table A-3. Results of Winter BACI Comparisons of AFDW-Biomass between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	Unpaired t-value	Probability (two-tailed) p < 0.05
W 83-85/86-89	18	0.056	NS	15	0.061	NS	-0.433	0.668
W 83/84	5	0.200	NS	5	0.882	NS	1.216	0.252
W 83/85	5	0.200	NS	6	0.246	NS	0.471	0.647
W 83/86	5	0.200	NS	5	0.834	NS	0.974	0.353
W 83/87	5	0.200	NS	1	-	-	2.861	0.029
W 83/88	5	0.200	NS	3	0.270	NS	-0.345	0.739
W 83/89	5	0.200	NS	3	0.093	NS	0.115	0.912
W 84/85	5	0.882	NS	6	0.246	NS	-0.505	0.624
W 84/86	5	0.882	NS	5	0.834	NS	-0.643	0.535
W 84/87	5	0.882	NS	1	-	-	1.686	0.143
W 84/88	5	0.882	NS	3	0.270	NS	0.799	0.447
W 84/89	5	0.882	NS	3	0.093	NS	1.152	0.283
W 85/86	6	0.246	NS	5	0.834	NS	0.111	0.914
W 85/87	6	0.246	NS	1	-	-	1.574	0.160
W 85/88	6	0.246	NS	3	0.270	NS	0.165	0.872
W 85/89	6	0.246	NS	3	0.093	NS	0.477	0.645
W 86/87	5	0.834	NS	1	-	-	4.262	0.005
W 86/88	5	0.834	NS	3	0.270	NS	0.173	0.868
W 86/89	5	0.834	NS	3	0.093	NS	1.069	0.316
W 87/88	1	-	-	3	0.270	NS	2.707	0.054
W 87/89	1	-	-	3	0.093	NS	2.72	0.053
W 88/89	3	0.270	NS	3	0.093	NS	0.418	0.691

*Data was log (x+1) transformed

Table A-4. Results of Summer BACI Comparisons of AFDW-Biomass Accrual between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE	Sig.	AFTER	Sig.	Unpaired	Probability	Sig.
		Prob.	p < 0.05	DF	p < 0.05	t-value	(two-tailed)	p < 0.05
6/83-4/86 //								
5/86-9/90	41	0.603	NS	47	0.305	NS	0.540	NS
S 83-85/86-90	21	0.912	NS	31	0.338	NS	0.380	NS
S 83/84	9	0.322	NS	5	0.455	NS	0.173	NS
S 83/85	9	0.322	NS	5	0.772	NS	0.438	NS
S 83/86	9	0.322	NS	5	0.551	NS	0.888	NS
S 83/87	9	0.322	NS	7	0.581	NS	0.403	NS
S 83/88	9	0.322	NS	9	0.431	NS	0.854	NS
S 83/89	9	0.322	NS	4	0.756	NS	0.732	NS
S 83/90	9	0.322	NS	3	0.587	NS	0.638	NS
S 84/85	5	0.455	NS	5	0.772	NS	0.146	NS
S 84/86	5	0.455	NS	5	0.551	NS	0.248	NS
S 84/87	5	0.455	NS	7	0.581	NS	0.338	NS
S 84/88	5	0.455	NS	9	0.431	NS	0.024	S
S 84/89	5	0.455	NS	4	0.756	NS	0.046	NS
S 84/90	5	0.455	NS	3	0.587	NS	0.018	S
S 85/86	5	0.772	NS	5	0.551	NS	0.557	NS
S 85/87	5	0.772	NS	7	0.581	NS	0.979	NS
S 85/88	5	0.772	NS	9	0.431	NS	0.146	NS
S 85/89	5	0.772	NS	4	0.756	NS	0.356	NS
S 85/90	5	0.772	NS	3	0.587	NS	0.056	NS
S 86/87	5	0.551	NS	7	0.581	NS	0.543	NS
S 86/88	5	0.551	NS	9	0.431	NS	0.726	NS
S 86/89	5	0.551	NS	4	0.756	NS	0.858	NS
S 86/90	5	0.551	NS	3	0.587	NS	0.506	NS

Table A-4. Results of Summer BACI Comparisons of AFDW-Biomass Accrual Cont.

Comparison	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE	Sig. $p < 0.05$	DF	AFTER	Sig. $p < 0.05$	Unpaired t-value	Probability (two-tailed) $p < 0.05$
S 87/88	7	0.581	NS	9	0.431	NS	1.461	0.464
S 87/89	7	0.581	NS	4	0.756	NS	0.629	0.542
S 87/90	7	0.581	NS	3	0.587	NS	1.725	0.112
S 88/89	9	0.431	NS	4	0.756	NS	-0.555	0.591
S 88/90	9	0.431	NS	3	0.587	NS	0.667	0.52
S 89/90	4	0.756	NS	3	0.587	NS	1.540	0.154

*Data was not transformed

Table A-4. Results of Winter BACI Comparisons of AFDW-Biomass Accrual between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE	AFTER	DF	Sig. p < 0.05	Unpaired t-value	Probability (two-tailed)	Sig. p < 0.05
W 83-85/86-89	19	0.003	0.090	15	NS	-0.545	0.590	NS
W 83/84	5	0.077	0.978	6	NS	-1.752	0.108	NS
W 83/85	5	0.077	0.043	6	NS	-0.395	0.701	NS
W 83/86	5	0.077	0.501	4	NS	-0.829	0.428	NS
W 83/87	5	0.077	-	1	NS	-2.444	0.050	NS
W 83/88	5	0.077	0.092	3	NS	-0.509	0.624	NS
W 83/89	5	0.077	0.678	4	NS	-0.322	0.755	NS
W 84/85	6	0.978	0.043	6	NS	1.107	0.290	NS
W 84/86	6	0.978	0.501	4	NS	1.244	0.242	NS
W 84/87	6	0.978	-	1	NS	-1.893	0.100	NS
W 84/88	6	0.978	0.092	3	NS	1.277	0.234	NS
W 85/89	6	0.978	0.678	4	NS	1.606	0.139	NS
W 85/86	6	0.043	0.501	4	S	-0.213	0.836	NS
W 85/87	6	0.043	-	1	S	-2.123	0.072	NS
W 85/88	6	0.043	0.092	3	S	-0.030	0.577	NS
W 85/89	6	0.043	0.678	4	S	0.147	0.889	NS
W 86/87	4	0.501	-	1	NS	-2.274	0.074	NS
W 86/88	4	0.501	0.092	3	NS	0.375	0.719	NS
W 86/89	4	0.501	0.678	4	NS	0.710	0.498	NS
W 87/88	1	-	0.092	3	-	2.004	0.116	NS
W 87/89	1	-	0.678	4	-	2.342	0.066	NS
W 88/89	3	0.092	0.678	4	NS	0.293	0.778	NS

*Data was not transformed

Table A-5. Results of Summer BACI Comparisons of Cell Density between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	Tukey's Test for Additivity*				t - test*				
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed), p < 0.05	Sig.
6/83-4/86 //									
5/86-9/90	0.466	NS	45	0.080	NS	83	2.933	0.004	S
S 83-85/86-90	0.327	NS	29	0.612	NS	48	2.730	0.009	S
S 83/84	0.302	NS	6	0.764	NS	11	0.242	0.813	NS
S 83/85	0.302	NS	6	0.038	S	11	0.013	0.990	NS
S 83/86	0.302	NS	5	0.413	NS	10	1.314	0.218	NS
S 83/87	0.302	NS	5	0.091	NS	10	1.720	0.116	NS
S 83/88	0.302	NS	4	0.173	NS	9	2.113	0.061	NS
S 83/89	0.302	NS	4	0.658	NS	9	1.890	0.085	NS
S 83/90	0.302	NS	4	0.126	NS	9	2.459	0.036	S
S 84/85	0.764	NS	6	0.038	S	12	-0.200	0.845	NS
S 84/86	0.764	NS	5	0.143	NS	11	0.832	0.423	NS
S 84/87	0.764	NS	5	0.091	NS	11	0.910	0.382	NS
S 84/88	0.764	NS	4	0.173	NS	10	1.320	0.214	NS
S 84/89	0.764	NS	4	0.658	NS	10	1.059	0.310	NS
S 84/90	0.764	NS	4	0.126	NS	10	1.075	0.308	NS
S 85/86	0.038	S	5	0.143	NS	11	1.104	0.293	NS
S 85/87	0.038	S	5	0.091	NS	11	1.255	0.236	NS
S 85/88	0.038	S	4	0.173	NS	10	1.678	0.122	NS
S 85/89	0.038	S	4	0.658	NS	10	1.428	0.179	NS
S 85/90	0.038	S	4	0.126	NS	10	1.483	0.169	NS
S 86/87	0.143	NS	5	0.091	NS	10	-0.034	0.973	NS
S 86/88	0.143	NS	4	0.173	NS	9	0.411	0.690	NS
S 86/89	0.143	NS	4	0.658	NS	9	0.053	0.958	NS
S 86/90	0.143	NS	4	0.126	NS	9	0.132	0.898	NS

Table A-5. Results of Summer BACI Comparisons of Cell Density Cont.

Comparison: (Bef/Aft., Bef/Bef, or Aft/Aft)			Tukey's Test for BEFORE			Additivity*			t - test*				
DF	Prob.	Sig.	DF	Prob.	Sig.	DF	Prob.	Sig.	DF	Unpaired t-value	Probability (two-tailed), p < 0.05	Sig.	
S 87/88	5	0.091	NS	4	0.173	NS	9	0.173	NS	9	0.520	0.614	NS
S 87/89	5	0.091	NS	4	0.658	NS	9	0.658	NS	9	0.107	0.917	NS
S 87/90	5	0.091	NS	4	0.126	NS	9	0.126	NS	9	0.212	0.837	NS
S 88/89	4	0.173	NS	4	0.658	NS	9	0.658	NS	9	-0.451	0.661	NS
S 88/90	4	0.173	NS	4	0.126	NS	9	0.126	NS	9	-0.345	0.738	NS
S 89/90	4	0.658	NS	4	0.126	NS	10	0.126	NS	10	0.108	0.916	NS

*Data was $\log(x+1)$ transformed

Table A-5. Results of Winter BACI Comparisons of Cell Density between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)		Tukey's Test for Additivity*				t - test*		
DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed), p < 0.05
18	0.766	NS	15	0.107	NS	33	1.088	0.284
5	0.225	NS	5	0.554	NS	10	-3.207	0.009
5	0.225	NS	6	0.534	NS	11	-1.574	0.144
5	0.225	NS	5	0.792	NS	10	-0.382	0.710
5	0.225	NS	1	-	-	6	-2.687	0.036
5	0.225	NS	3	0.159	NS	8	0.359	0.729
5	0.225	NS	3	0.345	NS	8	-1.535	0.163
5	0.554	NS	6	0.534	NS	11	1.129	0.283
5	0.554	NS	5	0.792	NS	10	3.404	0.007
5	0.554	NS	1	-	-	6	-0.547	0.604
5	0.554	NS	3	0.159	NS	8	2.871	0.021
5	0.554	NS	3	0.345	NS	8	1.658	0.136
6	0.534	NS	5	0.792	NS	11	1.402	0.189
6	0.534	NS	1	-	-	7	-1.077	0.317
6	0.534	NS	3	0.159	NS	9	1.567	0.152
6	0.534	NS	3	0.345	NS	9	0.189	0.855
5	0.792	NS	1	-	-	6	-3.416	0.014
5	0.792	NS	3	0.159	NS	8	0.706	0.500
5	0.792	NS	3	0.345	NS	8	-1.550	0.160
1	-	-	3	0.159	NS	4	2.217	0.091
1	-	-	3	0.345	NS	4	2.262	0.086
3	0.159	NS	3	0.345	NS	6	-1.513	0.181

*Data was log(x+1) transformed

Table A-6. Results of Summer BACI Comparisons of Cell Volume between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)			Tukey's Test for Additivity*			t - test*		
DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed), p < 0.05
38	0.022	S	45	0.070	NS	83	1.392	0.168
19	0.092	NS	29	0.916	NS	48	0.057	0.955
5	0.001	S	6	0.278	NS	11	-0.255	0.803
5	0.001	S	6	0.001	S	11	-1.355	0.203
5	0.001	S	5	0.848	NS	10	-0.368	0.720
5	0.001	S	5	0.279	NS	10	-0.169	0.869
5	0.001	S	4	0.197	NS	9	-0.822	0.433
5	0.001	S	4	0.863	NS	9	0.534	0.606
5	0.001	S	4	0.018	S	9	0.435	0.674
6	0.278	NS	6	0.001	S	12	-1.247	0.236
6	0.278	NS	5	0.848	NS	11	-0.170	0.868
6	0.278	NS	5	0.279	NS	11	0.118	0.908
6	0.278	NS	4	0.197	NS	10	-0.643	0.534
6	0.278	NS	4	0.863	NS	10	0.930	0.374
6	0.278	NS	4	0.018	S	10	0.184	0.857
6	0.001	S	5	0.848	NS	11	0.877	0.399
6	0.001	S	5	0.279	NS	11	1.502	0.161
6	0.001	S	4	0.197	NS	10	0.803	0.441
6	0.001	S	4	0.863	NS	10	0.846	0.417
6	0.001	S	4	0.018	S	10	-1.296	0.224
5	0.848	NS	5	0.279	NS	10	0.276	0.788
5	0.848	NS	4	0.197	NS	9	-0.331	0.748
5	0.848	NS	4	0.863	NS	9	0.312	0.762
5	0.848	NS	4	0.018	S	9	-0.035	0.973

Table A-6. Results of Summer BACI Comparisons of Cell Volume between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft) DF	Tukey's Test for Additivity*				t - test*		
	BEFORE Prob.	Sig. $p < 0.05$	DF	AFTER Prob.	Unpaired t-value	Probability (two-tailed), $p < 0.05$	Sig.
S 87/88	5	0.279	NS	4	0.197	-1.022	0.333 NS
S 87/89	5	0.279	NS	4	0.863	0.847	0.419 NS
S 87/90	5	0.279	NS	4	0.018	0.407	0.694 NS
S 88/89	4	0.197	NS	4	0.863	-0.382	0.711 NS
S 88/90	4	0.197	NS	4	0.018	-1.593	0.146 NS
S 89/90	4	0.863	NS	4	0.018	-1.212	0.288 NS

*Data was not transformed

Table A-6. Results of Winter BACI Comparisons of Cell Volume between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE	Sig.	AFTER	Sig.	Unpaired	Probability	Sig.
		Prob.	p < 0.05	Prob.	p < 0.05	t-value	(two-tailed)	p < 0.05
W 83-85/86-89	18	0.285	NS	0.381	NS	1.402	0.170	NS
W 83/84	5	0.872	NS	0.288	NS	-0.645	0.534	NS
W 83/85	5	0.872	NS	0.272	NS	-0.911	0.382	NS
W 83/86	5	0.872	NS	0.630	NS	-0.844	0.418	NS
W 83/87	5	0.872	NS	-	-	-0.704	0.508	NS
W 83/88	5	0.872	NS	0.593	NS	1.071	0.315	NS
W 83/89	5	0.872	NS	0.324	NS	1.388	0.203	NS
W 84/85	5	0.288	NS	0.272	NS	-0.502	0.626	NS
W 84/86	5	0.288	NS	0.630	NS	-0.633	0.541	NS
W 84/87	5	0.288	NS	-	-	-1.188	0.280	NS
W 84/88	5	0.288	NS	0.593	NS	1.744	0.119	NS
W 84/89	5	0.288	NS	0.324	NS	1.643	0.139	NS
W 85/86	6	0.272	NS	0.630	NS	-0.550	0.593	NS
W 85/87	6	0.272	NS	-	-	-0.359	0.730	NS
W 85/88	6	0.272	NS	0.593	NS	0.606	0.559	NS
W 85/89	6	0.272	NS	0.324	NS	1.143	0.282	NS
W 86/87	5	0.630	NS	-	-	0.210	0.841	NS
W 86/88	5	0.630	NS	0.593	NS	-0.285	0.783	NS
W 86/89	5	0.630	NS	0.324	NS	-0.064	0.950	NS
W 87/88	1	-	-	0.593	NS	0.207	0.846	NS
W 87/89	1	-	-	0.324	NS	0.520	0.630	NS
W 88/89	3	0.593	NS	0.324	NS	0.695	0.513	NS

*Data was not transformed

Table A-7. Results of Summer BACI Comparisons of Biovolume between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft) DF	Tukey's Test for Additivity*				t - test*		
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Unpaired t-value	Probability (two-tailed), p < 0.05	Sig.
6/83-4/86 //							
5/86-9/90	0.199	NS	45	0.141	2.531	0.013	S
S 83-85/86-90	0.948	NS	29	0.173	1.316	0.195	NS
S 83/84	0.640	NS	6	0.593	0.602	0.559	NS
S 83/85	0.640	NS	6	0.328	0.270	0.792	NS
S 83/86	0.640	NS	5	0.443	-0.178	0.863	NS
S 83/87	0.640	NS	5	0.056	0.384	0.709	NS
S 83/88	0.640	NS	4	0.058	-1.112	0.295	NS
S 83/89	0.640	NS	4	0.699	0.534	0.606	NS
S 83/90	0.640	NS	4	0.048	0.224	0.828	NS
S 84/85	0.593	NS	6	0.328	-0.493	0.631	NS
S 84/86	0.593	NS	5	0.443	-0.695	0.501	NS
S 84/87	0.593	NS	5	0.056	0.319	0.755	NS
S 84/88	0.593	NS	4	0.058	-1.388	0.195	NS
S 84/89	0.593	NS	4	0.699	0.930	0.374	NS
S 84/90	0.593	NS	4	0.048	0.714	0.492	NS
S 85/86	0.328	NS	5	0.443	-0.428	0.677	NS
S 85/87	0.328	NS	5	0.056	0.189	0.854	NS
S 85/88	0.328	NS	4	0.058	-1.476	0.171	NS
S 85/89	0.328	NS	4	0.699	0.846	0.417	NS
S 85/90	0.328	NS	4	0.048	0.526	0.610	NS
S 86/87	0.443	NS	5	0.056	0.502	0.627	NS
S 86/88	0.443	NS	4	0.058	-0.850	0.418	NS
S 86/89	0.443	NS	4	0.699	0.312	0.762	NS
S 86/90	0.443	NS	4	0.048	0.022	0.983	NS

Table A-7. Results of Summer BACI Comparisons of Biovolume between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)			Tukey's Test for Additivity*			t - test*			
DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed), p < 0.05	Sig.
5	0.056	NS	4	0.058	NS	9	-1.389	0.198	NS
5	0.056	NS	4	0.699	NS	9	0.847	0.419	NS
5	0.056	NS	4	0.048	S	9	0.583	0.574	NS
4	0.058	NS	4	0.699	NS	9	-0.382	0.711	NS
4	0.058	NS	4	0.048	S	9	-0.717	0.492	NS
4	0.699	NS	4	0.048	S	10	-0.393	0.702	NS

*Data was log (x + 1) transformed

Table A-7. Results of Winter BACI Comparisons of Biovolume between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft) DF	Tukey's Test for Additivity*				t - test*	
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Unpaired t-value	Probability (two-tailed), p < 0.05
W 83-85/86-89	18	0.392	NS	15	0.482	NS
W 83/84	5	0.276	NS	5	0.552	NS
W 83/85	5	0.276	NS	6	0.232	NS
W 83/86	5	0.276	NS	5	0.412	NS
W 83/87	5	0.276	NS	1	-	-
W 83/88	5	0.276	NS	3	0.982	NS
W 83/89	5	0.276	NS	3	0.373	NS
W 84/85	5	0.552	NS	6	0.232	NS
W 84/86	5	0.552	NS	5	0.412	NS
W 84/87	5	0.552	NS	1	-	-
W 84/88	5	0.552	NS	3	0.982	NS
W 84/89	5	0.552	NS	3	0.373	NS
W 85/86	6	0.232	NS	5	0.412	NS
W 85/87	6	0.232	NS	1	-	-
W 85/88	6	0.232	NS	3	0.982	NS
W 85/89	6	0.232	NS	3	0.373	NS
W 86/87	5	0.412	NS	1	-	-
W 86/88	5	0.412	NS	3	0.982	NS
W 86/89	5	0.412	NS	3	0.373	NS
W 87/88	1	-	-	3	0.982	NS
W 87/89	1	-	-	3	0.373	NS
W 88/89	3	0.982	NS	3	0.373	NS
					2.037	0.050
					2.048	0.065
					1.386	0.193
					-0.241	0.815
					1.370	0.220
					1.584	0.152
					-0.382	0.712
					-1.542	0.151
					-2.607	0.026
					0.032	0.975
					2.922	0.019
					1.632	0.141
					-1.831	0.094
					1.298	0.235
					2.686	0.025
					0.821	0.433
					1.689	0.142
					1.481	0.177
					-0.628	0.548
					1.639	0.176
					1.094	0.336
					-1.554	0.171

* Data was log (x + 1) transformed

Table A-8. Results of Summer BACI Comparisons of Diversity between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)		Tukey's Test for Additivity*				t-test*			
DF	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF	Unpaired t-value	Probability (two-tailed), p < 0.05	
38	0.835	NS	45	0.238	NS	83	-2.314	0.023	
6/83-4/86 //									
5/86-9/90								S	
S 83-85/86-90	19	0.896	NS	29	0.446	NS	48	-1.555	0.126
S 83/84	5	0.984	NS	6	0.917	NS	11	1.686	0.120
S 83/85	5	0.984	NS	6	0.957	NS	11	0.575	0.577
S 83/86	5	0.984	NS	5	0.753	NS	10	1.624	0.136
S 83/87	5	0.984	NS	5	0.396	NS	10	2.762	0.020
S 83/88	5	0.984	NS	4	0.802	NS	9	1.542	0.157
S 83/89	5	0.984	NS	4	0.895	NS	9	-1.164	0.274
S 83/90	5	0.984	NS	4	0.792	NS	9	-1.058	0.317
S 84/85	6	0.917	NS	6	0.957	NS	12	-0.997	0.338
S 84/86	6	0.917	NS	5	0.753	NS	11	-0.122	0.905
S 84/87	6	0.917	NS	5	0.396	NS	11	1.050	0.316
S 84/88	6	0.917	NS	4	0.802	NS	10	-0.125	0.903
S 84/89	6	0.917	NS	4	0.895	NS	10	0.628	0.544
S 84/90	6	0.917	NS	4	0.792	NS	10	0.698	0.501
S 85/86	6	0.957	NS	5	0.753	NS	11	0.894	0.390
S 85/87	6	0.957	NS	5	0.396	NS	11	1.927	0.080
S 85/88	6	0.957	NS	4	0.802	NS	10	0.835	0.423
S 85/89	6	0.957	NS	4	0.895	NS	10	-0.447	0.664
S 85/90	6	0.957	NS	4	0.792	NS	10	-0.369	0.720
S 86/87	5	0.753	NS	5	0.396	NS	10	1.259	0.237
S 86/88	5	0.753	NS	4	0.802	NS	9	-0.009	0.993
S 86/89	5	0.753	NS	4	0.895	NS	9	0.558	0.591
S 86/90	5	0.753	NS	4	0.792	NS	9	0.631	0.544

Table A-8. Results of Summer BACI Comparisons of Diversity Cont.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*			t - test*		
		BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	DF
S 87/88	5	0.396	NS	4	0.802	NS	9
S 87/89	5	0.396	NS	4	0.895	NS	9
S 87/90	5	0.396	NS	4	0.792	NS	9
S 88/89	4	0.802	NS	4	0.895	NS	9
S 88/90	4	0.802	NS	4	0.792	NS	9
S 89/90	4	0.895	NS	4	0.792	NS	10
						Unpaired t-value	Probability (two-tailed), p < 0.05
						-1.238	0.247
						1.916	0.088
						1.944	0.084
						0.736	0.48
						0.807	0.44
						-0.271	0.792

*Data was not transformed

Table A-8. Results of Winter BACI Comparisons of Diversity between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft) DF	Tukey's Test for Additivity*				t-test*		
	BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Unpaired t-value	Probability (two-tailed), p < 0.05	Sig.
W 83-85/86-89 18	0.961	NS	15	0.118	-1.179	0.247	NS
W 83/84 5	0.528	NS	5	0.742	-0.046	0.964	NS
W 83/85 5	0.528	NS	6	0.132	0.193	0.850	NS
W 83/86 5	0.528	NS	5	0.599	1.270	0.233	NS
W 83/87 5	0.528	NS	1	-	0.360	0.731	NS
W 83/88 3	0.232	NS	3	0.232	-0.129	0.900	NS
W 83/89 3	0.232	NS	3	0.296	-1.082	0.311	NS
W 84/85 5	0.742	NS	6	0.132	0.194	0.850	NS
W 84/86 5	0.742	NS	5	0.599	0.975	0.352	NS
W 84/87 5	0.742	NS	1	-	0.242	0.817	NS
W 84/88 3	0.232	NS	3	0.232	-0.124	0.904	NS
W 84/89 3	0.232	NS	3	0.296	-0.664	0.526	NS
W 85/86 6	0.132	NS	5	0.599	0.945	0.365	NS
W 85/87 6	0.132	NS	1	-	0.150	0.885	NS
W 85/88 3	0.232	NS	3	0.232	0.056	0.957	NS
W 85/89 3	0.232	NS	3	0.296	-0.613	0.555	NS
W 86/87 5	0.599	NS	1	-	-0.546	0.604	NS
W 86/88 3	0.232	NS	3	0.232	0.967	0.362	NS
W 86/89 3	0.232	NS	3	0.296	0.392	0.705	NS
W 87/88 3	0.232	NS	3	0.232	0.225	0.833	NS
W 87/89 3	0.232	NS	3	0.296	-0.575	0.596	NS
W 88/89 3	0.232	NS	3	0.296	-0.852	0.427	NS

*Data was not transformed

Table A-9. Results of Summer BACI Comparisons of Evenness between Control (FCD) and Experimental (FEX) Sites, 1983-90.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE Prob.	Sig. p < 0.05	DF	AFTER Prob.	Sig. p < 0.05	Unpaired t-value	Probability (two-tailed), p < 0.05
6/83-4/86 //	38	0.163	NS	45	0.075	NS	-3.592	0.0006
5/86-9/90								S
S 83-85/86-90	19	0.497	NS	29	0.084	NS	-2.108	0.040
S 83/84	5	0.563	NS	6	0.371	NS	1.904	0.083
S 83/85	5	0.563	NS	6	0.711	NS	0.565	0.584
S 83/86	5	0.563	NS	5	0.935	NS	1.372	0.200
S 83/87	5	0.563	NS	5	0.092	NS	2.829	0.018
S 83/88	5	0.563	NS	4	0.865	NS	2.147	0.060
S 83/89	5	0.563	NS	4	0.666	NS	-1.277	0.234
S 83/90	5	0.563	NS	4	0.739	NS	-1.085	0.306
S 84/85	6	0.371	NS	6	0.711	NS	-1.323	0.211
S 84/86	6	0.371	NS	5	0.935	NS	-0.324	0.752
S 84/87	6	0.371	NS	5	0.092	NS	1.525	0.155
S 84/88	6	0.371	NS	4	0.865	NS	0.625	0.546
S 84/89	6	0.371	NS	4	0.666	NS	0.445	0.666
S 84/90	6	0.371	NS	4	0.739	NS	0.787	0.449
S 85/86	6	0.711	NS	5	0.935	NS	0.863	0.406
S 85/87	6	0.711	NS	5	0.092	NS	2.418	0.034
S 85/88	6	0.711	NS	4	0.865	NS	1.661	0.128
S 85/89	6	0.711	NS	4	0.666	NS	-0.764	0.462
S 85/90	6	0.711	NS	4	0.739	NS	-0.538	0.602
S 86/87	5	0.935	NS	5	0.092	NS	1.564	0.149
S 86/88	5	0.935	NS	4	0.865	NS	0.799	0.445
S 86/89	5	0.935	NS	4	0.666	NS	0.092	0.929
S 86/90	5	0.935	NS	4	0.739	NS	0.356	0.730

Table A-9. Results of Summer BACI Comparisons of Evenness Cont.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*			Sig. p < 0.05	DF	t - test*		
		BEFORE Prob.	AFTER Prob.	DF			Unpaired t-value	Probability (two-tailed)	Sig. p < 0.05
S 87/88	5	0.092	0.865	4	NS	9	-0.853	0.416	NS
S 87/89	5	0.092	0.666	4	NS	9	1.663	0.131	NS
S 87/90	5	0.092	0.739	4	NS	9	1.992	0.078	NS
S 88/89	4	0.865	0.666	4	NS	9	0.980	0.353	NS
S 88/90	4	0.865	0.739	4	NS	9	1.368	0.204	NS
S 89/90	4	0.666	0.739	4	NS	10	0.190	0.853	NS

*Data was $\log(x+1)$ transformed

Table A-9. Results of Winter BACI Comparisons of Evenness between Control (FCD) and Experimental (FEX) Sites, 1983-89.

Comparison: (Bef/Aft, Bef/Bef, or Aft/Aft)	DF	Tukey's Test for Additivity*			t-test*		
		BEFORE Prob.	Sig. $p < 0.05$	AFTER Prob.	Sig. $p < 0.05$	Unpaired t-value	Probability (two-tailed), $p < 0.05$
W 83-85/86-89	18	0.098	NS	0.216	NS	-2.608	0.014
W 83/84	5	0.590	NS	0.719	NS	-0.165	0.872
W 83/85	5	0.590	NS	0.036	S	-1.013	0.333
W 83/86	5	0.590	NS	0.639	NS	1.106	0.295
W 83/87	5	0.590	NS	-	-	1.230	0.265
W 83/88	5	0.590	NS	0.018	S	-1.021	0.337
W 83/89	5	0.590	NS	0.566	NS	-1.327	0.221
W 84/85	5	0.719	NS	0.036	S	-0.880	0.398
W 84/86	5	0.719	NS	0.639	NS	1.191	0.261
W 84/87	5	0.719	NS	-	-	1.385	0.215
W 84/88	5	0.719	NS	0.018	S	-1.144	0.286
W 85/89	5	0.719	NS	0.566	NS	-1.549	0.160
W 85/86	6	0.036	S	0.639	NS	1.712	0.115
W 85/87	6	0.036	S	-	-	1.652	0.142
W 85/88	6	0.036	S	0.018	S	-1.677	0.128
W 85/89	6	0.036	S	0.566	NS	-2.018	0.074
W 86/87	5	0.639	NS	-	-	-0.141	0.893
W 86/88	5	0.639	NS	0.018	S	0.274	0.791
W 86/89	5	0.639	NS	0.566	NS	0.417	0.688
W 87/88	1	-	-	0.018	S	0.097	0.927
W 87/89	1	-	-	0.566	NS	0.505	0.64
W 88/89	3	0.018	S	0.566	NS	0.174	0.868

*Data was $\log(x+1)$ transformed

Table A-10. Results of BACI Comparisons of Gross Primary Production between Control (FCD) and Experimental (FEX) Sites, 1984-90.

Comparison	DF	Tukey's Test for Additivity*				t - test*		
		BEFORE	Sig. p < 0.05	DF	AFTER	Sig. p < 0.05	Unpaired t-value	Probability (two-tailed), p < 0.05
7/84-8/85 //	10	0.513	NS	44	0.001	S	0.466	0.643
6/86-8/90								
84/85	3	0.950	NS	6	0.620	NS	-0.745	0.475
84/86	3	0.950	NS	8	0.661	NS	-0.657	0.524
84/87	3	0.950	NS	5	0.103	NS	-0.661	0.527
84/88	3	0.950	NS	9	0.951	NS	-1.073	0.305
84/89	3	0.950	NS	9	0.814	NS	-0.427	0.677
84/90	3	0.950	NS	9	0.014	S	0.543	0.597
85/86	6	0.620	NS	8	0.661	NS	0.537	0.600
85/87	6	0.620	NS	5	0.103	NS	0.099	0.923
85/88	6	0.620	NS	9	0.951	NS	0.108	0.916
85/89	6	0.620	NS	9	0.814	NS	0.726	0.479
85/90	6	0.620	NS	9	0.014	S	1.592	0.132
86/87	8	0.661	NS	5	0.103	NS	-0.407	0.691
86/88	8	0.661	NS	9	0.951	NS	-0.750	0.464
86/89	8	0.661	NS	9	0.814	NS	0.328	0.747
86/90	8	0.661	NS	9	0.014	S	1.581	0.132
87/88	5	0.103	NS	9	0.951	NS	-0.043	0.966
87/89	5	0.103	NS	9	0.814	NS	0.595	0.562
87/90	5	0.103	NS	9	0.014	S	1.438	0.172
88/89	9	0.951	NS	9	0.814	NS	0.984	0.338
88/90	9	0.951	NS	9	0.014	S	2.062	0.054
89/90	9	0.814	NS	9	0.014	S	1.370	0.188

*Data was $\log(x+1)$ transformed

APPENDIX B:

BACI Analyses for Diatom Abundance

Table B-1. Results of BACI Comparisons of *Achnanthes minutissima* Abundance Data (Summer 1983-1990).

Species	Comparison	DF	Tukey's Test for Additivity				t - test			
			BEFORE		AFTER		Unpaired		Probability	
			Prob.	Sig. p<0.05	DF	Prob.	t-value	t-value	(two-tailed)	Sig. p<0.05
<i>Achnanthes minutissima</i>	S 83-85/86-90	13	0.064	NS	29	0.265	NS	1.223	0.228	NS
	S 83/84	1	-	-	5	0.383	NS	-0.658	0.535	NS
	S 83/85	1	-	-	5	0.106	NS	0.348	0.740	NS
	S 83/86	1	-	-	5	0.598	NS	-0.862	0.422	NS
	S 83/87	1	-	-	5	0.354	NS	-0.386	0.713	NS
	S 83/88	1	-	-	4	0.606	NS	0.079	0.940	NS
	S 83/89	1	-	-	4	0.001	S	0.446	0.667	NS
	S 83/90	1	-	-	4	0.406	NS	1.486	0.176	NS
	S 84/85	5	0.383	NS	5	0.106	NS	1.349	0.207	NS
	S 84/86	5	0.383	NS	5	0.598	NS	-0.528	0.609	NS
	S 84/87	5	0.383	NS	5	0.354	NS	0.034	0.974	NS
	S 84/88	5	0.383	NS	4	0.606	NS	0.986	0.350	NS
	S 84/89	5	0.383	NS	4	0.001	S	-0.659	0.526	NS
	S 84/90	5	0.383	NS	4	0.406	NS	0.185	0.858	NS
	S 85/86	5	0.106	NS	5	0.598	NS	-1.685	0.123	NS
	S 85/87	5	0.106	NS	5	0.354	NS	-0.934	0.372	NS
	S 85/88	5	0.106	NS	4	0.606	NS	-0.358	0.728	NS
	S 85/89	5	0.106	NS	4	0.001	S	0.623	0.549	NS
	S 85/90	5	0.106	NS	4	0.406	NS	1.602	0.144	NS
	S 86/87	5	0.598	NS	5	0.354	NS	0.448	0.664	NS
	S 86/88	5	0.598	NS	4	0.606	NS	1.335	0.215	NS
	S 86/89	5	0.598	NS	4	0.001	S	-1.056	0.318	NS
	S 86/90	5	0.598	NS	4	0.406	NS	-0.368	0.721	NS
	S 87/88	5	0.354	NS	4	0.606	NS	0.649	0.533	NS
	S 87/89	5	0.354	NS	4	0.001	S	-0.438	0.672	NS

Table B-1. Results of BACI Comparisons of *Achnanthes minutissima* Abundance Data (Summer 1983-1990) Cont.

Species	Comparison	Tukey's Test for Additivity				t - test		
		BEFORE	Sig. p<0.05	DF	AFTER	Sig. p<0.05	Unpaired t-value	Probability (two-tailed), p<0.05
	S 87/90	0.354	NS	5	0.406	NS	0.162	0.875
	S 88/89	0.606	NS	4	0.001	S	-0.004	0.997
	S 88/90	0.606	NS	4	0.406	NS	0.976	0.354
	S 89/90	0.001	S	4	0.406	NS	0.783	0.452

Table B-2. Results of BACI Comparisons of *Cocconeis* placentula Abundance Data (Summer 1983-1990).

Species	Comparison	DF	Tukey's Test for Additivity				t - test		
			BEFORE	Sig.	DF	AFTER	Unpaired	Probability	Sig.
			Prob.	p<0.05		Prob.	t-value	(two-tailed)	p<0.05
<i>Cocconeis placentula</i>	S 83-85/86-90	13	0.515	NS	29	0.012	-0.303	0.763	NS
	S 83/84	1	-	-	5	0.629	-2.620	0.040	S
	S 83/85	1	-	-	5	0.410	-2.322	0.059	NS
	S 83/86	1	-	-	5	0.836	-2.374	0.055	NS
	S 83/87	1	-	-	5	0.710	-1.060	0.330	NS
	S 83/88	1	-	-	4	0.285	-1.519	0.189	NS
	S 83/89	1	-	-	4	0.209	-0.757	0.470	NS
	S 83/90	1	-	-	4	0.045	-0.424	0.683	NS
	S 84/85	5	0.629	NS	5	0.410	0.197	0.848	NS
	S 84/86	5	0.629	NS	5	0.836	-0.989	0.346	NS
	S 84/87	5	0.629	NS	5	0.710	1.162	0.272	NS
	S 84/88	5	0.629	NS	4	0.285	-1.026	0.332	NS
	S 84/89	5	0.629	NS	4	0.209	0.926	0.379	NS
	S 84/90	5	0.629	NS	4	0.045	2.662	0.026	S
	S 85/86	5	0.410	NS	5	0.836	-1.089	0.302	NS
	S 85/87	5	0.410	NS	5	0.710	0.994	0.344	NS
	S 85/88	5	0.410	NS	4	0.285	-1.087	0.305	NS
	S 85/89	5	0.410	NS	4	0.209	0.864	0.410	NS
	S 85/90	5	0.410	NS	4	0.045	2.588	0.029	S
	S 86/87	5	0.836	NS	5	0.710	1.717	0.117	NS
	S 86/88	5	0.836	NS	4	0.285	-0.469	0.650	NS
	S 86/89	5	0.836	NS	4	0.209	1.703	0.123	NS
	S 86/90	5	0.836	NS	4	0.045	3.096	0.013	S
	S 87/88	5	0.710	NS	4	0.285	-1.518	0.163	NS
	S 87/89	5	0.710	NS	4	0.209	0.379	0.714	NS

Table B-2. Results of BACI Comparisons of *Cocconeis placentula* Abundance Data (Summer 1983-1990) Cont.

Species	Comparison	Tukey's Test for Additivity				t - test					
		BEFORE	Sig. p<0.05	DF	AFTER	Sig. p<0.05	DF	Unpaired t-value	Probability (two-tailed), p<0.05	Sig.	
	S 87/90	5	0.710	NS	4	0.045	S	9	0.964	0.360	NS
	S 88/89	4	0.285	NS	4	0.209	NS	9	0.948	0.368	NS
	S 88/90	4	0.285	NS	4	0.045	S	9	1.606	0.143	NS
	S 89/90	4	0.209	NS	4	0.045	S	10	-0.081	0.937	NS

Table B-3. Results of BACI Comparisons of *Achnanthes minutissima* Abundance Data (Winter 1983-1989).

Species	Comparison	DF	Tukey's Test for Additivity				t - test		
			BEFORE	Sig.	AFTER	Sig.	Unpaired	Probability	Sig.
			Prob.	p<0.05	DF	p<0.05	t-value	(two-tailed)	p<0.05
<i>Achnanthes minutissima</i>	W 83-85/86-89	16	0.084	NS	15	0.384	NS	31	NS
	W 93/84	5	0.199	NS	3	0.031	S	8	S
	W 83/85	5	0.199	NS	6	0.013	S	11	S
	W 83/86	5	0.199	NS	5	0.370	NS	10	NS
	W 83/87	5	0.199	NS	1	-	-	6	NS
	W 83/88	5	0.199	NS	3	0.009	S	8	NS
	W 83/89	5	0.199	NS	3	0.753	NS	8	NS
	W 84/85	3	0.031	S	6	0.013	S	9	S
	W 84/86	3	0.031	S	5	0.370	NS	8	NS
	W 84/87	3	0.031	S	1	-	-	4	NS
	W 84/88	3	0.031	S	3	0.009	S	6	NS
	W 84/89	3	0.031	S	3	0.753	NS	6	NS
	W 85/86	6	0.013	S	5	0.370	NS	11	S
	W 85/87	6	0.013	S	1	-	-	7	NS
	W 85/88	6	0.013	S	3	0.009	S	9	NS
	W 85/89	6	0.013	S	3	0.753	NS	9	S
	W 86/87	5	0.370	NS	1	-	-	6	NS
	W 86/88	5	0.370	NS	3	0.009	S	8	NS
	W 86/89	5	0.370	NS	3	0.753	NS	8	NS
	W 87/88	1	-	-	3	0.009	S	4	NS
	W 87/89	1	-	-	3	0.753	NS	4	S
	W 88/89	3	0.009	S	3	0.753	NS	6	NS

Table B-4. Results of BACI Comparisons of *Fragilaria vaucheriae* abundance Data (Winter 1983-1989).

Species	Comparison	DF	Tukey's Test for Additivity				t - test		
			BEFORE	Sig.	AFTER	Sig.	Unpaired	Probability	Sig.
		DF	Prob.	p<0.05	DF	Prob.	t-value	(two-tailed)	p<0.05
<i>Fragilaria vaucheriae</i>	W 83-85/86-89	16	0.668	NS	15	0.703	NS	31	NS
	W 83/84	5	0.044	S	3	0.299	NS	8	S
	W 83/85	5	0.044	S	6	0.697	NS	11	NS
	W 83/86	5	0.044	S	5	0.001	S	10	NS
	W 83/87	5	0.044	S	1	-	-	6	NS
	W 83/88	5	0.044	S	3	0.115	NS	8	NS
	W 83/89	5	0.044	S	3	0.080	NS	8	NS
	W 84/85	3	0.299	NS	6	0.697	NS	9	NS
	W 84/86	3	0.299	NS	5	0.001	S	8	NS
	W 84/87	3	0.299	NS	1	-	-	4	NS
	W 84/88	3	0.299	NS	3	0.115	NS	6	NS
	W 84/89	3	0.299	NS	3	0.080	NS	6	NS
	W 85/86	6	0.697	NS	5	0.001	S	11	NS
	W 85/87	6	0.697	NS	1	-	-	7	NS
	W 85/88	6	0.697	NS	3	0.115	NS	9	NS
	W 85/89	6	0.697	NS	3	0.080	NS	9	NS
	W 86/87	5	0.001	S	1	-	-	6	NS
	W 86/88	5	0.001	S	3	0.115	NS	8	NS
	W 86/89	5	0.001	S	3	0.080	NS	8	NS
	W 87/88	1	-	-	3	0.115	NS	4	NS
	W 87/89	1	-	-	3	0.080	NS	4	NS
	W 88/89	3	0.115	NS	3	0.080	NS	6	NS

Table B-5. Results of BACI Comparisons of Gomphonema olivaceum Abundance Data (Winter 1983-1989).

Species	Comparison	DF	Tukey's Test for Additivity				t - test		
			BEFORE	Sig.	DF	AFTER	Sig.	Unpaired	Sig.
			Prob.	p<0.05		Prob.	p<0.05	t-value	(two-tailed) p<0.05
Gomphonema olivaceum	W 83-85/86-89	16	0.313	NS	15	0.474	NS	1.004	0.323
	W 83/84	5	0.986	NS	3	0.693	NS	0.847	0.429
	W 83/85	5	0.986	NS	6	0.108	NS	-0.418	0.688
	W 83/86	5	0.986	NS	5	0.841	NS	-1.824	0.095
	W 83/87	5	0.986	NS	1	-	-	1.481	0.213
	W 83/88	5	0.986	NS	3	0.793	NS	2.467	0.039
	W 83/89	5	0.986	NS	3	0.173	NS	0.239	0.817
	W 84/85	3	0.693	NS	6	0.108	NS	2.066	0.073
	W 84/86	3	0.693	NS	5	0.841	NS	2.661	0.026
	W 84/87	3	0.693	NS	1	-	-	1.213	0.271
	W 84/88	3	0.693	NS	3	0.793	NS	2.155	0.075
	W 84/89	3	0.693	NS	3	0.173	NS	0.088	0.933
	W 85/86	6	0.108	NS	5	0.841	NS	1.546	0.153
	W 85/87	6	0.108	NS	1	-	-	2.580	0.026
	W 85/88	6	0.108	NS	3	0.793	NS	1.279	0.233
	W 85/89	6	0.108	NS	3	0.173	NS	-2.399	0.040
	W 86/87	5	0.841	NS	1	-	-	0.178	0.863
	W 86/88	5	0.841	NS	3	0.793	NS	2.069	0.072
	W 86/89	5	0.841	NS	3	0.173	NS	-1.597	0.149
	W 87/88	1	-	-	3	0.793	NS	1.104	0.331
	W 87/89	1	-	-	3	0.173	NS	-0.869	0.434
	W 88/89	3	0.793	NS	3	0.173	NS	-2.062	0.085

Table B-6. Results of BACI Comparisons of *Cymbella minuta* Abundance Data (Summer 1983-1990) Cont.

Species	Comparison	Tukey's Test for Additivity				t - test					
		BEFORE Prob.	Sig. p<0.05	DF	AFTER Prob.	Sig. p<0.05	Unpaired t-value	Probability (two-tailed; p<0.05)			
	S 87/90	5	0.019	S	4	0.724	NS	9	-0.438	0.672	NS
	S 88/89	5	0.982	NS	4	0.001	S	9	0.389	0.706	NS
	S 88/90	5	0.982	NS	4	0.724	NS	9	1.195	0.263	NS
	S 89/90	4	0.001	S	4	0.724	NS	10	1.911	0.085	NS

Table B-7. Results of BACI Comparisons of *Synedra ulna* Abundance Data (Winter 1983-1989).

Species	Comparison	DF	Tukey's Test for Additivity				t - test		
			BEFORE	Sig. $p < 0.05$	DF	AFTER	Sig. $p < 0.05$	Unpaired t-value	Probability (two-tailed), $p < 0.05$
<i>Synedra ulna</i>	W 83-85/86-89	16	0.538	NS	15	0.205	NS	-0.407	0.687
	W 83/84	5	0.898	NS	3	0.740	NS	0.211	0.838
	W 83/85	5	0.898	NS	6	0.160	NS	-0.906	0.384
	W 83/86	5	0.898	NS	5	0.609	NS	-1.109	0.293
	W 83/87	5	0.898	NS	1	-	-	0.959	0.374
	W 83/88	5	0.898	NS	3	0.644	NS	-0.324	0.754
	W 83/89	5	0.898	NS	3	0.566	NS	-1.437	0.189
	W 84/85	3	0.740	NS	6	0.160	NS	-0.844	0.421
	W 84/86	3	0.740	NS	5	0.609	NS	-1.086	0.309
	W 84/87	3	0.740	NS	1	-	-	1.850	0.138
	W 84/88	3	0.740	NS	3	0.644	NS	-0.474	0.652
	W 84/89	3	0.740	NS	3	0.566	NS	-1.506	0.183
	W 85/86	6	0.160	NS	5	0.609	NS	0.031	0.976
	W 85/87	6	0.160	NS	1	-	-	0.887	0.404
	W 85/88	6	0.160	NS	3	0.644	NS	0.545	0.599
	W 85/89	6	0.160	NS	3	0.566	NS	-0.109	0.915
	W 86/87	5	0.609	NS	1	-	-	1.152	0.293
	W 86/88	5	0.609	NS	3	0.644	NS	0.647	0.536
	W 86/89	5	0.609	NS	3	0.566	NS	-0.168	0.871
	W 87/88	1	-	-	3	0.644	NS	-0.862	0.437
	W 87/89	1	-	-	3	0.566	NS	-1.481	0.213
	W 88/89	3	0.644	NS	3	0.566	NS	-0.853	0.426

Element 3- Effects of Insect Grazer Populations on
Periphyton Communities.

Changes from workplan - None.

Rationale

Small E.L.F. electromagnetic radiation effects on aquatic systems may be unnoticeable, particularly if the impacts concern only very small, microscopic single celled algae species. If these impacted algae species are important food sources for selectively feeding stream grazers, severe disruptions of the trophic linkages within the system may occur. Restructuring of the species composition of the autotrophic community, leading to dominance by non-selected, non-palatable, or non-digestible algal species might be one such consequence. This could result in reduced growth, or lower overall production of benthic grazers. Thus, an essential invertebrate food source of predatory fish species might be significantly reduced.

Additionally, the potential may exist for E.L.F. electromagnetic radiation to cause behavioral changes in the grazers themselves. This might result in changes in feeding activity by increasing or decreasing feeding rates or otherwise changing "typical" grazer feeding behavior.

Most research on freshwater herbivore-algal interactions has been conducted in either ponds (Kesler 1981, Hunter 1980) or in laboratory streams (Colletti et al. 1987, Kehde and Wilhm 1972, Lamberti et al. 1989 and Sumner and McIntire 1982). Many of these studies have only documented grazer induced changes in periphyton standing crop, either by extracting chlorophyll *a* or by measuring accumulations of organic matter as ash free dry weight (AFDW). These measures provide only gross approximations of herbivore effects on the total periphyton community. These techniques provide little or no information on the dynamics of the algal species interactions in the presence or absence of herbivores. Ecological studies on the species responses of the algal community to aquatic herbivory have been largely ignored. Only a few studies have attempted to evaluate the effects of herbivores by examining other algal responses besides changes in levels of chlorophyll *a* or organic matter accumulation in the algal community. These include the studies of Lamberti and Resh (1983) on the

impact of grazing by the trichopteran larva, Helicopsyche. They measured algal turnover rates as well as chlorophyll a levels and noted that grazing resulted in an attached algal community consisting predominantly of a diatom monolayer. When Helicopsyche were excluded, the algal community changed from a diatom film to a thick growth of filamentous green algae. Grazing snails (Juga) in artificial streams changed the physiogamy of periphyton communities from an "erect" species dominated community to an adnate species dominated community (Lamberti et al. 1989). The snails also increased downstream transport of loose algae (a potentially important food source for net spinning invertebrates), reduced primary production rates and significantly altered the species composition of the community. All snail effects were strongest under low light conditions. Under high light conditions the algal community production was high enough to partially mitigate the impact of the snail grazers. Eichenberger and Schlatter (1978) found that grazing by Chironomidae in a stream channel maintained a mixture of filamentous green algae and diatoms. Exclusion of chironomid grazers from a second channel resulted in succession proceeding from filamentous green algae to blue-green algae. These studies have demonstrated that grazers can alter the succession of algal species on substrates. Dickman and Gochmayer (1978) indicated that grazer pressure in a stream prevented members of the algal genus Cocconeis from out-competing other algal species. This reduced competition may have increased the establishment of other algae and led to overall greater algal species diversity on the grazed substrates. Grazing mayflies (Ameletus validus) confined to in situ plexiglass flow-through chambers in a California stream for 23 days significantly reduced periphyton biomass (Hill and Knight 1987). In addition, members of the loose periphyton layer were disproportionately reduced in relative abundance while members of the tightly adhered adnate layer increased in relative abundance.

Several studies have documented the effects of algal distribution on intra- and inter-specific competition among grazers (Hart 1983, McAuliffe 1983, 1984, Wiley and Kohler 1984). These studies indicated that periphyton abundance and patchiness are important determinants of grazer distribution and abundance. Recent work on the Ford River by Webb and Merritt (1987) (included in the 1987 annual report; AE-058) on the importance of periphyton to the growth of the grazing mayfly Stenonema vicarium (Walker) also supports the need for further investigations into determining the magnitude of grazing induced changes on the algal community, and measuring the impact of grazing on the composition of this nutritionally important food source.

Our hypothesis is that grazer abundance is an important determinant of the structure of the attached algal community, and that the consequences of grazing can dramatically alter the algal species abundances in the periphyton.

Several other studies support the hypothesis that grazers can alter the structure of the attached algal community in streams (Hart 1985, Hershey et al. 1988, Hill and Knight 1988, Jacoby 1985, Lamberti et al. 1987a & b, Peterson 1987, Power et al. 1988, and Steinman et al. 1987).

Larvae of the trichopteran, Glossosoma nigrior (Banks) are known to be specialized grazers (Cummins 1973, Oemke 1983). Recent investigations of in situ food selections by various instars of the larvae (Oemke 1984) indicated that small, unicellular algal forms were more often ingested than were large, stalked or filamentous types of diatoms. Those diatom species which were preferentially ingested by grazing larvae sometimes showed significant differences between gut contents abundances and abundances of the surrounding periphyton community. Similarly, work by Hill and Knight (1987) indicated that mayfly grazing altered the community structure of the diatoms present. Thus, we hypothesized that grazing by Glossosoma would lead to reduced abundances of small growth forms of selected diatom species, like Cocconeis placentula, which are known to dominate the algal flora during the summer months (Oemke and Burton 1986) and to a concomitant increase in abundance of other non-selected diatom species or algal growth forms in the periphyton algal community.

Objective

The behavior of typical grazing invertebrates and their impact on the diatom community were determined to provide the data necessary for linking invertebrate herbivores to the periphyton community based on trophic level analyses. This objective included the determination of the effects of various levels of herbivory on periphyton community dynamics. The ultimate objective will be to determine whether or not E.L.F. electromagnetic radiation affects the interaction between grazing macroinvertebrates and their "prey", the benthic algae.

Materials and Methods

Small microcosm streamside flow-through artificial streams were used for monitoring effects of grazers on periphyton (Fig. 3.1). These 1.27 cm plexiglass streams were 1 m. long with three 15 cm wide channels fed from a

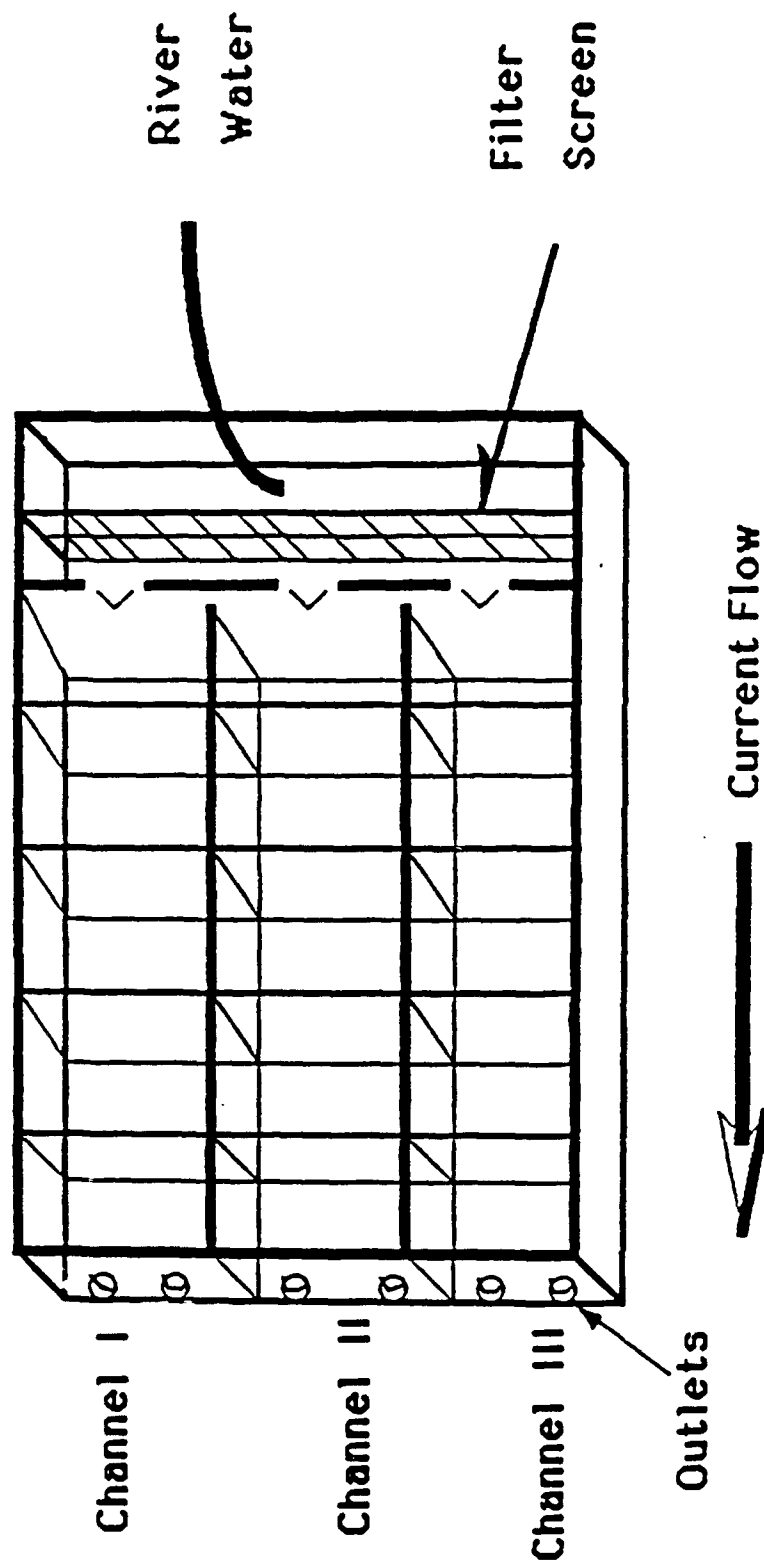


Figure 3.1 Experimental stream used in grazer studies.
Not drawn to scale.

common reservoir with water pumped from the Ford River. Each channel was subdivided into 4 chambers by a 0.5 mm mesh plastic screen to prevent exchange of grazers between chambers. The resulting 12 chambers could be used for individual treatments (Fig. 3.1). With daily cleaning, water flow through the screens between chambers was relatively unimpeded. Water was pumped from the river with a heavy duty marine battery and was filtered through a 300 micrometer mesh filter and rolls of polyester in the common reservoir before flowing into the individual channels. The plexiglass streams were located so that exposure to sunlight and shading by riparian vegetation was similar to that at the river surface. Two of these streams were constructed so that identical studies could be conducted at both the FEX and FCD sites simultaneously.

Since all three channels were fed from a common water source, the 12 chambers represented 12 replicates. This design simulated use of 12 separate chambers placed in the Ford River and avoided the problem of pseudoreplication as much as possible given the need to use the Ford River as a common water source. Use of additional stream channels would simply increase the replicates without solving the problem of the common water source. In 1987 and 1988, only 6 of these chambers were used per stream (3 controls and 3 experimental chambers), since we concluded that only one grazer level was needed. We used 4 controls and 4 experimental chambers in 1989.

In 1985, 86, 87 and 88 ceramic tiles (3.6 cm²) were placed in the river 25-30 days prior to experiments to allow time for algal colonization. Twenty randomly selected tiles were then placed in one of the four separated chambers along each of the three channels of the artificial streams. Tiles were taken at random from each control and treatment chamber at the end of each experiment for determination of chlorophyll *a*, (n=8 per chamber), organic matter biomass (n=8), and diatom species determinations (n=4). Each level of grazing was always replicated at least three times. The colonized tiles were exposed to grazing for a total of 6 or 7 days (usually 7 except in 1986 when a storm event caused the experiment to be terminated one day earlier than planned).

As indicated in the 1988 annual report, the above protocol was slightly changed for the 1989 experiment. In 1989, the grazer study was conducted for 14 days instead of 7 days as in previous years. This change was incorporated because of the possibility that 7 days is too short for some grazer effects to show up. Many of the studies in the literature, as reviewed above, lasted 14 days or longer. Four replicates of 2 grazer treatments (0 and 30

grazers/chamber) with 20 tiles/chamber were set up at each site on July 28. One half of the tiles (5 for chlorophyll *a* and 5 for species determination) were collected on August 4 and replaced with 10 colonized tiles of a slightly different size. On August 11 all 20 tiles in each chamber were collected and separated into 14 day tiles and a second set of 7 day tiles. These were used for chlorophyll *a* and species determinations as mentioned above.

In 1985 the 12 treatment chambers had three levels of grazing assigned to them in a random fashion and represented a randomized block design. The grazing levels chosen were: (1) no grazers, (2) a grazing level which represented about the average level of grazers found in favorable habitats in the Ford River (e.g. shallow, rapid current areas of the Ford for *Glossosoma*), and (3) a grazing level about double the average rate of grazing in the Ford (these levels were 0, 15, and 30 *Glossosoma* per chamber for the primary experiment). The results of this study were presented in the 1987 annual report.

In 1986, the studies at FEX contrasted the effects of grazing by limpets with the effects of grazing by the insect larva, *Glossosoma*. The results of this study were presented in the 1987 annual report (AE-071).

In 1987, 1988, and 1989, two levels of tricopteran larvae grazer (*Glossosoma nigrior*) were used (0 and 30 per chamber). The results of the 1987 and 1988 studies were discussed in the 1988 and 1989 annual reports, and the results of the 1989 study are discussed in full here.

Results and Discussion

Three level nested ANOVA comparisons using results from both sites for 1989 showed no significant differences in chlorophyll *a* between FEX and FCD after either 7 or 14 days of exposure (Table 3.1 and Table 3.2). The treatment effects (grazed versus ungrazed) were also not significant for either exposure period (Table 3.1, 3.2). Thus, grazing did not alter the standing crop of chlorophyll *a* on the tiles (Table 3.2). There were significant differences among replicates (chamber effects) for both exposure periods (Table 3.1).

As with chlorophyll *a*, evenness showed more variation between sites and replicates than between treatments (Tables 3.1, 3.2). Grazing caused no significant shift in evenness for either the 7 or 14 day exposure period (Table 3.1). There was a significant difference in evenness between FEX and FCD after 14 days but not after 7 days of exposure to

Table 3.1 Results of 3 level nested ANOVA test on 1989 biological parameters from the grazer studies.

Parameter	Source of Variance (Level)					
	Among Sites (FEX and FCD)		Among Treatments (Grazed and Ungrazed)		Among Replicates (3 Replicates/Treatment)	
	7 Day Exposure	14 Day Exposure	7 Day Exposure	14 Day Exposure	7 Day Exposure	14 Day Exposure
Chlorophyll <i>a</i>	NS	NS	NS	NS	p<0.01	p<0.01
Evenness	NS	p<0.01	NS	NS	p<0.01	p<0.001
Diversity	p<0.001	NS	NS	p<0.01	p<0.01	p<0.001
Cell Density	p<0.05	NS	p<0.001	p<0.001	NS	NS

Table 3.2 Means $\pm$ S.E. of biological parameters measured from the Glossosoma grazer study in 1989. Chlorophyll a = mg/m², Cell Density = cells/m² * 10e9, and N = 4.

Site	Exposure time	Chlorophyll <i>a</i>	Shannon Evenness	Shannon Diversity	Cell Density	
FCD	Grazed	7 days	10.63±1.34	0.57±0.01	1.93±0.02	11.67±0.17
		14 days	9.62±0.66	0.53±0.003	1.94±0.02	13.29±0.16
	Ungrazed	7 days	12.50±0.45	0.53±0.01	1.99±0.03	13.37±0.18
		14 days	9.29±0.63	0.50±0.01	2.26±0.03	14.96±0.21
FEX	Grazed	7 days	11.50±1.53	0.55±0.01	2.42±0.06	9.34±0.56
		14 days	10.36±0.98	0.72±0.01	2.01±0.04	11.37±0.65
	Ungrazed	7 days	10.42±0.90	0.56±0.01	2.23±0.04	14.18±0.81
		14 days	8.81±0.60	0.69±0.01	2.19±0.04	17.67±0.74

grazing. Evenness had increased substantially for both the grazed and ungrazed tiles at FEX from day 7 to day 14, while no such increase had occurred at FCD (Table 3.2).

Grazing did cause a significant decrease in diversity at both sites after 14 days of exposure (Tables 3.1, 3.2). No such effect was apparent after 7 days of exposure. There was a significant site difference between FEX and FCD with FEX having a significantly higher diversity for the 7 day exposure period (Table 3.2), but this difference had disappeared by day 14 (Tables 3.1, 3.2). As was true for chlorophyll *a* and evenness, there were significant differences among replicates (chamber effects, Table 3.1).

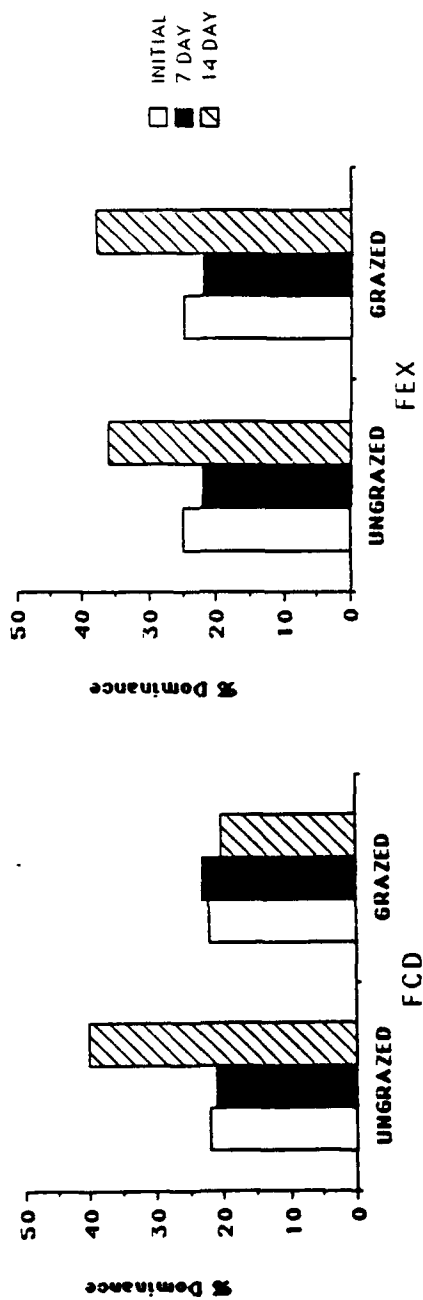
Diatom cell density showed the greatest response to grazing (Tables 3.1, 3.2). Grazing decreased cell density significantly at both FEX and FCD for both exposure periods (Table 3.2). There were no consistent differences between sites (Tables 3.1, 3.2). There were no significant differences among replicates (chambers) for this parameter (Table 3.1).

In the previous grazer studies, the primary grazer effect (present in 1985 and 86 but not in 87) was a decrease in Cocconeis placentula and an increase in Achnanthes minutissima. It was hypothesized that the grazers selected the larger Cocconeis over Achnanthes allowing Achnanthes to increase in dominance due to decreased competition with Cocconeis. In 1988, the grazer had a significant effect on all 6 of the most dominant species of algae. The primary result, however, was that A. minutissima dominance rank decreased due to grazing (slightly at FCD and dramatically at FEX) while C. placentula either increased (FCD) or was unaffected (FEX) by grazing.

In 1989, grazing significantly changed the dominance of Cocconeis and Achnanthes minutissima but caused no significant change in the dominance of the other 3 most common species present (Table 3.3, Fig. 3.2). However, the proportion of all 5 species had shifted significantly due to grazing by day 14 (Table 3.3). The shifts differed by species. At the control site (FCD), grazing caused no shift in dominance of A. minutissima after 7 days of exposure (Fig. 3.2). However, by day 14, this species had about doubled its dominance on the ungrazed tiles at FCD, while dominance on the grazed tiles was about the same as dominance at the start of the experiment (22 % dominance for initial counts, 21 % for day 7 on the ungrazed tiles, and 40 % for day 14 as contrasted to counts for the grazed tiles of 23 % by day 7 and 20 % dominance by day 14-see Fig. 3.2). This trend of increased dominance for A. minutissima through

Table 3.3 Results of 3 level nested ANOVA test performed on arcsine transformed proportions of the five most dominant diatom species on grazed and ungrazed tiles at FEX and FCD for the 1989 grazer study.

Species	Source of Variance (Level)					
	Among Sites (FEX and FCD)		Among Treatments (Grazed and Ungrazed)		Among Replicates (3 Replicates/Treatment)	
	7 Day Exposure	14 Day Exposure	7 Day Exposure	14 Day Exposure	7 Day Exposure	14 Day Exposure
<i>Achnanthes minutissima</i>	NS	NS	p<0.01	p<0.001	NS	NS
<i>Achnanthes linearis</i>	p<0.05	NS	p=0.06	p<0.001	p<0.01	NS
<i>Cymbella minuta</i>	NS	p<0.001	NS	p<0.001	p<0.01	NS
<i>Cocconeis placentula</i>	NS	p<0.001	p<0.001	p<0.05	NS	NS
<i>Fragilaria brevistriata</i>	NS	NS	NS	p<0.001	NS	NS



Achnanthes minutissima

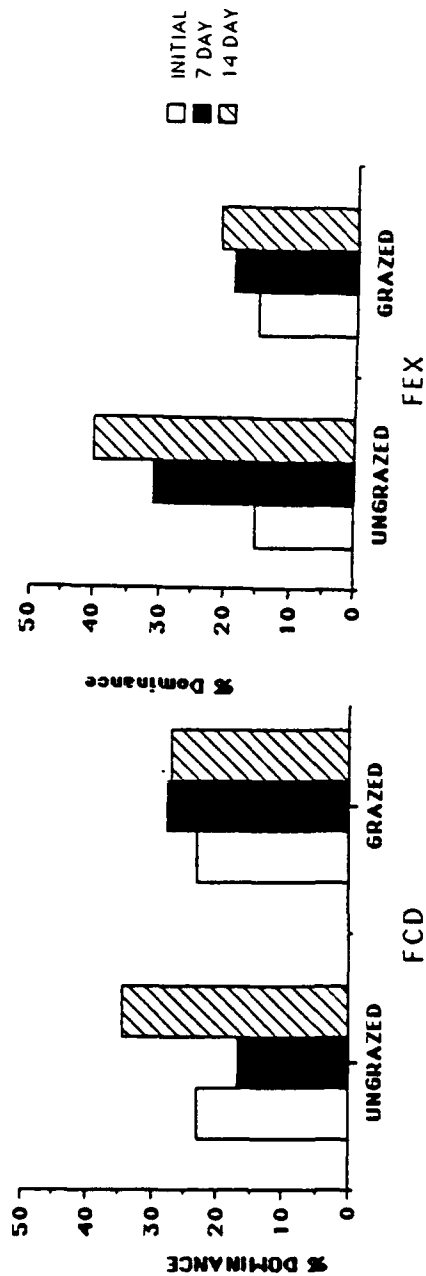


Figure 3.2 Percent Dominance of *A. minutissima* and *C. placentula* during the 1989 Grazer Study

time on the ungrazed tiles was also evident at FEX (15 % dominance initially, 31 % after day 7, and 40 % after day 14, Fig. 3.2). As at FCD, grazing kept this species from increasing its dominance significantly through time (19 % after day 7 and 21 % after day 14 as compared to the initial counts of 15 % dominance).

Cocconeis dominance followed similar patterns at both sites on the ungrazed tiles. At FCD, the initial dominance of 23 % decreased to 17 % by day 7 but then increased substantially to 34.5 % by day 14. At FEX, the initial dominance of 25 % decreased to 22 % on the ungrazed tiles by day 7 but then increased to 36 % dominance by day 14. The dominance of this species on the grazed tiles at FEX followed an almost identical pattern to the pattern it had exhibited on the ungrazed tiles decreasing to 22 % dominance by day 7 from the initial dominance of 25 % and then increasing its dominance to 38 % by day 14. However, the pattern was different at FCD with a slight increase in dominance from the initial 23 % dominance to 28 % dominance by day 7 and with no further change in dominance by day 14 (27 %). A. minutissima and C. placentula were the only two species to achieve greater than 10 % dominance in the community. The three most common other species (Table 3.2) were relatively minor components in the algal matrix (<10 % dominance). While significant differences in dominance did occur for all three species after 14 days of grazing (Table 3.3), these differences were minor and inconsistent between sites. Thus, the following comparisons of results between years will only consider A. minutissima and C. placentula.

Results for the late July-early August experiments on grazing are summarized in Table 3.4. No single parameter measured for the algal community for the grazer studies over the five year period from 1985 through 1989 changed consistently as a consequence of grazing (Table 3.4). There was never any significant difference in chlorophyll *a* between grazed and ungrazed tiles. Comparing the 7 day exposure period in 1989 to all the other 6-7 day experiments, grazing never resulted in any detectable difference in diversity of the diatom community. There was a significant decrease in diversity on the tiles exposed to grazing for 14 days in 1989 (Tables 3.1, 3.2, 3.4). Except for 1986, results for 7 day experiments for evenness were consistent with the results for diversity (Table 3.4). The decreased diversity for the 14 day exposures to grazing in 1989 was not accompanied by a significant change in evenness. Density decreased significantly as a consequence of grazing in 1988 but this decrease occurred only at FEX (Table 3.4). There was a consistent pattern of decreased density as a consequence of grazing for the first time in

Table 3.4: Effects of grazing by G. nigrilor (30 larvae/chamber) on the diatom community in late July - early August experiments. All experiments were run for 7 days except the 14 day 1989 experiment. NS = no significant change, + = significant increase, - = significant decrease.

YEAR	Chl. a	AFDW	Density	H'	J'	A. min.	C. pla.
1985	NS	+	NS	NS	NS	+	NS
1986*	NS	NS	NS	NS	-	+	NS
1987*	NS	NS	NS	NS	NS	NS	NS
1988*	NS	NS	-, NS	NS	NS	-	NS, +
1989*							
7 DAY	NS	----	-	NS	NS	-, NS	NS, +
14 DAY	NS	----	-	-	NS	-	NS, -

* - results from two separate sites; if the two sites differed the upstream site is listed first, otherwise the results were the same for both sites. Chl. a = chlorophyll a, AFDW = accumulation of organic matter on the substrates expressed as ash free dry weight, Density = total diatom cell density, H' = Shannon-Weiner diversity, J' = Simpson's evenness, A. min. = percent dominance by Achnanthes minutissima, C. pla. = percent dominance by Cocconeis placentula.

1989 (Tables 3.1, 3.2, 3.4), and this increase occurred after both 7 and 14 day exposures to grazing.

After the 1985 and 1986 results were obtained, we suggested that grazing shifted competition to consistently favor A. minutissima at the expense of C. placentula. This initial hypothesis was clearly incorrect as evidenced by the insignificant or opposite results obtained in the next three years (Table 3.4). These results may be linked to differences in initial cell densities at the start of the experiment. In 1985, cell densities were low (9×10^8 cells/m²), were intermediate in 1987 and 1988 ($29-56 \times 10^8$ cells/m²), and were highest in 1986 and 1989 ($92-177 \times 10^8$ cells/m²). The 1986 data do not fit a response related to initial total cell density. The tiles used in the 1986 experiment were not cleaned every few days during the colonization period and silt and organic matter had become quite dense by the start of the grazer experiment. Organic matter on tiles for the 1986 experiment was about 10 fold higher than for any other experiment. For all experiments after 1986, tiles were lightly brushed twice per week to limit the build up of silt and organic matter, since such a build up did not occur on the rocks in the river where the grazer was collected. If we eliminate the 1986 results, the shifts in dominance seem to occur according to a response curve as follows. Grazing by Glossosoma nigrior shifts dominance towards A. minutissima at initial diatom densities less than 10×10^8 cells/m², causes no shifts in dominance at intermediate levels of initial diatom cell densities (30×10^8 cells/m²) as in 1987, and causes a shift towards decreased dominance at initial cell densities of 50×10^8 cells/m² as at one of the sites in 1988 or greater as in 1989, especially after 14 days of grazing.

Regardless of whether the initial cell density affects results as suggested above or not, it is clear that effects are too variable and inconsistent from year to year to be of value in detecting E.L.F. effects. Thus, we propose to eliminate this element in upcoming years. We did not conduct any grazer experiment in 1990, opting instead to finish up the above analyses. Subject to reviewer comments, we do not expect to conduct any more such experiments. The efforts that would have gone into this task in 1990 were used to add the two additional sites for Element 2. These two additional sites allow us to increase the differences in exposures to E.L.F. electromagnetic radiation between the control and experimental sites while still retaining the original sites for continuity. We expect to continue these added analyses in Element 2 in the future and abandon this element.

Summary

Grazing macroinvertebrates can change the composition of the diatom community at densities equal to or greater than densities found in the Ford River. Specifically, Glossoma nigrior, a grazing caddisfly, caused a shift in dominance within the diatom community in 1985 and 1986 with Cocconeis decreasing in abundance and Achnanthes increasing in abundance as grazing pressure increased. Such shifts in community structure occurred at both FEX and FCD despite no significant changes in community based parameters such as diversity, chlorophyll a and organic matter biomass accumulation expressed as ash free dry weight. Results from 1985 were somewhat different from results from 1986. In 1986, the trend towards decreased abundance of Cocconeis and increased abundance of Achnanthes occurred at both sites but was not as significant as in 1985. In 1987, there was no measurable impact of grazers on any aspect of the periphyton community with the possible exception of shifts in dominance of a couple of minor taxa at FEX. In 1988 and 1989, there was a grazer impact on the dominance of Achnanthes but this impact resulted in a decrease in dominance (opposite the results of 1985 and 86). Between year differences in the impact of grazers on the diatom communities in our streamside channels may be due to the initial densities of the diatoms on the colonized tiles used in the experiment and/or to silt decreasing the ability of the grazer to utilize the algae in the organic matrix on the tiles. Regardless of the reasons for the year to year variability, such variability limits the usefulness of these studies in detection of E.L.F. effects on the stream biota. Thus, we propose to eliminate this element from the study in the future and increase our efforts for Element 2.

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Element 4: Species Richness and Biomass of Stream Insects From Artificial Substrates in Riffles

Changes from Original Synopsis - A new site, FEX.LINE, 10 m downstream from the crossing of the E.L.F. line over the Ford River, was added in June, 1991, which is subject to higher E.L.F. exposure levels than the FEX experimental site. The original FEX site remains operational.

Objectives

1) To determine whether structural community parameters and functional community parameters are affected by E.L.F. electromagnetic fields, and 2) to determine whether growth rates six species of aquatic insects are altered after E.L.F. activation.

Rationale

Extremely low frequency electromagnetic fields may affect structural and functional community parameters (A.I.B.S. 1985) as well as life histories of insects (Walters and Carstensen 1986). Although a number of terrestrial animals, including insects (Bindokas et al. 1989, Kirschvink 1989) have been studied to see whether electromagnetic fields affect their behavior, no studies other than this one have been done on stream insects. Because aquatic biota, including bacteria (Frankel et al. 1978) and several species of aquatic vertebrates (Kirschvink 1989) contain magnetite, and some of those species respond to E.L.F. fields in water, it is possible that aquatic insects can detect E.L.F. fields and alter their responses accordingly.

Structural Community Indices: Taxon Diversity (H'), evenness (J') and taxon richness (S) as developed by Shannon and Weiner (see Tramer 1969) have been shown to be useful in the detection of alterations, both natural and anthropogenic, in the community structures. These indices have been central to studies on effects of rock size and microspatial complexity (Hart 1978), p-cresol (Stout and Cooper 1983) and construction of impoundments (Ward and Stanford 1979) on stream dwelling benthic invertebrates. As this is the first study aimed at looking at possible effects of E.L.F. on stream dwelling invertebrates, indices such as these are expected to be useful in the detection of both natural environmental and of E.L.F. operational effects on invertebrates in the Ford River, Michigan.

In general, benthic insect samples include a large number of chironomids (Chironomidae). Our samples can contain up to 3,000 individuals. Because identifications to genus, let alone to species level are very time consuming for large numbers such as these, efforts at adjusting to possible differences in numbers of taxa between the experimental (FEX) and reference (FCD) sites were made. Structural community indices were computed both with and without chironomids at each of the two sites, and separate analyses were performed on the two data sets to determine whether the unavoidable bias for this taxonomic family unit differentially affected the indices at the two sites.

Functional Community Indices: The most encompassing index, total insect biomass, was used to determine whether there might be dramatic effects, owing to E.L.F. operation, on the production of benthic insects. This index was also segregated into functional units, known as functional feeding groups (See Merritt and Cummins 1984). Mass values for collector-gatherers, filter-feeders, grazers, shredders, and predators, as well as for chironomids as a taxonomic grouping were determined at each site over time with the rationale that E.L.F. may affect some functional feeding groups more than others. If, for example, E.L.F. effects impacted primary producers in the stream, the insect functional feeding group to first respond may be the collector-gatherers and grazers that consume periphyton. In addition, a synthetic index, predator/prey ratios was generated as a monitoring tool to determine if the interactive dynamic of potential prey and potential predators in the system were altered before versus after E.L.F. activation.

In addition to the above functional community indices, changes in growth rates or patterns were monitored for six taxa, most of whom are collector-gatherers or grazers. If their major source of nutrition were affected by E.L.F. operations, then growth patterns and rates of these consumers of primary production may be altered as well. Efforts were made at selecting those species that were numerically reasonably visible at the two sites so that analyses would not be plagued by low numbers problems.

Past statistical analyses included power tests, coefficient of variation values, Student-t tests, linear regressions, 2-Way and 3-Way ANOVAS, and ANCOVAS. This year's Report includes multiple linear regressions relating physical factors (including ELF cumulative exposure values) with biological variables. B.A.C.I. tests (Stewart-Oaten et al. 1986) were also included in this Report. They were performed for parameters that showed significant year effects as determined by 2-Way and 3-Way ANOVAS to see whether there were significant before versus after ELF activation effects. In this report,

B.A.C.I. tests were performed on seasonal data groupings. Seasonal data groupings include: 1) spring: April, May; 2) summer: June, July, August, and; 3) autumn-winter: September, October, November, December. The seasonal groupings were created, based on coefficient of variation value differences for the parameters for each month. It was found (See 1988 Annual Report) that the spring and fall periods were periods of transition. Coefficient of Variation (CV) values were at their highest levels during those periods; whereas, during the summer months, the CV values were consistently low. During the spring, both spring run-off, as reflected in high fluctuations in discharge and water temperatures, and changes in taxa and biomass are at their highest. During the fall, alterations in species composition and increases in growth rates of fall-winter growing species affected CV values as well. Our rationale was that the most probable season for the detection of subtle E.L.F. effects may be during the summer "stable" periods.

E.L.F. fields may not operate in biological systems in ways similar to other anthropogenic agents. This may make it difficult to determine proper measures of exposure (e.g., intensity, frequency, electromagnetic excursions during activation and deactivation periods) for relating those exposures to biotic responses (O.T.A. 1989). One may not be able to make simple assumptions regarding dose-response curves. However, as a first approximation, we used cumulative ground exposure values which are daily ground intensity times duration values summed over the incubation period of the samples. We also plan on looking at ground intensity alone, duration alone, and (if possible) numbers of activation and deactivation periods accumulated over time. We plan on analyzing magnetic flux values in the same manner. For this report, cumulative exposure values were used as one of three physical independent variables in a series of multiple linear regressions for five separate biological parameters. Although initial activation occurred in late May of 1986, full power over extended periods began only in the fall of 1989. Our analyses at this time include benthic insect identifications and counts through November of 1989.

Materials and Methods

From November of 1983 through September of 1990, 60 micron mesh-lined half cylinder 18 x 28 x 10 cm substrate plastic sampler baskets were filled with benthic substrata and buried flush with the stream bottom at FEX and FCD. In May, 1990, a new site downstream from FEX was selected, based on E.L.F. field measurements. The new site, we call FEX.LINE, as far as E.L.F. field differences between experimental and reference sites is a

definite improvement over the original FEX experimental site. However, before impact data sets are not available for this site. Even so, the data from this site will be processed and treated in the same manner as for the FEX and FCD sites with the caveat that before versus after impact comparisons cannot be made. Inferences, if the data are similar to those for FEX, can be made. If, however, there are significant differences between this site and the FEX site, it will be a challenge to interpret the data and to relate it to possible ELF effects. If FEX and FEX.LINE are different, no interpretation as to the 'before' state will be possible.

From May through September each year, seven replicates for each site were collected monthly, with replacement. Each September, sufficient samplers were placed at the sites to allow for late fall, winter, and early spring collections. (After 1986, January through March collections were excluded, owing to past sampling difficulties.) Meier et al. (1979) showed that 30 to 39 days' incubation of samples in substrates in southern Michigan showed the maximum numbers of individuals colonizing substrates. Our colonization studies in 1983 showed that 30 days' incubation was the most parsimonious incubation period (1984 Annual Report).

Samples were processed by placing samplers in separate buckets, washing substrata thoroughly and retaining the suspended animals in a 60 micron mesh soil sieve. Animals were preserved in 80% ethyl alcohol. In the laboratory, insects were picked from detritus and then separated to order level. Next, specimens were identified to the lowest taxon possible, and measured to the nearest mm for biomass estimates (after Smock 1980). Numbers of individuals, taxon diversity (H'), richness (S'), evenness (J') and percent numerical dominance for selected species were determined for each sample. Total sample biomass, biomass for functional feeding groups (after Merritt and Cummins 1984) and mean dry mass per individual (MDW/IND) values were computed. Discharge and chronological time as well as physiological time, cumulative degree days, were used as independent variables. Data came from ambient monitoring of discharge and from maximum-minimum daily water temperatures at each site. Before installation of the automatic ambient monitoring system in April and after the system was dismantled in late October, daily maximum - minimum temperatures were recorded at FCD with a chart recorder. Before 1988, when chart recorders were not used, estimates of water temperatures based on monthly visits were made for March, November, and December each year.

MDW/IND values were plotted against chronological time and/or against physiological time. All six species monitored for changes in MDW/IND values

have major growth periods during the summer months. Data have been processed only through November of 1989, so results for the 1990 season will appear in the 1991 Annual Report.

Results and Discussion

Structural Community Indices

Taxon diversity, evenness, richness, and number of individuals were first analyzed with 2-Way ANOVA tests to see whether there were year, site, and year/site effects in addition to interactions between and among the factors. Table 4.1 contains results for these indices that include chironomids as a single taxonomic unit. Chironomids were excluded from H', J' and numbers of individuals in separate analyses and appear in Table 4.2.

TABLE 4.1
2-Way ANOVA Tests for Structural Community Parameters
WITH CHIRONOMIDS

F VALUES, LEVELS OF SIGNIFICANCE					
Source	d.f.	Diversity	Evenness (ArcSin)	Richness	Numbers of Individuals
Years, Site	5	0.12	0.37	0.42	0.63
Years	5	3.71**	5.52***	7.31***	2.01
Site	1	1.18*	2.74	6.43**	22.87***
Error, MSE	84	.268	27.67	44.61	1,194,915

p < .05 = *; p < .01 = **; p < .001 = ***

There are no significant interaction terms (Years by Site) for the indices, whether or not chironomids are included. However, there are significant year effects for H' and J' when chironomids are included in the analysis (Table 4.1), but no year differences when chironomids are excluded from the 2-Way ANOVAS. Thus, the year to year oscillations in chironomid abundances differ significantly enough to impact H' and J'. There are significant site differences for diversity when many chironomids as a single unit are included in the analysis (Table 4.1). There are no site differences for diversity (H') when chironomids are excluded (Table 4.2). The reference site, FCD, contains more sand relative to larger particles than does the experimental site, FEX. A lower abundance of chironomids relative to other taxa at FCD during the summer

months, and then a higher abundance of chironomids relative to other taxa during the fall and winter months at FCD results in higher diversity values at FCD in the summer and lower diversity values at FCD during the fall, Figure 4.1. Note that areas to the left of vertical hatch marks on graphs are 'before' data; to the right are 'after' data. This bias in numbers for chironomids, which affects diversity values, is excluded in the results for Table 4.2.

TABLE 4.2
2-Way ANOVA Tests for Structural Community Parameters
WITHOUT CHIRONOMIDS

F VALUES, LEVELS OF SIGNIFICANCE				
Source	d.f.	Diversity	Evenness (ArcSin)	Numbers of Individuals
Years, Site	5	0.06	0.30	0.61
Years	5	0.62	0.55	0.81
Site	1	0.82	10.86**	28.81***
Error, MSE	84	.355	44.54	320,129

p < .05 = *; p < .01 = **; p < .001 = ***

Differences in evenness between the two sites (Figure 4.2, with chironomids) have a more even see-saw pattern than do differences in diversity between the two sites. There are no site differences in J' when chironomids are included. Curiously enough, there are site differences for J' when chironomids are excluded from the 2-Way ANOVAS. Without the high numbers of chironomids impacting J', J' is usually higher at FEX than at FCD. Numbers of taxa are usually higher at FEX than at FCD (Table 4.1; Figure 4.3). From 1986 through 1987 taxon richness was consistently higher at FEX; richness showed not only significant site but also significant year differences (Table 4.1).

Whether or not chironomids are included in the analyses, there are no significant yearly differences in numbers of individuals. However, there are significant site differences (Figure 4.4, with chironomids). Samples from FEX over the years almost always yielded more individuals. The more heterogeneous substrata at FEX may be the main factor relating to a numerically and taxonomically richer insect fauna.

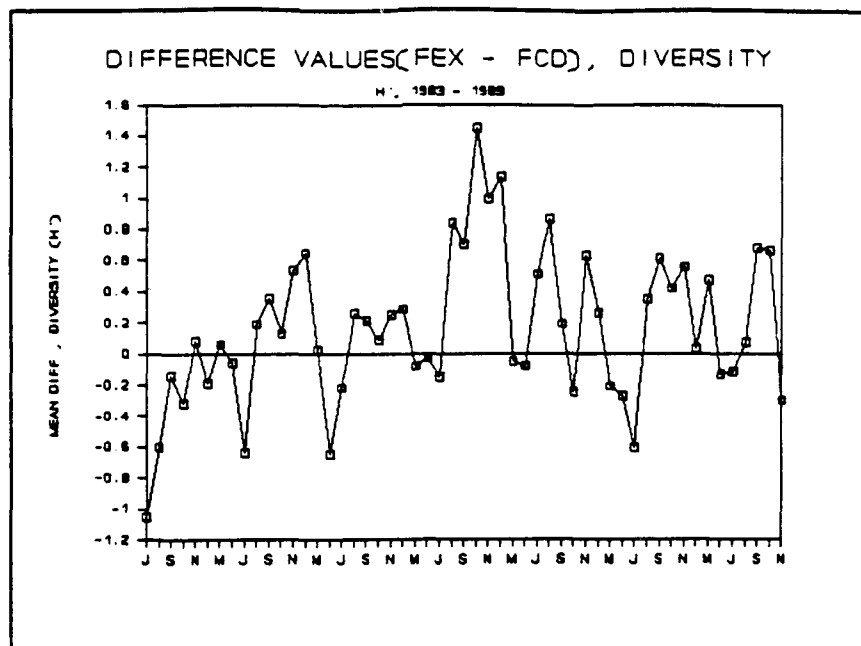


Figure 4.1. Differences in mean taxon diversity, FEX - FCD. July 83 - Nov 89.

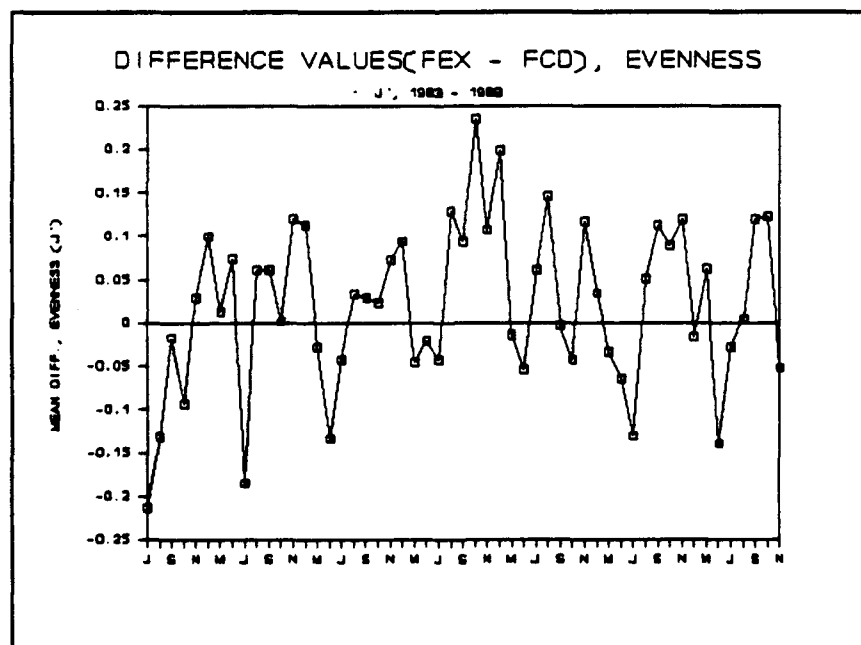


Figure 4.2. Differences in mean taxon evenness, FEX - FCD. July 83 - Nov. 89.

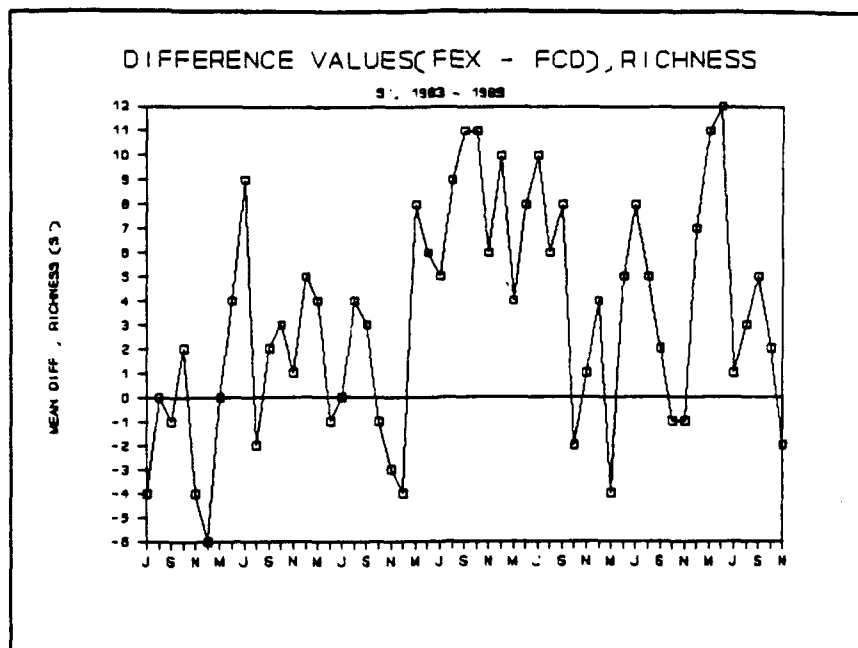


Figure 4.3. Differences in mean taxon richness, FEX - FCD. July 83 - Nov. 89.

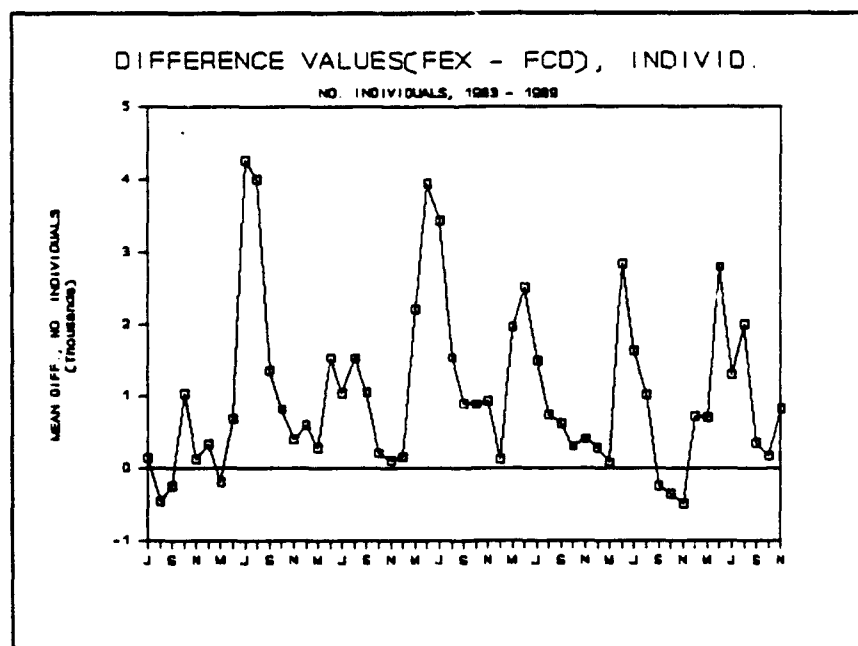


Figure 4.4. Differences in mean number of individuals, FEX-FCD. July 83 - Nov. 89

Aquatic insect community structure differs over the seasons. Not only do species assemblages change over the year, but, as species emerge as adults and then lay eggs, numbers of individuals fluctuate as well. With this in mind, structural community indices were analyzed according to season. April and May of each year represents the spring season; June through August represents the summer season, and the fall-winter season incorporates data for September through November of each year in the following 2-WAY ANOVAS. They were used to detect any seasonal differences for these parameters. Two datasets were used: One including chironomids, and one excluding chironomids. Table 4.3 presents results where chironomids as a single taxonomic unit were included. Table 4.4 presents results where chironomids were excluded from the seasonal analyses.

TABLE 4.3
2-Way ANOVA Tests for Seasonal Differences,
Structural Community Parameters
WITH CHIRONOMIDS

Parameter, Source	d.f.	Spring	Summer	Fall
		F-value	F-value	F-value
DIVERSITY				
Site	1	1.18	0.03	34.17***
Year	5	10.40***	7.28***	13.23***
Site, Yr. 5	5	1.18	2.72*	3.13**
EVENNESS, arcsin transform				
Site	1	6.04*	3.55	33.91***
Year	5	10.26***	9.98***	21.46***
Site, Yr. 5	5	0.78 ns.	2.65*	2.78*
RICHNESS				
Site	1	5.05*	27.16***	7.96*
Year	5	13.14***	12.79***	24.88***
Site, Yr. 5	5	1.86	0.95	2.46*
NO. INDIVIDUALS				
Site	1	17.07***	225.49***	37.02***
Year	5	10.30***	15.89***	17.48***
Site, Yr. 5	5	2.63*	4.92***	5.18***

Error, D.F.		108	168	168

TABLE 4.4
2-Way ANOVAS for Seasonal Effects
Structural Community Parameters
WITHOUT CHIRONOMIDS

Parameter, Source	d.f.	Spring	Summer	Fall
		F-value	F-value	F-value
DIVERSITY				
Site	1	3.94	8.47**	2.14
Year	5	3.01*	7.35***	14.14***
Site, Yr. 5		2.13	0.48	2.18
EVENNESS, arcsin transform				
Site	1	10.77**	31.42***	12.97***
Year	5	6.22***	4.66***	7.46***
Site, Yr. 5		4.08**	1.75	1.87
NO. INDIVIDUALS				
Site	1	22.98***	187.12***	85.76***
Year	5	9.78***	6.42***	11.27***
Site, Yr. 5		4.07***	2.78*	4.43**

Error, D.F.		108	168	168

It is apparent from comparing Table 4.1 with Table 4.3 that, had we only looked at year, site, and year by site terms, we would not have detected significant seasonal differences for a number of indices, which included chironomids. The same pattern held true for the datasets where chironomids were excluded. (Compare Table 4.2 with Table 4.4.) All parameters tested for year by site interactions were non-significant; yet, when months were grouped into seasons, significant year by site interactions were found for some of the seasons. Overall, the fall season showed the most significant year and site by year interactions. This was especially true for numbers of individuals. The dynamic nature of the fall period when the 'summer' species have emerged and the fall species are beginning their growth and active movement stage is reflected by significant yearly and site differences. Since the beginning of this study, the Ford River has experienced years of heavy rain, years of drought, years of high spring and/or summer temperatures, and years of cool summer weather. Are these differences most reflected in the indices in question during the fall transition period, or are these differences at all related to ELF effects? In order to separate these factors in the best ways possible, B.A.C.I. tests were performed on the seasonal data to determine if there were any trends

prior to June of 1986 that were not matched by results after activation of the ELF fields. In addition, some physical factors that may play a major role in our results were analyzed; in particular, discharge and temperature regimes throughout the study.

A comparison of Table 4.3 and Table 4.4 also reveals additional information relative to H', J' and S. Diversity, evenness and richness indices were either non-significant or close to the $p = 0.05$ level for the spring and summer months when chironomids were included in the analyses. This was not the case for similar analyses where chironomids were excluded. FEX supports a higher number of species than FCD (Figure 4.3). When the high numbers of chironomids were excluded from the H' and J' indices, the power of the higher taxon richness at FEX and more equitable apportionment of individuals among the species at that site appeared as highly significant site differences for evenness values during the spring and summer months (Table 4.4). Diversity was also higher at FEX during the summer months when chironomids were excluded from the index. Are the significant differences found among years for most of the parameters attributable to natural environmental events, or are there systematic differences before June of 1986 as compared with after that time?

B.A.C.I. tests were performed on the seasonal datasets where chironomids were excluded, so that the effect of identifying chironomids only to family level would not seriously impact H' and J' indices. The primary value in using B.A.C.I. tests is that one can detect a before versus after effect on a large data set. One restriction of the B.A.C.I. method is that one uses only sample means rather than all the sample values. In order to run the tests, the data set prior to impact (in our case, the years 1984, 1985, and some of 1986) must pass the test of additivity, and therefore, not show significance in a linear regression analysis. With the small numbers of values, there is always a chance that the data will not "pass the regression" test. This happened only once for diversity and twice for numbers of individuals.

Table 4.5 presents results of B.A.C.I. tests for *structural community* parameters on a season by season basis. As previously stated, there were significant year differences for richness (Table 4.3), diversity, evenness, and numbers of individuals (Table 4.4). In the B.A.C.I. tests, where t-tests were possible, there were no significant spring as well as summer differences before versus after ELF activation. The fall season, however, showed significant before versus after differences (Table 4.5).

TABLE 4.5
Results of B.A.C.I. Comparisons for Structural
Community Parameters; Spring, Summer, Fall

Spring BEFORE: 1984-1986, AFTER: 1987-1989
Summer BEFORE: 1984-1985, AFTER: 1987-1989
Fall BEFORE: 1983-1985, AFTER: 1987-1989

Index, Comparison	Trans- form Type	Tukey's Test for Additivity		t-test, Signif.	
		df.	F-value, sig.	df.	T-value sig.
DIVERSITY					
Spring	NO	4	15.65**		n.a.
Summer	NO	4	3.21	16	-0.313
Fall	NO	7	-0.80	22	4.72***
EVENNESS					
Spring	Arcsin	4	20.90**		n.a.
Summer	Arcsin	4	4.63	16	0.086
Fall	Arcsin	7	1.72	22	5.31**
RICHNESS					
Spring	NO	4	7.63	10	-0.96
Summer	NO	4	6.54	16	-1.59
Fall	NO	7	1.72	22	-16.81***
NO. INDIVIDUALS					
Spring	log(X+1)	4	5.71	10	-3.38**
Summer	log(X+1)	4	135.43***		n.a.
Fall	log(X+1)	7	21.17***		n.a.

* = <.05, ** = <.01, *** = <.001 n.a. = not appropriate

Physical Factors as Related to Biological Variables

Two physical factors differed among the fall seasons before *versus* after ELF activation: Discharge and water temperatures. Figures 5.5A, 5.5B, and 5.5C show that discharge values for each spring period diminished after April of 1986. Summer values were more random across years, with June of 1985 and 1989 and July of 1984 and 1987 having peak discharge values. The fall periods not only showed a diminishing of discharge after 1985, but the difference between FEX and FCD were greater during the fall periods of 1986 and 1988 (Figure 4.5C). This was especially true in October of 1988 when discharge values were much higher at FCD than at FEX.

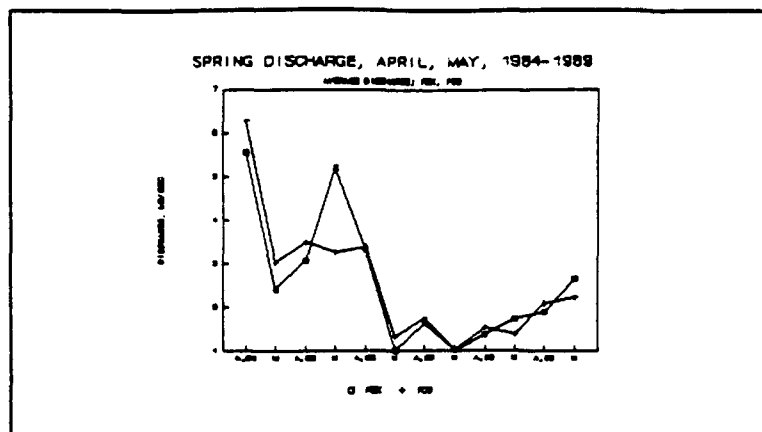


Figure 5.5A.

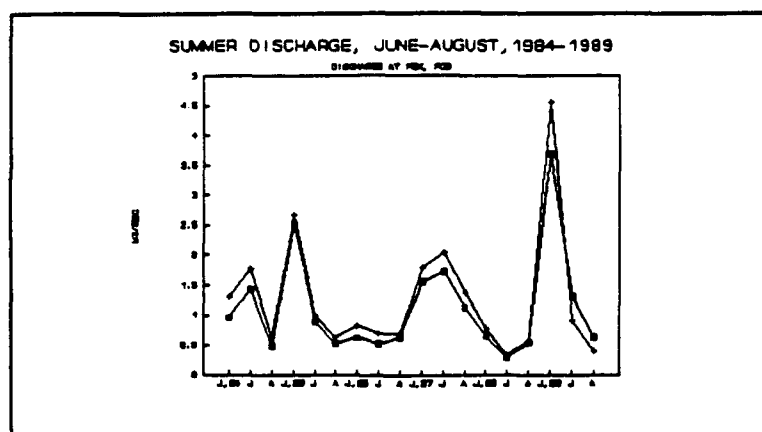


Figure 4.5B.

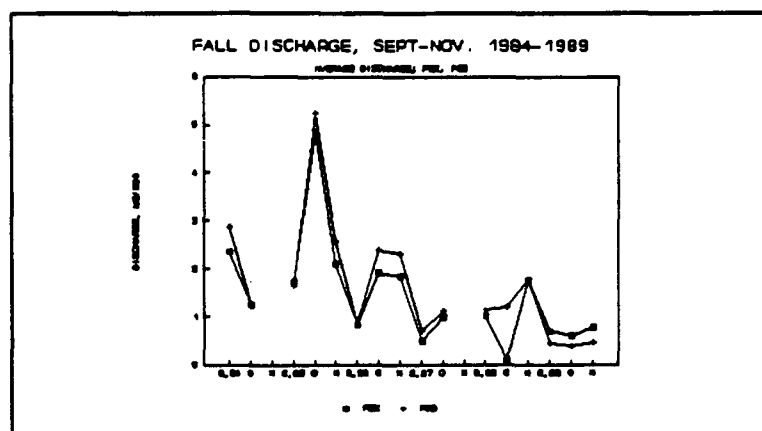


Figure 4.5C.

Figure 4.5A: SPRING; 4.5B: SUMMER; 4.5C: FALL. Average discharge per month at FEX and FCD. 1984 - 1989

All structural parameters shown in Table 4.5 showed their values were much lower at FCD than at FEX (Figures 4.6A,B,C; 4.7A,B,C; 4.8A,B,C, 4.9A,B,C)

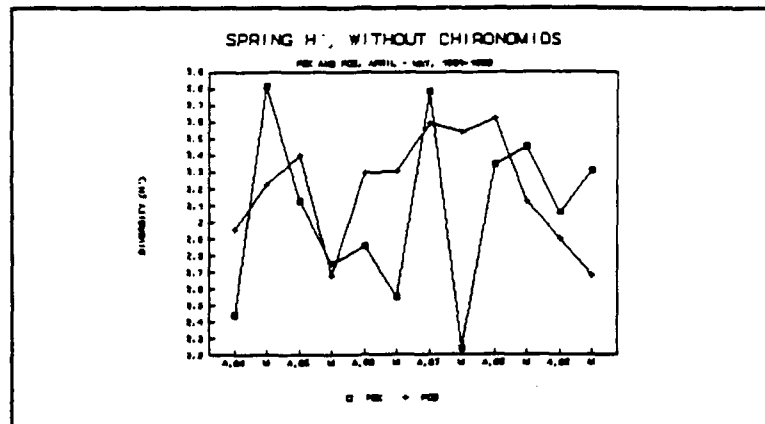


Figure 4.6A. SPRING

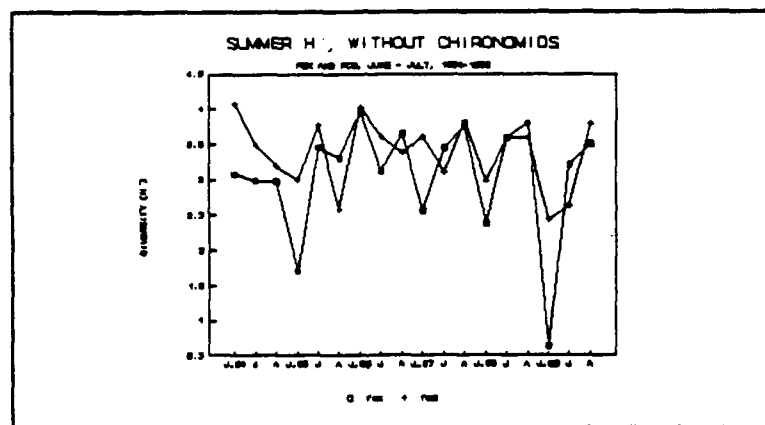


Figure 4.6B. SUMMER

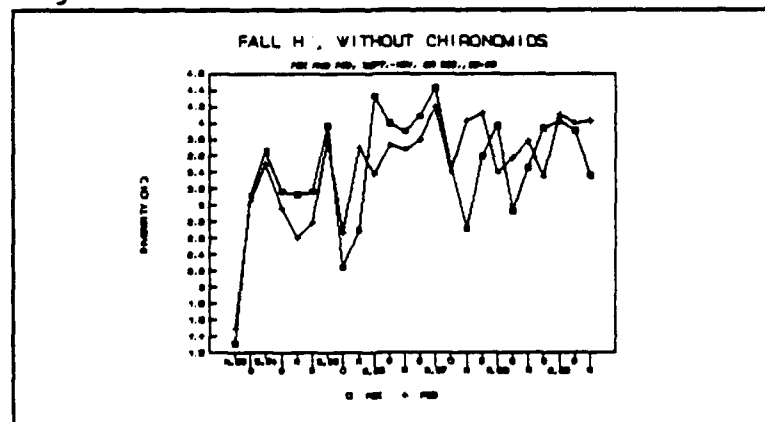


Figure 4.6C. FALL

Figures 4.6A - C: H' without chironomids. FEX and FCD. 1984 - 1989.

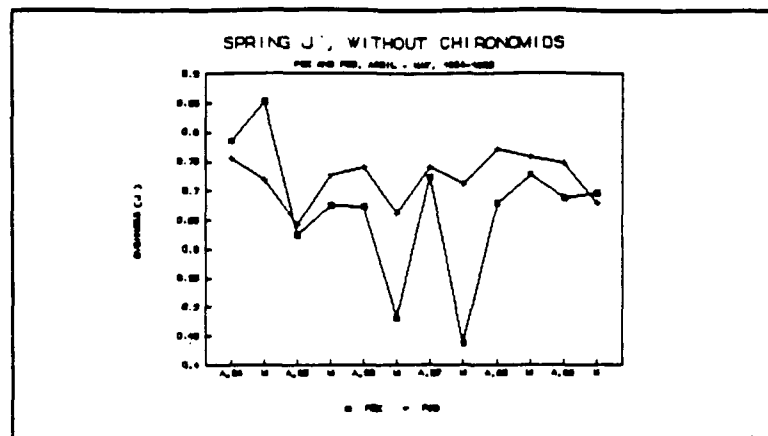


Figure 4.7A. SPRING.

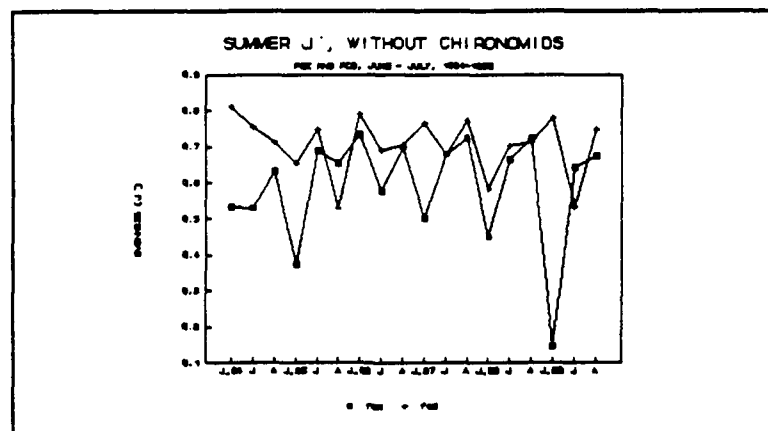


Figure 4.7B. SUMMER.

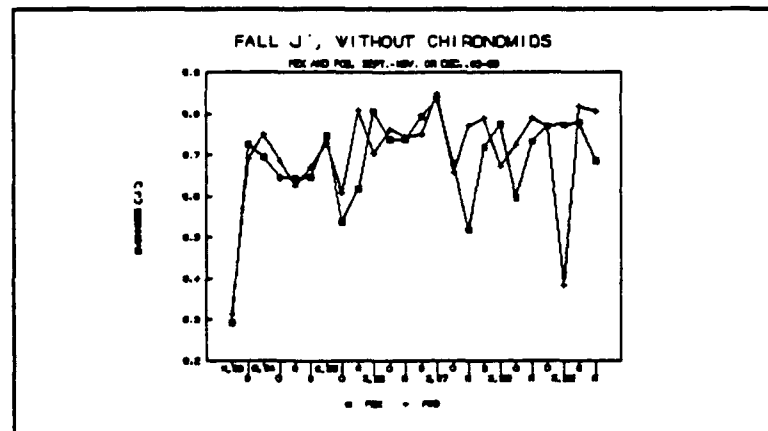


Figure 4.7C. FALL.

Figures 4.7A, 4.7B, 4.7C. Evenness (J') without chironomids. FEX (squares) and FCD (X's). 1984-1989 (spring and summer); 1983-1989 (fall). Vertical Hatch: ELF activation point.

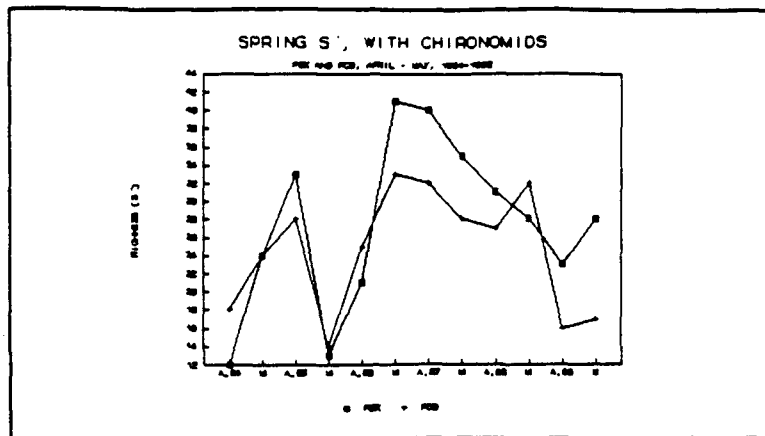


Figure 4.8A. SPRING.

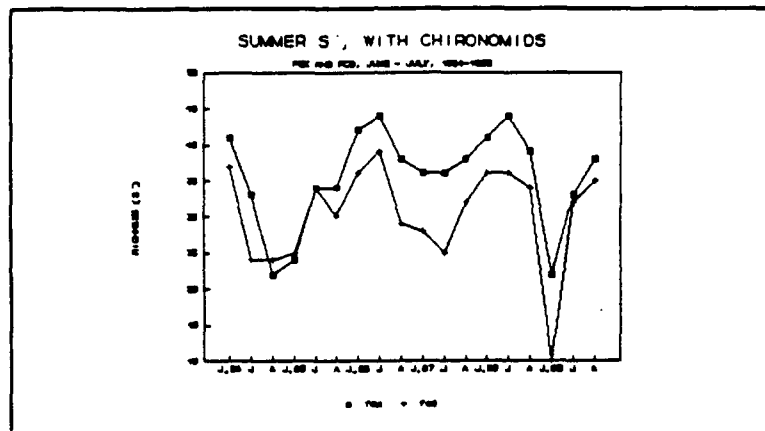


Figure 4.8B. SUMMER.

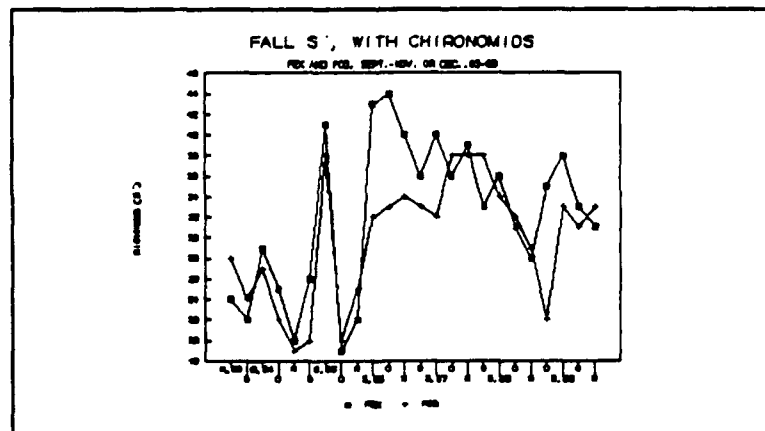


Figure 4.8C. FALL.

Figures 4.8A, 4.8B, 4.8C. Richness (S') without chironomids. FEX (squares) and FCD (X's). 1984-1989 (spring and summer); 1983-1989 (fall). Vertical Hatch: ELF activation point.

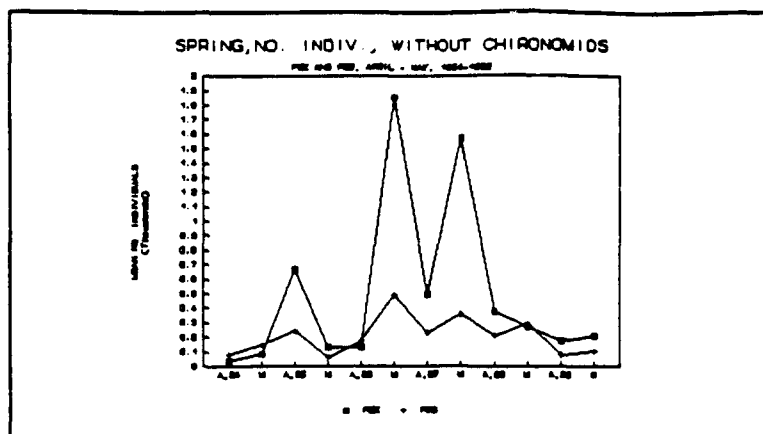


Figure 4.9A. SPRING.

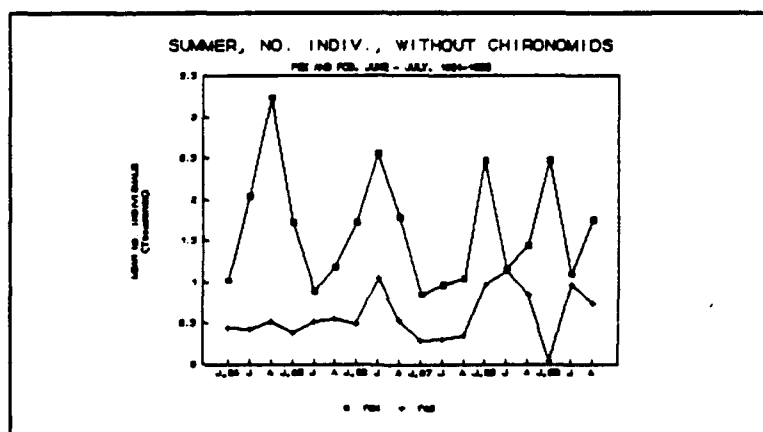


Figure 4.9B. SUMMER.

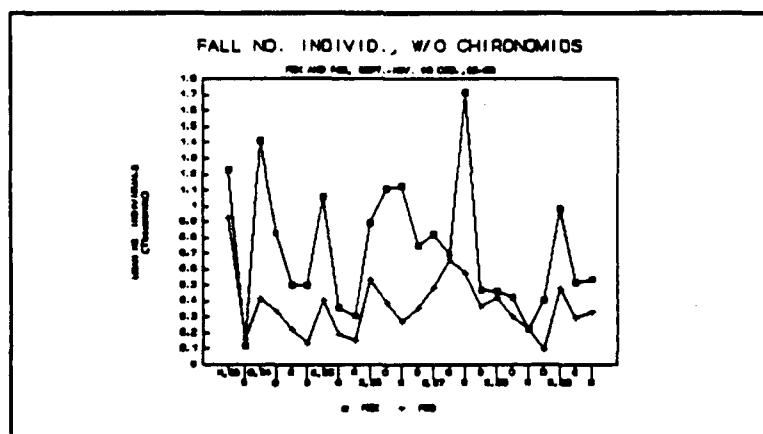


Figure 4.9C. FALL.

Figures 4.9A, 4.9B, 4.9C. Numbers of individuals without chironomids. FEX (squares) and FCD (X's). 1984-1989 (spring and summer); 1983-1989 (fall). Vertical Hatch: ELF activation point.

Because B.A.C.I. tests (Table 4.5) showed significant differences, especially for the fall periods, ANCOVA analyses using discharge as the covariate (Table 4.6) were performed on data where B.A.C.I. tests showed significant differences. Diversity (H') was significantly different for September and October. Although there were no differences between means (y-intercept in ANCOVA), there were significant differences in slopes (Table 4.6). This would suggest that insects at FCD responded either differentially to periods of high water, or that discharge values were different there than at FEX during the fall periods. Figure 4.5C shows that there was a large difference between discharge values during the month of October, 1988. Discharge often was higher at FCD than at FEX. Figure 4.6C shows that during that month the mean H' value at FCD was much lower than at FEX. The reference site, FCD, contains much more sand relative to cobble. Increased flooding may affect more individuals of species adapted to shifting sands, which would increase the J' component of H' at FCD. Rather than invoking ELF effects, it is much more probable that both lower discharge values after ELF activation and differential discharge at the two sites resulted in the B.A.C.I. tests showing significance for H' . (Note that in Figure 4.6A diversity values criss-cross for the two sites during the spring months before ELF activation, resulting in an inability to achieve additivity for the B.A.C.I. analyses (Table 4.5).)

Although B.A.C.I. tests also showed significant differences for evenness (J') during the fall periods, the slopes for the two sites, as related to discharge values were non-significant. They were close to significance, however. Had we been able to use November data in these analyses, there may have been significant slope differences for this parameter. The same rationale, as described for diversity, above, would have been invoked. Note that J' was higher at FCD than at FEX in October of 1988 when discharge was high at FCD relative to FEX (Figure 4.7C).

Taxon richness (S') showed significant before versus after differences for the fall months. In this case, there were differences in the y-intercepts (Table 4.6). Figures 4.8 A and B show that FEX often supports more taxa than does FCD during the spring and summer months. Before 1986, the numbers of taxa were similar at the two sites during the fall periods. After 1986, when the ELF had been activated, the number of taxa were lower at FCD than at FEX (Figure 4.8C) during the fall years 1986 and 1988 when discharge at FCD was higher than at FEX (Figure 4.5C). The higher discharges at the sandy FCD site may have washed out more taxa there than at FEX. This is certainly a more parsimonious conclusion than suggesting that ELF activation increased numbers of taxa at FEX relative to FCD.

TABLE 4.6

ANCOVAS for Mean Discharge (m3/sec) and H'
J', S', No. Individuals, 1984-1989

Season, Source	d.f.	SS	MS	F, sign.
FALL, DIVERSITY				
Diff. between adj. means				
Adj. Means	1	.00007	.00007	.003 n.s.
Error	117	2.52396	.02157	
Diff. between slopes				
Slopes	1	.12709	.12709	6.151***
Sum group dev.	116	2.39687	.02066	
			Common slope: -.09653	

FALL, EVENNESS				
Diff. between adj. means				
Adj. Means	1	.02879	.02879	2.264 n.s.
Error	117	1.48803	.01272	
Diff. between slopes				
Slopes	1	.04181	.04181	3.353 n.s.
Sum group dev.	116	1.44622	.01247	
			Common slope: -.06259	

FALL, RICHNESS				
Diff. between adj. means				
Adj. Means	1	.47313	.47313	10.715**
Error	117	5.16628	.04416	
Diff. between slopes				
Slopes	1	.00830	.00830	.187 n.s.
Sum group dev.	96	5.15798	.04447	
			Common slope: -.1140	

SPRING, NUMBERS OF INDIVIDUALS				
Diff. between adj. means				
Adj. Means	1	13.63010	13.63010	49.032***
Error	117	32.52422	.27798	
Diff. between slopes				
Slopes	1	.09711	.09711	.347n.s.
Sum group dev.	116	32.42711	.27954	
			Common slope: .0108	

* = p<.05, ** = p<.01, *** = p<.001

Numbers of individuals, with or without chironomids, were almost always higher at FEX than at FCD. In the B.A.C.I. analysis, only the spring period data prior to ELF activation were additive (Table 4.5). Then, numbers of individuals were higher at FEX than at FCD. After ELF activation, numbers of individuals were much higher at FEX. Spring discharge, as related to this parameter (Table 4.6) showed that the mean numbers at FEX were even higher than at FCD after ELF activation. Figure 4.5A shows that spring discharge values were lower after the spring of 1986, the same time that ELF fields were activated. Given the fact that the mean spring discharge was also lower during that time and that an ANCOVA (Table 4.6) showed a mean difference during the spring for this parameter, it is probable that numbers of individuals during the spring at FEX responded more to lower discharge than did numbers of individuals at FCD. The alternative hypothesis at this time is that ELF effects increased numbers of insects, an improbable conjecture.

In order to determine whether discharge, water temperature and/or ELF cumulative exposure values affected H', J', S', and numbers of individuals, multiple linear regressions were performed for each site, season by season. Results appear at the end of this Element, as the functional community parameter, insect mass, was included in the analysis.

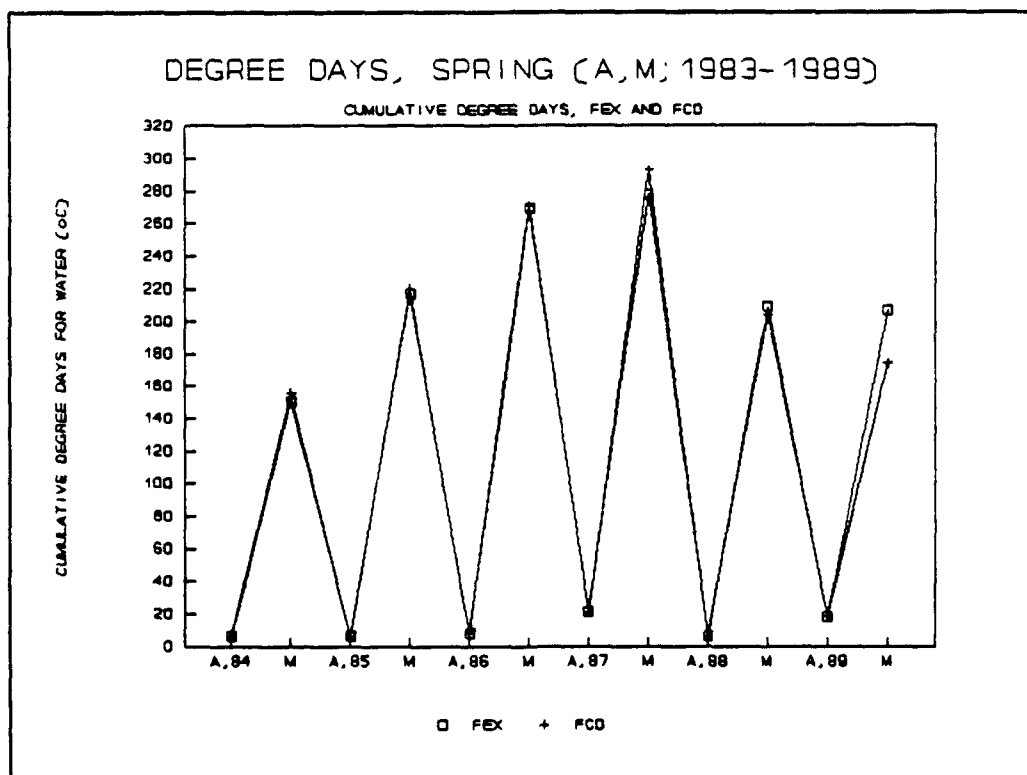


Figure 4.10A. Cumulative degree days at FEX and FCD. Springs (April, May) 1984 - 1989.

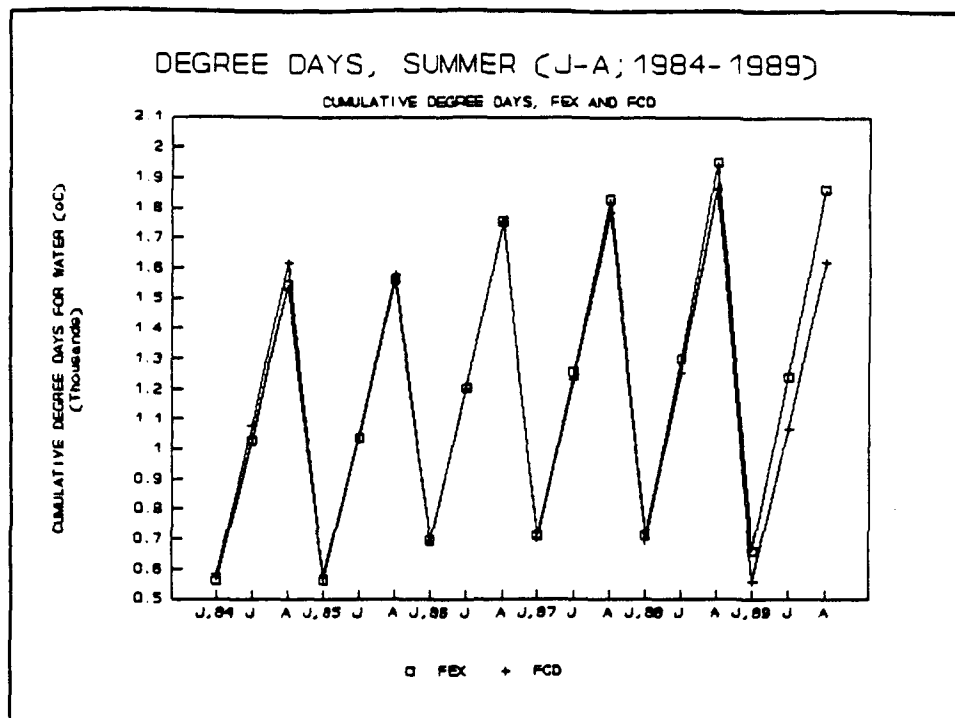


Figure 4.10B. Cumulative Degree Days. FEX and FCD. Summers (June, July, August) 1984 - 1989.

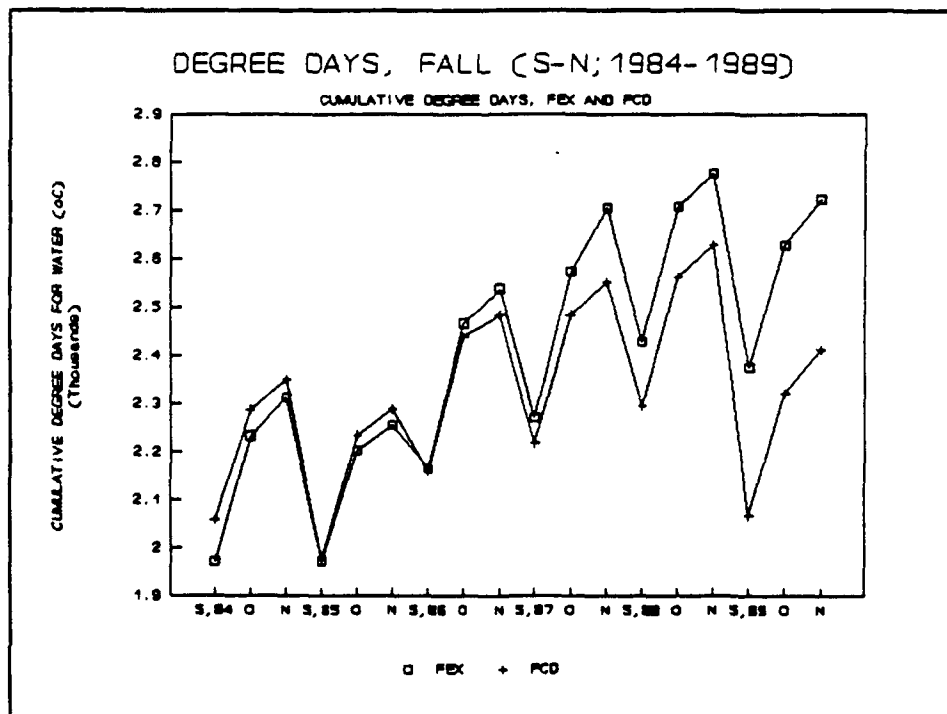


Figure 4.10C. Cumulative Degree Days. FEX and FCD. Falls (Sept., Oct., Nov.) 1984 - 1989.

Functional Community Indices

Total Insect Mass and Functional Feeding Group Mass:

Total insect mass was significantly different among years, months, and between sites (Table 4.7). All interaction terms were also significant at the $p = 0.05$ level.

TABLE 4.7

3-Way ANOVA for Differences in Total Mass of Aquatic
Insects at FEX and FCD from April through November each Year
(1984 - 1989)

Source	SS (gms.)	d.f.	MSS (gms.)	F-ratio
Years	1004.53	5	200.91	32.4 ***
Months	995.42	7	142.20	22.9 ***
Site	476.17	1	476.17	76.8 ***
Years, Months	1385.82	35	39.59	6.4 ***
Years, Months, Site	420.43	35	12.01	1.94 **
Months, Site	93.91	7	13.42	2.16 *
Years, Site	239.82	5	47.96	7.7 ***
Error	2,381.69	384	6.20	

Figure 4.11, a plot of the mean difference between FEX and FCD for total insect mass, shows that peak differences between the two sites occurred at least once a year, even though the amplitude and duration of the differences varied. The peak differences also usually occurred during the summer months. The majority of the points occur above the zero line and indicate that total insect mass is often higher at FEX than at FCD. During the fall and mild winter of 1986 - 1987, the difference between FEX and FCD remained high.

The data were separated into seasons to determine statistical patterns based on naturally grouped data (Table 4.8). By grouping the data into seasons, several patterns emerged that had been obscured when the months were separate (Table 4.7). In the spring months of 1986 and 1987 total mass of insects was higher than for spring in other years. This was reflected in year differences for the spring months. During the summer months, the site differences and year differences were not significant. It is during these times

that total insect mass is usually at its highest. As for structural community parameter data, total insect mass fluctuated between sites and among years during the fall. These fluctuations, if incorporated for analyses such as in Table 4.7, could confound the results for spring and summer analyses.

TABLE 4.8
2-Way ANOVA for Differences in Total Mass of Aquatic
Insects by Season, FEX vs. FCD
1984 - 1988

Source	d.f.	F VALUES, LEVEL OF SIGNIFICANCE		
		Spring	Summer	Fall
Site	1	3.47	0.66	32.76***
Year	4	9.38***	1.00	24.44***
Site x Yr.	4	1.14	1.03	9.71***
Error,	d.f.	108	168	168

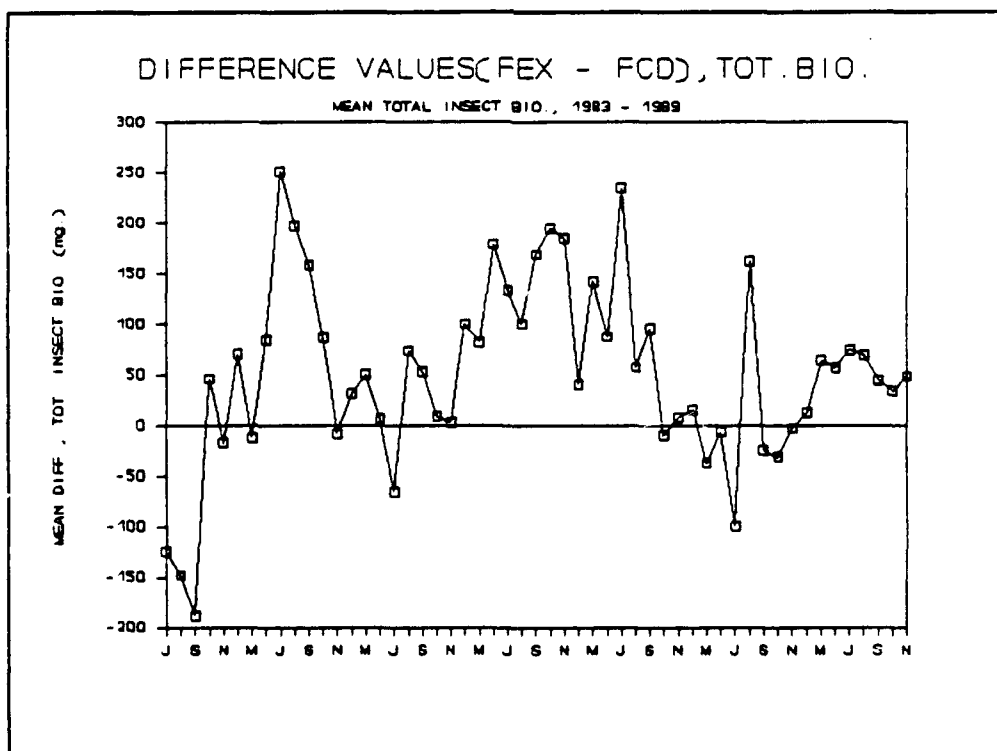


Figure 4.11. Differences in mean total insect mass (mg.). FEX - FCD. April through November each year, 1983-1989.

B.A.C.I. tests were performed on mean total insect mass to see whether any significant year differences within seasons could be associated with ELF activation (Table 4.9).

TABLE 4.9
Results of B.A.C.I. Comparisons for Insect Mass
at FEX vs. FCD. Spring, Summer, Fall

Spring BEFORE: 1984-1986, AFTER: 1987-1989
Summer BEFORE: 1984-1985, AFTER: 1987-1989
Fall BEFORE: 1983-1985, AFTER: 1987-1989

SEASON	Transform	Tukey's Test for Additivity		T-test	
		df.	F-value, sig.	df.	T-value sig.
Spring	$\log(X+1)$	4	2.412	10	-0.389
Summer	NO	4	7.701	16	0.075
Fall	$\ln(\log(X+1))$	7	3.633	22	0.039

There were no before versus after differences for insect mass during the spring, summer and fall periods. Structural community parameters showed before versus after ELF activation associations, which were more attributable to differences in flow regimes before 1986 as compared with after 1986. However, total insect mass values were not significantly different before June of 1986 as compared with data after ELF activation. It appears that total insect mass was not differentially affected by reductions in flow after 1986, even by reductions that were most pronounced during the fall periods. As H' was reduced at FEX relative to FCD in the fall, it appears that the increased flow at FCD affected small rather than large individuals.

Total insect mass was analyzed according to functional feeding groups, including collector-gatherers, collector-filter-feeders, shredders and predators. Figures 4.12A and 4.12B illustrate differences between FEX and FCD with respect to collector-gatherers and collector-filter-feeders. Figures 4.13A and 4.13B present those differences for shredders and predators.

The relationship between predators and their potential prey is biologically meaningful in community analyses. Differences between FEX and FCD with respect to predator/prey ratios are illustrated in Figure 4.14.

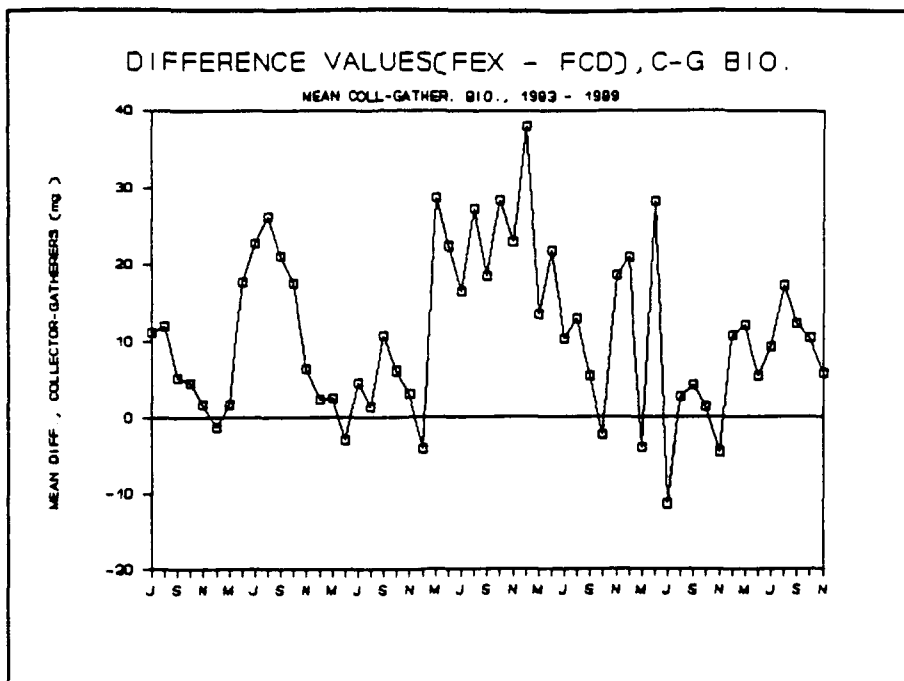


Figure 4.12A. Difference values for mean collector-gatherer mass at FEX minus FCD. July 1983 - November 1989.

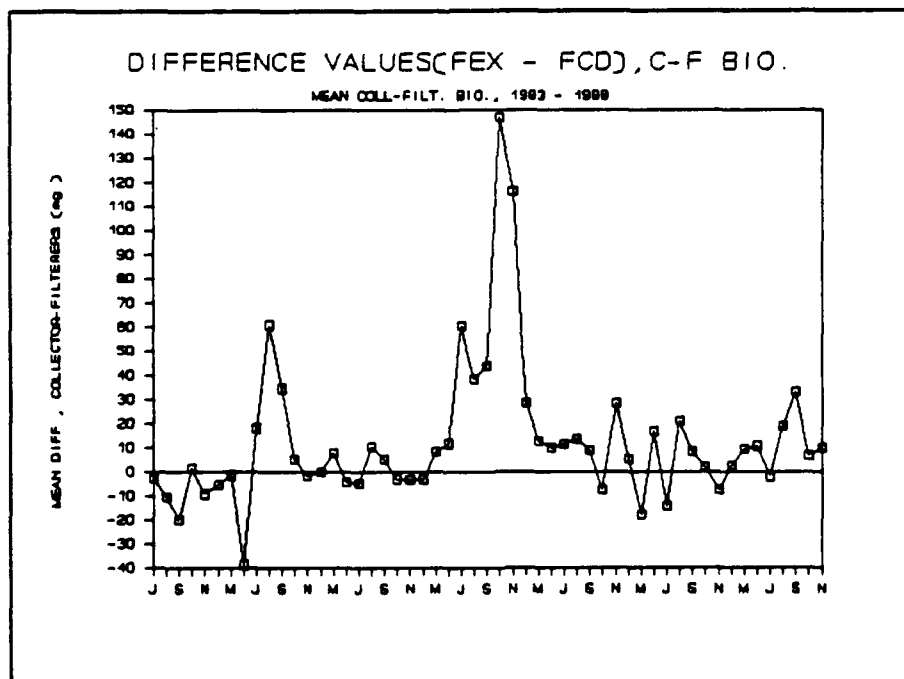


Figure 4.12B. Difference values for mean Collector- Filter Feeder mass at FEX minus FCD. July 1983 - November 1989.

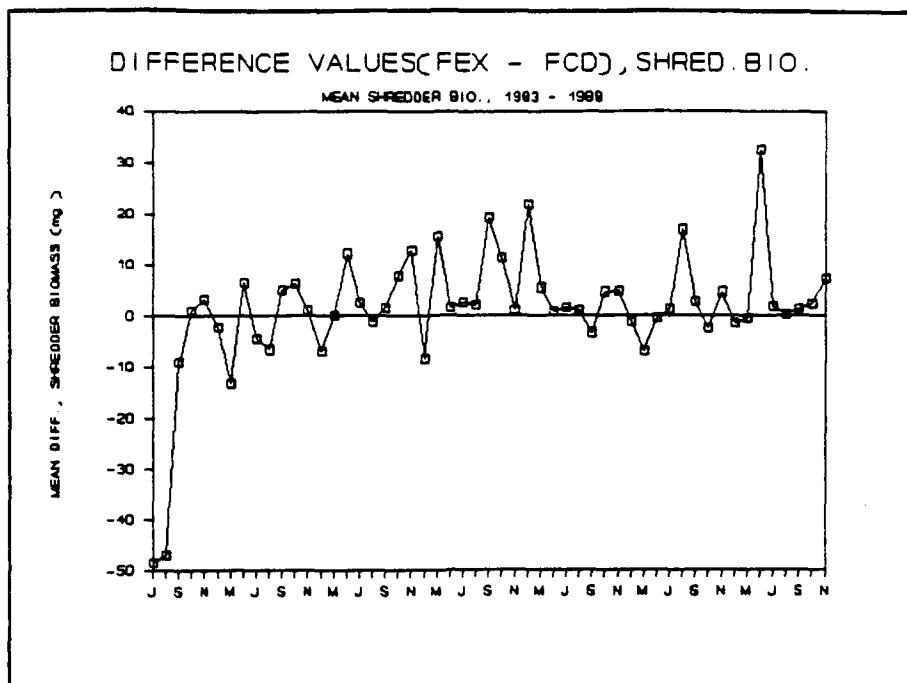


Figure 4.13A. Difference values for mass of Shredders at FEX minus FCD. July 1983 - November 1989.

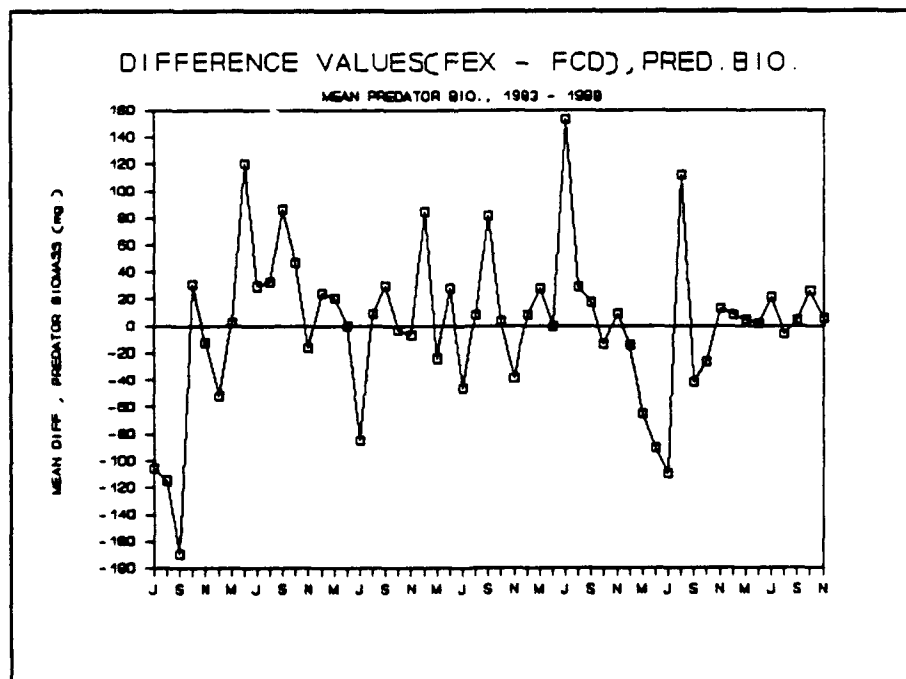


Figure 4.13B. Difference values for mass of Predators at FEX minus FCD. July 1983 - November 1989.

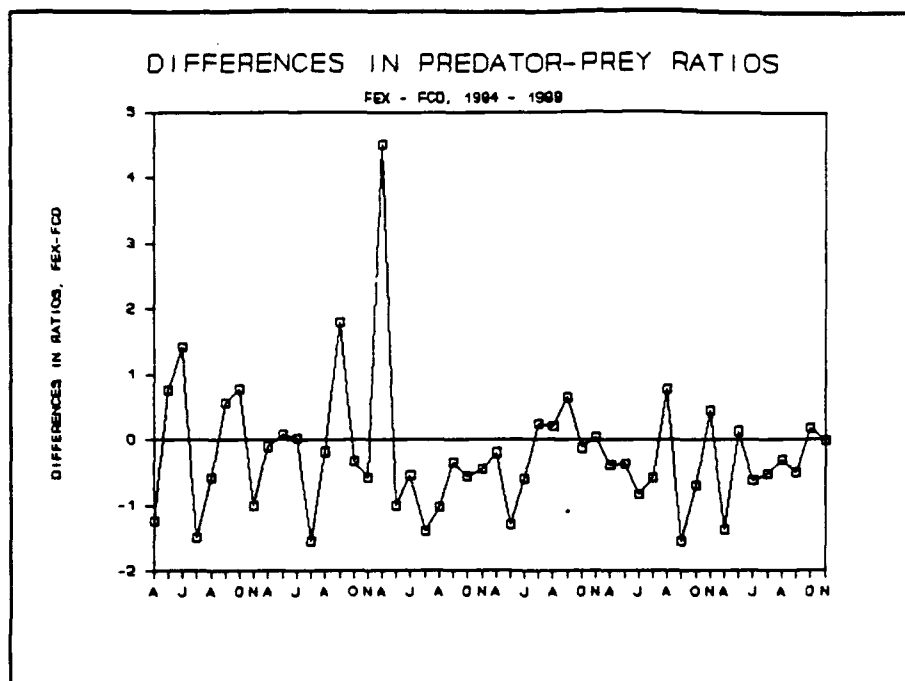


Figure 4.14. Difference values for Predator/Prey ratios, FEX minus FCD. April 1984 - November 1989.

Given that, 3-Way and 2-Way ANOVAS were performed on predator/prey ratios to see if any changes had occurred after 1986 when ELF activation was initiated. Table 4.10 presents the 3-WAY ANOVA for looking at site, year and month effects.

TABLE 4.10

3-Way ANOVA for Differences in Predator/Prey Mass (Arcsin Transformation) at FEX and FCD, April through November (1984 - 1989)

Source	SS	d.f.	MSS	F-ratio
Site	15,495.5	1	15,495.5	24.95**
Years	11,642.7	5	2,328.5	3.75**
Months	18,764.8	7	2,680.7	4.32***
Years, Months	33,355.3	35	953.0	1.53*
Years, Months, Site	64,195.4	35	1,834.2	2.95***
Months, Site	7,576.4	7	1,082.3	1.74 ns
Years, Site	7,262.7	5	1,452.5	2.30*
Error	238,477.4	384	621.0	

In order to unconfound seasonal differences, 2-WAY ANOVAS were performed for the spring, summer and fall seasons for 1984 through 1988 data, Table 4.11. This ratio showed site differences during the spring and summer months, but no site differences for the fall months. In the summer months, not only was the predator/prey ratio significantly different between the two sites, but there were significant year and site x year interaction differences. In the April of 1986, a very large number of predators relative to prey were collected at FEX. The predators, for the most part were dragonfly naiads of Ophiogomphus colubrinus, the predator we used in our mark-recapture studies (Element 5, 1989 Annual Report). In the summer of 1986, a period when insect biomass was at its highest for the entire period of the study, a consistently higher biomass of predators relative to prey were collected at FCD as compared with FEX (See Figure 4.14). (The predator/prey ratio index was the only data set where FCD often had a higher ratio than did FEX.). This ratio, as well as total insect mass values will be important parameters to monitor during the course of the study, as they encompass much data regarding community dynamics. Given that results for both are usually not confounded by site x year interactions, these parameters will continue to be valuable in our monitoring program.

TABLE 4.11

2-Way ANOVAS for Tests of Differences in Predator/Prey
Ratios (Arcsin Transformation) by Season

A = 1984 through 1989

B = 1984, 1985, 1987 - 1989

A. ALL YEARS				
Source	d.f.	F-VALUES, LEVEL OF SIGNIFICANCE		
		Spring	Summer	Fall
Site	1	9.74**	14.44***	1.41
Year	5	1.47	2.30*	2.62*
Site x Year	4	0.84	2.31*	1.88
Error degrees of freedom				
d.f. = 108 spg d.f. = 168 summ; d.f. = 168 fall				

B. EXCLUSION OF 1986				

Site	1	9.06**	5.89*	0.09
Year	3	1.33	2.23	3.07*
Site x Year	3	1.10	1.39	1.40
Error degrees of freedom				
d.f. = 90 spg d.f. = 140 summ; d.f. = 140 fall				

Because there were significant year differences for the predator/prey ratios, with all the data included, for the summer and fall months, B.A.C.I. tests were run to see whether the 1984 - 1986 years were systematically different from the 1987 - 1989 years for the summer and fall seasons (Table 4.12).

TABLE 4.12
Results of B.A.C.I. Comparisons for Predator/Prey
Ratios at FEX vs. FCD. Summer, Fall

Summer BEFORE: 1984-1985, AFTER: 1987-1989
Fall BEFORE: 1983-1985, AFTER: 1987-1989

SEASON	Transform	Tukey's Test for Additivity		T-test	
		df.	F-value, sig.	df.	T-value sig.
Summer	log (X+1)	4	0.72 n.s.	16	0.21 n.s.
Fall	log (X+1)	7	9.00 *	22	n.a.

There were no significant differences before versus after ELF activation for predator/prey ratios during the spring (Table 4.11) and summer months (Table 4.12). As the fall data did not pass Tukey's Test, the significant year differences for the fall cannot be analyzed with a B.A.C.I. test.

Physical Factors as related to Total Insect Mass and Diatom Densities

Discharge rate and water temperature were two physical parameters associated with biological parameters, including total insect biomass and periphyton density. Table 4.13 gives correlation coefficient values for them from October 1983 through October 1989. (November through March data each year are excluded, as discharge data are lacking during those times.)

Figures 4.15A and 4.15B show the negative relationship between discharge rate and insect biomass and between discharge rate and periphyton density. May is a month when both insect biomass and periphyton density have a potential for being high. However, discharge intensities can fluctuate during that month, depending on past snow cover and the timing of the influx of melt waters. For those reasons May values for each year are marked. Before 1989, the relationship between discharge and insect biomass values each May was clearly linear. Discharge rates in the spring could be a good index for insect and periphyton mass at that time in the Ford River.

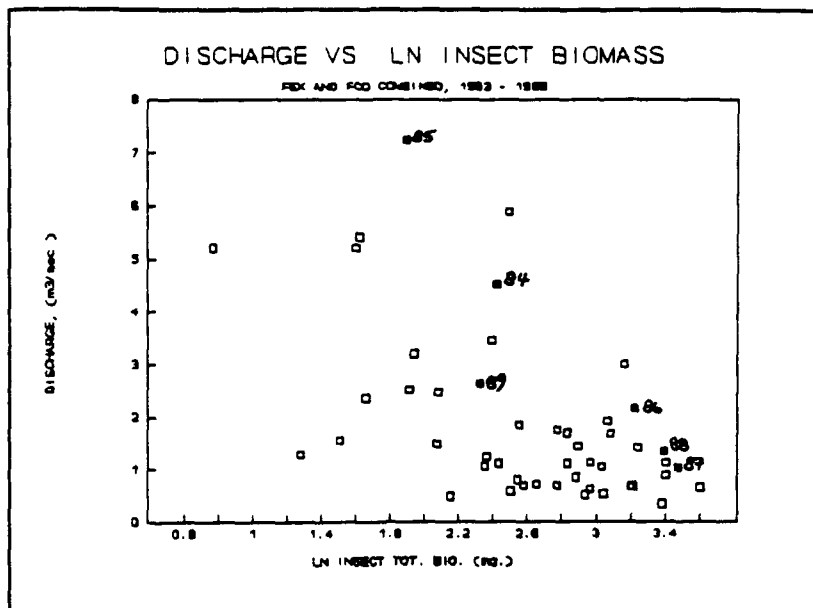


Figure 4.15. Discharge versus Ln of mean insect mass (mg.). July 1983 - November 1989. Black squares: May of each year

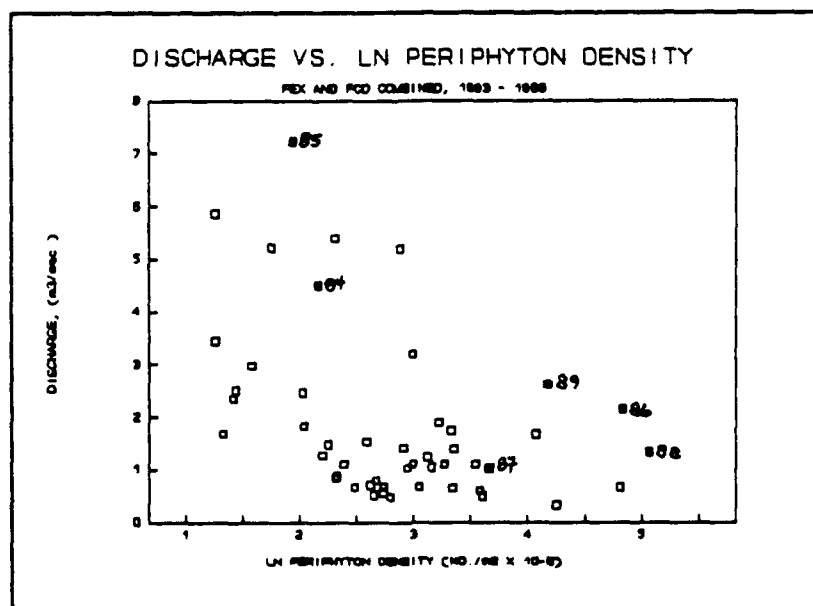


Figure 4.16. Discharge versus Ln Periphyton Density (No./m² x 10-8), both sites combined. July 1983 - November 1989. Black squares = May of each year.

□

TABLE 4.13

Correlation Coefficients for Biological
and Physical Parameters from October 1983
through October, 1989.

	Ln Perif. Density No/M2 X 10-8	Ln Insect Biomass mg X 10-1	Water Temp. °C.	Discharge Rate M3/Sec.
Ln Perif.	1.00			
Ln Insect	.52	1.00		
Water	.44	.55	1.00	
Discharge	-.43	-.54	-.47	1.00

Critical value (1-tail, .05) = $\pm$ 0.25

Critical value (2-tail, .05) = $\pm$ 0.29

Because ln total insect mass was correlated with mean discharge values, ANCOVAS were performed, using discharge as the covariate and total insect mass as the variate (Table 4.14). These analyses were performed for the spring, summer, and fall months separately and replicates rather than sample means (used in B.A.C.I. tests) were used.

TABLE 4.14

ANCOVAS for Total Insect Mass (mg.) and
Mean Discharge (m³). Spring, Summer, Fall
1984 - 1989

Season, Source	d.f.	SS	MS	F, sign.
SPRING				
Diff. between adj. means				
Adj. Means	1	1.0991	1.0991	1.314 ns.
Error	117	97.8000	.8366	
Diff. between slopes				
Slopes	1	3.8150	3.8150	4.705*
Sum group dev.	116	94.0650	.8109	
			Common slope: -.3765	
FCD slope: -.245				
FEX slope: -.494				

TABLE 4.14, continued

Season, Source	d.f.	SS	MS	F, sign.
SUMMER				
Diff. between adj. means				
Adj. Means	1	9.6367	9.6367	30.99***
Error	177	55.0472	.3110	
Diff. between slopes				
Slopes	1	.9542	.9542	3.10 ns.
Sum group dev.	176	54.0930	.3074	
				Common slope: -.4791

FALL				
Diff. between adj. means				
Adj. Means	1	9.7638	9.7638	23.74***
Error	117	48.1138	.4112	
Diff. between slopes				
Slopes	1	.0510	.0510	.12 ns.
Sum group dev.	116	48.0630	.4143	
				Common slope: -.3174

ANCOVAS showed that the pattern for the spring months differed from the summer and fall months. In the spring, the adjusted mean values between the sites did not differ, but the slopes differed significantly. With increasing discharge (up to 6.27 m³), responses to insect mass loss differed between sites; more mass was lost at FEX (Table 4.14, Spring). During the summers, mean discharge values never exceeded 4.56 m³. In that season insect mass at FEX was higher than at FCD, resulting in a significantly higher adjusted mean value at FEX. The fall period showed the same pattern as the summer period. There were no slope differences between sites during the summer and fall months, indicating that although insect mass was higher at FEX, insect responses to discharge at each site were similar.

Changes in Mean Dry Weights Per Individual:

Six species were selected for studies on changes in MDW/IND values: three collector-gatherer mayflies, Paraleptophlebia mollis, Ephemerella invaria, and Ephemerella subvaria; two collector-grazer caddisflies, Glossosoma nigrior and Protoptila sp.; and one coleopteran, Optioservus sp. (Samples were collected mid-month each year. They were collected within five days of each other for each month every year.).

Figures 4.17A and 4.17B show changes in MDW/IND for E. invaria and E. subvaria.

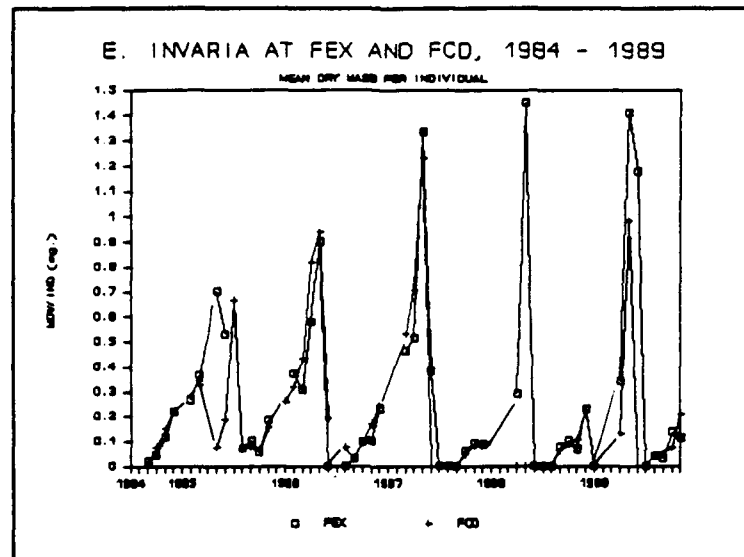


Figure 4.17A. Changes in MDW/IND values for Ephemerella invaria at FEX and FCD. June 1984 - November 1989.

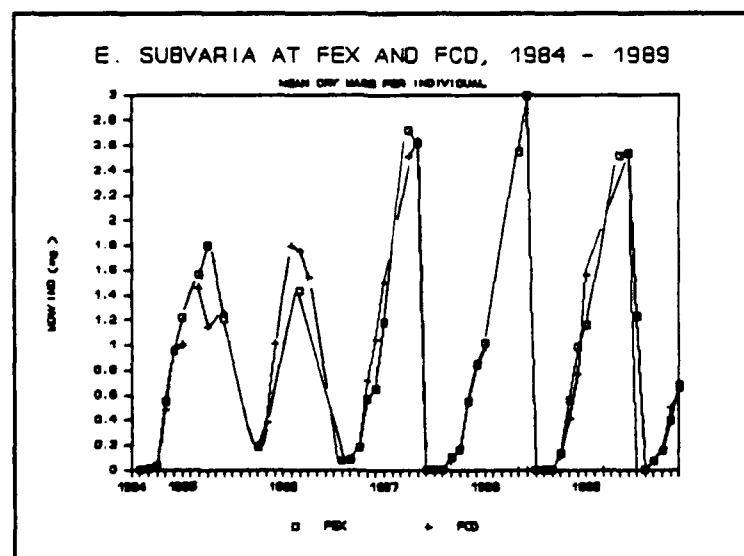


Figure 4.17B. Changes in MDW/IND values for Ephemerella subvaria at FEX and FCD. June 1984 - November 1989.

Ephemerella invaria is most abundant in the early fall when its MDW/IND value is low. It is univoltine, with its major emergence being in late spring. It is only half the size of its sister species, E. subvaria. We collect samples once a month. We were able to collect the final instars of E. invaria in May of 1987, 1988 and 1989. Graphical analysis (Figure 4.17A) does not reveal differences in emergence times after ELF activation. The gaps in this figure are owing to the fact that we no longer sample in December through March each year. Ephemerella subvaria is less common than is E. invaria, and therefore, there are more gaps in Figure 4.17B. However, it is possible to see the major emergence periods for this univoltine species. Its major peaks were in May of 1987 and in June of 1988 and 1989.

Paraleptophlebia mollis has very regular emergence patterns. It is also very common at both sites throughout the year. This species best fulfills our criteria of a univoltine and numerically abundant species, Figure 4.18A.

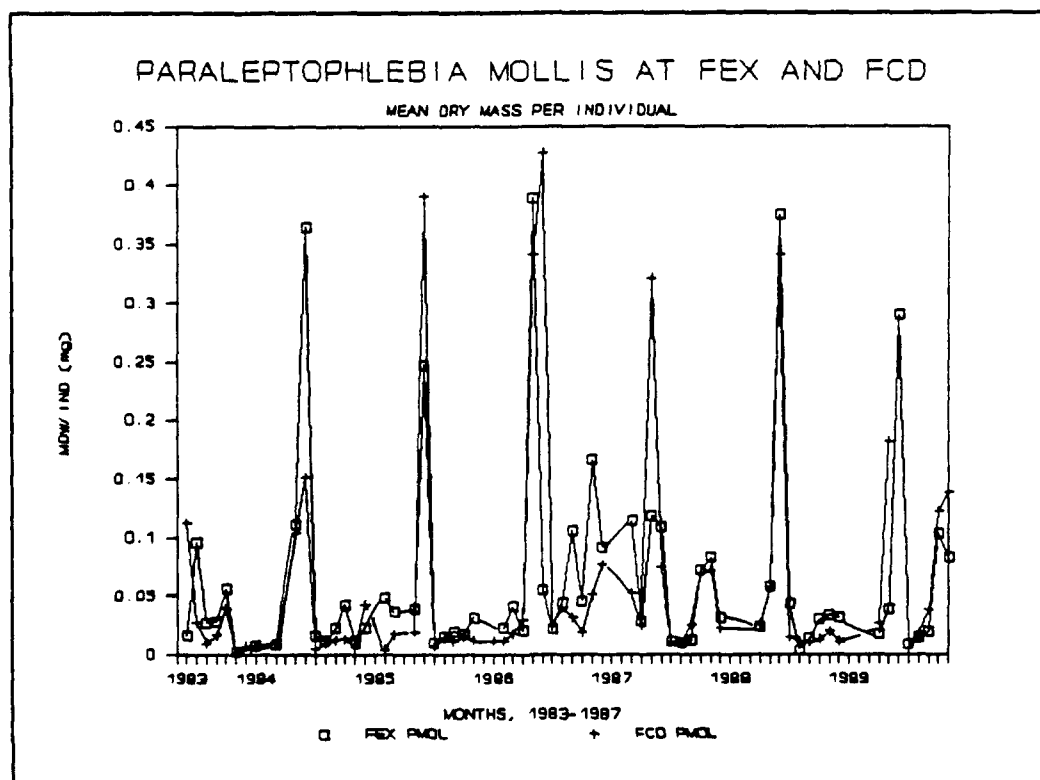


Figure 4.18A. Changes in MDW/IND values for Paraleptophlebia mollis at FEX and FCD. November 1983 to November 1989.

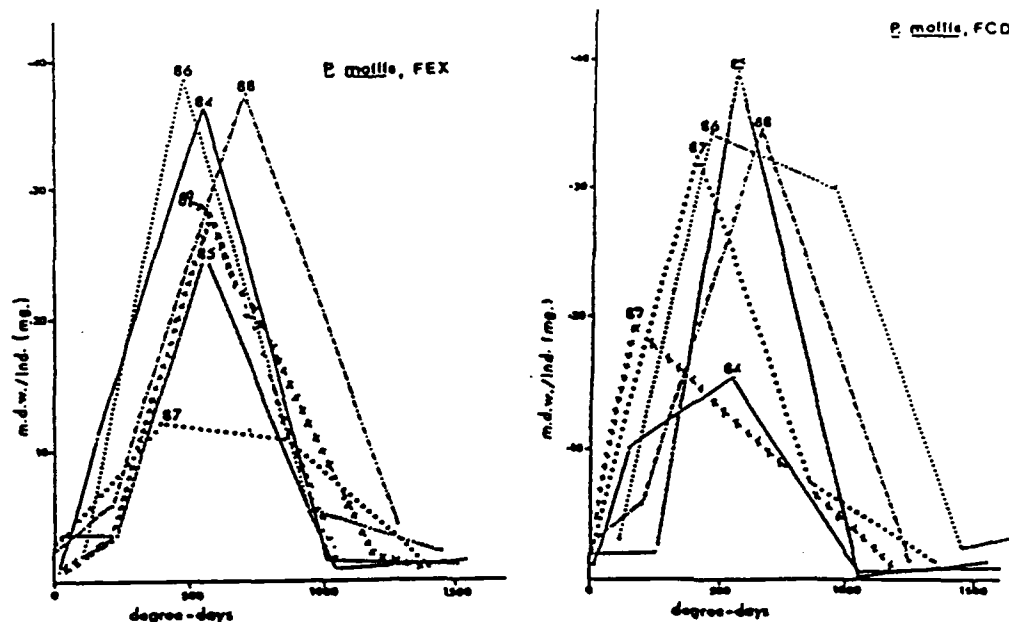
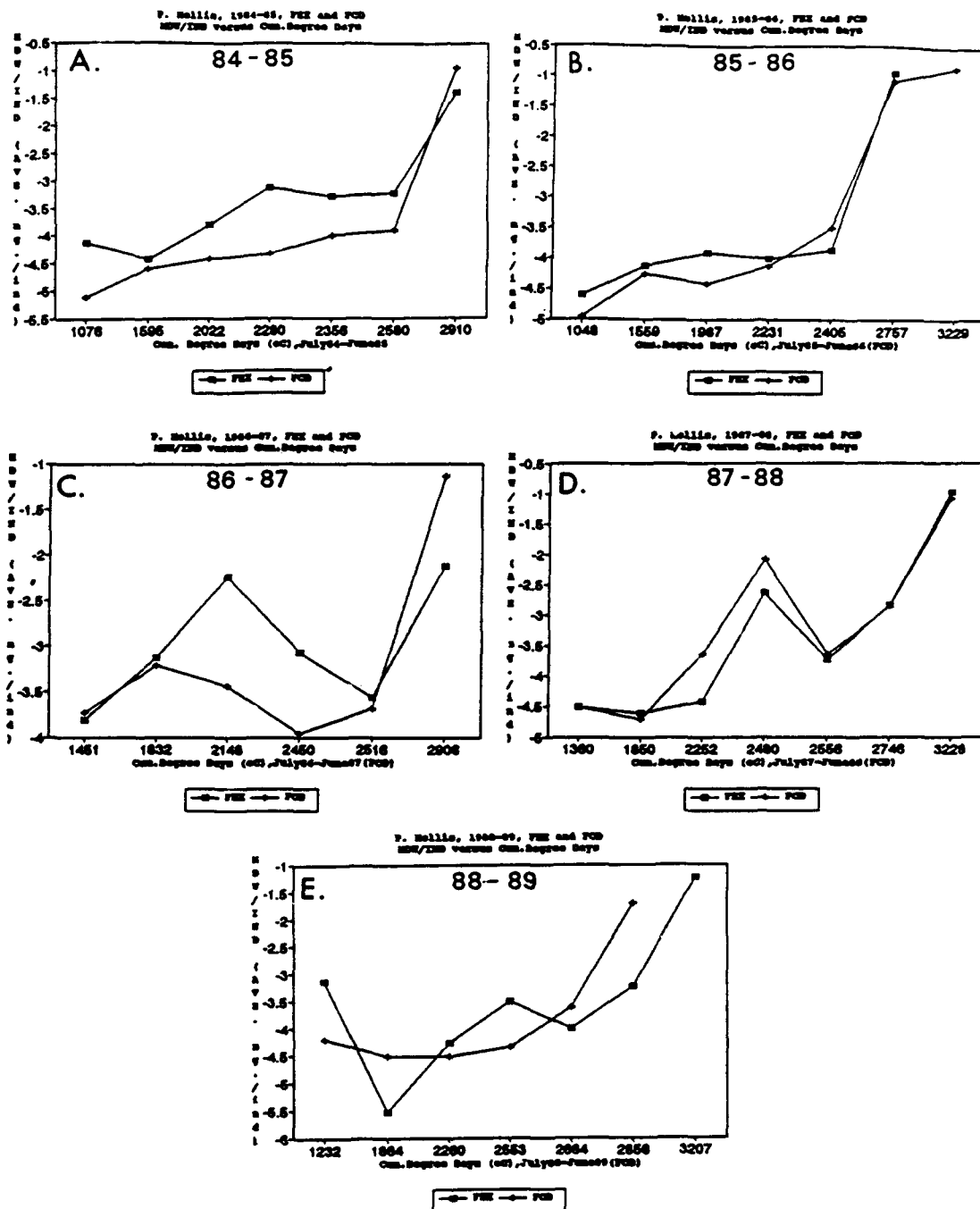


Figure 4.18B. Changes in MDW/IND values for Paraleptophlebia mollis versus cumulative degree days. FEX= first panel; FCD= second panel. April - July data, 1984 through 1989.

Figure 4.18B shows changes in MDW/IND values according to cumulative degree days. By presenting the data in this manner, it is possible to more easily see whether the peaks in individual biomass were found at each site. More importantly, we can see the number of cumulative degree days it took to achieve a certain size class at each site. If ELF seriously affected numerical abundance, seasonal growth patterns, and/or emergence patterns of this species, we should be able to detect changes more easily, using cumulative degree days. Figures 4.19 A,B,C,D, and E show plots of growth rates (as estimated from $\ln$ MDW/IND values) versus cumulative degree days at each site from 1984-85 through 1988-89. In 1984 through 1986 there is a steady increase in growth rates for the species at both sites, with maximum growth occurring between May and June each year. In the following years, for the most part, there were spurts of growth during the fall. Figure 4.19 C shows a decided increase in growth rate between August and September at FEX; Figure 4.19 D shows decided increases in growth rates between September and November; and Figure 4.19 E shows an increase between August through October at FEX. The decided decreases in MDW/IND values from September or November to April may be owing to several factors, none of which appear to be ELF-related. There could be size-selected predation of this species by insectivorous fish during those mild winters when P. mollis increased in size. There could be differential losses in



Figures 4.19 A,B,C,D,E. Ln changes in MDW/IND for *P. mollis* at FEX and FCD from July through the following May or June each year versus cumulative degree-days ($^{\circ}\text{C}$) at FEX and at FCD. A: 1984-1985; B: 1985-86; C: 1986-87; D: 1987-88; E: 1988-89.

the larger size classes during springfloods, or, finally, there could be sampling error ($n=5$). In any case, the overall patterns between FEX and FCD for this species are very similar. These growth rates cannot be linearized by any transform, including the $\ln$ transform. Although there is year to year variability, sites each year are similar, suggestive of no ELF effects.

Maximum sizes for *P. mollis* were always found in May or June each year. We made efforts to see whether cumulative degree differences could account for the observed maximum size classes. Figures 4.20A and B show no relationship between MDW/IND and cumulative degree days. It is not appropriate to perform ANCOVA analyses. We collect substrates once a month, and in so doing, may "miss" the maximum size class prior to ecdysis. The leafpack studies (Element 6) contain more temporally fine-tuned data, and can be analyzed statistically, using ANCOVAS.

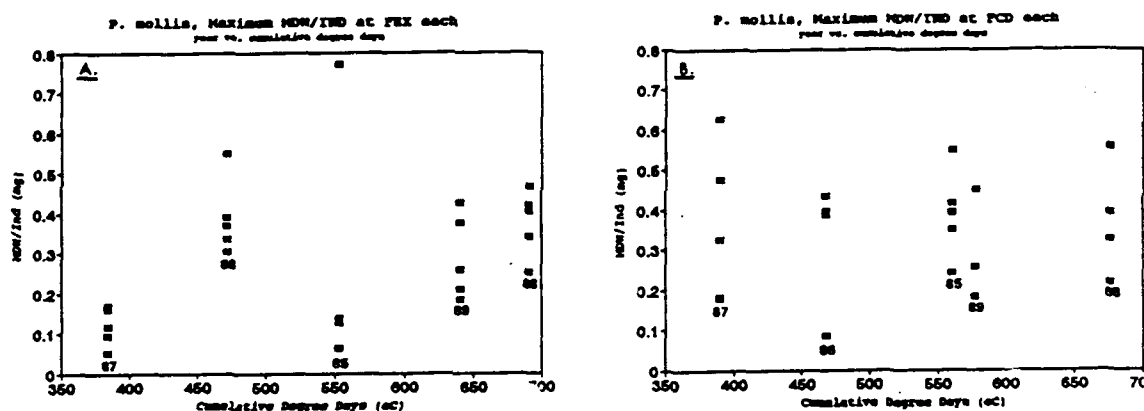


Figure 4.20A, 4.20B. $\ln$ MDW/IND values of *P. mollis* versus cumulative degree days. A: FEX; B: FCD.

Optioservus sp. is a genus that probably has more than one species in the Ford River. However, because of its high numbers, changes in numbers of adults, numbers of nymphs, and changes in MDW/IND values are monitored. Figure 4.21A presents numbers of adults at FEX and FCD, and Figure 4.21B presents numbers of larvae at FEX and FCD. There have been consistently more adults and more larvae at FEX than at FCD over time. This has been true before as well as after ELF activation. In future reports, analysis of larval to adult ratios among seasons will be made.

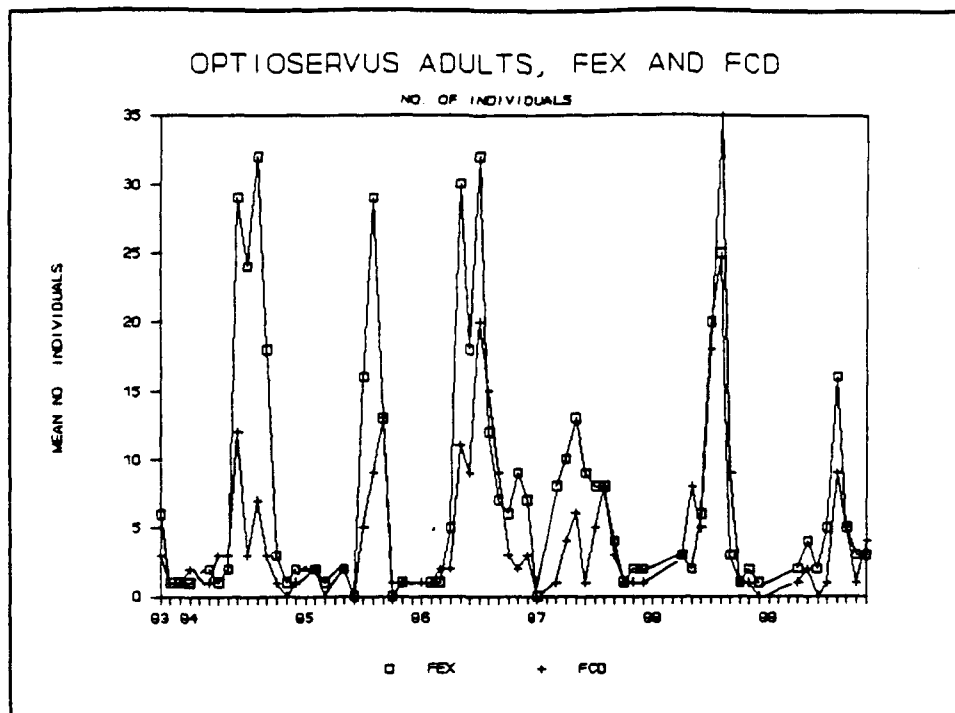


Figure 4.21A. Numbers of adults of Optioservus sp. at FEX and FCD. November 1983 through November 1989.

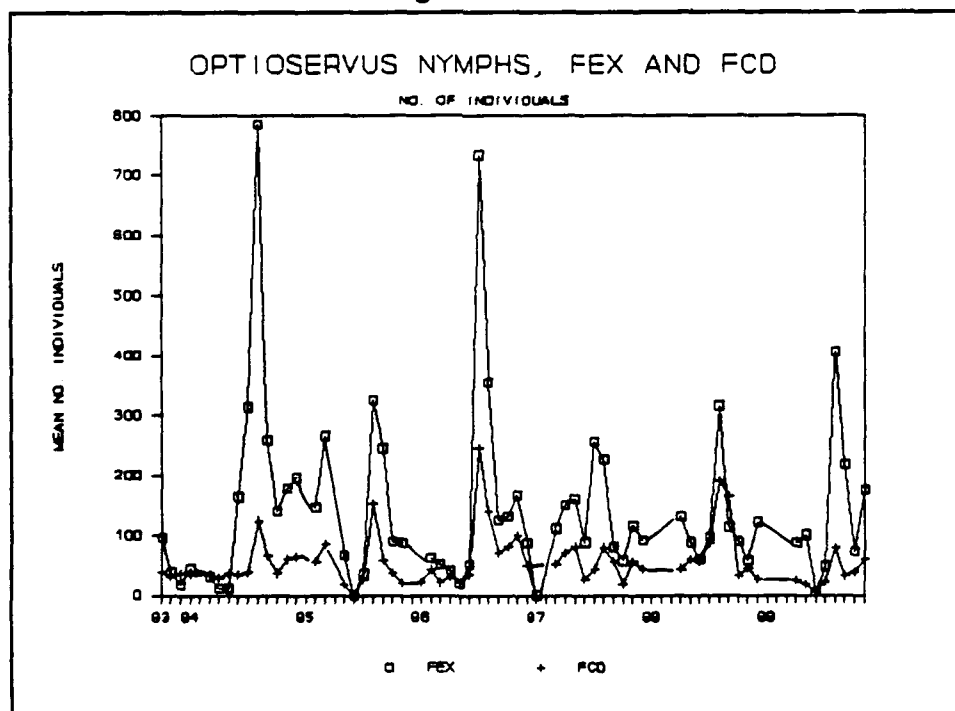


Figure 4.21B. Numbers of larvae of Optioservus sp. at FEX and FCD. November 1983 through November 1989.

Protophila sp. is most common during the mid-summer (Figure 4.22A), just after emergence in mid-May (Figure 4.22B) of the prior year's young. In 1989, there were heavy rains in late May and in June, which we feel contributed to the low numbers of individuals and lack of large individuals during that time. Numbers of individuals will be compared at the two sites to see whether there were any differences among the years. We feel we have 'captured' too few large-sized individuals; therefore, analyses of changes in MDW/IND may be impossible.

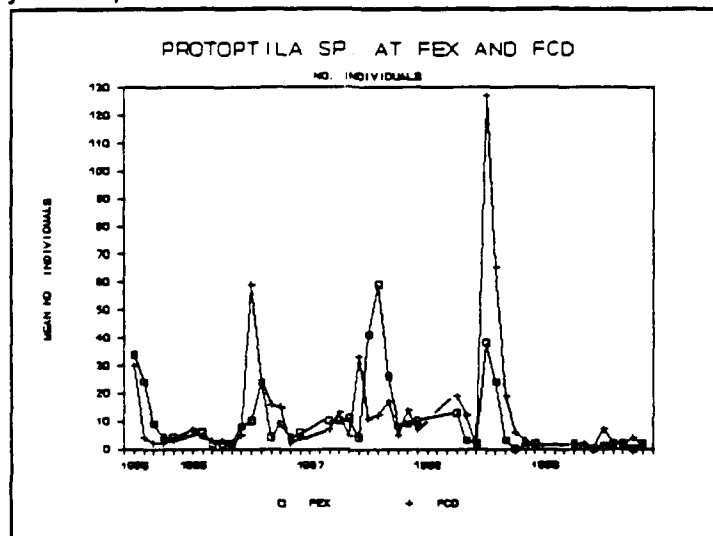


Figure 4.22A. Changes in numbers of individuals of Protophila sp. at FEX and FCD. May 1985 through November 1989.

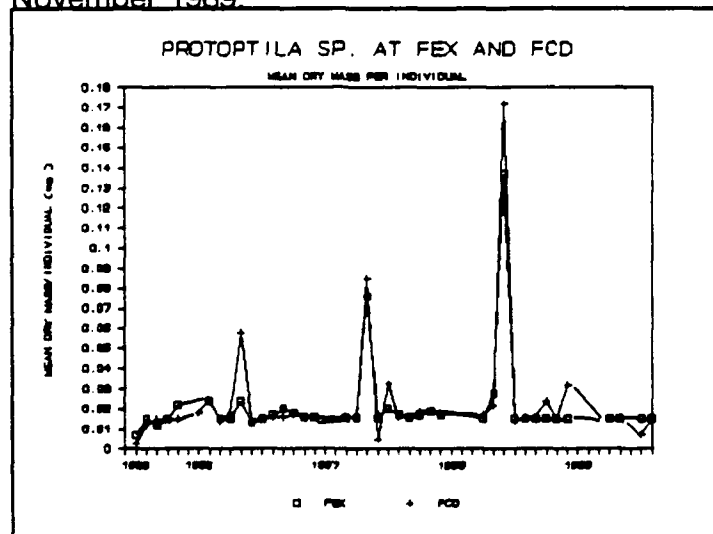


Figure 4.22B. Changes in MDW/IND for Protophila sp. at FEX and FCD. May 1985 through November 1989.

Glossosoma nigrior, which is in the same family as Protophila and is a collector-grazer, is most abundant at FEX (Figure 4.23A). The numbers of individuals at the two sites are during the summer periods; its peak size is in May of each year (Figure 4.23B). We have found fewer numbers of individuals of this species at the two sites than of Protophila sp. Analyses similar to those for that latter species will be made for G. nigrior for the future Annual Report.

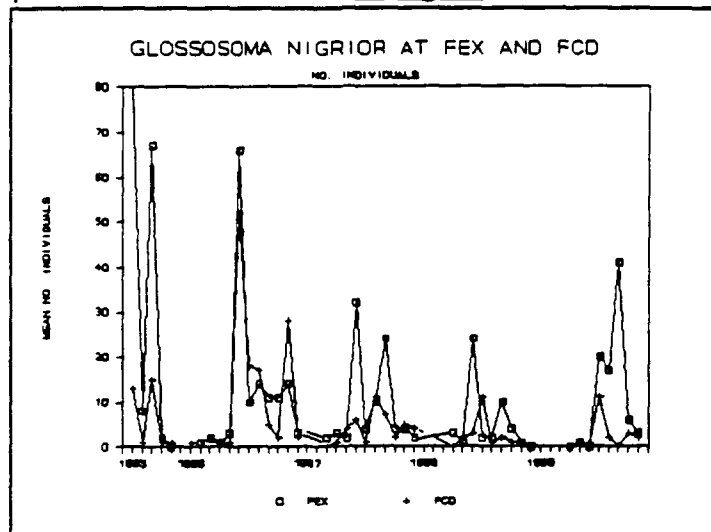


Figure 4.23A. Numbers of individuals of Glossosoma nigrior at FEX and FCD. May 1985 through November 1989.

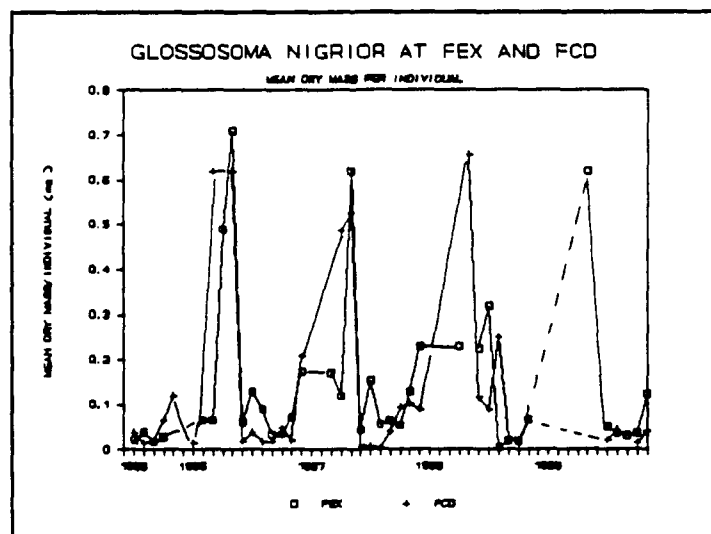


Figure 4.23B. Changes in MDW/IND for Glossosoma nigrior at FEX and FCD. May 1985 through November 1989.

Chironomids were only identified to family level for reasons explained earlier. As there are so many individuals of this family in samples, a plot of changes in MDW/IND values is presented (Figure 4.24). Even though the graph represents size classes of a number of species, there is a general pattern that emerges; i.e., large individuals are more abundant during the summer months and small individuals are more abundant during the fall and early winter months. These seasonal differences probably reflect replacements of summer emerging with fall growing species. If person power and money were no object, it would be a good idea to select at least one species and follow its numbers and growth patterns through the seasons.

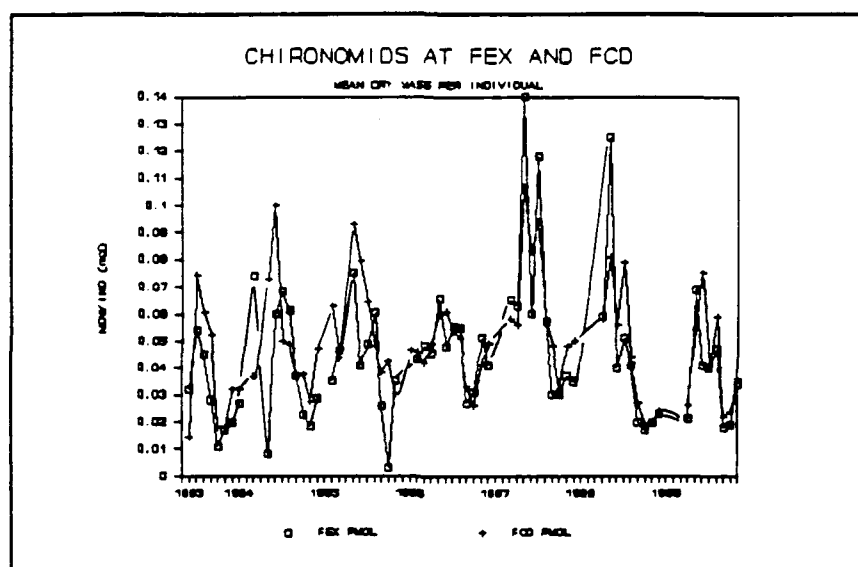


Figure 4.24. Changes in MDW/IND for chironomids at FEX and FCD. November 1983 through November 1989.

Structural and Functional Community Parameters as related to E.L.F. Cumulative Exposure, Discharge, and Temperature

At least once each year, ELF fields are measured at the experimental and reference sites on the Ford River. The measurements are then used to determine intensities (millivolts) when the ELF system is operational. Cumulative exposure data were determined by multiplying ground intensity (from known amperage) by duration for each exposure day. Raw data were kindly supplied by I.T.T.R.I. Figure 4.25A shows an arithmetic plot and Figure 4.25B shows a log plot of cumulative exposure for each collection period (cumulative millivolts) versus time at FEX and FCD.

Figure 4.25A.
Cumulative exposure to
ELF fields by insects in
substrates at FEX and
FCD. April 1986 -
November 1989.

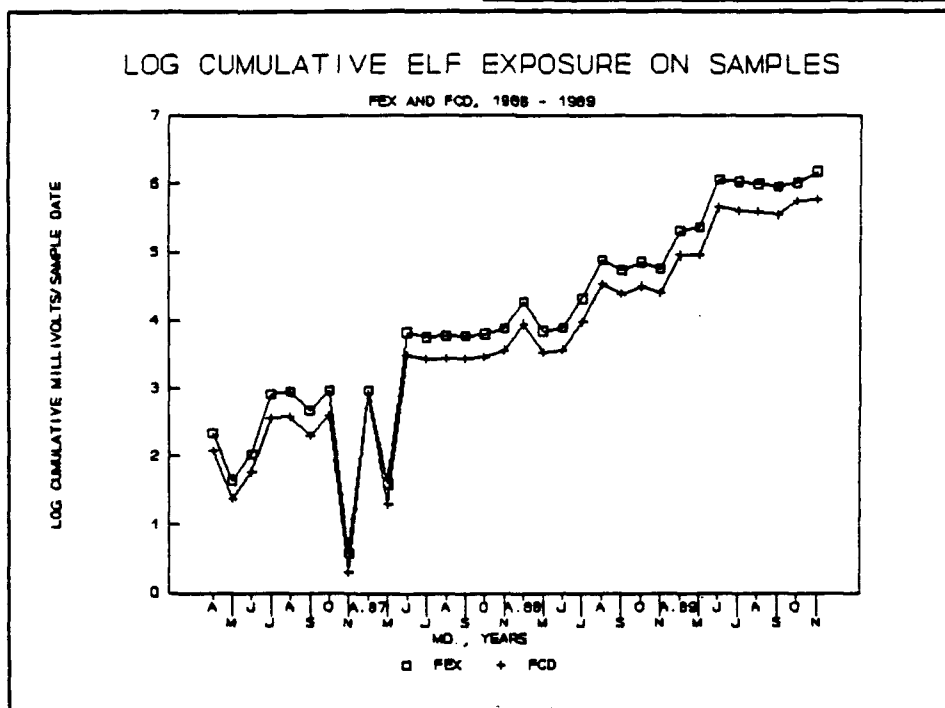
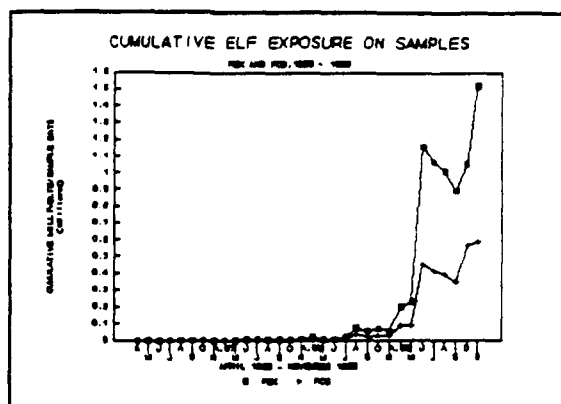


Figure 4.25A. Log cumulative exposure to ELF fields by insects in
substrates at FEX and FCD. April 1986 - November 1989.

Cumulative exposure to the insects in the substrate samplers were determined by taking the date the samplers were put in the stream (Day 0) and then summing the daily exposure values until the samplers were retrieved. The time span was 28 to 30 days for May through October each year. April samples (and sometimes May samples if water was too high to sample with replacement) would have been in samplers at the experimental and reference sites from mid-September of the previous year. November samples would

also have been exposed from mid-September. As described in the Materials and Methods section, it is not feasible to replace samplers when ice and cold weather prevent samples from being processed on-site and prevent samplers from being placed at least 15 cm into the substrates.

Independent variables include years, ELF cumulative exposure to ground fields, discharge, and cumulative degree days (Table 4.15) season by season. The dependent variables included the structural community variables taxon diversity, evenness, richness, and numbers of individuals. Those excluded the family Chironomidae, as it was not feasible to identify the midges below family level. The functional community variable, total insect mass, was also used as a dependent variable for these analyses. That parameter included chironomid mass, as identifications were immaterial to the values.

TABLE 4.15
Multiple Linear Regressions for Biotic Parameters versus
E.L.F. Cumulative Exposure, Discharge, Cumulative Degree Days
Spring, Summer, Fall, 1986 - 1989

<u>SPRING</u>					
<i>Dependent Variables, R² and F Values</i>					
<i>Independent variables</i>	Diversity	Evenness	Richness	Ln Number of Individuals	Total Biomass
FEX					
R ²	.347	.475	.433	.695	.363
Years	1.485	2.182	.310	.846	.665
ELF	2.785	4.515**	.000	2.982	1.441
Discharge		.299	.270	9.663***	16.199***
Cum.D.Day	3.522	2.487	.974	.980	.275
FCD					
R ²	.297	.092	.529	.616	.583
Years	.039	.322	1.569	3.239	.823
ELF	.194	.328	.017	.475	.025
Discharge	1.447	.375	7.711***	17.085***	11.34***
Cum.D.Day	3.405	2.870	.129	.668	.226

Coefficient of Multiple Determination (R²) is > 0.50.

Table 4.15, continued

<u>SUMMER</u>					
<i>Dependent Variables, R² and F Values</i>					
<i>Independent variables</i>	Diversity	Evenness	Richness	Ln Number of Individuals	Total Biomass
FEX					
R ²	.843	.792	.718	.391	.391
Years	7.355**	6.066*	.002	9.020**	1.462
ELF	10.016**	7.982**	.222	8.252**	.740
Discharge	4.838	3.463	31.876***	7.660**	11.330**
Cum.D.Day	39.539***	37.546***	.271	20.184***	1.305
FCD					
R ²	.385	.275	.618	.387	.629
Years	1.066	.705	2.000	6.710*	1.775
ELF	3.943	2.641	2.610	3.673	3.402
Discharge	.020	16.774***	23.900***	7.494**	32.12***
Cum.D.Day	7.722**	7.283***	.466	.290	2.017
<u>FALL</u>					
FEX					
R ²	.496	.373	.572	.524	.426
Years	.271	.007	4.184	.160	.040
ELF	.164	.176	.014	3.212	1.811
Discharge	.077	.002	.546	2.383	1.581
Cum.D.Day	21.79***	14.5850***	17.845***	18.875***	5.465**
FCD					
R ²	.153	.187	.019	.163	.101
Years	.122	1.348	.010	.495	2.020
ELF	.002	.394	.334	.387	3.903
Discharge	.376	.102	.387	5.753**	1.169
Cum.D.Day	1.139	2.184	.126	.041	1.688

Coefficient of Multiple Determination (R²) is > 0.50.

In the spring seasons, discharge accounted for more of the variation in richness, numbers of individuals and mean total biomass than any other independent variable. In the summer seasons, both discharge and/or cumulative degree days accounted for most of the variation in H' , J' , S , numbers of individuals and total biomass. In the fall seasons, cumulative degree days accounted for most of the variation around each of the dependent variables at FEX. Coefficient of multiple determination values were all very low for dependent variables at FCD during the fall season, and all F -values for the independent values at that site were very low as well (Table 4.15). It was only in the summer seasons at the experimental site that ELF cumulative exposure showed a significant relationship with any dependent variable. Even so, F -values were much higher for discharge or for cumulative degree days than for ELF cumulative exposure or for years (Table 4.15).

Because coefficient of variation values (CV) for the biotic variables used in the multiple linear regression analyses lowest during the summer and sometimes fall seasons, (Figures 4.26 A,B,C through 4.30 A,B,C), effects of ELF fields on those biological variables are most detectable during the summer and, sometimes, fall seasons. Precisely when CV values were low in the summers (Figures 4.26B, 4.27B), most of the variation around the mean values for diversity and evenness at FEX was explained by discharge and cumulative degree days rather than by ELF cumulative exposure.

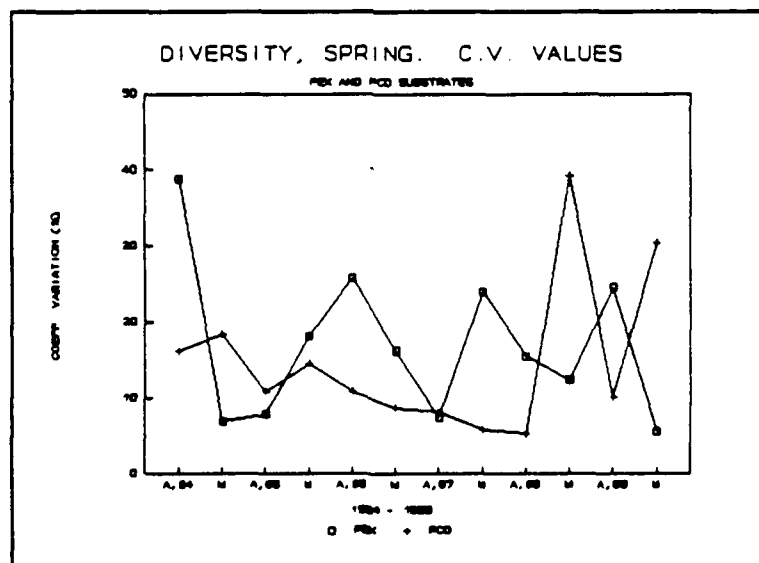


Figure 4.26A. Coefficient of Variation values for Taxon Diversity, without chironomids. SPRING. FEX and FCD. April-May, 1984-1989.

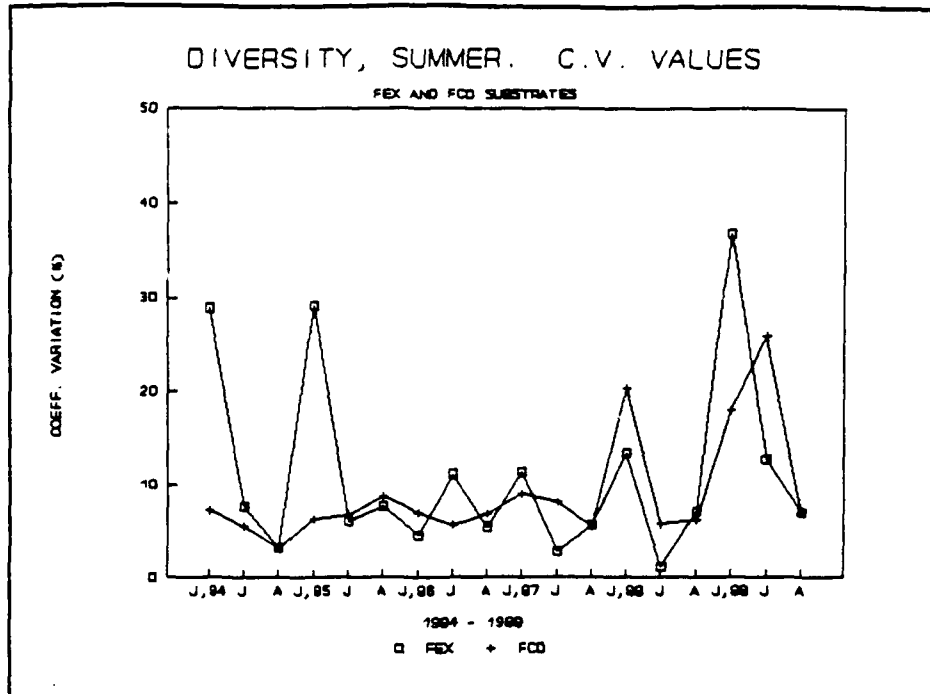


Figure 4.26B. Coefficient of Variation Values for Taxon Diversity, w/o chironomids. SUMMER. FEX and FCD. June-Aug., 1984-1989.

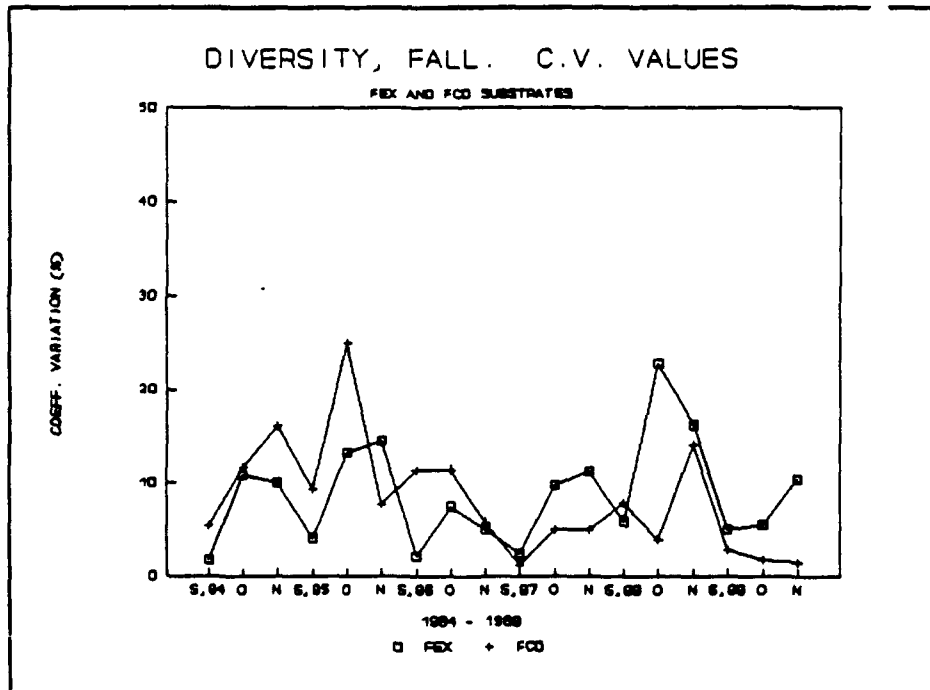


Figure 4.26C. Coefficient of Variation values for Taxon Diversity, without chironomids. FALL. FEX and FCD. Sept.-Nov., 1984-1989.

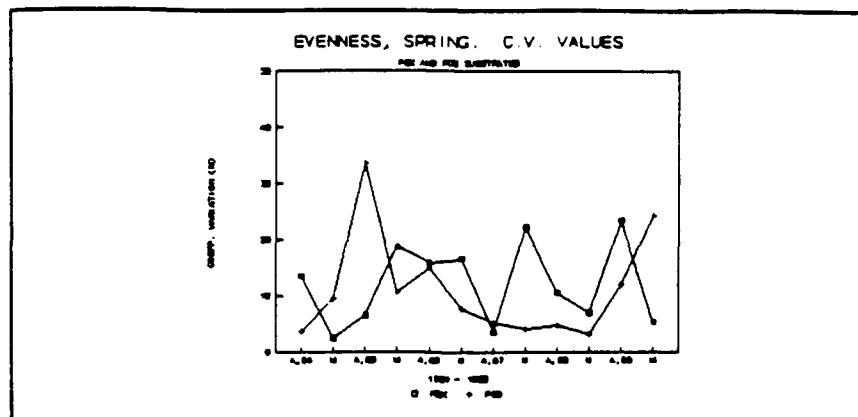


Figure 4.27A. SPRING., April-May.

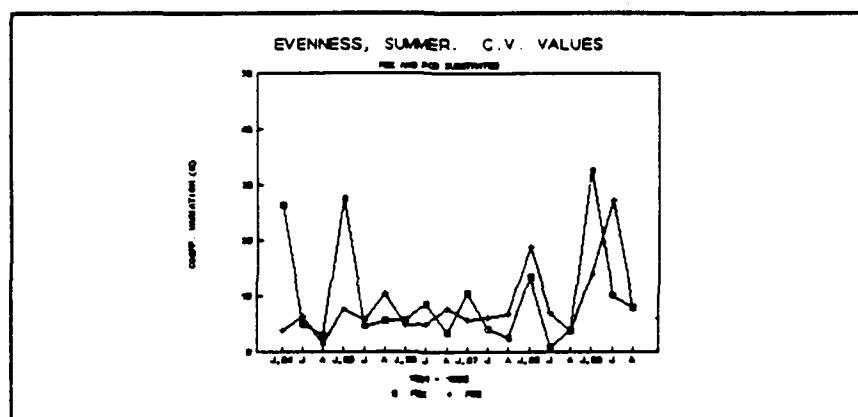


Figure 4.27B. SUMMER, June - August.

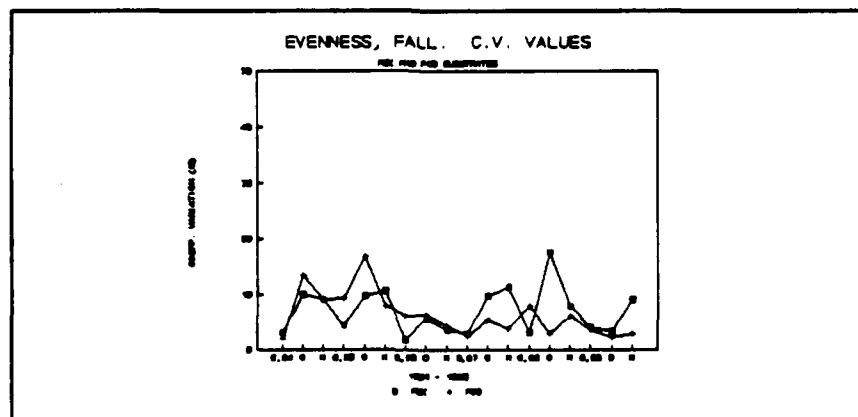


Figure 4.27C. FALL. Sept.-Nov.

Figures 4.27A, 4.27B, 4.27C. Coefficient of Variation values for Evenness, without chironomids. FEX (squares) and FCD (X's). 1984-1989. A: SPRING. B: SUMMER C: FALL

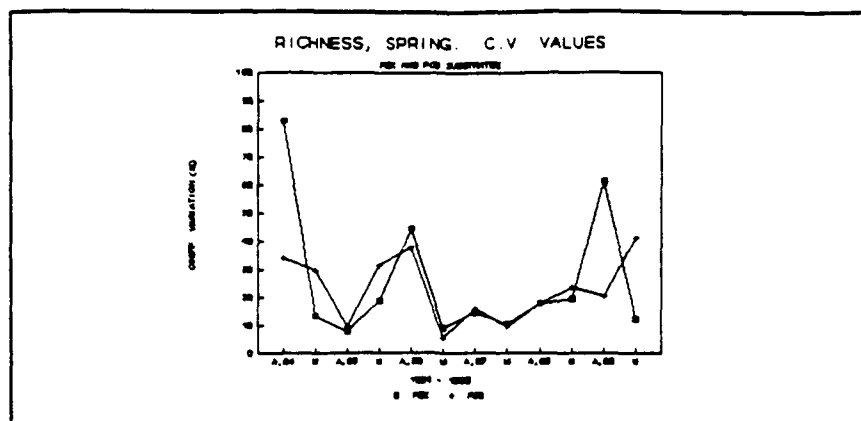


Figure 4.28A. C.V. values. SPRING

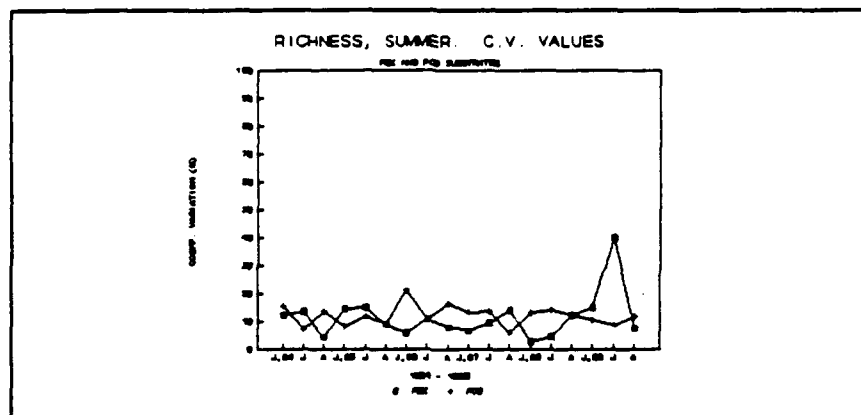


Figure 4.28B. C.V. values, SUMMER.

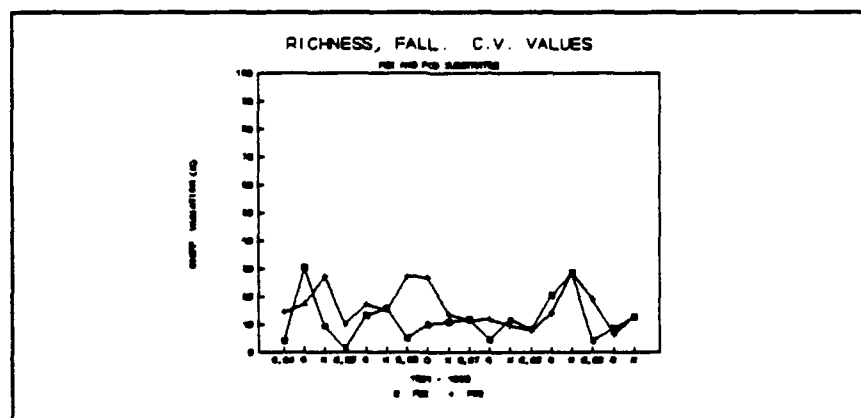


Figure 4.28C. C.V. values, FALL

Figures 4.28A, 4.28B, 4.28C. Coefficient of Variation values for Richness (S') without chironomids. FEX (squares) and FCD (X's). 1984-1989. A: SPRING B: SUMMER C: FALL

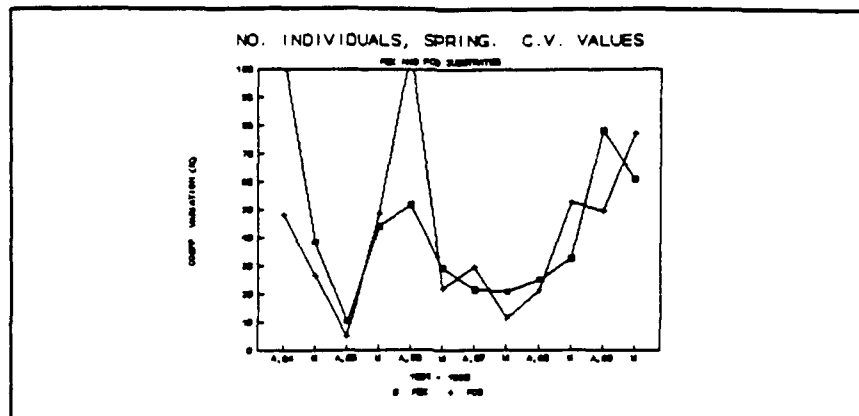


Figure 4.29A. C.V. values, SPRING.

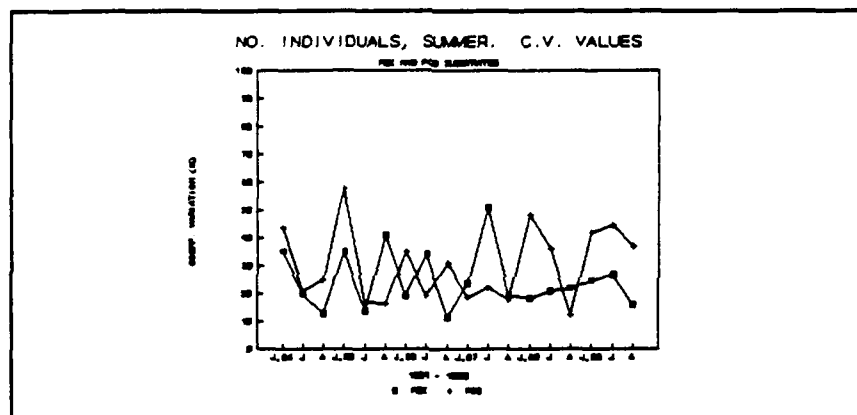


Figure 4.29B. C.V. values. SUMMER.

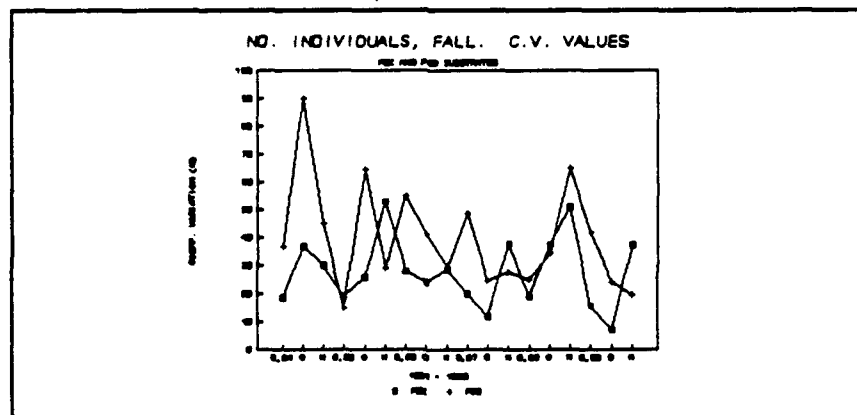


Figure 4.29C. C.V. values. FALL

Figures 4.29A, 4.29B, 4.29C. Coefficient of Variation values for Numbers of Individuals (w/o chironomids). FEX (squares) and FCD (X's). 1984-1989. A: SPRING B: SUMMER C: FALL

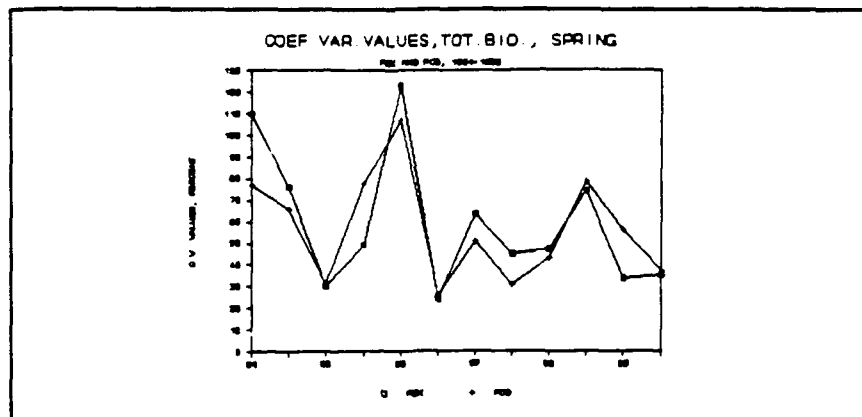


Figure 4.30A. C.V. values, SPRING.

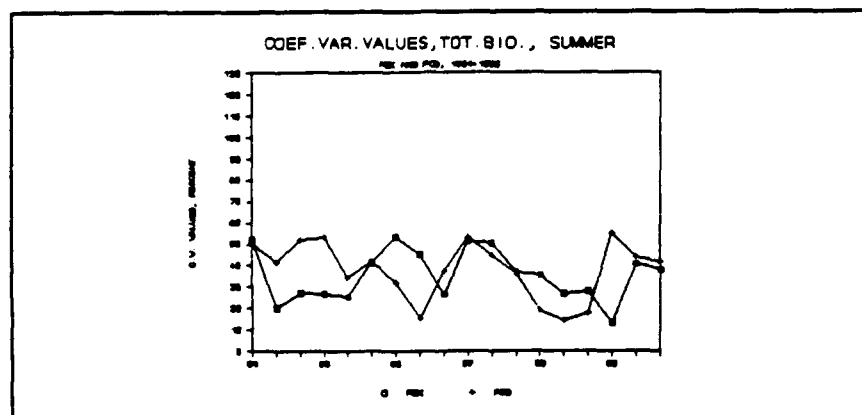


Figure 4.30B. C.V. values, SUMMER.

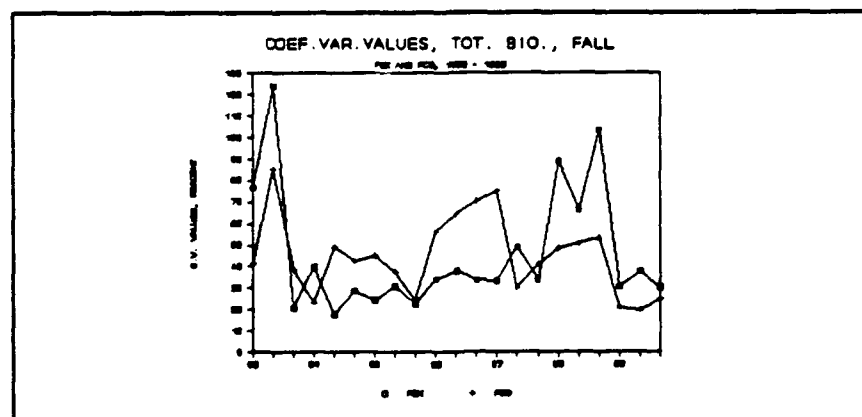


Figure 4.30C. C.V. values, FALL.

Figures 4.30A, 4.30B, 4.30C. Coefficient of Variation values for Insect Biomass (with chironomids). FEX (squares) and FCD (X's). 1984-1989. A: SPRING B: SUMMER C: FALL.

A note of caution has to be given at this juncture before interpreting standard partial regression values for spring and fall seasons. Average spring discharge over the years since ELF activation has shown a distinct trend upwards (Figure 4.5A). It has been lower during the summer months and the yearly variation has shown no trend (Figure 4.5B). Fall discharge, after ELF activation, has shown a decidedly downward trend (Figure 4.5C). Cumulative degree days have shown a decidedly warmer trend after ELF activation, especially during the fall months (Figure 4.10C). Figures 4.31A and 4.31B show that 1986 through 1989 have been warmer years than the years before ELF activation (1983 - 1985). 1990 water temperatures were more 'average' and more similar to the 1983 through 1985 years than they were to the 1986 - 1989 years. If cumulative degree days have a strong impact on insects in the substrates of the Ford River, one would expect that the 1990 Annual Report will reveal less of a before versus after difference than has this Report. Even though ELF fields would not be expected to be related to discharge or to water temperatures (except in some wildest imaginations), they all, nevertheless, show non-randomness through the springs and through the falls of 1986 - 1989. The three independent variables are more orthogonal to one another during the summer months because there is no distinct trend over the years for discharge (Figure 4.5B) and for water temperatures, as reflected by cumulative degree days (Figure 4.10B). One is on 'sturdier' ground when interpreting summer data for this reason as well as for the reason that CV summer values are lower than for spring and fall biological data.

As presented earlier, Two-Way ANOVA tests showed that there were site as well as year differences for taxon diversity and evenness during the summer months (Table 4.4). B.A.C.I. tests for those variables showed there were no significant differences before versus after ELF activation between the two sites (Table 4.5). Multiple linear regression tests (using all the replicates rather than the means needed in B.A.C.I. tests) showed that ELF cumulative intensity accounted for little of the variation in diversity and evenness during the summer months over all the years of the study. In the next Annual Report, these multiple linear regressions will be performed separately; first, on years before ELF activation, and second, on years after ELF activation. If the same pattern emerges for both periods of time, the effects of ELF activation will be shown to be trivial in comparison with the non-anthropogenic physical factors, that is, discharge and cumulative degree days. As for now, it makes biological sense that discharge should be most important in the spring transition period; that discharge and cumulative degree days should be most important in the summer stable period, and that cumulative degree days be the most important physical variable in the fall cooling down period.

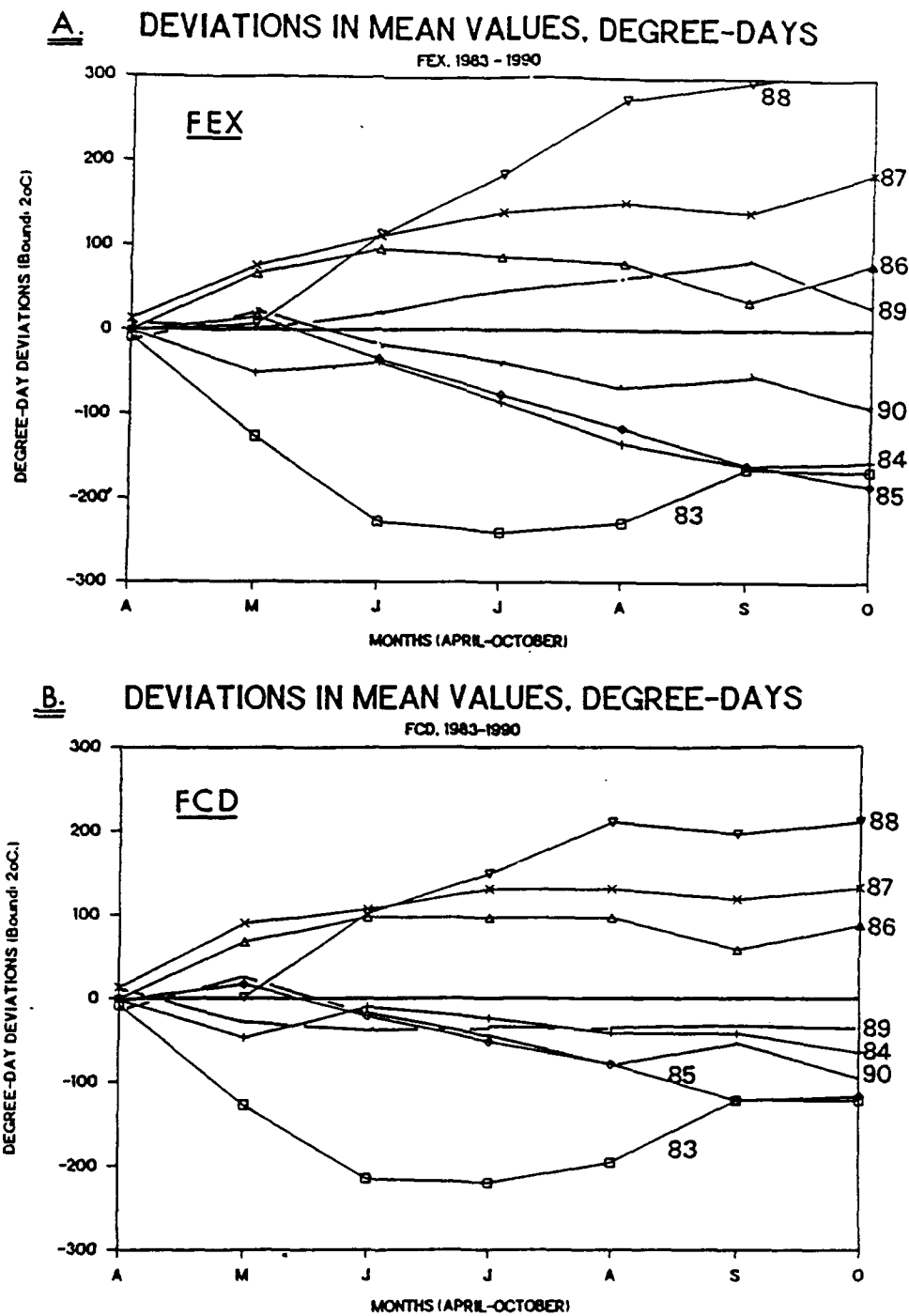


Figure 4.31A, 4.31B. Deviations in mean values over eight years for cumulative degree days, 1983 - 1990. 4.30A: FEX 4.30B: FCD

The relative contribution of ELF cumulative exposures, as well as two other physical factors, to explaining the variability of biotic parameters for insects in substrates has been presented in the above analyses. We realize, however, that other phenomena associated with ELF fields may be even more critical; for example, responses to activation-deactivation transitions or magnetic flux data rather than ground fields. In future analyses, alternative analyses will be performed, using ELF field data.

Future Plans for This Element

The same design and accumulation of data will continue, with the addition of a new site, FEX.LINE. The new site was added in May, 1990 because ELF ground fields are much greater there than at the FEX site. Analyses will include 2-Way and 3-Way ANOVAS, B.A.C.I. tests for before versus after effects, and ANCOVAS and multiple linear regressions for looking at the relationships between physical and biotic variables. In addition, studies will continue to be made on ELF cumulative exposure values. Future studies on possible effects of excursions from 'on-off' times will also be used.

As it appears that cumulative degree days is an important independent variable for changes in MDW/IND values for the six species studied, degree days as well as chronological time will be continue to be used for determining whether E.L.F. has any effect on changes in growth rates. In addition, changes in numbers of individuals for these species will be analyzed, using 2-Way ANOVAS for seasonally grouped data, and, when appropriate, B.A.C.I. and ANCOVA analyses. In the next report, a taxonomic similarity matrix on a seasonal basis will be included. Seasonal groupings of those matrices are biologically more meaningful than any other grouping, as determined by coefficient of variation values and by ANCOVAS. The taxa identified thus far at FEX and at FCD appear in Appendix I of this Report.

Summary

Structural and functional community data were grouped according to season for statistical analyses. After looking at coefficient of variation values, the data were grouped into spring (April, May), summer (June through August), and fall (September through November) seasons. The lowest coefficient of variation values were during the summer 'stable' periods. Spring and fall seasons are transitional seasons for the insects. As such, coefficient of variation values are highest during those seasons. Seasons were first analyzed, using 2-Way ANOVAS. When significant year effects for a given

index were found, B.A.C.I. tests were run to determine whether there were significant before ELF activation versus after ELF activation associations. In cases where they were found, ANCOVAS, using physical covariates were run on the data. In most of the cases where B.A.C.I. tests showed significance, there was also a physical covariate that showed significant association with the 'before' versus 'after' data. This occurred because both water temperatures and discharge values differed significantly before 1986 as compared with after 1986 for the spring and fall seasons. This was not true for the summer 'stable' season. It is the summer season where coefficient of variation values are low that the highest probability of detecting an ELF effect exists.

Taxon diversity (H'), taxon evenness (J'), richness (S') and numbers of individuals indices showed the most year to year differences for the fall season. In the nine cases where there were significant year effects for these indices grouped into seasons (determined by 2-Way ANOVAS), B.A.C.I. tests showed a significant before versus after difference in four cases. Three of these four datasets were from the fall season. It was in the fall that the greatest differences in discharge values and in water temperature values occurred after as compared with before ELF activation. ANCOVA analyses associating physical factors with the significant biotic datasets showed significant associations in every case. It appears more parsimonious to attribute significant B.A.C.I. results to physical, natural factors than to ELF effects at this point in time.

Total insect biomass values, grouped into seasonal datasets, showed significant year, site, or year by site effects in four out of the nine cases. Of those four, all three ANOVA factors were significant for the fall season. B.A.C.I. tests for significant year effects were all non-significant. Predator/prey ratio values at the two sites, as analyzed by season using Two-Way ANOVAS, showed significant year effects in the summer and fall seasons. B.A.C.I. analyses showed that there were no significant before versus after effects for those two seasons.

Both discharge values and water temperatures were significantly correlated with $\ln$ insect biomass and with $\ln$ periphyton density. ANCOVA analyses showed that discharge varied with insect biomass. During the spring discharges, biomass of insects at FEX were more negatively impacted than was biomass of insects at FCD. There were significant differences in the means between the two sites during the summer and fall seasons. FEX almost always supports a higher biomass of insects than does FCD.

Graphical analyses were presented for changes in mean dry weight values per individual for six prominent taxa and the two sites. Changes were presented in terms of chronological time, and in one case, in terms of physiological time, cumulative degree day water temperatures.

Paraleptophlebia mollis emerged in May or June of each year. Although the patterns of growth differed from year to year, within each year growth patterns were similar at the experimental (FEX) and reference (FCD) sites, indicating that ELF activation did not affect growth rates of this species. This is the species for which we have the most data, as it is common throughout the years.

Changes in numbers of individuals for these taxa were also presented. In the next Annual Report, these values will be analyzed in a similar fashion as were the structural and other functional community parameters described in this Element.

Multiple linear regressions, using years, ELF cumulative exposure, mean discharge, and cumulative degree days for each collection period as independent variables, showed that in the spring seasons, discharge accounted for more of the variation in richness, numbers of individuals and mean total biomass than any other independent variable. In the summer seasons, both discharge and/or cumulative degree days accounted for most of the variation in H', J', S, numbers of individuals and total biomass. In the fall seasons, cumulative degree days accounted for most of the variation around each of the dependent variables at FEX. Coefficient of multiple determination values were all very low for dependent variables at FCD during the fall season, and all F-values for the independent values at that site were very low as well (Table 4.15). It was only in the summer seasons at the experimental site that ELF cumulative exposure showed a significant relationship with any dependent variable. Even so, F-values were much higher for discharge or for cumulative degree days than for ELF cumulative exposure or for years.

A list of taxa collected at the two sites and on leafpacks appears as Appendix I in this Element. In the 1991 Annual Report, a similarity matrix, grouped by season, will be analyzed. (Similarity matrices were presented in the 1989 Annual Report, but shortage of time at this point prevents their inclusion. Completion of insect identifications through November of 1989 occurred the first week of December, 1990, which prevented construction of the similarity indices for this Report.)

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APPENDIX I

List of Aquatic Insect Taxa from the FEX and FCD sites in the Ford River

EPHEMEROPTERA

Tricorythodes
Drunella cornutella
Dannella simplex
Ephemerella invaria
E. needhami
E. rotunda
E. subvaria
Serratella deficiens
S. sordida
Eurylophella bicolor
Baetis flavistriga
B. vagans
B. macdunoughi
B. pygmaeus
Pseudocloeon parvulum
P. punctiventris
Isonychia sp.
Siphonorus rapidus
Paraleptophlebia mollis
Leptophlebia cupida
Epeorus vitrea
Rhithrogena jejuna
Stenonema vicarium
S. modestum (= S. rubrum)
S. exiguum (= S. quinquespinum)
S. pulchellum
Leucrocuta hebe (= Heptagenia hebe)
Nixe lucidipennis
Stenacron interpunctatum
Baetisca laurentina
Ephemera simulans
Hexagenia limbata

ODONATA

Ophiogomphus colubrinus
O. carolus
Gomphus (Stylurus) scudderi
G. lividus
Dromogomphus spinosus

Hagenius brevistylus
Boyeria vinosa
Cordulegaster maculatus
Calopteryx sp.

PLECOPTERA

Allocaenia
Paracania
Capnia
Haploperla
Alloperla
Suwallia
Acroneuria lycorias
A. abnormis
Paragnetina media
Isogenoides
I. olivaceous
Isoperla transmarina
I. slossonae
Amphinemura
Paranemoura
Pteronarcys
Taeniopteryx nivalis

HEMPITERA

Belostoma flumineum
Lethocerus

TRICHOPTERA

Brachycentrus numerosus
Glossosoma intermedium
G. nigrior
Protophila tenebrosa
Anabolia
Hydatophylax argus
Platycentropus
Pycnopsyche subfasciata
Neophylax nacatus
Ceratopsyche morosa
C. sparna
Cheumatopsyche analis
Potamyia

Hydroptila
Leucotrichia pictipes
Neotrichia
Oxyethria
Lepidostoma
Oecetis avara
Ceraclea angustus
Triaenodes tarda
Mystacides
Setodes incertus
Psilotreta indecisa
Molanna
Chimarra aterrima
Dolophilodes distinctus
Ptilostomis
Neureclipsis crepuscularis
Nyctiophylax moestus
Psychomyia flavida
Lype diversa
Helicopsyche borealis

COLEOPTERA

Ancyronyx variegata
Optioservus
O. fastiditus
O. trivittatus
Macronychus glabratus
Dubiraphia
Helichus lithophilus
Gyrinus
Celina
Dytiscus harrisi
Laccophilus
Paracymus subcupreus

MEGALOPTERA

Nigronia
Sialis

DIPTERA

DOLICHOPODIDAE

Rhaphium

EMPIDIDAE

Hemerodromia

Clinocera

Chelifera

BLEPHARICERIDAE

Blepharicera

TABANIDAE

Tabanus

Chrysops

TIPULIDAE

Antocha

Tipula

T. abdominalis

Hexatoma spinosa

Dicranota

Hesperoconopa

CERATOPOGONIIDAE

Probezzia

Culicoides

CHIRONOMIDAE

Tanytarus

Rheotanytarsus

Microspectra

Stempellinella

Stempellina

Ablabesymia

Pentaneura

Thienemannimyia

Labrundina

Procladius

Procladius cf. sublettei

Nilotanypus

Brillia flavifrons

Parametriocnemus

Corynoneura

Eukiefferiella

E. devonica
E. claripennis
Rheocricotopus
Cricotopus
Thienemanniella
Synorthocladius
Orthocladius
Tventenia bavarica group
T. discoloripes
Diplocladius
Lopescladius
Nannocladius
Chaetocladius
Symposiocladius
Heterotrissocladius marcidus
Xylotopus par
Polypedilum lonvictum
P. scalaenum
P. halterale
P. aviceps
Robackia
R. demeijerei
Microtendipes
Stenochironomus
Cryptochironomus
Saetheria
Parachironomus
Chironomus
Cryptotendipes
Xenochironomus
Paraleuterborniella
Potthastia
Pagastia

ATHERICIDAE

Atherix variegata

SIMULIIDAE

Cnephia mutata
Simulium euryadminiculum
S. corbis
S. quebecense
S. venustum
S. rugglesi

S. jenningsi
S. tuberosum
Prosimulium mixtum
P. mysticum
Ectemnia invenusta

Element 5 - Movement Patterns of *Ophiogomphus colubrinus*

This element was deleted after the field season of 1989, owing to results presented below. The following is a paper submitted to The Journal of Freshwater Biology.

MOVEMENTS OF A DRAGONFLY NAIAD (*Ophiogomphus colubrinus*) IN A NORTHERN MICHIGAN STREAM: A FIVE YEAR STUDY

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ABSTRACT

*Movement patterns of dragonfly naiads in a small northern Michigan stream were followed to determine whether Extremely Low Frequency (ELF) electromagnetic fields could be detected as affecting orientation and rates of movements for this predator. Mark-recapture techniques at two sites, an experimental and a reference site on the Ford River, showed that *O. colubrinus* only moved in a downstream direction and it moved relatively short distances. Nine 24 hr and eleven 48 hr recapture series from 1985 through 1989 showed no consistent differences between the sites with respect to distances travelled even though ELF lines were activated in 1986 and increased in amperage and duration from that time until the system went to full power in 1989.*

INTRODUCTION

Drift is considered as a major phenomenon associated with movements of aquatic insects in streams and rivers (Müller 1974, Waters 1972, Wilzbach et al. 1986). By using drift nets as sampling units, the periodicity of insect downstream dispersion, the behavioral responses of insects to life cycle transitions, density-dependent factors associated with increased downstream dispersion, and responses to increases in discharge, temperature, and anthropogenic inputs can be assessed. However, those assessments are limited to a downstream direction. The results can be confounded if actively moving insects travelling in other directions are caught in the passive drift nets but are recorded as being in the drift. The use of drift nets without other techniques are insufficient when questions as to natural recruitment, recolonization after disturbance, or as to movement dynamics in response to biotic interactions are posed.

Mark-recapture studies employ simple methodologies, but provide a database for answering questions concerned with directions and distances travelled and population size alterations, before and/or after natural or anthropogenic events of interest. They can be used to assess responses to biotic interactions, or to assess any tendencies that a particular species has to home, to name only a

few. As mark-recapture studies using paint or small tags do not require extensive field equipment (as might radioactive isotopes, for example), they are well suited to field work in streams and rivers far distant from the base of operation. Because rheophilic insects are small and usually delicate, few stream ecologists have employed these techniques, even though tag and release methods are the cornerstone for fisheries biologists studying fish movements. The major challenge for the stream ecologist who wants to gather quantitative data on movement patterns of rheophilic insects involves proper selection of the insect group that is appropriate to the question and to the technique. Most aquatic insects are very small and delicate. Even if marking were feasible, many species would experience severe stress if they were partially dried prior to being marked. However, there are several groups of aquatic insects that can be easily and efficiently marked and can be handled without being greatly stressed. They include beetles, true bugs (Stout 1981, 1982), dobsonflies, some stoneflies, and dragonflies (this paper).

Movement patterns of naiads of the dragonfly predator, Ophiogomphus colubrinus, were studied over a five year period in a fourth order river, the Ford River, Dickinson Co., Michigan to determine whether extremely low frequency electromagnetic fields (ELF) altered naiad orientation and subsequent movement patterns. By using mark-recapture techniques, distances travelled per unit time, directions travelled, and population density estimates could be made. This very common predator in the Ford River has physiological and behavioral characteristics that made it well suited for such a study. It has no delicate external parts that can be damaged during the marking process; it can breathe after being removed from water, wiped dry and painted. In the stream, it behaves as a sit-and-wait predator (personal observation) and therefore does not move long distances each day. In one day the entire section of stream in which the marked animals would potentially move can be sampled.

Until now, no research has been published on the potential effects of ELF fields on aquatic insects. ELF fields affect honeybee behavior and orientation (Bindokas et al. 1989, Walker and Bitterman 1989), bacterial orientation (Kalmijn and Blakemore 1978) and movements of several species of aquatic vertebrates (Kalmijn 1978). Magnetite, a biogenic compound that is associated with geomagnetic sensitivity, has been found in a myriad of organisms, including freshwater bacteria (Frankel and Blakemore 1989, Kalmijn and Blakemore 1978) and eukaryotic algae (Kirschvink 1989). Tenford (1989) reports that "...weak electrical and magnetic fields of aquatic organisms are sensed by potential predators". Our experimental animal, an aquatic predator, may use electrical and magnetic fields to locate its prey. That was not the direct question in our study, however. We wanted to know whether ELF fields altered the direction and/or distances travelled. Mechanisms underlying any alterations could be looked for later. Given that other physical and biological phenomena should influence movement patterns of O. colubrinus, we wanted to know whether responses to ELF electromagnetic fields could be detected under field conditions.

METHODS AND MATERIALS

Study Sites

Two sites were selected along the Ford River, Dickinson Co., Michigan in 1983. The experimental site, designated FEX (Ford Experimental), is at 46°07' N latitude and 87°053'W longitude. The reference site, designated FCD (Ford Control Downstream), is at 46°06' N latitude and 87°47' W longitude, approximately 7 km downstream from the FEX site (Figure 1). Efforts were made at having the sites as similar to one another, except for ELF fields once they became operational. Streamside vegetation at both sites primarily consist of Speckled Tag Alder (*Alnus rugosa* (DuRoy) Spreng), Balm of Gilead (*Populus gileadensis* Rouleau) and Red-Osier Dogwood (*Cornus stolonifera* Michx.). This hardwater brook trout stream contains cobble and sand substratum.

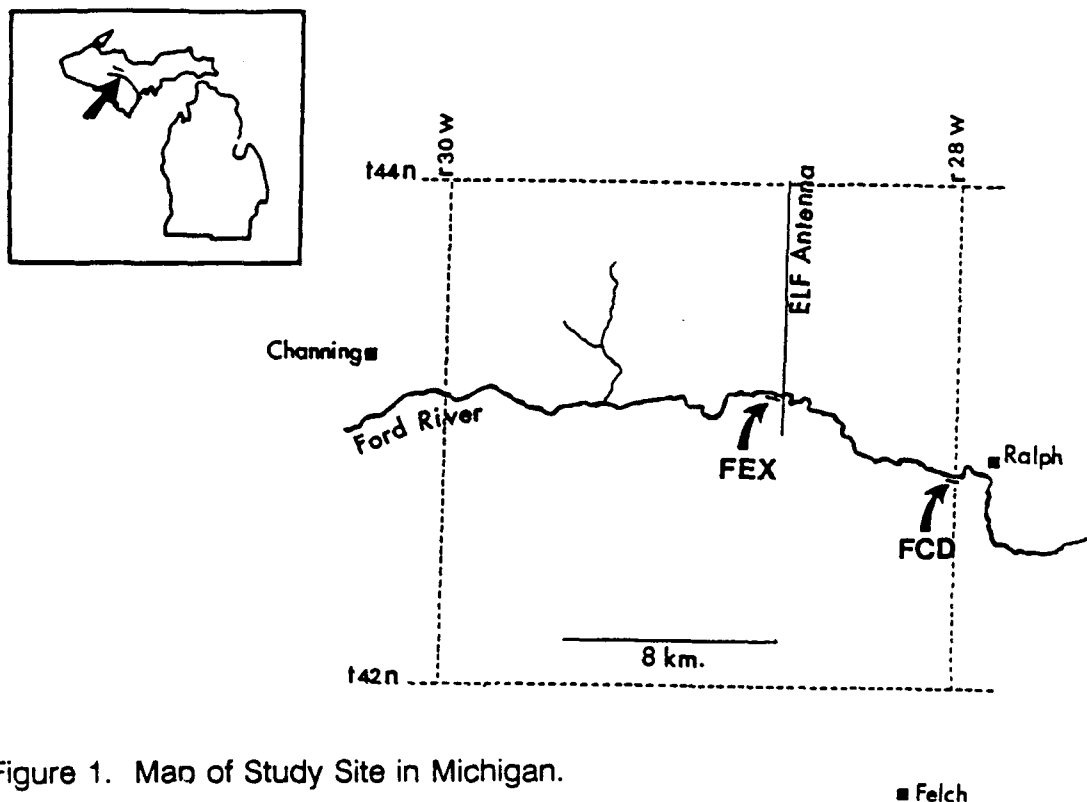


Figure 1. Map of Study Site in Michigan.

Stream widths at FEX and FCD were similar, varying between nine and 11 m. Summer water velocities were also similar at low water, with the fastest areas approximating 50cm/sec. Mean depths at FEX were lower than at FCD (e.g., 1988 mean depth data: FEX: 16.5 cm; FCD: 23.7 cm; student t-test = -5.80, d.f., 94, $p < 0.0001$). At FEX, the first pool below the release site was 35 m downstream; at FCD the first pool was 55 M downstream from the release site. There were no significant differences between the sites with respect to water chemistries and discharge (Annual Reports for ELF Monitoring Program, data

available upon request). The recapture area extended downstream to approximately 10 m below our ambient monitoring station and 40 m upstream of the North-South leg of the ELF system, which crosses the Ford River. The FCD release site was approximately 150 m downstream from a second automated ambient monitoring station (Figure 1). Distances for recaptures extended to more than 45 m below the FEX release site (into the first deep pool), and to more than 55 m below the FCD release site (beyond the first deep pool).

ELF Operation

The above-ground antenna system, built by the U.S. Navy, and supported by poles for a total of 28 linear miles, is built in the form of a double-crossed T, the longest axis being north-south, with two shorter lines running east-west. The system was completed in 1985. In 1986, testing of the antenna system was initiated by the Navy, with operation restricted to daylight hours at 4 to 6 amps for several days from July to October. During the mark-recapture periods in 1987, ELF activation was at 15 amps. Again, as for 1986, activation and deactivation over the test days occurred. From November, 1987 to May, 1989 power was at 75 amps for most working days. After May 1, 1989 exposure was at 150 amps continuously between 1600 and 0800 hrs throughout the weekdays and weekends and was on intermittently between 0800 and 1600 hours on weekdays. On October 7, 1989 the antenna became fully operational. The 1985 mark-recapture data are considered as being pre-operational data; data from 1986 through the summer of 1989 are defined as being transitional data. Within the 1986 through 1989 period, 1986 and 1987 data are considered low intensity years; 1988 intermediate intensity, and 1989 full intensity years. We did not know *a priori* when the lines would be activated during each mark-recapture experiment. Only after the fall of each year did we receive the data for ELF operation, which minimized potential biases.

Field Sampling

At the beginning of each summer field season, 1.0 m grids were measured and flagged with metal stakes. Current directions were determined by floating an orange down the stream, beginning in the middle of each 1m increment across the upstream end of the site and recording its path. Depths were measured at each flag, and widths were recorded. Prior to each mark-recapture period, velocities were recorded at 1 m intervals across the stream every 5 m downstream with a Gurley flowmeter. A release site was prepared at the head end of FEX and FCD by placing 45° baffles in the 1 m² square grid to minimize current flow in the release grid. This was not done in 1985, and so placement of insects in the stream took a longer period that year. In 1986-1987, baffles consisted of large rocks; in 1988-1989 baffles were plywood boards wedged in by concrete reinforcing rods. Although, changes were made during the study in an effort to facilitate placement of marked animals, any changes were effected in a similar manner at both sites each year. If ELF fields were to affect movements

of the marked animals, one would expect to see differences between FEX and FCD each year after ELF activation even though the duration of the release period varied among years.

Naiads of O. colubrinus were collected by a 1 m² metal handscreen at least 500 m upstream of each release site. They were placed in holding pans with stream water until over 300 animals greater than 9 mm in length had been collected. Each individual was removed from the holding pan, the dorsum blotted dry with a 'Kimwipe', and then marked with Testors enamel paint. It was moved to a second holding pan for approximately five minutes to allow the paint to dry. After all the animals were marked, they were placed in a third holding pan with stream water to test the adherence of the paint. At least 300 individuals were marked for each marking series. For each series, a unique color of paint was used so that later recaptures throughout the season could be distinguished from one another according to the day they were marked.

Marked animals were released in a 1 m² grid at the upstream end of the study area. While balancing a handscreen between the 'releaser's' legs, the holding pan containing the animals was slowly let down at a forward angle until the bottom edge of the pan touched the substrate. Any animals lost by this procedure drifted into the handscreen. Those animals were positioned in the release grid by slowly angling the handscreen forward until it was flush with the substratum. Two people stood downstream of the release site with handscreens to catch any animals that had not attached to the stream bottom. They were positioned by hand with the other marked animals. This was repeated until all animals were on the substratum. Baffles and handscreens were removed from the area. The entire procedure of marking and releasing animals took most of a day, and so the second site was treated in the same manner the following day. If heavy rains occurred before animals were released at both sites, the experiment was halted and another series begun at a later time.

The animals were recaptured after 24 or after 48 hrs each each site. The data presented herein represents recaptures where there were no intervening recapture disturbances, as it was found in 1985 that recapture activity severely altered movement patterns. On recapture days, two people armed with 1 m² kickscreens began downstream the farthest distance thought to be possible for the animals to travel. They worked in unison, with the kickscreens overlapping to prevent animals from drifting in between the screens after being uplifted. Each person would kick a 1 m² area above the screen a specified number of times and at specified angles; the dislodged animals would then drift onto the screens. This would be repeated across the width of the stream. At least two m upstream distance had to be sampled without recovering a marked animal. If one were taken, the 'kickers' would move downstream another five m and begin the process again. This was repeated back and forth until the entire area had been sampled. A recorder would write the number and color marked for each 1 m² grid of the stream. Marked animals were kept in holding trays in a two-person

rubber boat, which was anchored downstream of the activity. As kickscreening proceeded upstream, the boat was moved along and behind the area yet to be sampled. On days when population estimates were taken, all dragonfly naiads of all sizes were counted and recorded. Recapture efforts continued to at least 2 m upstream (and along the full stream width) from where the last marked animal had been captured. If another marking day was planned, the recaptured animals and other unmarked animals were painted and placed in the release site. If not, recaptured animals were released at least 25 m below the downstream pool.

Table 1 gives the recapture dates over the years according to 24 and 48 hr recaptures at FEX and FCD. Excluded are recaptures when sufficiently heavy rains lowered percent recapture values and increased difficulty in sampling.

Table 1. Recapture dates for *Q. colubrinus* from 1985 through 1989 after 24 and 48 hr at FEX and FCD sites.

Year	24 HOUR RECAPTURE		48 HOUR RECAPTURE	
	FEX	FCD	FEX	FCD
1985	09 July 02 August	16 July 10 August*	11 July	18 July
1986	25 June 26 June 29 July	01 July 02 July 05 August	31 July	07 August*
1987	26 June	30 June	28 June	02 July
1988	21 June 27 July	24 June 02 August	23 June 29 July	26 June 04 August*
1989	28 June*	29 June*	19 July 21 July 23 July 18 August 20 August 07 Sept.	20 July 22 July 24 July 19 August 21 August 08 Sept.

*: Denotes high waters, owing to rains between marking and recapturing.

RESULTS AND DISCUSSION

Naiads of *Q. colubrinus* were rather sessile during the summer months of the studies. The net movement direction was downstream. Marked animals were never recaptured above the release points. Recapture success was high throughout the studies (Table 2). Percent recaptures improved as techniques for

recapturing the animals improved. By overlapping the two handscreens used for recapture, animals that may have drifted between the two nets was kept to a minimum. This change was made in 1988, with a concomitant increase in width of handscreens. Population estimates, based on 24 hr recaptures, using the Lincoln Index method were similar over the years (Table 2).

Table 2. Percent recapture success and population estimates¹ for Q. colubrinus from 1985 through 1989.

DATE	PERCENT RECOVERY				POP. ESTIMATES	
	FEX		FCD		(No./m ²)	
	24 Hr	48 Hr	24 Hr	48 Hr	FEX	FCD
1985, July	31.45	30.92	33.85	27.2	40.32	43.01
August	40.45		28.08		19.32	40.83
1986, June-July	43.70		49.84		39.7	*
June-July	42.51		46.57		15.1	
July-Aug.	47.81	45.87	50.12	32.89	17.58	37.3
1987, June-July	55.21	46.56	54.00	49.68	37.15	36.64
1988, June		47.23	34.90	62.23	52.00	32.4121.37
July-Aug.	73.87	47.67	66.67	51.00	24.80	24.19
1989, June		38.46		8.01		*
July		80.02		75.46		
July		72.78		66.67		
August		82.50		72.03		
August		79.44		82.69		
September		66.77		67.19		

¹Based on 24 hr recapture studies.

*Not possible, either owing to high water to extensive distances

When the site was disturbed by the first recapture series each field season, subsequent population estimates lowered at FEX. The disturbance caused by recapturing activities did not alter population estimates as much at FCD. Overall, population estimates approximated 40 per square meter at each site. Because many marked animals tended to remain at the release site rather than to randomly disperse within the unmarked population, an assumption in estimating population sizes was violated. Even so, our estimates were very similar to a direct count for numbers of Q. colubrinus per square meter over the summer of 1984 by David Cornelius, a graduate student in the Department of Zoology, Michigan State University, East Lansing, Mi.). Table 3 give the results of his data, which were never published.

Table 3. Population estimates of O. colubrinus, based on direct counts (number per m²).

	SITES AND DATES					
	FEX			FCD		
	12/VII	26/VII	23/VIII	11/VII	25/VII	22/VIII
Mean	47.3	47.6	48.6	73.3	50.9	71.4
S.D.	25.3	14.0	15.9	28.9	31.7	43.3
No.						
Samples	7	7	7	7	7	7

Table 2 shows that, overall, percent recapture success was very high throughout the study. In 1989, when the technique for placement of wooden baffles and for placement of handscreens during recaptures were perfected, recapture success was very high for the 48-hour recapture efforts. Although the same was done for the 24-hour recaptures that year, high water in June made both placement of the animals and recaptures of marked animals very difficult. This is reflected in the low recapture success, especially at FCD. For those reasons, no population estimates were made for the 24-hour recaptures.

24-Hour Recaptures

Figures 2A and 2B show the percent of the total marked animals that travelled each 2m downstream from the release site after being in the stream for 24 hrs in the pre-operational period (Figure 2A) and the low ELF intensity period (Figure 2B) at FEX and FCD. Figures 3A and 3B show the percent of the total marked animals that travelled each 2 m downstream in the intermediate ELF intensity years (3A) and in the full ELF intensity year (3B). In the full ELF intensity year, 1989, proportionately fewer individuals of O. colubrinus were collected near the release sites than in prior years, owing to high water during the 24 hr recaptures in June of 1989. That month, there were two prior mark and release periods, but no recaptures were possible in the deep and rapidly flowing waters.

For each study throughout the years, many marked animals did not leave the release site. Unpaired t-tests were, therefore, excluded those animals that remained in the 1 m² release site. The question asked: Did the animals move either significantly longer or significantly shorter distances at the experimental site, FEX, than at the reference site, FCD, each year? As we had no reason to know *a priori* what influence, if any, ELF fields might have on movements of these animals, the tests were two-tailed. If there were ELF effects, one would expect that the difference between distance moved at FEX versus FCD would increase with increasing ELF intensity; that is, 2-tailed unpaired t-tests should show greater significant differences, beginning in 1986 and ending in 1989. (Numbers captured at each distance were multiplied by that distance for the analysis.)

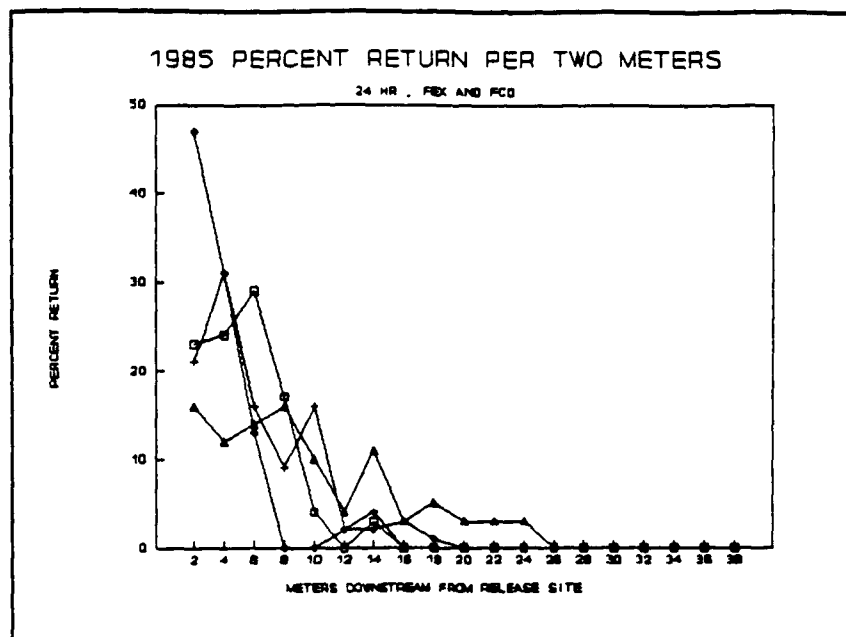


Figure 2A. 24 Hour Recaptures at FEX and FCD in 1985. Percent Return each Two Meters Downstream from Release Site. FEX: squares, pluses. FCD: Diamonds, triangles.

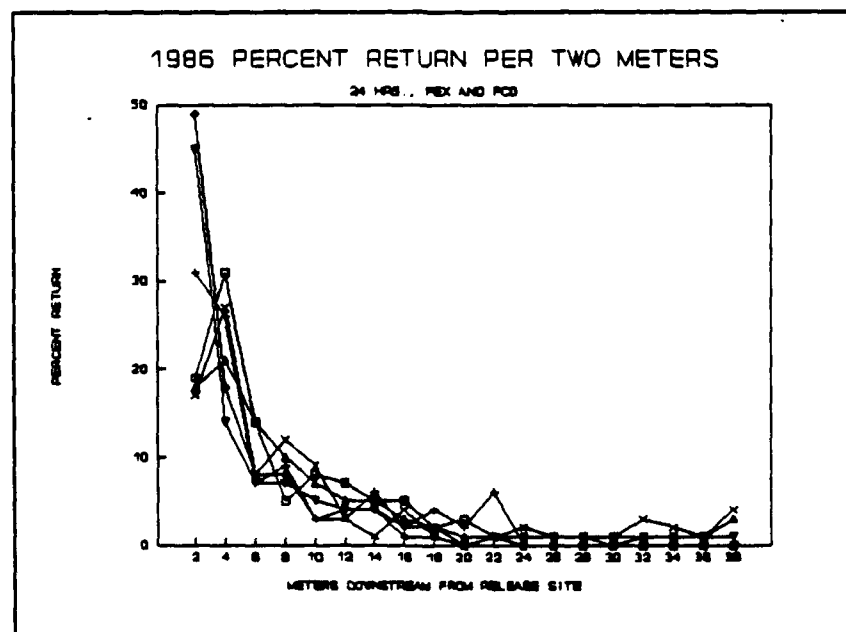


Figure 2B. 24 Hour Recaptures at FEX and FCD in 1986. Percent Return each Two Meters from Release Site.

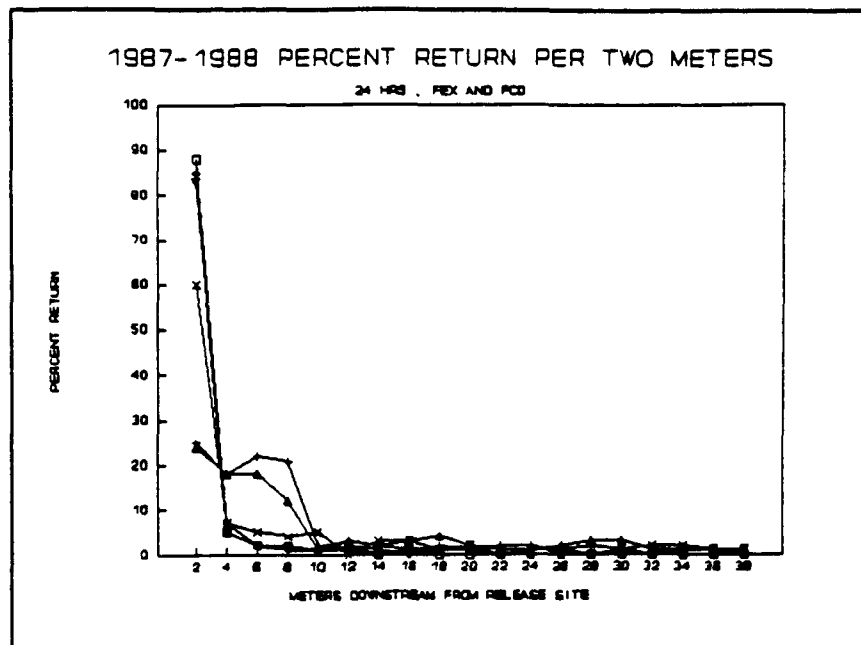


Figure 3A. 24 Hour Recapture at FEX and FCD. Percent Return per Two Meters from Release Site.

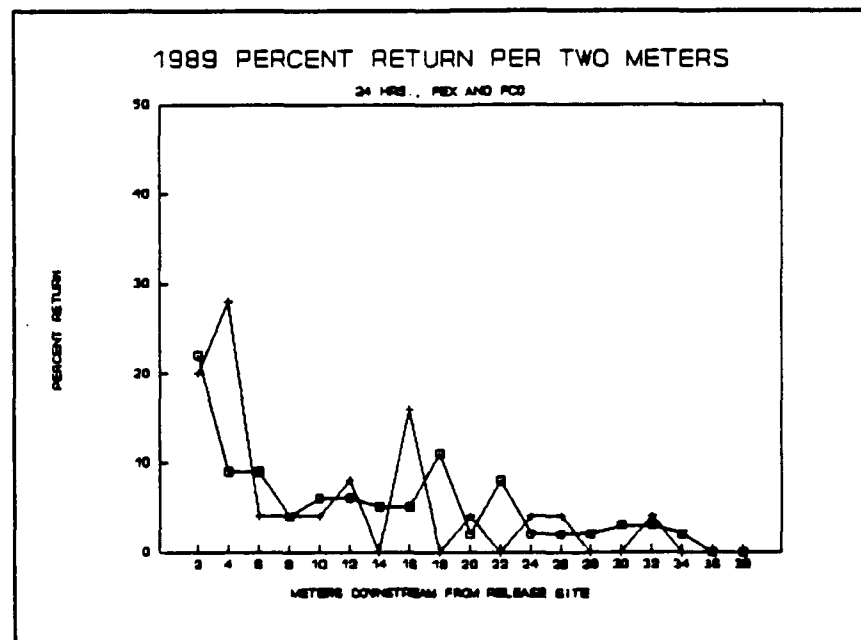


Figure 3.B. 24 Hour Recaptures at FEX and FCD, 1989. Percent Recaptured per Two Meters Downstream from Release Site. Squares: FEX; Pluses: FCD.

Although seven of the nine 24 hr mark-recapture studies showed significant differences with respect to distances travelled at each site, animals that moved away from the release site moved farther at FEX in 1985 and in 1989. 1985 was the pre-operational year and 1989 was the year with the highest ELF intensity. For the remaining years showing significance, animals that moved away from the release site moved farther downstream at FCD than at FEX (those bars below the zero line in Figure 4).

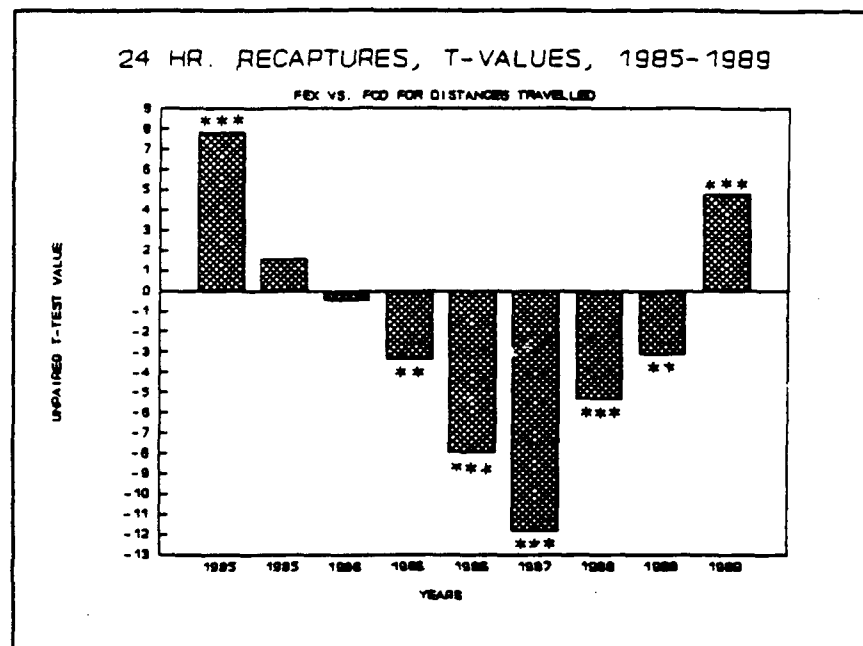


Figure 4. Comparison between FEX and FCD for Distances Travelled after 24 Hours, 1985 - 1989. Unpaired T-Tests. Level of significance: * <.05, ** <.01, *** <.001.

48 Hour Recaptures

The 48 hr recapture experiments were analyzed following the same methods described for the 24 hr experiments. Major efforts were placed on the 48 hr experiments in 1989 rather than on 24 hr experiments because we felt that by leaving the insects in the stream for 48 hr, we might reduce the variance problems associated with having many of the animals remaining at the release site after the first 24 hr had elapsed. Three pairs of experiments were performed in July; two in August, and one in September of 1989 (Table 1). The differences between the two sites in percent return for animals recaptured were very small (Table 2). Overall percent recapture success in 1989 was very high (FEX mean: 75.5%, FCD mean: 71.8%). Comparisons of figures 5A and 5B with figures 6A and 6B show that 1988 and 1989 were similar with respect to distances travelled. In 1985 through 1987, a lower percentage were recaptured near the release sites than in 1988 and 1989; either the improved 'settling' techniques were effective, or

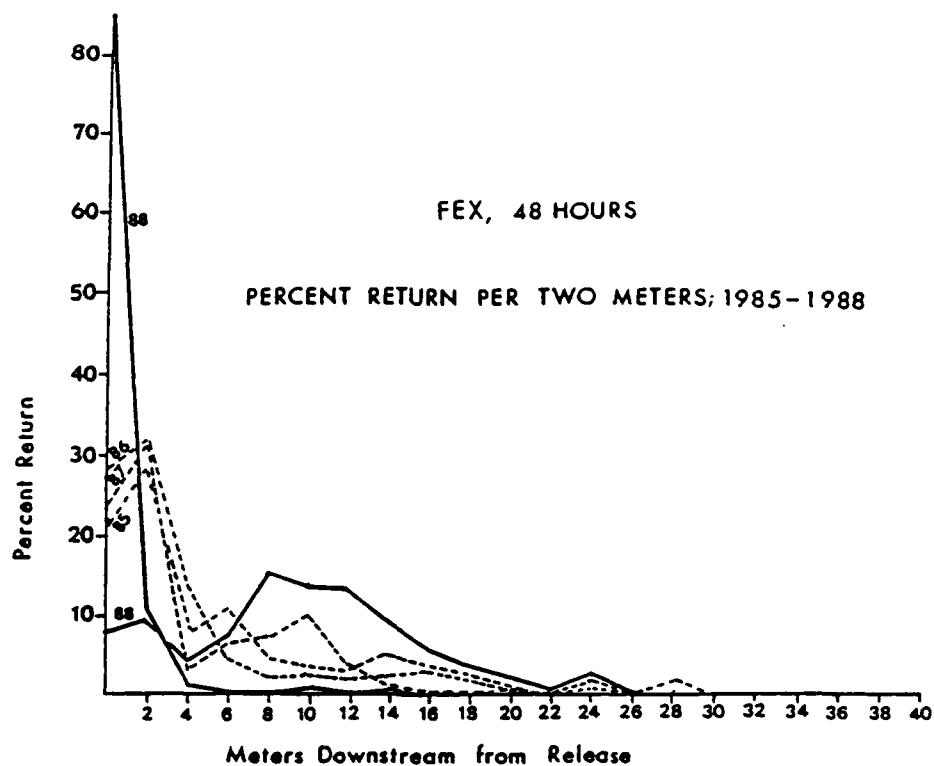


Figure 5A. 48 Hour Recaptures at FEX and FCD, 1985-1989. Percent Recaptured per Two Meters Downstream from Release Site.

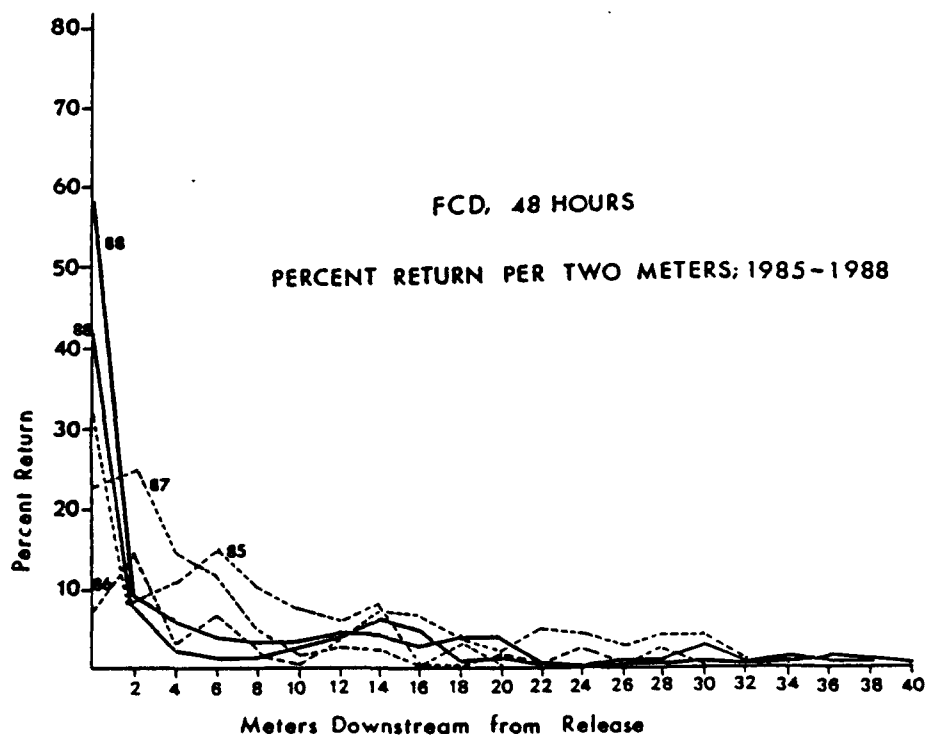


Figure 5B. 48 Hour Recaptures at FEX and FCD, 1985-1988. Percent Recaptured per Two Meters Downstream from Release Site.

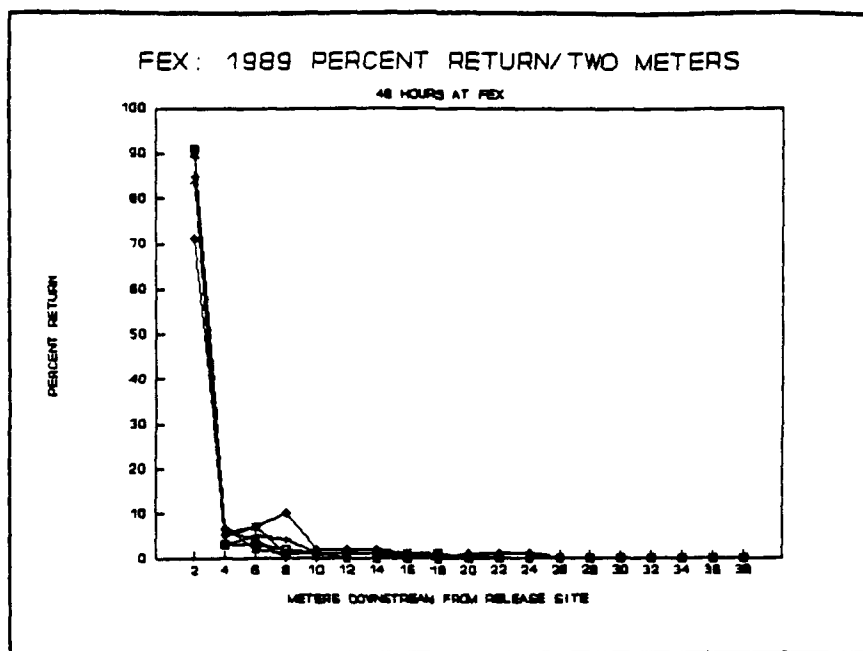


Figure 6A. 48 Hour Recaptures at FEX, 1989. Percent Recaptured per Two Meters Downstream from Release Site.

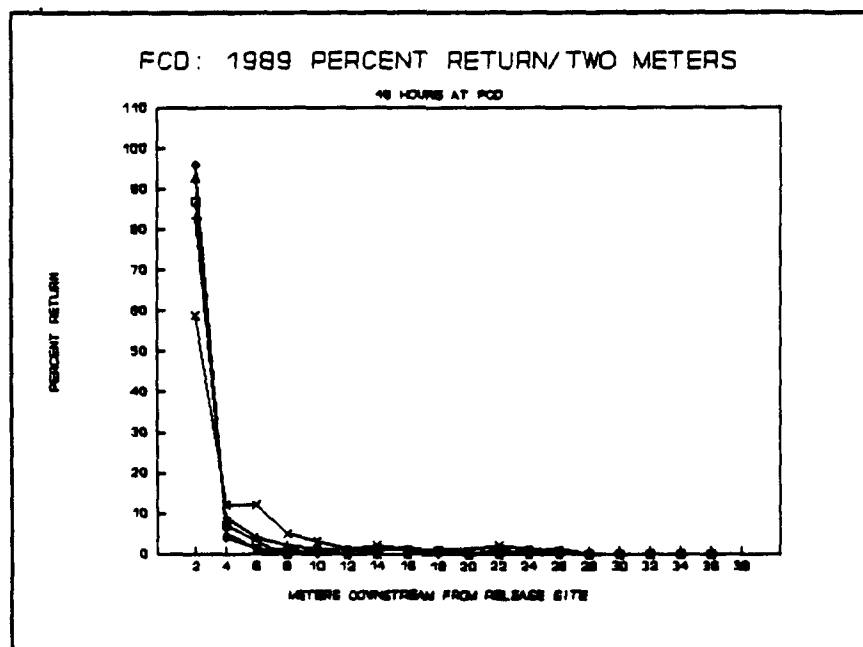


Figure 6B. 48 Hour Recaptures at FCD in 1989. Percent Recaptured per Two Meters Downstream from Release Site.

In July and August of 1989, most of the marked animals were recovered within 2 m of the release site. In September some animals at FCD moved almost twice as far as those at FEX, and many animals were found more than 2 m below the release site that month as well. *Ophiogomphus colubrinus* may naturally travel more as water temperatures begin to cool down. No mark-recapture studies were performed in September of any previous years so there are no further data to support this view.

There were significant differences in distances travelled for *O. colubrinus* for six out of 11 mark-recapture 48 hr recapture series (Figure 7). In 1985 and in 1989 animals travelled significantly farther at FEX than at FCD, as shown by the unpaired t-tests. In 1988 and for the first recapture series in 1989 animals moved significantly farther at FCD than at FEX. 1986, 1987, and at least one series in 1988 and 1989 showed no significant differences between the two sites for distances travelled any combination of years. Thus, there was no pattern with respect to ELF intensity for distances travelled by the naiads.

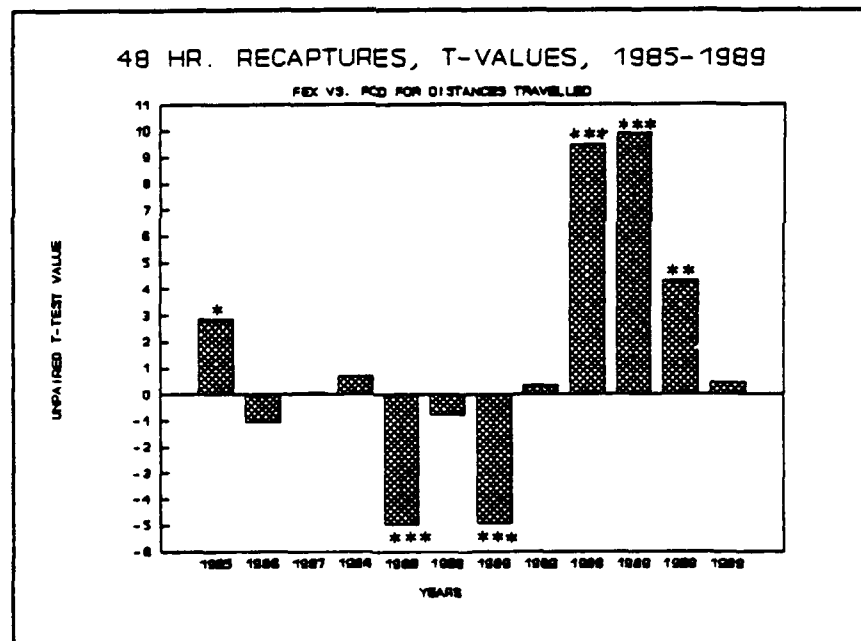


Figure 7. Comparisons between FEX and FCD for Distances Travelled after 48 Hours, 1985 - 1989. Unpaired T-Tests. Levels of Significance: * < .05, ** < .01, *** < .001.

No consistent pattern emerges for our 48 hr mark-recapture studies. Variances among years, between sites, and distances moved are high. Even in 1989, when we performed six separate 48 hr experiments at each site, the significant difference between sites for those moved versus those not moved were not similar to other post-operational years. The environmental variables coupled with the behavior of this animal may make it very difficult to detect any small differences in movement patterns owing to E.L.F. effects.

ACKNOWLEDGEMENTS

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Element 6 - Leaf Litter Processing

Changes from the Work Plan - Added a new site, FEX.LINE, to increase the differential between E.L.F. fields at an experimental site and FCD.

Objectives

1) To quantify leaf processing rates for fresh and autumn abscised speckled (tag) alder leaves (*Alnus rugosa*) each year to see whether leaf processing rates differ as a function of E.L.F. fields; 2) to determine structural and functional community indices for insects colonizing tag alder leaves for subsequent analyses as to E.L.F. effects; 3) to measure growth rates (changes in mean dry weights per individual) for two species of mayflies and one species of stonefly each year to see whether E.L.F. affects growth rates.

Rationale

Processing rates of leaves incorporate the functional responses of fungi, bacteria, protozoans and leaf feeding invertebrates, especially shredding insects (Cummins et al. 1989, Petersen and Cummins 1974, Stout and Taft 1985). E.L.F. fields may influence some of those processors with regard to orientation, activity, or both, as many aquatic plant and animal species contain magnetite crystals (Kirschvink 1989). Some of these species, including freshwater bacteria and algae, are magnetotactic, (Tenforde 1989). It is conceivable that some aquatic species in the Ford River respond to E.L.F. fields as well as to other geomagnetic fields. If so, not only might their activities or growth rates be altered, but leaf processing rates, the resultant sum of their activities, may also be altered.

Many non-anthropogenic environmental factors can affect leaf processing rates: water temperature and flow rates (Kaushik and Hynes 1971), leaf chemistry (Iverson 1974, Stout 1989), and beaver activity (Naiman et al. 1984) may all play a role in the Ford River. Some of these factors may override any E.L.F. effects (see Tenforde 1989) or some E.L.F. perturbations may themselves "...be within the ranges of disturbances that a system can experience and still function properly." (O.T.A. 1989). In either case, any potential E.L.F. effects may or may not be detectable even though coefficient of variation values for many biotic parameters are very low for this Element are very low.

A number of anthropogenic factors can also affect leaf processing rates and colonization of insects on those leaves. Examples include chemical inputs

(Fairchild et al. 1984, Stout and Cooper 1983, Cairns 1985), thermal stress associated with impoundments and commercial industries (Gersick and Brusven 1981), and forest alterations (Webster and Waide 1982). As E.L.F. fields appear to be an anthropogenic phenomenon for which there is no analog, the foundations for decisions as to which factors may most strongly affect any given organism -- intensity, duration, transient behavior -- are poorly understood (O.T.A. 1989). This problem is especially critical when studying potential effects under field conditions, where several non-anthropogenic and anthropogenic factors may interact. Considering these uncertainties, the continual monitoring of biological parameters that show low variation in time and space is the most pragmatic approach for detecting any E.L.F. effects under field conditions.

Materials and Methods:

A. Leaf Preparation and Processing

Fresh tag alder leaves were collected from a grove adjacent to the Ford River near FCD each year. Leaves were removed from whole branches at the laboratory and weighed into individual leafpacks with an average fresh mass of 6.5 gm. Prior to 1988, fresh mass varied between 4.8 and 5.2 gm. After that time, fresh mass was increased to between 6 and 7 gm so that the fresh leafpacks and autumn abscised leafpacks would have similar numbers of leaves and similar initial dry weights.

After leafpacks were weighed, they were taken to the field, lashed to bricks using rubber bands to which replicate identification numbers were attached, and placed in riffles at the FEX and FCD sites. Seven replicates per collection date, per site, and per treatment (fresh versus autumn-abscised) were used. (In 1984, only five replicates were used.) In the fall of 1990, a new site, called FEX.LINE was added to the studies for this Element after field testing for ELF intensities showed that the new site experienced higher intensities than did the original FEX experimental site.

In 1984 autumn abscised tag alder were collected in September and used the year of collection. We planned on using leaves reserved from the 1984 leaf collection for 1985 studies; however, we had insufficient numbers and abandoned the autumn leaf study for 1985. Instead, we oven-dried fresh leaves. They proved to be more similar to fresh leaves than to autumn-

abscised leaves with respect to their processing rates and so there is a gap in the data for autumn-abscised leaves (1985). In October of 1985 we collected sufficient numbers of leaves for the 1986 study so that we would have autumn abscised leaves available when we collected fresh leaves in 1986. That way, both leaf treatments could be put in the river at the same time. This procedure has been followed throughout the remaining years.

Leafpacks for both treatments, fresh and autumn-abscised, were collected six times over a three to four month period. After 1986, it was determined that the critical incubation period was between 21 and 28 days. At those incubation times, the coefficient of variation values for insects colonizing leaves were very low for most of the structural and functional community parameters. We also found that variability for all parameters was very high after 80 days' incubation. As 50% of the dry mass of leaves is usually gone after 54 days, we changed our collection schedule in 1986 to more carefully bracket the critical period between three and four weeks and to delete leaf collection after 90 days. Thus, collection days changed from 3, 9, 24, 50, 90 and 120 days to 7, 14, 21, 28, 50 and 80 days, weather and travelling permitting. On collection days, each leafpack was removed carefully from its brick and placed in a plastic box. The portion of the brick touching the leafpack was carefully washed into that box. After returning to the laboratory, each leafpack was washed over a 60 micron mesh sieve, which retained the insects. Insects were preserved in 90% alcohol; leaves were placed in paper triangles and dried at less than 40°C for 48 hr, at which time they were weighed to the nearest 0.01 gm.

Leaf processing rates were computed as $-k/\text{day}$ after Petersen and Cummins (1974). Fresh and autumn-abscised leaf data were analyzed as separate experiments because their physiological differences are considerable. Two-Way ANOVAs were performed on leaf losses after three and one-half to four weeks' incubation to determine any site, year or site-year interaction differences. This incubation period was chosen, as it consistently showed low coefficient of variation values. Processing rates, $-k/\text{day}$ values, were regressed against year, cumulative degree days, and discharge values in a multiple regression analysis. B.A.C.I. tests could not be performed on these data sets, as there is only one value mean for each processing rate for each leaf treatment each year. Those tests could not use leaf losses from each collection period either, as leaf losses are related to incubation periods and are fixed to Time 0 when the leaves were put in the stream.

B. Colonization of Insects on Leaves

The insect taxa from the leaves were determined to the lowest taxon possible. Identified insects were then measured to the nearest mm length for later computation of biomass values (after Smock 1980). Species diversity (H') and richness (S') were computed for each sample, along with numbers of individuals and total biomass. For certain taxa, percent numerical dominance, mean dry biomass per individual (MDW/IND), or both, were determined for each collection date. Coefficient of variation (C.V.) values for each estimated parameter from each set of samples were obtained. A power test was used to determine if there were sufficient replicates to be confident 95% of the time that the mean varied no more than $\pm 40\%$ with an alpha of .05. (Seven replicates were sufficient if the parameter had a C.V. value of 20% or less.) If values for any parameter were not normally distributed, they were transformed prior to analysis (e.g., percent data). The lowest C.V. values for H' , S' , numbers of individuals, and total insect biomass adjusted to leaf biomass occurred between 24 and 28 days. H' , S' , numbers of individuals, and mean insect biomass adjusted to leaf mass during that time period were analyzed, using 2-Way ANOVA tests, to determine whether there were site, year, or site x year differences. Multiple regression analyses were performed when there were significant year differences. Years, cumulative degree days and mean discharge values were used in those regressions.

Three species, Ephemerella subvaria, E. invaria, and Isoperla transmarina were analyzed for differences in growth rates (MDW/IND) between sites and among years. Both chronological time (days in stream) and physiological time (cumulative degree days) were used as independent variables. Chronological time was used in ANCOVA tests and physiological time was used for graphical purposes for these three winter growing species.

Results and Discussion

Leaf Processing Rates

1. Fresh Leaves

Processing rates ($-k/\text{day}$) were similar at FEX and FCD except in 1985. That year leaves were processed much faster at FEX, and much faster than fresh leaves at FCD for any year (Figure 6.1A, 6.1B; Table 6.1). The yearly variation was also greater at FEX than at FCD. There were no significant site differences for fresh leaves ($T = 0.681$, $df = 12$, $p = .254$).

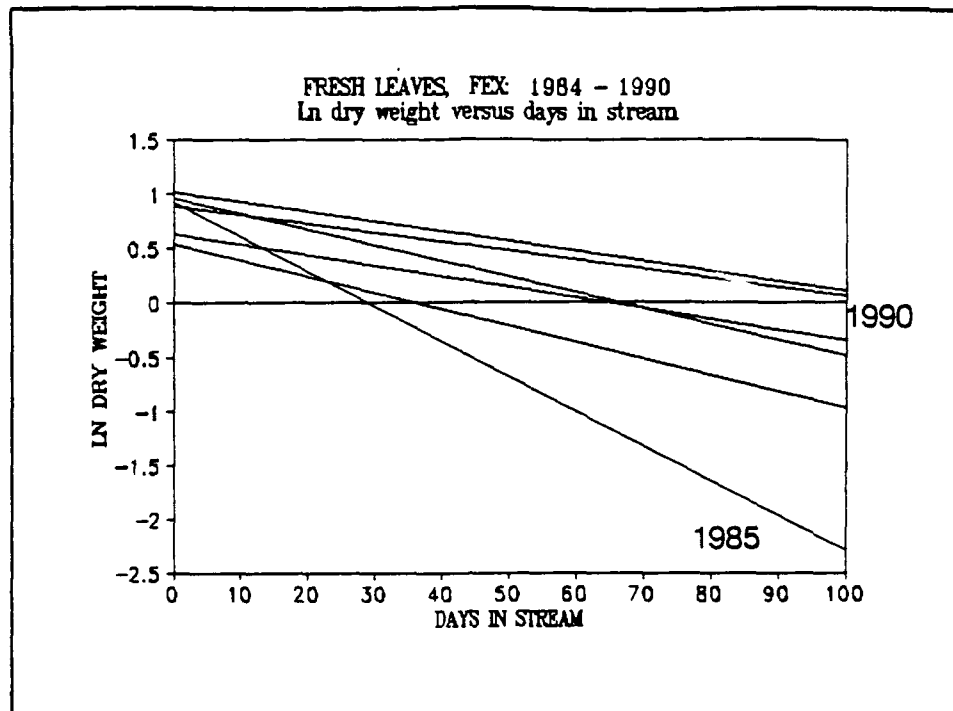


Figure 6.1A. Leaf losses (ln dry mass) for fresh leaves at FEX, 1984 - 1990.

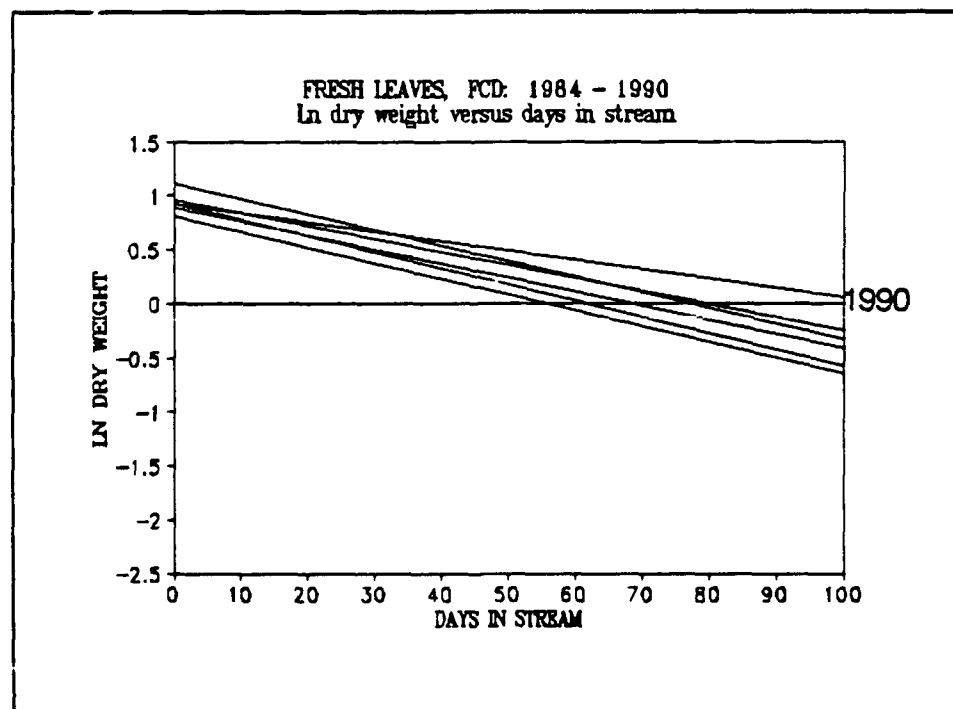


Figure 6.1B. Leaf losses (ln dry mass) for fresh leaves at FCD, 1984 - 1990.

The variance from year to year for processing rates has been very low for the reference site, FCD (C.V. = 18.25%). In 1985, processing rates for fresh leaves at FEX was very high (Figure 6.1A, steepest slope). In 1985, leaves were placed 1000 m upstream of the present FEX site. In addition, fall discharge values were also high (See Table 6.2). The variance for other years was also higher than for FCD (See Figures 6.1A, 6.1B) and the C.V. value at FEX across years was 56.16%. Multiple regression analyses were performed to see which physical factors were most related to differences in $-k$ /day values and whether any of the factors varied more at FEX than at FCD.

Table 6.1 shows that the partial regression for discharge at FEX was very high. The partial regression value for years was not very high, suggesting that the variation in fresh leaf losses at or near FEX were related more to variation in discharge than to before versus after effects of ELF. At the reference site, FCD, no variables including discharge, were strongly correlated with leaf losses. Either the location for the leafpacks at FCD was less subject to abrasion, or more years of data may be required before any effects of discharge can be detected.

TABLE 6.1

Multiple Regression Values for Fresh Leaf Processing Rates
from 1984 through 1990 at FEX and FCD

1. FEX Fresh Leaves

Variable	Reg.Coeff.	Std.Err	T(df=3)	P	Partial
Year	-.00086	.0018	-.474	.668	.070
Cum.Deg.Day	.00001	.00003	.406	.712	.052
Discharge	.0049	.0017	2.879	.064	.734

Std.Err.Est.: .0047 R²: .835

2. FCD Fresh Leaves

Variable	Reg.Coeff.	Std.Err	T(df=3)	P	Partial
Year	-.00086	.0018	-.474	.668	.070
Cum.Deg.Day	.00001	.00003	.406	.712	.052
Discharge	.0049	.0017	2.879	.064	.734

Std.Err.Est.: .0029 R²: .209

The lowest C.V. values for leaf loss over the years were during the first month the leaves were in the water. Thus, variation in mass remaining values were low for Day 7, 14, 21 and Days 24 through 28, depending on the collection year. A 2-Way ANOVA was performed on ln leaf dry mass after four weeks' incubation each year. There were significant site ($p < .001$), year ($p < .001$) and site by year ($p < .001$) effects for fresh leaves. From 1984 through 1990, initial fresh weights of leaves were increased to try to have the same final dry mass values as for the autumn leaves. The initial fresh weights increased from 4 gm to 7 gm. This change in procedure did not alter rate of change values over the years, but it did alter final dry mass values each year. Thus, any analysis using mass rather than rates for fresh leaf losses would have incorporated these procedural alterations, creating biased results.

The cumulative degree day and mean discharge values at the two sites were computed by taking the time from Day 0 when the leaves were put in the stream each year and accumulating, in the case of cumulative degree days, degree day water temperatures until the leaves were collected at the fourth week. The same was true for determining the mean discharge value during that period each year. These values were used for multiple regression analyses for leaf losses (Table 6.1, Table 6.3) as well as for multiple regression analyses for insect colonization data. Table 6.2 presents values for those physical variables that were used in the multiple regression tests.

TABLE 6.2

Values for Cumulative Degree Days and Discharge Means
at FEX and FCD from 1984 through 1990

Year	Incubation Days	Day Out	Cumulative Degree Days		Mean Discharge	
			FEX	FCD	FEX	FCD
1984	24	13 Oct.	187	169	1.27	1.30
1985	24	12 Oct.	172	188	4.85	5.26
1986	27	7 Oct.	261	244	1.93	2.41
1987	26	23 Sept.	354	337	0.50	0.71
1988	28	6 Sept.	480	446	1.03	1.15
1989	27	11 Sept.	464	408	0.70	0.44
1990	27	17 Sept.	399	400	0.44	0.48

2. Autumn-Abscised Leaves

Autumn-abscised leaves were processed somewhat faster at FEX than at FCD (Figure 6.2A, 6.2B, Table 6.4). However, there were no significant site differences for autumn leaves ($T = .871$, $df = 10$, $p = 0.202$). In 1990, autumn leaf processing rates were faster than in previous years (see figures and table above); yet the same differences between FEX and FCD held; autumn leaves were processed faster at FEX than at FCD. The variance from year to year for processing rates at both sites has been relatively high (C.V. at FEX = 42.17%; C.V. at FCD = 52.81%). Was the variation from year to year owing to ELF effects or to some physical factor(s) that affected processing rates? Multiple linear regression tests were performed to see whether differential physical factors relating to time of year and to yearly differences were associated with different processing coefficients, $-k/\text{days}$, Table 6.3. No independent variable was significantly associated with autumn leaf processing rates although each had a high partial coefficient and the overall R^2 values were very high at both sites.

TABLE 6.3

Multiple Regression Values for Autumn Leaf Processing Rates
from 1984 through 1990 at FEX and FCD

1. FEX. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=2)	P	Partial
Year	-.0013	.0011	-1.167	.364	.405
Cum.Deg.Day	.00002	.00002	1.034	.410	.348
Discharge	.0038	.0028	1.361	.306	.481

Std. Err. Est. = .0027		R ² = .762			

2. FCD. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=2)	P	Partial
Year	-.0021	.0011	-1.999	.184	.666
Cum.Deg.Day	.00004	.00002	1.751	.222	.605
Discharge	.0025	.0017	1.443	.286	.510
Std. Err. Est. = .0022			R ² = .833		

Figures 6.2A and 6.2B show autumn leaf losses at the two sites in 1984 and in 1986 through 1990. Note the steeper slopes in 1990 at FEX and FCD.

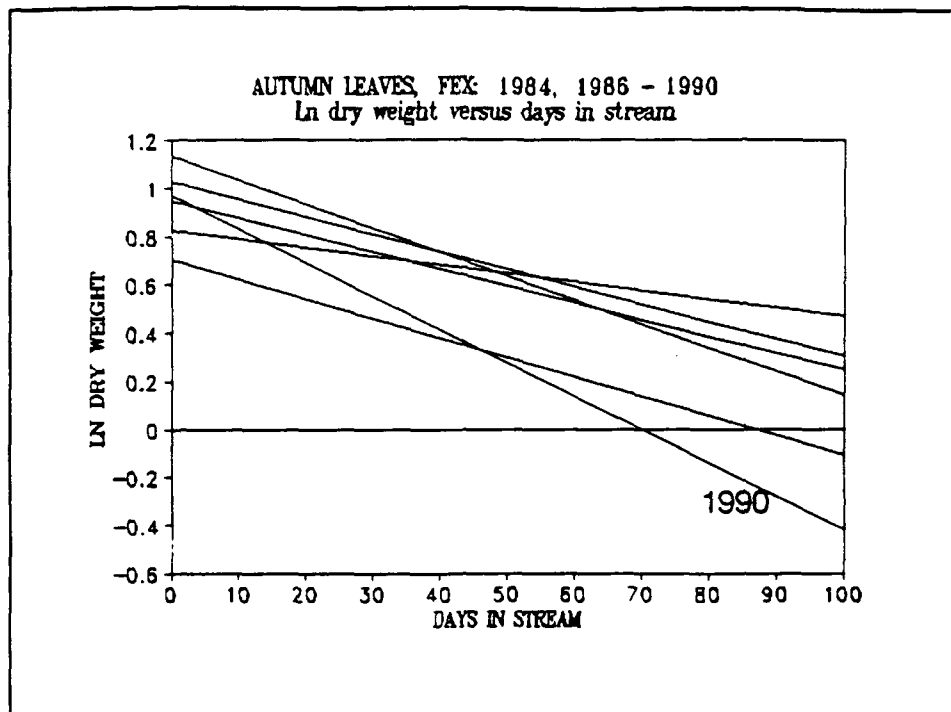


Figure 6.2A. Leaf losses (ln dry mass) for autumn leaves at FEX. 1984; 1986 - 1990.

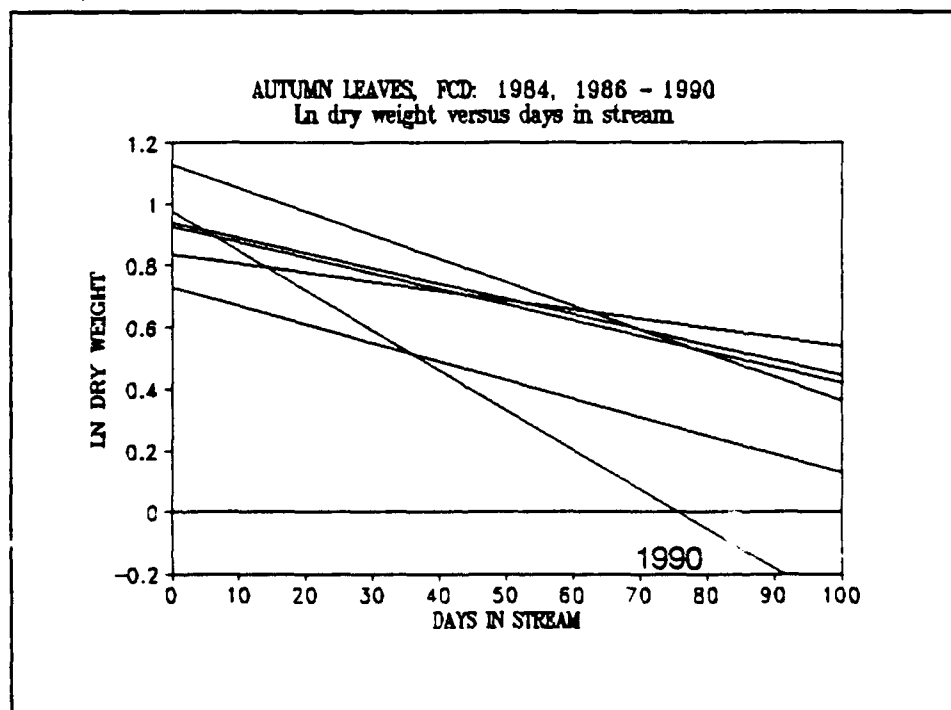


Figure 6.2B. Leaf losses (ln dry mass) for autumn leaves at FCD. 1984; 1986 - 1990.

The full r^2 values were high for leaves at both sites. The partial r^2 values were also high for years, cumulative degree days and discharge variables. Although the C.V. values were high for $-k/day$ across years, the yearly differences between the sites were minimal except for 1990 (Figure 6.3). A 2-Way ANOVA, comparing year and site differences for autumn leaves at Day 24 to Day 28 showed that there were no site nor year by site differences, but highly significant year differences ($p < .001$). B.A.C.I. tests to see whether there are before versus after differences cannot be performed because the data are not independent (depends on prior samples in the time series). But multiple regression tests show that cumulative degree days and mean discharge values account for much of the variation in $-k/day$ values.

3. Fresh and Autumn-Abscised Leaf Loss Comparisons.

Table 6.4 shows $-k/day$ values for fresh and autumn-abscised leaves.

TABLE 6.4

Processing Coefficients ($-k/day$) and Regression
Coefficients for Fresh and Autumn Leaves
in the Ford River, 1984 - 1990

Year	FEX		FCD					
	Fresh $-k/day, r^2$	Autumn $-k/day, r^2$	Fresh $-k/day, r^2$	Autumn $-k/day, r^2$				
1984	.0151	.78	.0081	.67	.0149	.83	.0060	.50
1985	.0321	.62	-		.0146	.47	-	
1986	.0099	.69	.0035	.86	.0105	.68	.0029	.36
1987	.0124	.80	.0070	.52	.0130	.74	.0050	.27
1988	.0145	.70	.0072	.83	.0122	.57	.0049	.42
1989	.0102	.84	.0099	.77	.0087	.74	.0076	.60
1990	.0091	.78	.0139	.56	.0144	.78	.0128	.72

	FEX.LINE							
1990	.0081	.62	.0082	.65				

Figure 6.3 is a plot of the difference values (FEX minus FCD) for fresh and for autumn-abscised leaf processing rates over the years of the study.

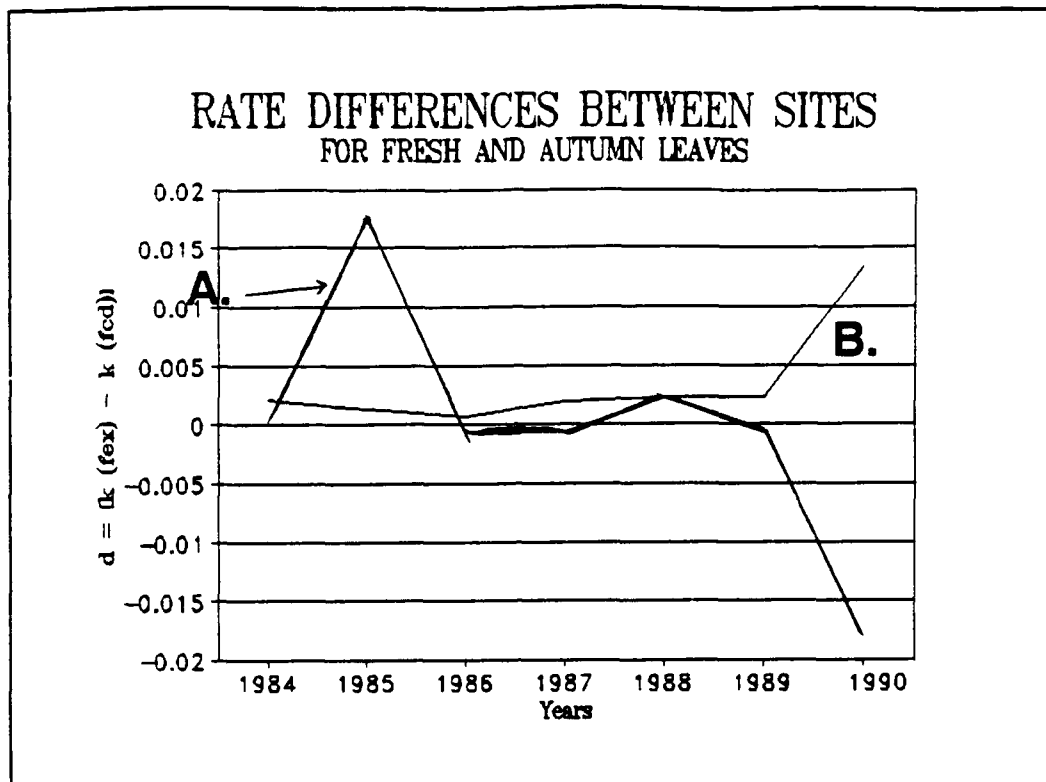


Figure 6.3. Leaf processing rate differences between FEX and FCD for fresh (A) and autumn-abscised (B) leaves from 1984 through 1990. No data are available for autumn leaves in 1985. A continuous line is drawn for heuristic purposes

The fast processing coefficient for fresh leaves at FEX in 1985 has been already described (see Figure 6.3 also). Leaf processing rate differences for both fresh and autumn leaves deviated in 1990. Although autumn leaves were always processed faster at FEX than at FCD, a high $-k/day$ value at FEX in 1990 increased the difference between the two sites for this coefficient (Figure 6.3, Table 6.4). Fresh leaves were processed very slowly at FEX relative to FCD, dramatically shifting the difference values well below the 0 difference line. Reasons for these altered patterns in 1990 are unknown. The collection protocol, leafpack preparation, and location of leafpacks in the river were similar to prior years. In 1990 autumn leaves were processed faster than fresh leaves at FEX. This has never happened before. Although autumn leaves were processed faster at FCD than ever before, fresh leaves were processed at a rate within the range of prior years. E.L.F. was fully operational in 1990. If E.L.F. affects leaf processing rates, the responses by autumn leaves differ from the responses of fresh leaves. Autumn leaf processing rates would be increased, but fresh leaf decomposition would be slowed. Fresh leaves have

more potential resources for fungal and bacterial activity. Theoretically, E.L.F. may be inhibiting microbial activity, which would potentially affect the better microbial resource, fresh leaves. Future data, now that the E.L.F. lines are fully operational are critical in determining whether 1990 was an aberrant year or whether E.L.F. affects processing rates. As an alternative for results found for fresh leaves, fresh leafpacks were placed at FCD early in the morning. The next set went into the new FEX.LINE site. By the time we were ready to put the fresh leafpacks in at FEX, the heat of the day (even though the leafpacks were in the shade) may have altered their physiological state. This possibility is somewhat remote, as fresh leaves at the new site, FEX.LINE were processed at a slow rate as well. We had never used this site before, so we cannot compare the 1990 processing rate with other years.

Figure 6.4 shows the results for leaf losses of fresh and autumn leaves at FEX.LINE. Both leaf "types" were processed at nearly identical rates. As we accumulate more years at this site, we will be able to interpret the data. Both fresh and autumn leaves were processed at a rate one would expect for autumn leaves, based on results in prior years (Table 6.4). The only habitat available at that site that is close enough to the maximum ELF intensities, is protected from human activity, and has sufficient water depth is near the streambank. The leafpacks are farther out in the stream, both at FEX and at FCD. We feel we have balanced, as much as possible, the variables that went into making the placement decision at FEX.LINE. As more data are gathered, we'll be able to judge our choice of location for the leafpacks there.

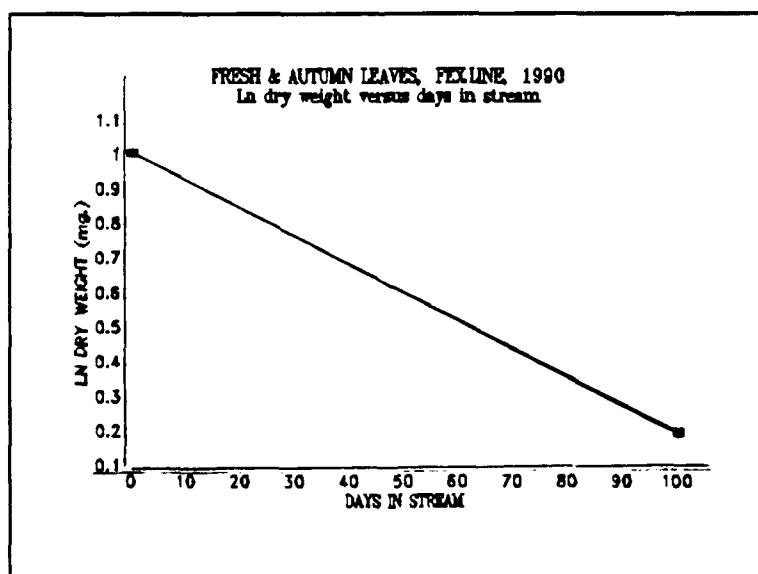


Figure 6.4. Leaf losses (ln dry mass) for fresh and autumn leaves at FEX.LINE. 1990.

Insects Colonizing Leafpacks

Structural Community Parameters:

In previous annual reports, we showed that the lowest mean to variance ratios (C.V. values) for structural community parameters occurred after leaves had been in the river approximately four weeks. We therefore used data for that time period to look for any differences between the two sites across years. We have also previously shown that the two treatments, fresh and autumn leaves, usually differed within any year with respect to substrate preferences for the aquatic insects. Those two treatments are handled separately in the statistical analyses. Both treatments are presented together in the figures for illustrative purposes. (1990 data for insect colonization will not be completed until the 1991 Annual Report.)

Taxon diversity (H') was higher on autumn leaves than on fresh leaves, except for 1984 (Figure 6.5). In 1988, H' values for both treatments were lower than for previous years. In 1989, H' returned to previous levels for fresh leaves and near previous levels for autumn leaves. When within treatment differences are considered, communities were more diverse at FEX than at FCD throughout the years.

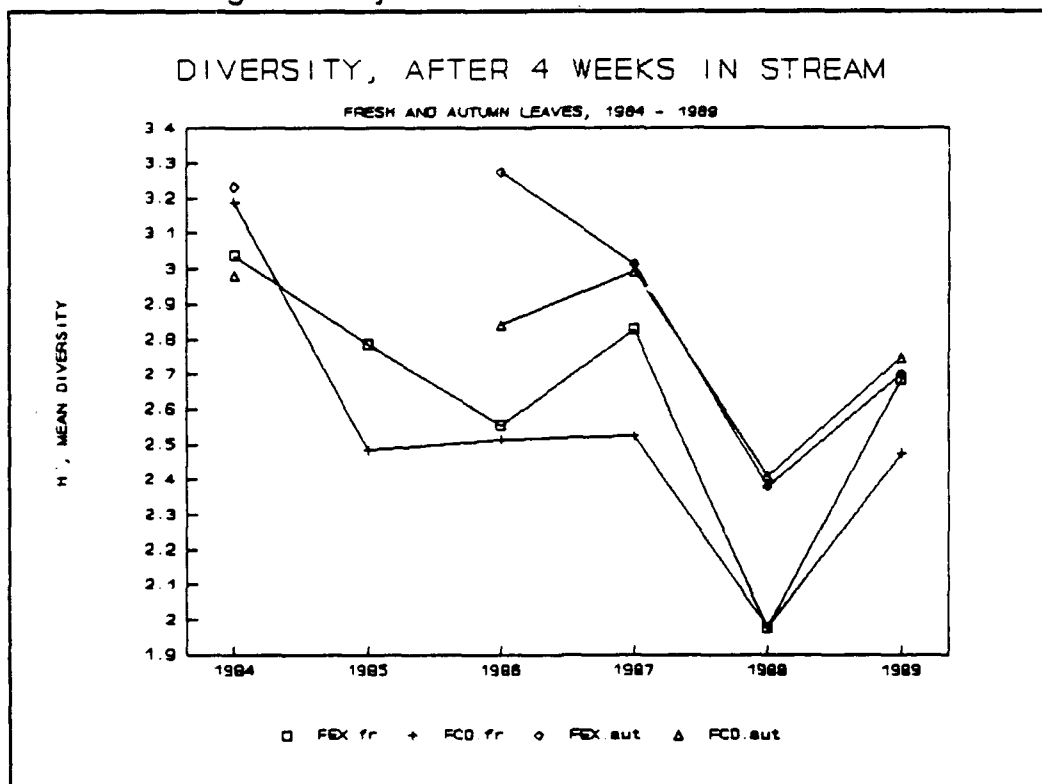


Figure 6.5. Taxon diversity on fresh and autumn leaves, 1984-1989. Squares: FEX.Fresh; Pluses: FCD.Fresh; Diamonds: FEX.Autumn; Triangles: FCD.Autumn

A Two Way ANOVA for fresh leaves, looking for year, site and year x site differences for taxon diversity (H') showed very significant differences among years, and significant differences between sites for both treatments (Table 6.5). In 1984, insects on fresh leaves were more diverse at FCD than at FEX. This was never the case in later years (Figure 6.5). Taxon diversity showed a downward trend for fresh leaves until 1989, at which time, H' increased. Taxon diversity for insects on autumn leaves was higher at FEX throughout the years. But, as for fresh leaves, H' dropped until 1989 (Figure 6.5).

TABLE 6.5

Two-Way ANOVA Tests for H' of Insects on (A) Fresh and on (B) Autumn Abscised Leaves After 24 to 28 Days, 1984 through 1989

Source	d. f.	SS	MSS	F value
(A) Fresh Leaves				
Years	5	6.808	1.362	25.741***
Site	1	0.620	0.620	11.728**
Interaction	5	0.632	0.126	2.389*
Error	72	3.807	0.053	
(B) Autumn Leaves				
Years	4	4.754	1.189	12.279***
Site	1	0.412	0.412	4.252*
Interaction	4	0.499	0.125	1.290 ns
Error	60	5.810	0.097	

A multiple regression was run on each dataset to look at the impact of years, cumulative degree days, and discharge on taxon diversity (Table 6.6). The overall R^2 values high for FEX autumn and FCD fresh leaves. Most of the variation in H' for them could be accounted for by either discharge (FEX autumn leaves) or by cumulative degree days (FCD fresh leaves). The R^2 values for the remaining two analyses were low but much of that variation was attributable to cumulative degree days and discharge. Thus, much of the variation in diversity could be attributable to physical factors rather than to time alone. This suggests that ELF effects alone did not play a statistically visible role in the diversity of insects coming on to fresh and autumn leaves after the first month the leaves had been in the stream sites.

TABLE 6.6

Multiple Regression Values for Taxon Diversity of Insects on
Fresh and Autumn Leaves, FEX and FCD
24 to 28 Days' Incubation

1. FEX. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	0.1102	.0931	1.185	.244	.034
Cum.Deg.Day	-.0036	.0015	-2.433	.020	.135
Discharge	-.1118	.0429	-2.607	.013	.152

Std. Err. Est. = .2725		R ² = .340			

2. FCD. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	0.0728	.0697	1.043	.303	.028
Cum.Deg.Day	-.0052	.0012	-4.353	.0001	.333
Discharge	-.1679	.0286	-5.874	<.0001	.476

Std. Err. Est. = .2366		R ² = .695			

3. FEX. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	0.3216	.1001	3.213	.003	.250
Cum.Deg.Day	-.0074	.0016	-4.680	<.0001	.414
Discharge	-.1168	.1209	-0.966	.341	.029

Std. Err. Est. = .2866			R ² = .589		

4. FCD. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	0.1141	.1010	1.130	.267	.040
Cum.Deg.Day	-.0039	.0017	-2.272	.030	.143
Discharge	-.1533	.1011	-1.517	.139	.0691
Std. Err. Est. = .3394			R ² = .268		

A Two-Way ANOVA testing for site and year differences for taxon richness (S) showed that there were no significant site differences for insects colonizing fresh leaves but that there were significant site differences at the $p < .05$ level for insects colonizing autumn leaves. There were highly significant year differences (Table 6.7). In general, taxon richness has continued to increase over the years (Figure 6.6). In 1989, richness values were higher on leaves, independent of physiological state, at FEX.

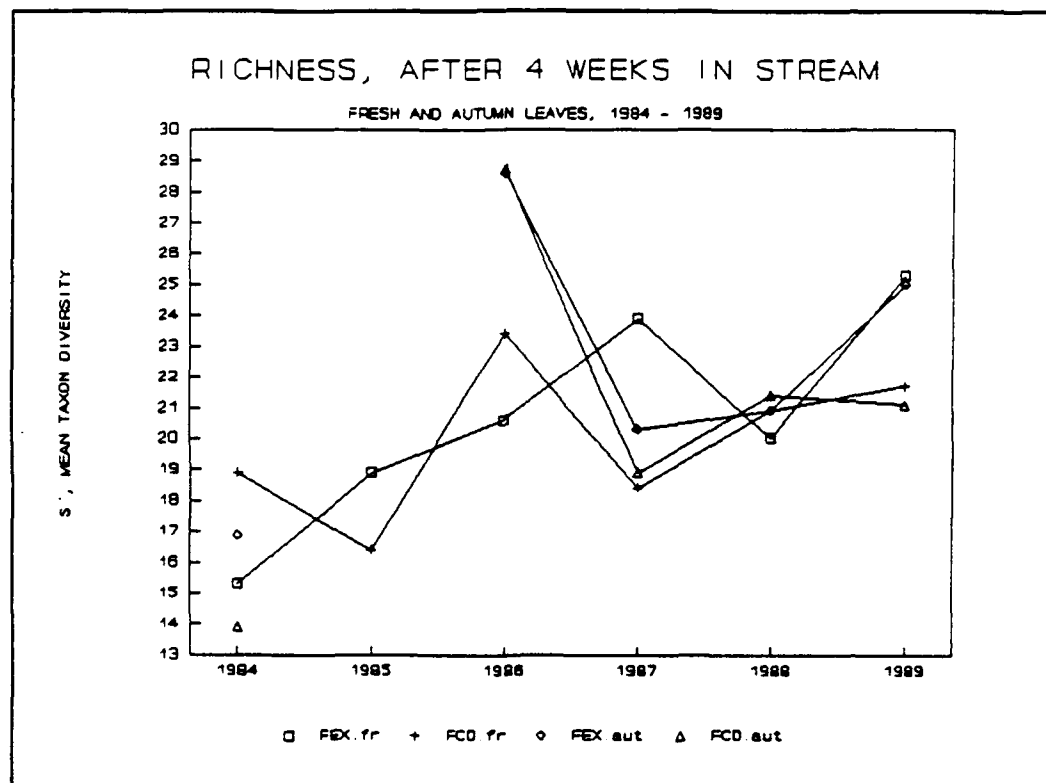


Figure 6.6. Taxon Richness (S) on Fresh and Autumn Leaves at FEX and FCD. 1984 - 1989. Squares: FEX.Fresh; Pluses: FCD.Fresh; Diamonds: FEX.Autumn; Triangles: FCD.Autumn.

Because the site differences for S' were highly significant, a multiple regression analysis was performed to see whether physical factors had more importance than years alone to account for the variance in S' for insects colonizing fresh and autumn leaves at the two sites (Table 6.8). Certainly, the highly significant year effects (Table 6.7) are more related to year or discharge values than to cumulative degree days in the three cases where the regression coefficients were high (FEX fresh leaves and FEX and FCD autumn leaves).

TABLE 6.7

Two-Way ANOVA Tests for Insect Taxonomic Richness on (A) Fresh and on (B) Autumn Abscised Leaves After 24 to 28 Days, 1984 through 1989

Source	d.f.	SS	MSS	F value
(A) Fresh Leaves				
Years	5	438.774	87.755	13.258***
Site	1	10.012	10.012	1.513 ns
Interaction	5	234.202	46.840	7.077***
Error	72	476.571	6.619	
(B) Autumn Leaves				
Years	4	1330.771	332.693	41.537***
Site	1	40.129	40.129	5.010*
Interaction	4	51.800	12.950	1.617 ns
Error	60	480.570	8.010	

TABLE 6.8

Multiple Regression Values for Taxon Richness of Insects on Fresh and Autumn Leaves, FEX and FCD 24 to 28 Days' Incubation, 1984 through 1989

1. FEX. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	5.0695	.9303	5.449	<.0001	.432
Cum.Deg.Day	-.0563	.0146	-3.854	.0004	.276
Discharge	-.8922	.4299	-2.076	.045	.100

Std. Err. Est. =		2.741	R ² =		.593

2. FCD. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	1.3718	.9209	1.490	.145	.055
Cum.Deg.Day	-.0176	.0158	-1.117	.2710	.032
Discharge	-.5936	.3778	-1.571	.1244	.061

Std. Err. Est. =		3.119	R ² =	.175	

Table 6.8, continued

3. FEX. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	5.8503	.7560	7.739	<.0001	.659
Cum.Deg.Day	-.0633	.0118	-5.343	<.0001	.479
Discharge	6.0243	.9051	6.656	<.0001	.588

Std. Err. Est. = 2.201		R ² = .791			

4. FCD. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	4.0737	1.0074	4.044	.0003	.345
Cum.Deg.Day	-.0284	.0171	-1.660	.1070	.082
Discharge	7.2899	1.0074	7.236	<.0001	.628
Std. Err. Est. = 3.384			R ²	= .690	

A large percent of the variance in S' for autumn leaves at both sites is accounted for by years and discharge. Unlike for fresh leaves, the relationship between numbers of taxa and discharge is a positive one for autumn leaves. It was in 1986 when numbers of taxa were very high, especially on autumn leaves (Figure 6.6). That year, discharge values were also high (Table 6.2). This and the fact that there are no data for 1985 fall leaves accounts for the positive relationship between S' and discharge for fall leaves. Overall, however, much of the variation in richness can be accounted for on the basis of years. Figure 6.6 shows that 1986 was an unusual year. ELF activation occurred in 1986. From that year on, richness values show no particular pattern. If anything, richness values were higher after 1986 than before 1986.

Numbers of individuals reached their peak values for both treatments at both sites in 1989 (Figure 6.7). There were more insects on fresh than on autumn leaves and the variation within physiological type was very low. A Two-Way ANOVA on data from 1984 through 1989 shows that there were no site differences for numbers of individuals, either on fresh or on autumn leaves (Table 6.9). There were highly significant year differences for both leaf types. A multiple regression analysis was performed for each dataset (Table 6.10). Although much of the variation for numbers of individuals could be attributable to a year effect, cumulative degree days and discharge played a significant role in accounting for the variation in numbers of individuals.

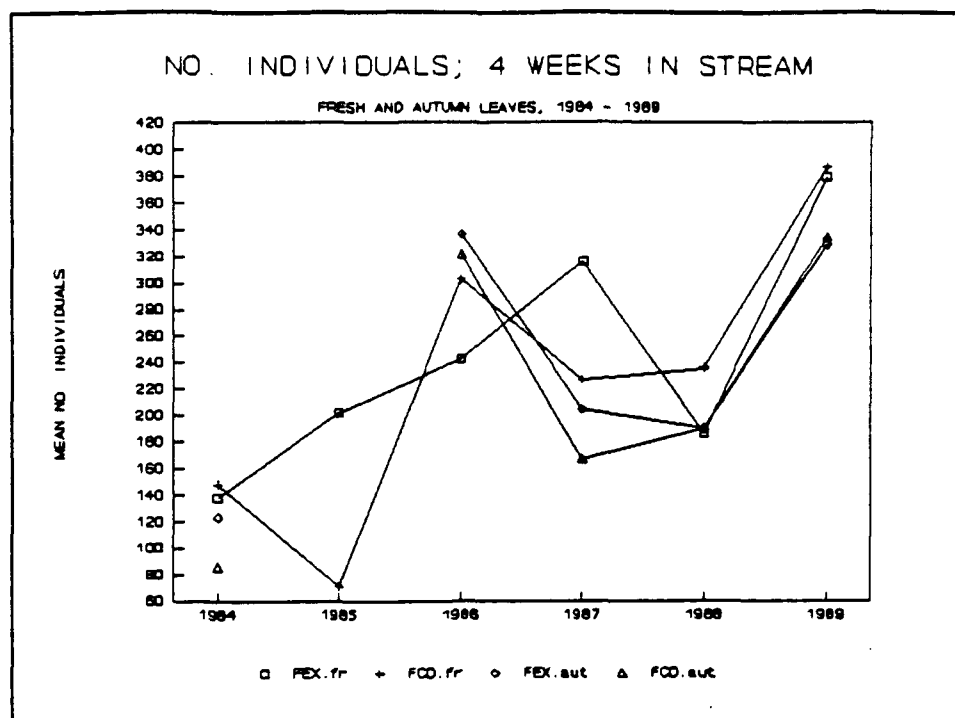


Figure 6.7. Mean numbers of individuals on fresh and autumn leaves at FEX and FCD, 1984 - 1989. Squares: FEX.Fresh; Pluses: FCD.Fresh; Diamonds: FEX.Autumn; Triangles: FCD.Autumn.

TABLE 6.9
Two-Way ANOVA Tests for Numbers of Insects on (A) Fresh and
on (B) Autumn Abscised Leaves After 24 to 28 Days,
1984 through 1989

Source	d.f.	SS	MSS	F value
(A) Fresh Leaves				
Years	5	605859	121172	49.478***
Site	1	5154	5154	2.105 ns
Interaction	5	104308	20861	8.518***
Error	72	176326	2449	
(B) Autumn Leaves				
Years	4	540871	135218	34.658***
Site	1	3183	3183	0.816 ns
Interaction	4	4271	1068	.274 ns
Error	60	234089	3901	

TABLE 6.10

Multiple Regression Values for Numbers of Insects on
Fresh and Autumn Leaves, FEX and FCD
24 to 28 Days' Incubation, 1984 through 1989

1. FEX. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	146.067	18.817	7.763	<.0001	.613
Cum.Deg.Day	-1.829	.296	-6.173	<.0001	.501
Discharge	-32.583	8.670	-3.758	.0006	.271

Std. Err. Est. = 55.110		R ² = .699			

2. FCD. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	107.882	17.313	6.231	<.0001	.505
Cum.Deg.Day	-1.358	.296	-4.579	<.0001	.356
Discharge	-34.674	7.103	-4.882	<.0001	.385

Std. Err. Est. = 58.633		R ² = .741			

3. FEX. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	137.892	17.619	7.826	<.0001	.664
Cum.Deg.Day	-1.576	.276	-5.713	<.0001	.513
Discharge	85.269	21.095	4.042	.0003	.345

Std. Err. Est. = 51.305		R ² = .746			

2. FCD. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	136.516	20.919	6.526	<.0001	.579
Cum.Deg.Day	-1.155	.355	-4.364	.0001	.381
Discharge	74.215	20.919	3.548	.0013	.289
Std. Err. Est. = 70.266			R ² = .666		

Functional Community Parameters

1. Total Insect Biomass

Total Insect Biomass, adjusted for leaf mass, was exceedingly high in 1989 for all leaves at both sites (Figure 6.8). Large individuals of the stonefly, *Acroneuria* sp. accounted for most of the increased insect biomass. Because the large stoneflies were found on fresh and autumn leaves at both sites, there were no differences in insect biomass at either site that year. Over the years, insect biomass, adjusted for leaf mass was higher on fresh leaves at FEX than on fresh leaves at FCD. This held true for autumn leaves as well (Figure 6.8). Two-Way ANOVA tests were run on the fresh leaf and autumn leaf data to see whether there were site or year effects from 1984 through 1989. Table 6.11 shows that there were significant site effects only for fresh leaves, but they were not highly significant. There were highly significant differences among years for biomass of insects on fresh and on autumn leaves.

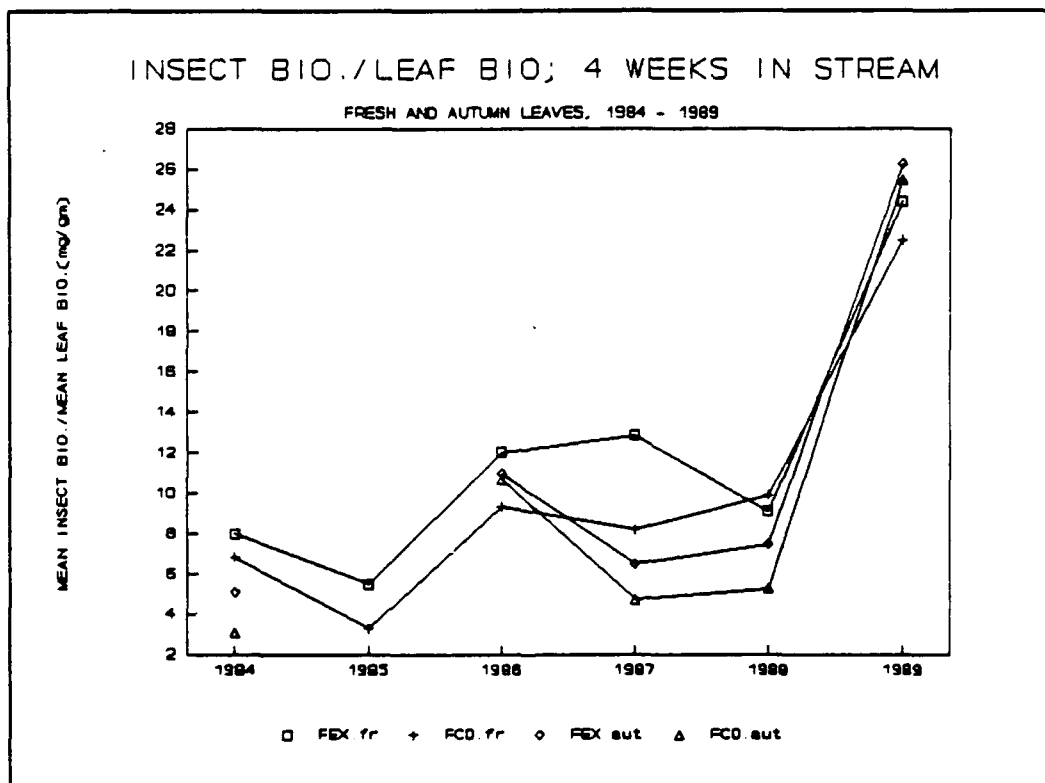


Figure 6.8. Total Insect Biomass/ Leaf Biomass on fresh and autumn leaves at FEX and FCD. 1984 - 1989. Squares: FEX.Fresh; Pluses: FCD.Fresh; Diamonds: FEX.Autumn; Triangles: FCD.Autumn.

TABLE 6.11

Two Way ANOVA Tests for Mean Total Insect Biomass,
Adjusted for Leaf Mass on
Fresh (A) and Autumn Abscised (B) Leaves
After 24 to 28 days, 1984 through 1989

Source	d. f.	SS	MSS	F value
(A) Fresh Leaves				
Years	5	2988.763	597.753	39.624***
Site	1	81.799	81.799	5.422*
Interaction	5	57.281	11.456	0.759 ns
Error	72	1086.166	15.0856	
(B) Autumn Leaves				
Years	4	4464.504	1116.126	8.708***
Site	1	35.527	35.527	0.277 ns
Interaction	4	10.357	2.589	0.020 ns
Error	60	7690.055	128.168	

Because there were significant year differences for both leaf types, a multiple regression test was done for each treatment and site to see how much of the variance in this parameter could be attributable to years, cumulative degree days and discharge (Table 6.12). The overall R^2 values were very high for FEX (0.57) and FCD (0.74) fresh leaves. Prior analyses showed that fresh leaves appeared to be preferred over autumn leaves; however, there was a lag of insect colonization as compared with autumn leaves. After the fourth week, both processing rates and colonization of insects on leaves increased as compared with autumn leaves (1985 through 1989 Annual Reports). All three partial regression coefficients accounted for a significant amount of the variance of insect biomass on fresh leaves.

A lesser proportion of the variance in insect biomass/autumn leaf mass was attributable to the combined physical factors (FEX=0.22; FCD=0.37). Years explained most of the variation at FEX. Years and cumulative degree days explained most of the variation at FCD.

Because there is only one mean value per year for insect mass, adjusted to leaf mass, no B.A.C.I. tests can be run on these data. The above sorts of analyses, combined with graphical analyses are presently used to see whether there is a before versus after effect. It may be that ELF intensity, duration,

and/or frequency values can be used in multiple regression analyses or in ANCOVA analyses to determine ELF impacts on the various biological variables we have been following for this Element.

TABLE 6.12
Multiple Regression Analyses for Insect Mass/Leaf Mass on
Fresh and Autumn Leaves, FEX and FCD
24 to 28 Days' Incubation, 1984 through 1989

1. FEX. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	8.8023	1.796	4.905	<.0001	.394
Cum.Deg.Day	-.1086	.0283	-3.836	.0005	.284
Discharge	-2.9631	.8244	-3.594	.0009	.259

Std. Err. Est. =		5.221	R ² =		.572

2. FCD. Fresh Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=38)	P	Partial
Year	6.9295	1.0270	6.747	<.0001	.545
Cum.Deg.Day	-.0866	.0176	-4.926	<.0001	.390
Discharge	-1.7903	.4214	-4.249	.0001	.322

Std. Err. Est. =		3.4781	R ² =		.741

3. FEX. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	10.1553	4.3595	2.329	.0263	.145
Cum.Deg.Day	-.1098	.0681	-1.613	.1165	.075
Discharge	1.2773	5.0891	.251	.8034	.002

Std. Err. Est. =		12.717	R ²	= .218	

4. FCD. Autumn Leaves

Variable	Reg. Coeff.	Std. Err.	T(df=31)	P	Partial
Year	12.1474	3.1690	3.833	.0006	.322
Cum.Deg.Day	-.1642	.054	-3.050	.0047	.231
Discharge	-1.0321	3.1691	-0.326	.7469	.003

Std. Err. Est. =		10.645	R ² =		.371

It appears as though discharge does not negatively affect autumn leafpacks nearly as much as it affects fresh leafpacks in the stream because the partials for discharge account for very little of the variation in insect mass/leaf mass. Higher stream flow may not only dislodge insects but may increase breakage of the leaves themselves. There are several possibilities to consider. Are there more active and fewer sessile insects on the fresh leaves, allowing for a greater loss of insects with increased flow? Are these green food islands in the stream less evenly colonized by insects; that is, once they are found, do the active insect consumers passively or actively exclude others? This would lead to higher variation in insect mass and higher variation in ways the leaves are consumed, as compared with the more common leaf type in the stream during that time of year; namely, autumn leaves.

2. Mean Dry Weight per Individual (MDW/IND)

Individuals of species that are found in sufficient numbers on leafpacks and grow during the autumn and winter seasons can be followed for possible changes in growth rates from year to year at the experimental and reference sites. Three species fulfilled those two criteria: Ephemerella invaria, Ephemerella subvaria (mayfly collector-gatherers) and Isoperla transmarina (a predatory stonefly).

Changes in MDW/IND values for each species were plotted against chronological time, days in stream, as well as physiological time, cumulative degree days with the accumulations beginning the first day the leaves were placed at the site. Growth rates over time was linear and so ANCOVAs with days in stream for the covariate was used for statistical purposes (Table 6.13). Growth was related to reductions in daily water temperatures were graphed for heuristic purposes to show that these species grew faster as water temperatures decreased in the fall and winter months (Figures 6.9 through 6.11). Rather than being linear plots (chronological time), these were exponential, with the fastest growth rates being when the lowest cumulative degree days occurred between sampling dates. By late October through December, the waters had cooled and the leaf inputs were high for these collector-gatherers and predators. All three species emerge in the late spring-early summer each year (See Element 4, This Report.). They had not attained their peak growth by the end of the leafpack experiments, but accelerated rates of growth occur during the leafpack experiments. If ELF alters growth rates, one would expect the effects to be apparent in rate changes and/or in maximum size at emerge time. This Element and Element 4 are designed to identify any changes if they are statistically significant under natural conditions.

Table 6.13 are the ANCOVAS relating MDW/IND values of Ephemerella subvaria (for all replicates over time) to days in stream. Comparisons are between FEX and FCD, year by year.

TABLE 6.13

ANCOVAS for MDW/IND Changes in Ephemerella subvaria, FEX vs. FCD
Fresh (A) and Autumn (B) Leaves, 1984 - 1989

A. FRESH LEAVES			B. AUTUMN LEAVES		
Year	F-values		Year	F-values	
	Adj.Means	Slopes		Adj. Means	Slopes
1984	.688	.001	1984	8.239**	5.748*
1985	1.951	.066			
1986	8.357***	31.026***	1986	2.385	3.586
1987	4.096*	5.960*	1987	1.644	0.020
1988	1.797	1.555	1988	.241	.248
1989	4.240*	7.308**	1989	.996	.386

Ephemerella subvaria, a collector-gatherer mayfly found on fresh leaves showed significance for mean values and significance for differences between slopes (growth rates) in 1986, 1987, and 1989. Figure 6.9A shows the the major reason for the significance was that mean sizes for this animal at the two sites on the final collection date were very different. Sizes were similar for the prior collection dates each each year. A robust regression analysis may be preferable to the ANCOVA in these cases.

Growth rates for this species on autumn leaves were significantly higher in 1984 and 1986. Both years, the FCD site showed the highest growth rate. The only year in which there were significant difference for both leaf types in 1986, the first year the ELF line was activated. Activation increased in intensity and in duration from 1986 through 1989; yet, there was no pattern between FEX and FCD with respect to significant growth rate differences across the years for E. subvaria on fresh and autumn leafpacks. (Note that the mean mass for individuals was higher in 1984 through 1986. Those years, leafpack experiments were initiated in mid-September. In later years the experiments began in mid-August.

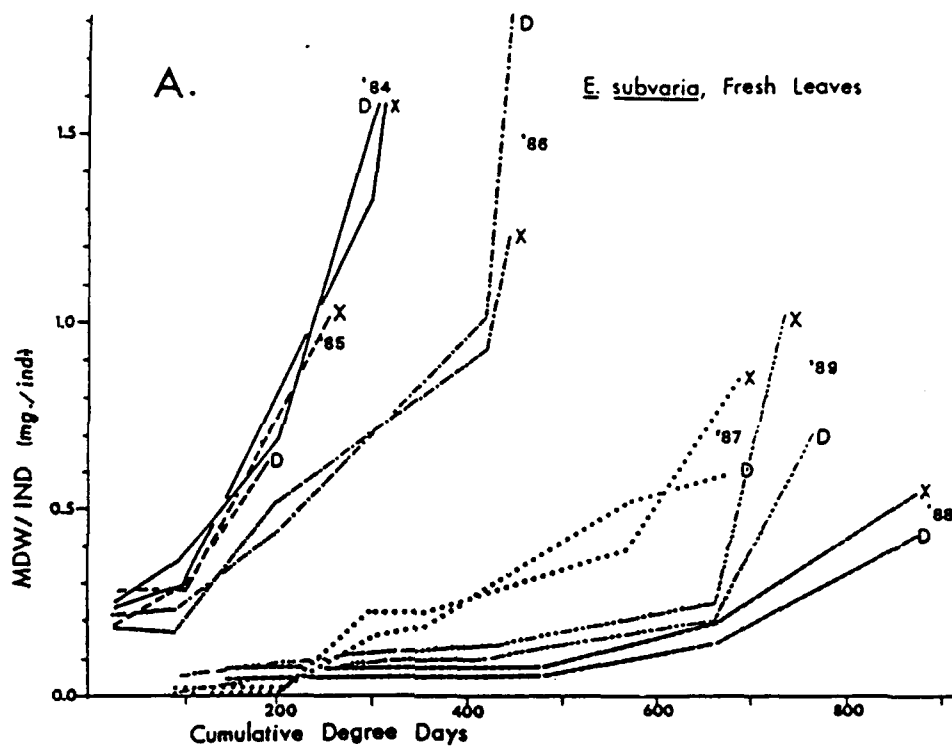


Figure 6.9A. *Ephemerella subvaria* on Fresh Leaves. Changes in Mean Dry Weight/Individual against Cumulative Degree Days. FEX and FCD, 1984-1989.

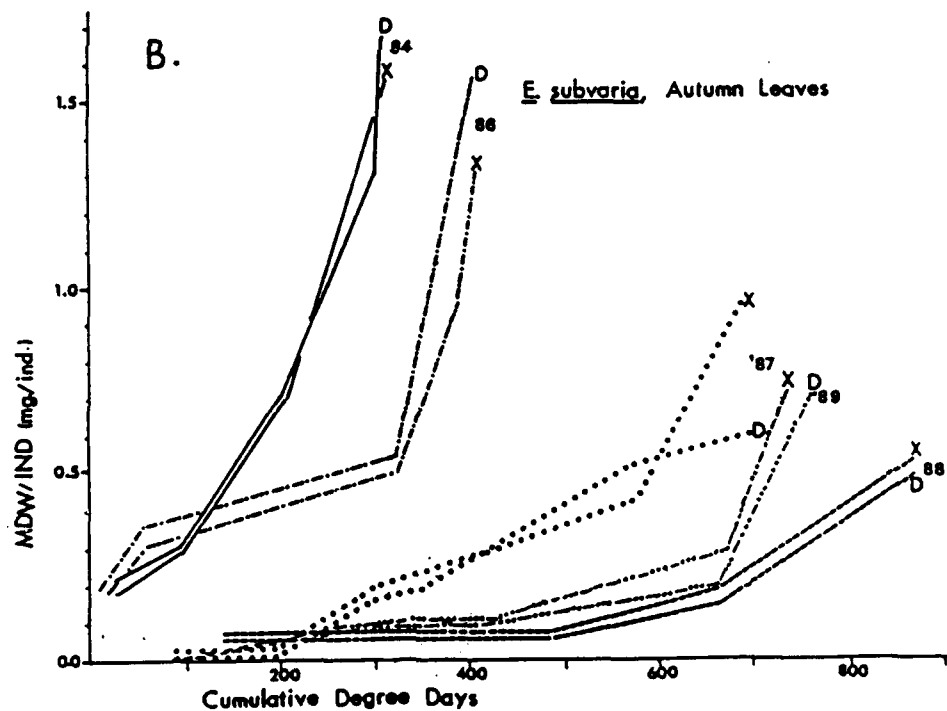


Figure 6.9B. *Ephemerella subvaria* on Autumn Leaves. Changes in Mean Dry Weight/Individual against Cumulative Degree Days. FEX and FCD, 1984-1989.

Growth rates for Ephemerella invaria on fresh leaves were never significantly different between FEX and FCD (Table 6.14; Figure 6.10A).

TABLE 6.14

ANCOVAS for MDW/IND Changes in Ephemerella invaria, FEX vs. FCD
Fresh (A) and Autumn (B) Leaves, 1984 - 1989

A. FRESH LEAVES			B. AUTUMN LEAVES		
Year	F-values		Year	F-values	
	Adj. Means	Slopes		Adj. Means	Slopes
1984	.503	.460	1984	.121	.410
1985	1.605	.434			
1986	2.332	.034	1986	.698	6.116*
1987	1.400	.007	1987	.410	2.753
1988	1.332	.691	1988	.226	4.081
1989	1.413	.048	1989	2.875	21.246***

There were significant differences for growth rates of E. invaria on autumn leaves in two out of four post-operational years (Table 6.14, Figure 6.10B). In each year, growth rates were higher at the reference site, FCD than at the experimental site, FEX. The greatest difference in rates was in 1989 when full operation of ELF began. In 1990 leafpack studies were initiated under the ELF lines, approximately 150 m downstream from the extant FEX site. ELF ground intensities are higher at the FEX.LINE site. If, in 1990, we find that growth rates of this species are significantly lower there than at the FEX site, and the growth rates for this species at FEX are also lower than at FCD, an ELF effect on growth rates for E. invaria may be suspected. For now, I can envision no reason why growth rates did not differ when E. invaria was on fresh leaves but did differ when it was on autumn leaves at the two sites.

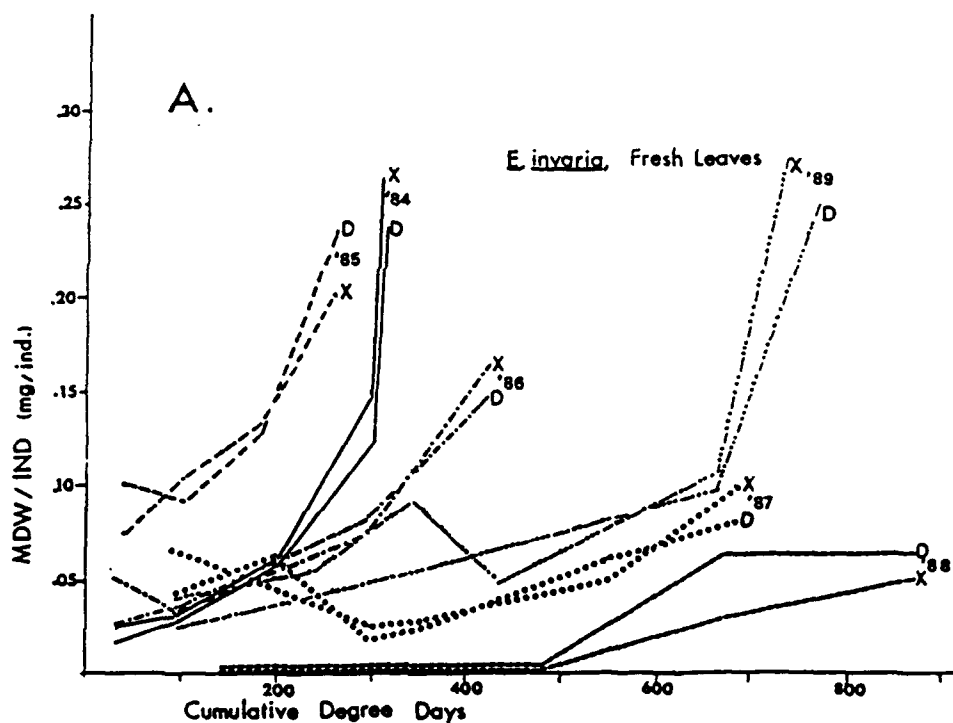


Figure 6.10A. *Ephemerella invaria* on Fresh Leaves. Changes in MDW/IND against Cumulative Degree Days. FEX and FCD, 1984 - 1989.

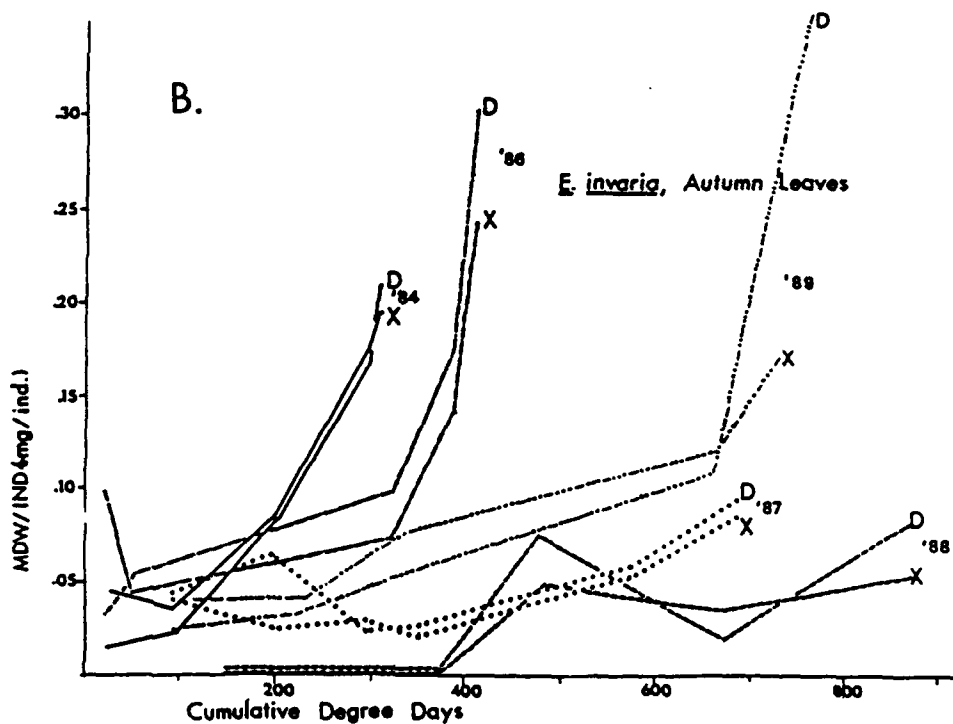


Figure 4.10B. *Ephemerella invaria* on Autumn Leaves. Changes in MDW/IND against Cumulative Degree Days. FEX and FCD, 1984; 1986 - 1989.

A predatory stonefly, Isoperla transmarina on fresh leaves, showed significant growth rate differences in 1986 and in 1989. In 1986 the mean mass per individuals was greater at FCD and in 1989 it was greater at FEX (Table 6.15, Figure 6.11A). There were no significant differences in growth rates between the two sites for this insect found on autumn leaves (Table 6.15, Figure 6.11B). (In 1988 too few individuals were collected on either fresh or autumn leaves for statistical analyses.)

TABLE 6.14

ANCOVAS for MDW/IND Changes in Isoperla transmarina, FEX vs. FCD
Fresh (A) and Autumn (B) Leaves, 1984 - 1989

A. FRESH LEAVES			B. AUTUMN LEAVES		
Year	F-values		Year	F-values	
	Adj. Means	Slopes		Adj. Means	Slopes
1984	4.329*	1.963	1984	.284	.247
1985	2.310	1.674			
1986	.452	3.172	1986	.431	1.328
1987	.002	.380	1987	.064	.954
1988	Too few data		1988	Too few data	
1989	.875	5.853*	1989	.158	.956

In summary for changes in MDW/IND values, only one of the three species, namely E. invaria, showed a positive trend in growth rate differences as related to ELF activation. This trend occurred only for that species on autumn leaves. The 1990 and 1991 studies at the three sites, a new one being under the ELF line, will be crucial in determining whether ELF activation is associated with growth rate changes for this species.

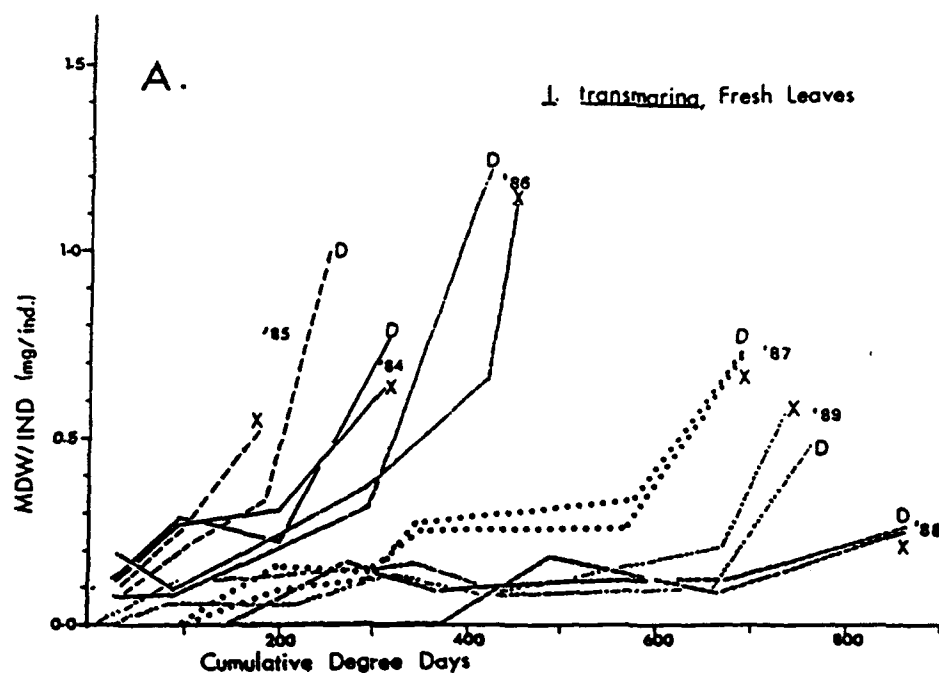


Figure 6.11A. *Isoperla transmarina* on Fresh Leaves. Changes in Mean Dry Weight/Individual against Cumulative Degree Days. FEX and FCD, 1984-1989.

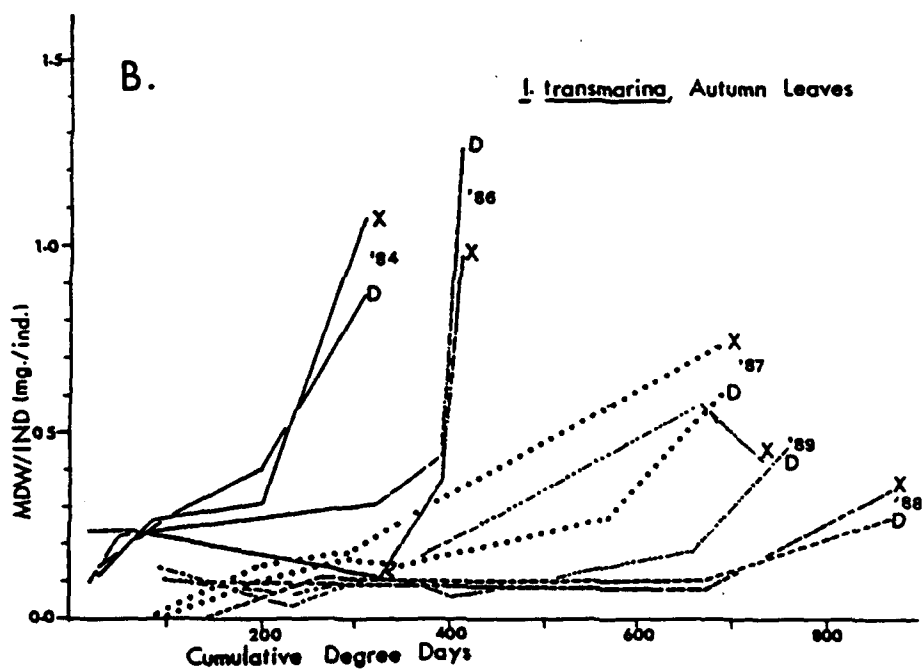


Figure 6.11B. *Isoperla transmarina* on Autumn Leaves. Changes in Mean Dry Weight/Individual against Cumulative Degree Days. FEX and FCD, 1984-1989.

Future Plans for This Element

Fresh and autumn abscissed leaf experiments will begin each year in late August so that the last retrieval date will be in mid-November. In the past, December retrievals were often difficult. When gauss-days are collated, they will serve as an independent variable for leaf processing rates, taxon diversity, and numbers of individuals. Very little is known regarding the potential effects of extremely low frequency electromagnetic fields on biological systems. Accordingly, any insights germane to the transient behavior of the fields during changes in activity, or any other factors associated with the fields will be used in the analyses of the least varying biological variables for this element.

FEX.LINE will continue to be used as the third site in 1991. Comparisons among FEX.LINE, FEX and FCD will be made, usually using ANCOVA analyses.

Summary

Each year, fresh leaves were processed faster than autumn leaves at each site. There were no site differences for fresh leaves and no site differences for autumn leaves when all the years were analyzed together. In 1990, when the E.L.F. lines were full operational, fresh leaves were processed much more slowly at FEX relative to FCD. Conversely autumn leaves were processed faster at FEX relative to FCD. There were, therefore, strong deviations between sites that cannot be accounted for by techniques or by an unusual fall season. 1991 should be an important year for determining whether the 1990 results will be repeated. The addition of the new site below the E.L.F. antenna should be especially helpful.

Taxon diversity, richness, numbers of individuals, and mean total biomass (adjusted for leaf mass) of insects on autumn leaves after the leaves had been incubated approximately four weeks showed significant yearly variation. Significant site variation for fresh and autumn leaves occurred only for taxon diversity; for richness on fresh leaves; and for insect biomass/leaf biomass on autumn leaves. There were highly significant year differences for all parameters analyzed. Multiple regression analyses, using years, cumulative degree days and mean discharge values for the datasets showing low coefficient of variation values; that is, data from the fourth week of incubation in the sites. The physical variables, cumulative degree days and mean discharge values explained most of the variation among years for taxon diversity. Years, cumulative degree days and mean discharge values together explained much

of the variation for leaf processing rates (-k/day), taxon richness, numbers of individuals and total insect biomass/leaf biomass. In no case did years alone explain most of the variation for the above parameters. B.A.C.I. tests could not be run on these data, as there is only one mean value for any given year for each treatment and site. In looking at the graphical presentations of these data, there appears to be no trend for any parameter related to before versus after ELF activation. When ELF intensity, duration, and frequency data are analyzed, we will include these values in further statistical tests, including multiple regression analyses and ANCOVAS.

Growth rates Ephemerella subvaria, Ephemerella invaria, and Isoperla transmarina were usually not significantly different between sites, using ANCOVA analyses. In only one case, individuals of E. invaria on autumn leaves, was there a trend related to ELF activation. Growth rates were lower at the FEX than at FCD after ELF activation and the maximum difference occurred in the fall of 1989, the time when ELF went on full power and duration. Data from the 1990 and 1991 seasons at FEX and FCD as well as at the new site, FEX.LINE, should reveal whether this pattern occurred by chance alone or whether the individuals of this species that occur on autumn leaves grow at slower rates when under the influence of ELF fields.

Appendix II presents a first draft of a paper on the effects of condensed tannins on leaf processing rates from boreal, mid-latitudinal (including tag alder leaves), and tropical regions. This paper is being reviewed by other authors of the paper. By mid-1991, the paper should be submitted for review in a peer-reviewed journal. Appendix III is a paper written by Ms. Jennelle Marcereau, a senior student at Michigan State University, who was a field assistant the summer of 1990. The work and paper represent an independent study which she did on her own time for later university credit under R. Jean Stout.

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APPENDIX II

THE ROLE OF CONDENSED TANNINS IN STREAM PROCESSING OF LEAF LITTER: EXPERIMENTAL STUDIES ACROSS LATITUDINAL GRADIENTS

INTRODUCTION

Defensive compounds are pivotal foci for plant-animal interaction studies in terrestrial communities (Feeny 1970, Harborne 1988, Rosenthal and Janzen 1979, Zucker 1983). Defensive compounds that are either sequestered back into plant tissue prior to leaf abscission or are easily leached in water are not expected to play a role in the utilization of leaf litter in streams. There are, however, a number of plant defensive compounds that can continue to alter biotic activity after leaves and twigs die and fall on forest floors and into streams. A suite of protective agents that remain in leaf tissue after senescence are the condensed tannins (proanthocyanidins). They are candidates for playing critical roles in the processing of leaf tissue in streams (Stout 1989). Condensed tannins can inhibit fungal penetration and later bacterial invasion into plant material (Zucker 1983, Benoit et al. 1968, Harrison 1971, Grant 1976).

There is a continuum of leaf processing rates among plant taxa for leaves that fall into streams. In the initial conditioning phase, leaves are leached and then penetrated by colonizing aquatic hyphomycetes, preparing the way for bacterial invasion (Suberkropp and Klug 1976, 1981). This critical phase can be qualitatively and quantitatively different when condensed tannins are present in leaf tissue (Stout 1989, Irons et al. 1988). Because aquatic invertebrates prefer conditioned leaves (Kaushik and Hynes 1968, Triska 1970, Barlocher 1980), not only could the initial processing of leaves be hindered, but large leaf losses attributable to invertebrate consumption could be reduced. In fact, condensed tannins may be so effective as inhibitors of fungal and bacterial invasion that they may consistently slow down decompositional processes irrespective of the environment in which they finally reside after cellular death of the plant tissue.

Seven stream ecologists, using five research sites extending from 65° N to 10° N latitude, each contributed leaves from two species of plants, one thought to be high and one low in condensed tannins, based on the literature or experimental data (See Stout 1989). We hypothesized that leaves high in condensed tannins would be processed more slowly in streams than leaves low or lacking in condensed tannins, irrespective of the original locale for the leaves. As the sites extended from Alaska to Costa Rica, water temperatures were taken to compute cumulative degree-day differences among sites for the international reciprocal leaf transfer experiment. This paper describes leaf losses from 10 species, two of which are native and the remaining exotic, in an Alaskan, Michigan, and a Costa Rican stream. We also present results of insect colonization patterns on leaves of 12 plant species in the Michigan

stream. Although the original design included streams in New York, North Carolina, and Puerto Rico, methodological problems at the first two locations and no leaves being sent for tannin analysis from the last site forced exclusion of those sites from data analysis. Leaves from New York and North Carolina were shipped to all investigators and they were used in Alaska, Michigan and Costa Rica. As no leaves were shipped from Puerto Rico to Alaska, those two species were excluded from leaf processing results herein presented. (They were used in Michigan and in Costa Rica, and results for those two species, Dacryodes excelsa (Burseraceae) and Sapium laurensce (Euphorbiaceae) are available upon request.

METHODS

Leaves were collected from 10 to 12 species of riparian trees in six sites (See Table 1 for site descriptions and plant species), pressed and dried at $<50^{\circ}\text{C}$ for 48 hr. They were then frozen for over 48 hr prior to shipment to minimize introduction of exotic micro-organisms. Upon arrival at each site, leaves were again dried at $<40^{\circ}\text{C}$ for 24 hr, weighed into 3 gm (+ or - 0.1 gm) packets, hydrated to prevent breakage and then placed in 2 cm opening bird netting mesh envelopes. Each envelope was sewn into six pockets with two envelopes comprising each replicate set. Assignments as to location of each species within envelopes were made according to a table of random numbers. The envelopes were kept moist in coolers and transported to the stream where each envelope was placed just above the substrate and perpendicular to the current and then tied between two concrete reinforcing rods or wooden dowling (Alaska). Leaves were placed in Monument Creek, Alaska October 5, 1988; in the Ford River, Michigan on August 20, 1988, and in the El Salto Creek, Costa Rica on August 3, 1988. On each collection day, five replicates for each species were gathered. Each pocket was cut out and placed in its own zippered plastic bag and placed in a cooler for transport to the laboratory. There, they were washed over a 60 μm mesh soil seive. Insects were preserved in 70% alcohol and leaves were dried at $<50^{\circ}\text{C}$ for 48 hr and reweighed. Leaves were collected and dried after 2 (the initial conditioning phase), 14, 28, 56 and 75 days in Monument Creek, Alaska, after 2, 14, 21, 28, 54 and 84 days in Michigan, and after 2, 14, 28, 40, 56, and 86 days in El Salto Creek, Costa Rica.

Maximum-minimal daily to weekly temperatures were recorded for each site. Those data were used to compute cumulative degree days for later analysis. Percent dry weight remaining values were used to calculate chronological processing rates, $-\dot{k}/\text{day}$ values (after Petersen and Cummins 1974). Physiological processing rates, $-\dot{k}/\text{degree day}$ were also computed,

using the data from maximum-minimum water temperatures. The threshold value for accumulation of degree days was 0°C.

Post leached leaves collected from the streams after 2 days immersion were sent to Alaska where they were analyzed for tannins using the butanol-HCl reaction for proanthocyanidins (Martin and Martin 1982). Tannin concentration was determined colorimetrically on a Perkin-Elmer Spectrophotometer at an absorbance wavelength of 550 nm. Data are reported as absorbance at 500 nm and as Quebracho equivalents. the calibration equation used to convert absorbance to Quebracho equivalents is: $Tannin = 429.607(A550) - 61.588(A550)^2$ where A550 is the absorbance at 550 nm and Tannin is the amount of tannin in the sample in units of mg/0.3 ml (F ratio - 5513.383, $r^2 = 0.999$. Data were then converted to percent tannin in the remaining leaf material (by dry weight). Nitrogen and phosphorus concentrations were determined on a Technicon Autoanalyzer by a sulfuric/selenious acid digestion and colorimetric analysis with ferricyanide blue reaction for nitrogen and molybdate blue for phosphorus.

Insects on the leaves in the Ford River, Michigan were identified to the lowest taxon possible, measured and counted. Biomass estimates were made (after Smock 1980) and structural community parameters including numbers, diversity (H' after Shannon-Weiner 1949), evenness, and taxon richness were determined.

TABLE 1
Sites for Collection and Plant Species

Site, Participants	Species (Family)
Fairbanks, ALASKA	Salix alaxensis (Salicaceae)
M. W. Oswood, J. G. Irons III, J. P. Bryant	Alnus crispa (Betulaceae)
Oswego, NEW YORK	Acer saccharum (Aceraceae)
W. Mc.Dowell	Fagus grandifolia (Fagaceae)
Dickinson Co. MICHIGAN	Alnus glutinosa (Betulaceae)
R. J. Stout	Quercus rubra (Fagaceae)

Table 1, continued

Site, Participants	Species (Family)
Chapel Hill NORTH CAROLINA	Cornus florida (Cornaceae)
S. R. Reice	Quercus falcata (Fagaceae)
Sites, Participants	Species (Family)
La Selva COSTA RICA	Trema micrantha (Ulmaceae)
	Pithecellobium longifolium (Fabaceae)
C. M. Pringle	
El Verde PUERTO RICO	Sapium laurensce (Euphorbiaceae)
	Dacryodes excelsa (Burseraceae)
C. Asbury	

RESULTS

A. Tannin content of leaves

We selected the riparian plant species for our study, based on chemical data from the literature (see Stout, 1989). Only after the field work was completed were we given condensed tannin concentrations for the selected species, as performed by Jack Irons and his colleagues at The University of Alaska. Only one species, Salix alaxensis from Alaska, had a lower post leaching condensed tannin value than expected. Pre-leaching values done in the same laboratory had been high for this species and it was expected to be one of the species high in condensed tannins. Figure 1 shows that leaves of the two species from Costa Rica and from the two species from North Carolina fulfilled our goal of having one species high and one species low in condensed tannins. New York and Michigan were intermediate in their differences for condensed tannin content, but leaves from Alaska were both low with respect to post-leaching condensed tannin concentrations.

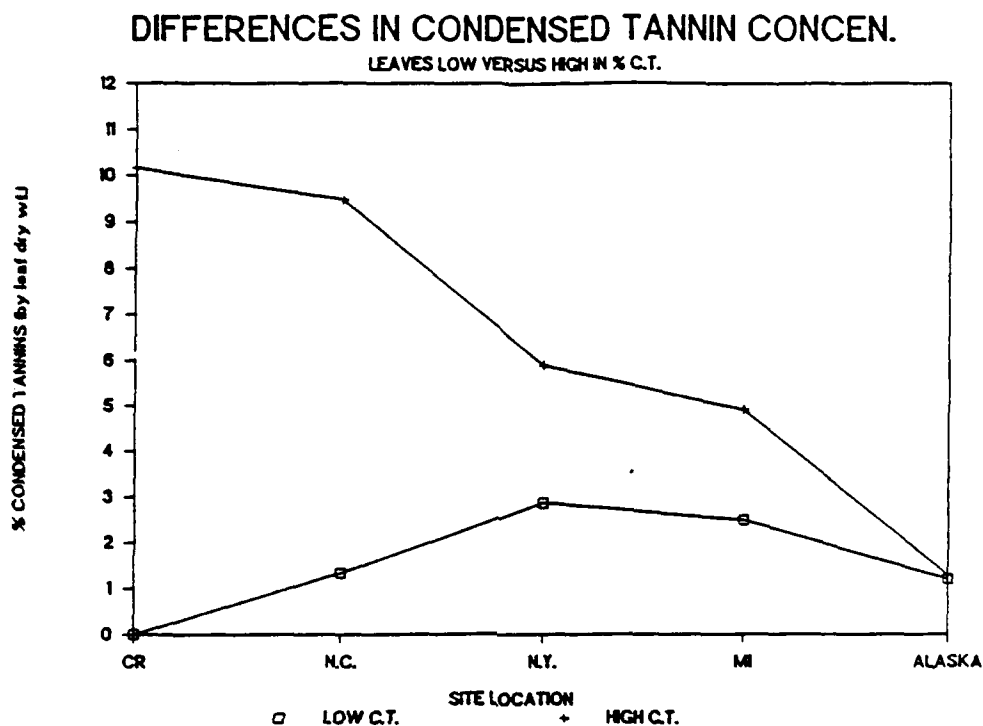


FIGURE 1

Figure 1. Tannin content of leaves from Costa Rica, North Carolina, New York, Michigan, and Alaska (% condensed tannins of dry wt. of Leaves). Each site includes two plant species; one high and one low in condensed tannins. Only leaves from Alaska showed no differential, after analysis.

B. Processing rates of leaves

1. **Alaska.** Leaves low in condensed tannins were processed faster than leaves high in condensed tannins in Monument Creek (60oN, 140oW), irrespective of place of origin (squares, Figure 2A). The native alder, Alnus crispa, was processed the fastest; tag alder from Michigan, Alnus rugosa, was next fastest, and Trema micrantha, a species from Costa Rica that lacked condensed tannins, was third in its chronological processing rate. In all, leaves of six species were processed fast in Monument Creek (fast = $-k/day$ greater than 0.01). Those six species contained less than three percent condensed tannins. Leaves that were processed at intermediate to slow rates ($-k/day$ = 0.0053 to 0.0011) contained from nearly five percent to over 10 percent condensed tannins (Table 2). The chronological processing rates in that table are arranged from fastest to slowest rates, with Alaska being the reference site.

Processing rates, according to physiological time, $-k/degree\ day$ (Table 3), showed deviations from chronological time, $-k/day$ (Table 2), only for leaves lacking or low in condensed tannins (crosses versus squares, Figure 2A). There were no deviations between physiological and chronological time for leaves rich in condensed tannins.

TABLE 2
Chronological Processing Rates ($-k/day$) and % Condensed
Tannins for Leaves in Alaskan, Michigan, and Costa
Rican Streams

Species C.T.	Alaska	Michigan	Costa Rica	%
<u>Alnus crispa</u>	0.0741	0.0134	0.4066	1.21
<u>Alnus rugosa</u>	0.0698	0.0130	0.3904	2.48
<u>Trema micrantha</u>	0.0459	0.0833	0.5233	0.00
<u>Salix alaxensis</u>	0.0380	0.0172	0.0767	1.30
<u>Cornus florida</u>	0.0266	0.0210	0.4980	1.34
<u>Acer saccharum</u>	0.0146	0.0181	0.1506	2.85
<u>Fagus grandifolia</u>	0.0053	0.0065	0.0819	5.86
<u>Quercus rubra</u>	0.0049	0.0122	0.1210	4.88
<u>Quercus falcata</u>	0.0020	0.0058	0.0726	9.46
<u>Pithecellobium longifolium</u>	0.0011	0.0035	0.0175	10.16

MONUMENT CREEK ALASKA

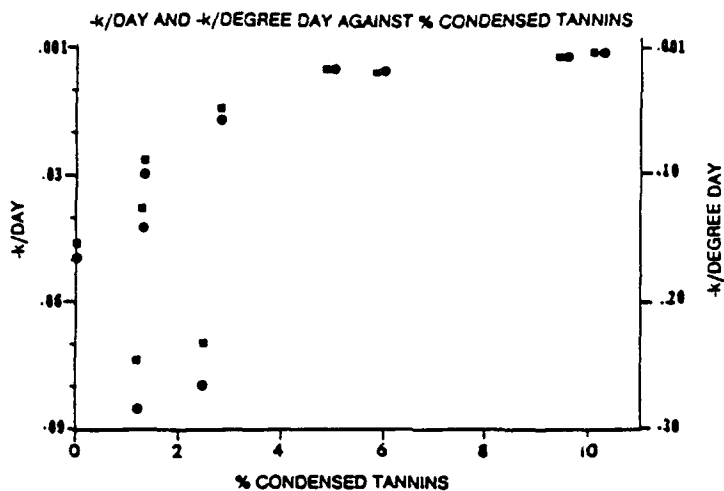


FIGURE 2.A

FORD RIVER, MICHIGAN

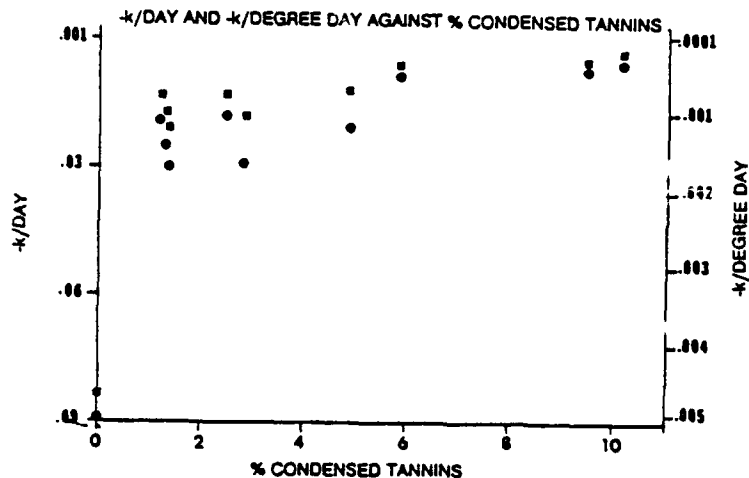


FIGURE 2.B

EL SALTO, COSTA RICA

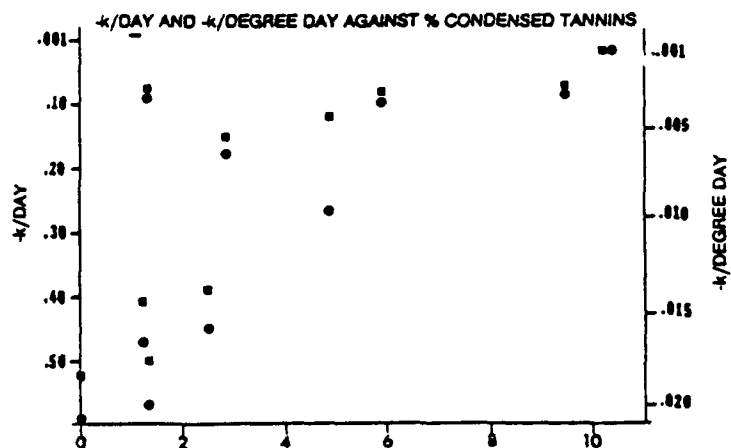


FIGURE 2.C

Figures 2.A, 2.B, 2.C. Chronological processing coefficients ($-k/\text{day}$) versus % condensed tannin content: SQUARES. Physiological processing coefficients ($-k/\text{cum. degree day}$) versus % condensed tannin content: CIRCLES. 2.A: Leaves in Alaskan stream. 2.B: Leaves in Michigan stream. 2.C: leaves in Costa Rican stream.

TABLE 3
Physiological Processing Coefficients, $-k/\text{cum.degree day}$
and % Condensed Tannins for Leaves in Alaskan,
Michigan, and Costa Rican Streams

Species C.T.	Alaska	Michigan	Costa Rica	%
<i>Alnus crispa</i>	0.2823	0.0011	0.0163	1.21
<i>Alnus rugosa</i>	0.2658	0.0010	0.0156	2.48
<i>Trema micrantha</i>	0.1649	0.0050	0.0209	0.00
<i>Salix alaxensis</i>	0.1435	0.0014	0.0030	1.30
<i>Cornus florida</i>	0.1003	0.0017	0.0199	1.34
<i>Acer saccharum</i>	0.0520	0.0016	0.0060	2.85
<i>Fagus grandifolia</i>	0.0197	0.0005	0.0033	5.86
<i>Quercus rubra</i>	0.0193	0.0012	0.0091	4.88
<i>Quercus falcata</i>	0.0077	0.0005	0.0028	9.46
<i>Pithecellobium longifolium</i>	0.0046	0.0004	0.0010	10.16

2. **Michigan.** Leaves containing zero to less than three percent condensed tannins were also processed fast in the Ford River (48oN, 87oW) irrespective of place of origin (squares, Figure 2B). *Trema micrantha* from Costa Rica, was processed the fastest. *Cornus florida* from North Carolina and *A. saccharum* from New York were the second and third, respectively, fastest decomposing species. The Michigan species low in condensed tannins, *A. rugosa*, was the sixth fastest species to be processed. Of the four remaining species, which were intermediate to high on condensed tannins, the native red oak was the fastest species to be processed. The most slowly processed species was the Costa Rican legume, *P. longifolium*.

Relative deviations between physiological (crosses, Figure 2B) and chronological time (squares, Figure 2B) occurred for all species. The lowest deviations were for the non-native species high in condensed tannins.

3. **Costa Rica.** Almost all species of leaves placed in the Costa Rican stream (10oN, 84oW) were processed very fast over chronological time ($-k/\text{day}$ more than 0.07, Table 2). Only the native species high in condensed tannins, *P. longifolium*, was processed slowly relative to the other species ($-k/\text{day} = 0.0175$). Leaves of the native species, which lacked condensed tannins, *T. micrantha* was processed the fastest, and *C. florida* from North Carolina was processed nearly as fast (squares, Figure 2C; Table 2). The two alders, one from Michigan and one from Alaska, had similar processing rates. One species, exotic to Costa Rica, *Salix alaxensis*, was low in condensed tannins but was processed slower than leaves of the other species low in condensed

tannins. Leaves of that Alaska species, whose post-leaching condensed tannin content was one of the lowest in the study (Table 1) had the third slowest processing rate in the Costa Rican stream. This was the only species that was low in condensed tannins and, yet, was processed slowly.

Deviations between physiological and chronological processing rates (crosses and squares, respectively, Figure 2C) were the smallest for leaves of the three species highest in condensed tannins, as well as for the Alaskan willow, S. alaxensis.

4. Comparisons among Sites

Differences between physiological and chronological processing rates were greatest for leaves low or lacking in condensed tannins for each of the sites in which the leaves were placed. The greatest differences were in the Alaskan stream. The intermediate differences were in the Michigan stream, and the lowest differences occurred for leaves in the Costa Rican stream (Figure 3; also compare Table 2 and Table 3).

Even though leaves for eight of the ten species placed in each stream were exotic to the streams' environment, the rates of decomposition were related to condensed tannin concentrations rather than to the site of origin for the species of leaves.

C. Insects on Leafpacks, Michigan

The data presently available come from leaves placed in the Ford River, Michigan. In addition to the 10 species used for the leaf processing studies, two species, Sapium laurensce (theorized to be low in condensed tannins) and Dacryodes excelsa (theorized to be high in condensed tannins) came from Puerto Rico. Although the leaves were not analyzed for condensed tannin concentrations (see Methods section), insects colonizing those leaves are included.

Taxon diversity (H') and numbers of individuals were usually higher on boreal and mid-latitude leaves than on tropical leaves over time (Table 4). Within each biome, there was no relationship between condensed tannin concentration and H' or numbers of individuals. The highest diversity and abundances of insects were on leaves of the American Beech, Fagus grandifolia. Although this tree is no longer native to the Upper Peninsula of Michigan, prior to burning and logging in the 19th Century, it had been a dominant tree species (Woods and Davis 1989).

FIGURE 3

DIFFERENCE BETWEEN $-k/\text{DEGREE DAY}$ AND $-k/\text{DAY}$
AGAINST PERCENT CONDENSED TANNINS

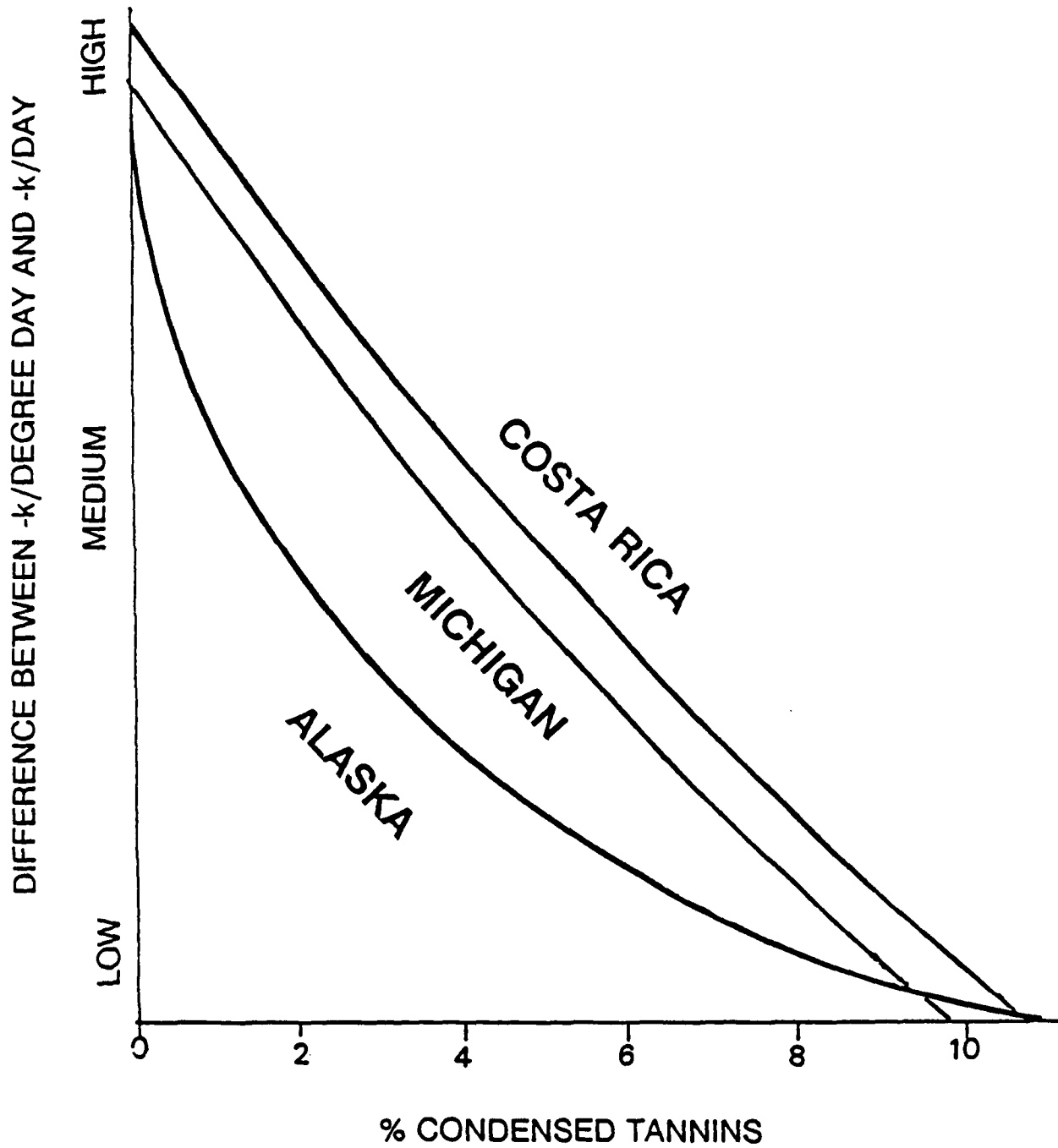


Figure 3. Difference between physiological processing and chronological processing for leaves placed in Alaskan, Michigan, and Costa Rican streams. (Hand-drawn curves).

Taxon evenness (J') increased over time for all insect communities on leaves, irrespective of tannin content or of native habitat of leaves (Table 4). Taxon richness (S) showed no clear pattern with respect to condensed tannin concentration or leaf origin (Table 4). As for diversity, the highest numbers of taxa were found on F. grandifolia.

Maximum insect mass, adjusted for leaf mass occurred after leaves had been in the Ford River for 28 days (Table 4). (This was also the period when the variance of the sample mean was lowest) The sugar maple Acer saccharum and F. grandifolia contained the highest mass of insects, adjusted for leaf mass at the time.

An aquatic insect functional feeding group, shredders, have been shown to prefer conditioned, nutritive leaves (references). If any functional group would reflect a possible unpalatable resource as might occur in leaves high in condensed tannins, it would be this group. Shredders were not more common on leaves low or lacking in condensed tannins (Figure 4A, 4B). But they were more abundant on mid-latitude and boreal leaves than on tropical leaves (Figure 4A, 4B). Shredder abundances usually peaked after 54 days' immersion. The most 'attractive' mid-latitude leaves were Quercus falcata, Acer saccharum, Cornus florida, and Fagus grandifolia. The first and last species are high in condensed tannins and the second and third species are low in condensed tannins (Table 2). The least 'attractive' mid-latitude leaves were the two species native to the Ford River. Whereas, the mean number of shredders was as high as 24 on the mid-latitudinal Q. falcata, the highest mean number on tropical leaves never exceeded five (Dacryodes excelsa on Day 28). For the most part, tropical leaves harbored only two to three shredders per leafpack.

TABLE 4
Mean Values for Structural and Functional Community Parameters
of Insects Colonizing Leaves

Spp.	Days In	% leaf remain.	H'	J'	S	#Ind.	Insect/ Leaf Bio
Salix alaxensis	14	70	1.58	0.40	16	131	2.09
	21	63	1.58	0.53	8	58	3.52
	28	66	2.18	0.58	14	87	5.87
	54	57	1.39	0.45	9	72	3.97
	84	23	1.87	0.69	9	50	4.80
Alnus crispa	14	68	0.93	0.36	8	88	8.14
	21	59	1.42	0.56	7	43	2.93
	28	61	1.61	0.50	9	69	6.46
	54	43	1.21	0.44	7	51	5.30
	84	27	0.84	0.35	3	110	5.26

Table 4, continued

Spp.	Days In	% leaf remain.	H'	J'	S	#Ind.	Insect/ Leaf Bio
<i>Quercus rubra</i>	14	83	0.84	0.30	7	98	4.89
	21	-	-	-	-	-	-
	28	70	1.20	0.40	6	66	5.25
	54	61	1.33	0.47	2	57	2.42
	84	3	1.64	0.75	5	20	5.25
<i>Fagus grandifolia</i>	14	85	1.44	0.36	17	187	6.92
	21	83	-	-	-	-	-
	28	81	1.92	0.49	16	136	10.31
	54	78	1.33	0.43	9	88	6.42
	84	53	2.22	0.69	12	58	15.60
<i>Quercus falcata</i>	14	90	1.24	0.39	9	86	4.09
	21	-	-	-	-	-	-
	28	90	1.20	0.46	6	42	2.52
	54	86	1.58	0.53	8	64	3.85
	84	69	1.66	0.53	11	90	5.19
<i>Cornus florida</i>	14	69	1.29	0.46	7	71	3.52
	21	66	1.45	0.56	7	46	2.67
	28	65	1.40	0.46	8	67	5.31
	54	44	1.63	0.51	9	74	4.49
	84	22	1.30	0.38	9	88	6.27
<i>Acer saccharum</i>	14	60	0.73	0.27	7	114	8.18
	21	43	1.58	0.56	8	53	3.78
	28	43	1.64	0.46	12	100	29.18
	54	34	1.80	0.54	11	81	4.20
	84	17	1.38	0.47	10	207	18.52
<i>Alnus rugosa</i>	14	77	1.02	0.32	10	107	8.84
	21	75	1.52	0.45	9	99	4.45
	28	73	1.66	0.52	10	58	2.84
	54	68	1.48	0.53	7	44	1.94
	84	34	1.48	0.48	8	46	3.95
<i>Trema micrantha</i>	14	25	0.85	0.27	9	97	4.32
	17	19	0.74	0.32	5	42	3.53
	21	12	0.65	0.41	5	50	3.46
	28	7	0.65	0.47	3	27	1.70
<i>Sapium laurensce</i>	14	77	0.75	0.26	8	89	4.33
	21	75	1.09	0.38	7	49	2.65
	28	73	0.66	0.28	5	54	3.79
	54	68	1.57	0.67	5	19	3.55
	84	34	1.59	0.65	7	22	5.10

Table 4, continued

Spp.	Days In	% leaf remain.	H'	J'	S	#Ind.	Insect/ Leaf Bio
Dacryodes	14	80	0.86	0.28	9	118	4.65
excelsa	21	-	-	-	-	-	-
	28	77	1.37	0.42	11	87	4.82
	54	70	0.71	0.41	3	28	1.23
	84	53	1.90	0.70	7	20	14.89
Pithecellobium							
longi-	14	90	1.28	0.38	11	107	6.94
folium	21	-	-	-	-	-	-
	28	86	1.17	0.44	7	47	3.30
	54	77	1.10	0.65	3	18	0.76
	84	72	1.74	0.87	4	8	2.46

CONCLUSIONS

Leaves high in condensed tannins were processed more slowly than leaves low in condensed tannins in each of the three streams studied, irrespective of the site of origin for the leaves. Leaves of P. longifolium from Costa Rica, Q. falcata from North Carolina, F. grandifolia from New York, and Q. rubra from Michigan were all processed more slowly at each of the three sites than were the remaining six species of leaves lacking or low in condensed tannins.

Leaves high in condensed tannins were less affected by water temperatures in the streams than were leaves lacking or low in condensed tannins. The impact of the physiological time, $-k/\text{degree day}$, was much greater for leaves lacking or low in condensed tannins. These results support the view that condensed tannins inhibit fungal and/or bacterial invasion. The biological activity of micro-organisms is expected to increase and then peak as water temperature increases. Since rates of decomposition for leaves rich in condensed tannins were not affected by increased water temperatures but leaves with little if any condensed tannins were affected, the most parsimonious view would be that condensed tannins reduced micro-organismal degradation activity.

There was no pattern indicating that insects colonizing leaves in the Ford River preferred leaves low in condensed tannins. This suggests that the presence of condensed tannins does not reduce the "attractiveness" of the leaves by the colonizing insects in the Ford River. Given the slower chronological and physiological processing rates for leaves rich in condensed tannins, it appears as though microbial processing of leaves is more important in processing rates than is insect processing of the leaves studied. Support for this

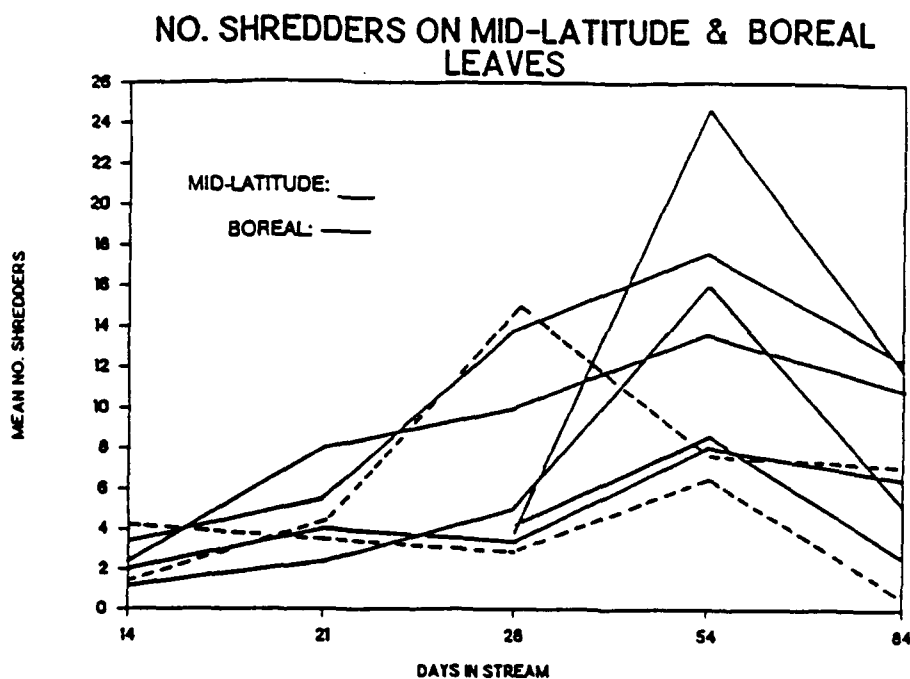


FIGURE 4.A

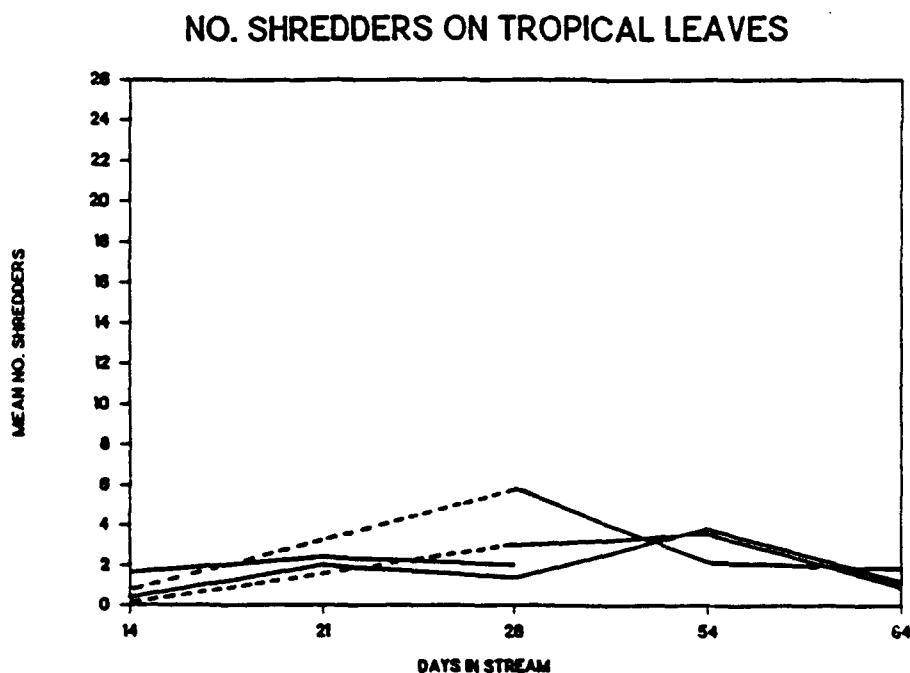


FIGURE 4.B

Figure 4.A. Numbers of shredders on boreal (dashes) and mid-latitude (solid line) leaves, placed in the Michigan stream.

Figure 4.B. Mean Numbers of shredders on tropical leaves, placed in the Michigan stream (dashes are connections between Day 14 and Day 28 when leaves rich in condensed tannins were not sampled).

view will come as data on insects colonizing leaves placed in the Alaskan and the Costa Rican streams become available. In this study, we did not analyze the microbial communities on leaves. Future, similar studies would be enhanced by their inclusion.

The faster chronological processing rates for leaves low in condensed tannins, the increased physiological processing rates for those leaves as compared with leaves high in condensed tannins, and the lack of a relationship between condensed tannin concentration and insect colonization patterns lead us to suggest that there is probably a strong microbial community - condensed tannin connection in running water systems.

As is often the case, we have raised more questions than we have answered. For example, what are the temperature threshold curves for microbial communities? Do they differ across latitudinal or altitudinal gradients? Are microbial population densities and activity rates lower on leaves rich in condensed tannins whether or not they finally reside in rivers and streams? Are there some bacteria and/or fungi that can facilitate readily to some condensed tannins and thereby utilize the carbon sources therein?

A better understanding of interactions between the microbial community and chemical constituents of plant material can have applied value. In landscape ecology, decisions as to maintenance or resoration of damaged aquatic-terrestrial linkages can be more enlightened. Processing of paper as well as by-products of timbering may be facilitated. Aquatic bacteria and/or fungi that can utilize plant material rich in chemical microbial inhibitors may be most probably isolated from environments where plants rich in defensive compounds are found; e.g., tropical lowland streams as well as streams draining coniferous forests. Condensed tannins by virtue of their microbial inhibitory characteristics may have medicinal value. Lastly, economically valuable plants that are vulnerable to microbial pathogens may be protected by the insertion of genes capable of synthesizing condensed tannins specifically targeted to the potentially invasive pathogen or pathogens.

ACKNOWLEDGEMENTS

anyone whose name is not on authorship, first. Then ...Support for part of this work was by the U.S. Navy, Contract #N000039-81-C-0357. Then, rest of authors add any help and support they received.

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APPENDIX III

AQUATIC INSECT FOOD CHOICES FOR LEAVES INCUBATED IN A RIVER FOR DIFFERING TIMES

Jennelle Marcereau
Independent Project
(with Jean Stout)

Introduction

Decomposition of green leaves constitutes a source of nitrogen and phosphorus in a heterotrophic stream (McArthur et al. 1986). Decomposition may be slowed by certain chemicals and physical structures in the leaf such as plant phenols, cellulose, and lignin. They are complex structures and are difficult to attack by macroinvertebrates (Covich 1988, Sparling et al. 1988, Valiela 1979). Green leaf decomposition may also be delayed if the leaves contain toxic or inhibitory compounds used for defense against terrestrial organisms (Leff and McArthur 1990). Once inhibitory or toxic compounds and complex structures are broken down by stream leaching and by aquatic microbial activity, the leaves' nutrients become available to the ecosystem. Feeding activity of aquatic insects; namely shredders, enhances the decomposition rate of green leaves.

Shredder activity may be affected by nutrient levels in the leaves during different processing stages. In this study, shredder activity by Pteronarcys sp. was observed for green Tag Alder (Alnus rugosa) leaves conditioned in the control sites (FCD) of the Ford River at different successional days to determine whether that species preferred leaves of a particular successional day. Initially, it was hypothesized that shredder activity would be greater among successional day leaves that contained higher available nutrients; that is, after leaves had been in the stream for between 14 and 23 days.

Materials and Methods

The experimental site was located in a fourth order stream on the Ford River in Dickinson Co., Michigan at a site called FCD (Ford Control Site) used for the ELF (Extremely Low Frequency Electromagnetic Fields) project funded by the U.S. Navy. The stream bottom there is primarily sand and small gravel.

Green leaves selected were Tag Alder, which are abundant along the river's banks. Tag Alder leaves of equal petiole size and toughness were hand picked on 25 July 1990 and placed in a drying oven at 40°C for 24 hr. The leaves were dried and preserved so that all successional day replicates (2, 7, 14, 23, and 35) could be collected from the river at the same time. This meant that there was a temporally staggered placement of the leaves. Beginning on

27 July, four replicates for Day 35 were placed in the stream, using fishing line to wrap the leaves around a brick. Twelve days later, four replicates of Day 23 were placed in the stream in a row behind Day 35. Replicates for days 14, 7, and 2 followed according to their successional day.

On 30 August, 15 leaf squares (three replicates for five successional days) were cut in the field from leaves on the four bricks for each successional day. Each leaf square of 5.0 square cm was cut from the edge of a leaf selected from the top of the brick. Each leaf square was attached with insect pins onto a wooden block next to one of 15 randomized numbers 2.54 cm apart, giving a total of 15 leaf squares per block. The randomized numbers represented the replicate number of each successional day.

Each wooden block was fastened to a brick with waxed string and placed 3.81 cm below water level in a plastic basket. The plastic basket allowed water to flow through three circular 1 mm mesh screens near the top. All baskets were placed in a single row, perpendicular to the stream flow. Washed rocks and gravel substrate, free of invertebrates and debris, were placed in the baskets. Each basket 'habitat' was 60 cm by 30 cm in surface area. On the first day of the feeding experiment, flow rates were taken just upstream of each basket, which had been placed at equal depths.

Individuals of Pteronarcys sp. were collected over a five day span near the study site, using a one meter square kickscreen. The shredders were kept in a plastic basket with food while they were being collected. Prior to the feeding experiment, eight Pteronarcys sp. of similar sizes were placed in each of the four plastic baskets and were then starved for 24 hr.

Four bricks, with 15 leaf squares attached to the top were placed into the four plastic baskets on 30 August and then the stoneflies were added for the beginning of the feeding experiment. Silt and debris that accumulated on the mesh screens were cleared daily. Photographs were taken three of the five days of the experiment. After five days, the experiment was disassembled and the area of the remaining leaf squares were determined with a Licor leaf area meter.

The effect of leaf incubation day, a possible basket placement effect and any interaction between the two factors were compared, using a Two-Way ANOVA test.

Results

Values of leaf area loss for all successional days on each brick were used to conduct the 2-Way ANOVA, Table 1.

TABLE 1
Two-Way ANOVA for Feeding Effect and for Brick Effect
Pteronarcys sp. Feeding on Tag Alder

Effect	SS	D.F.	MSS	F-Ratio	Prob.
Leaf Days	7.971	4	1.993	3.758	.011*
Brick Location	19.277	3	6.426	12.118	<.0001***
Interaction	17.139	12	1.528	1.428	.009***
Error	21.211	40			

There was a successional day effect, brick effect, and an interaction effect. The successional day effect is shown in Figure 1. The brick effect is shown in Figure 2. In that graph, mean values of leaf area remaining included all successional days.

Figure 1 shows that Day 14 had the most leaf area lost, followed by days 7 and 23. It appears that the shredders preferred leaves that had been conditioned from one to three weeks. Because there was a brick effect and an interaction between leaf conditioning time and brick location, interpretation of the data are difficult. Brick number 3 had the greatest leaf area loss of the four bricks. Flow rates in front of this basket that contained the brick were the lowest, as compared with other baskets (Basket 1: 25, Basket 2: 24, Basket 3: 17, Basket 4: 24 cm/sec). As no rain occurred throughout the experiment, the flows remained rather constant.

Discussion

Microbial and shredder activity account for much of the leaf processing that occurs in streams. Aquatic fungi have enzymes necessary for the breakdown of a leaf's complex structures: Cellulose, hemicellulose, pectin, and lignin. Lignin often is the last structure remaining because it is a polymeric substance interwoven with other types of structural polysaccharides, through cellulose fibrils in the plant cell wall (Lehninger 1982). Enzymes used to break down leaves are named according to the structure on which they react; for example, cellulase for activity on cellulose. Once some of the leaf's complex structures are broken down, nutrients become available to the remainder of the biotic community (Leff and McArthur 1990). Most shredders depend on fungal

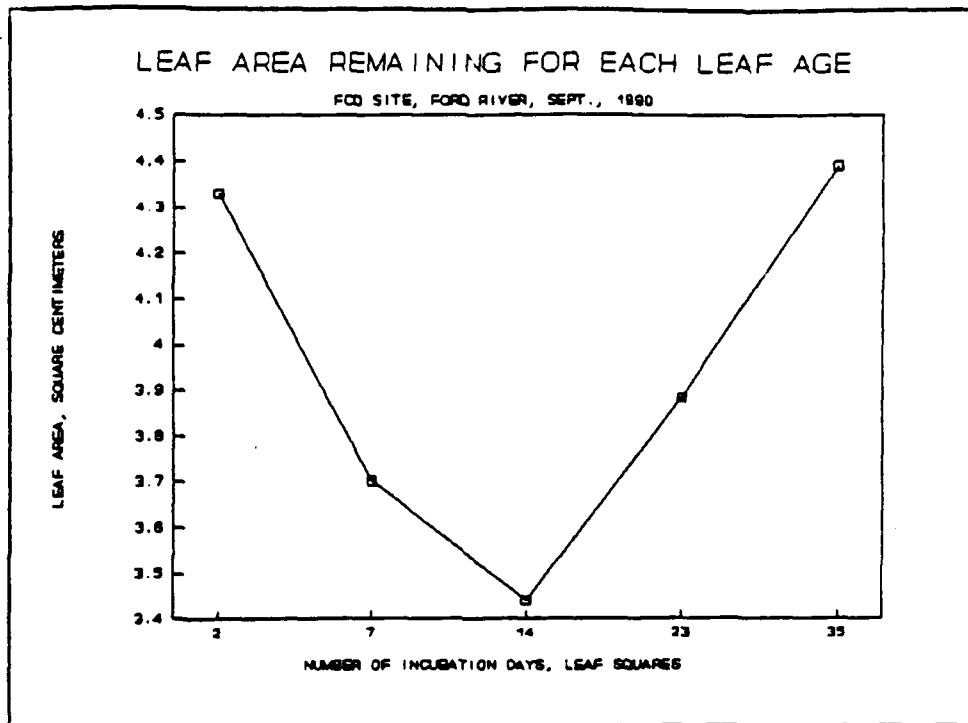


Figure 1. Leaf Area Remaining (cm²) of Leaf Squares Incubated Over Differing Times. FCD, September 1990.

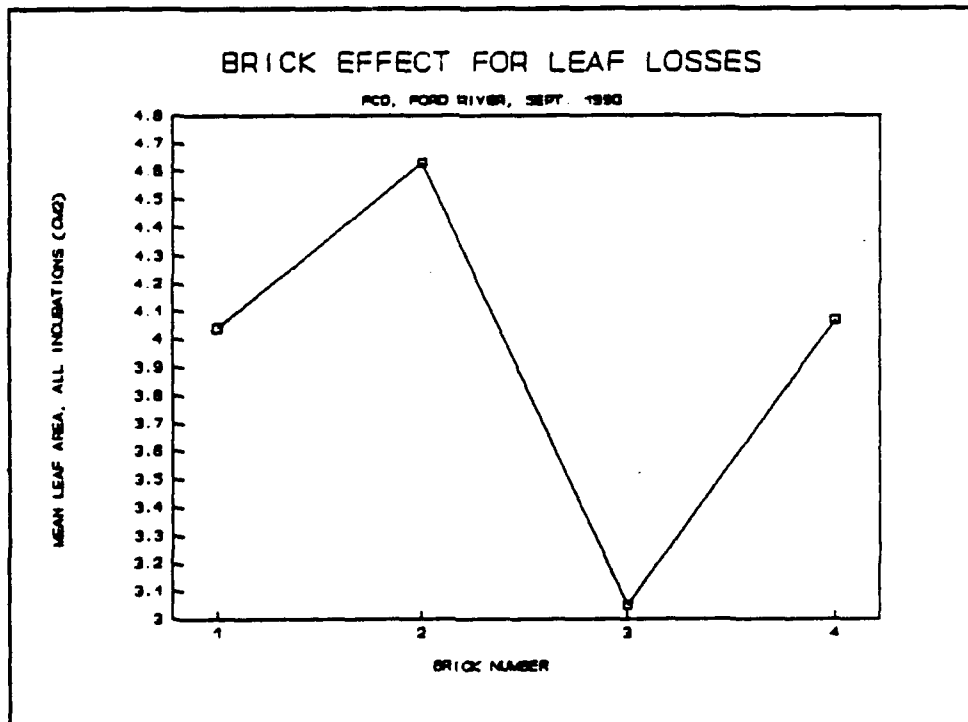


Figure 2. Leaf Loss, as it Relates to Brick Location. Leaf area remaining = mean of the sum of leaf area over all incubation days.

enzymatic activity because they do not possess the enzymes necessary to break up complex structures in the leaves.

In the feeding experiment, shredders preferred leaves conditioned 14 days in the stream, but days 7 and 23 followed close behind. Day 2 may not have been preferred by the shredders because fungal colonization may not have occurred in this short time span. Also, toxic or inhibitory compounds, which may be present in the leaf, may not have had sufficient time to be leached out, thus preventing fungal colonization. Without fungal colonization, nutrients in the leaf were not available to the shredders.

Higher nutrient levels available in the leaves at different succession days may account for shredder preferences. By Day 7, microbial populations may have had sufficient time to colonize and to begin breakdown of complex leaf structures, allowing nutrients to become available to the biotic community. Also, compounds inhibitory to microbial activity probably have had sufficient time to be leached out, allowing fungal colonization to begin. Fungal colonization and enzymatic activity by Day 7 may account for shredder preference over Day 2. Leaves conditioned 14 days in the stream show the greatest shredder preference, possibly owing to peak nutrient availability from fungal activity.

Nutrients available to shredders may be beginning to decline in leaf squares conditioned 23 days in the stream. Shredder preference was still high at Day 23, but not as great as at Day 14. By Day 35, nutrient levels may have been even lower than Day 23, accounting for very low shredder preference among all of the successional day leaf squares.

A great deal of leaf loss occurred on Brick #3 (See Graph 2). The only variable that differed among the baskets was the water flow at each location. Baskets 1, 2 and 4 all had similar flows while Basket 3 had a considerably slower flow rate. A slower flow rate may have made eating the leaf squares easier for the shredders. Slower currents may be advantageous for Pteronarcys sp. to maximize eating activity. Further study must be conducted with more replicates to test various flow rates, including very slow to very rapid currents. This may help in determining whether there is an optimal flow for the stonefly's activity.

Setting up a control basket for leaf area loss, owing to stream current alone would have provided additional information. It would have allowed a separation of current flow effects from shredder effects or location of basket effects. For future studies, positioning bricks so that current runs perpendicular rather than parallel over the bricks will minimize physical breakage.

Further experiments must be conducted before a solid conclusion can be reached on Pteronarys sp. preferences for varying incubation ages of tag alder leaves. For this experiment, however, it was shown that shredders preferred successional Day 14, with Days 7 and 23 following in preferences. Preference for Day 14 may be attributable to higher available nutrients in the leaves.

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Element 7 - Fish Community Composition and Abundance

Changes from workplan: Data analysis design structured in this manner; pre-operational years (1983-1985), transitional years (1986-1989), and post-operational years (1990-1991). The primary analysis presented in this report compare pre-operational years with transitional years. Detailed statistical analysis of the post-operational years cannot be done with only data from one year (1990). When the 1991 data become available, comparisons of all periods will be performed.

Objectives

The overall goal of this element is to determine the effects of the Navy's ELF project on the fish community structure and movement characteristics in the Ford River. Our specific objectives are to determine: 1) The fish community species composition and relative abundance at FEX and FCD; 2) The age, length/weight characteristics, growth, and condition of the species most represented in the gear (burbot, common shiners, creek chubs and white suckers) excluding brook trout (see Element 8); 3) The relative mobility of the fish community excluding brook trout (see Element 8) in the Ford River.

Materials and Methods

A. Community Composition and Abundance

Fish were caught using fyke nets fished in tandem, one facing upstream and one facing downstream, at FEX and FCD. In addition, two 1/2 inch wire mesh weir sites (FCU and TM), in a configuration similar to Hall's (1972), were fished in an effort to determine the movement patterns and rates of fish marked at FEX and FCD. In 1990, nets and weirs were fished continuously from May 25 to August 1 with the exception of 4 days in mid June when discharge levels were above gear and personnel capabilities to fish. When catch rates were low (< 1 fish/day) from August 1 through September 15, the gear was fished 4 days/week (deployed on Monday and removed on Friday). All gear was checked every 24 hours. The number of sampling days for each year is reported in Figure 7.1.

All fish were enumerated, measured for total length, weighed and marked by a fin clip distinctive for each study site. The fish were then returned to the water upstream or downstream from the station in their original direction of travel.

SITE

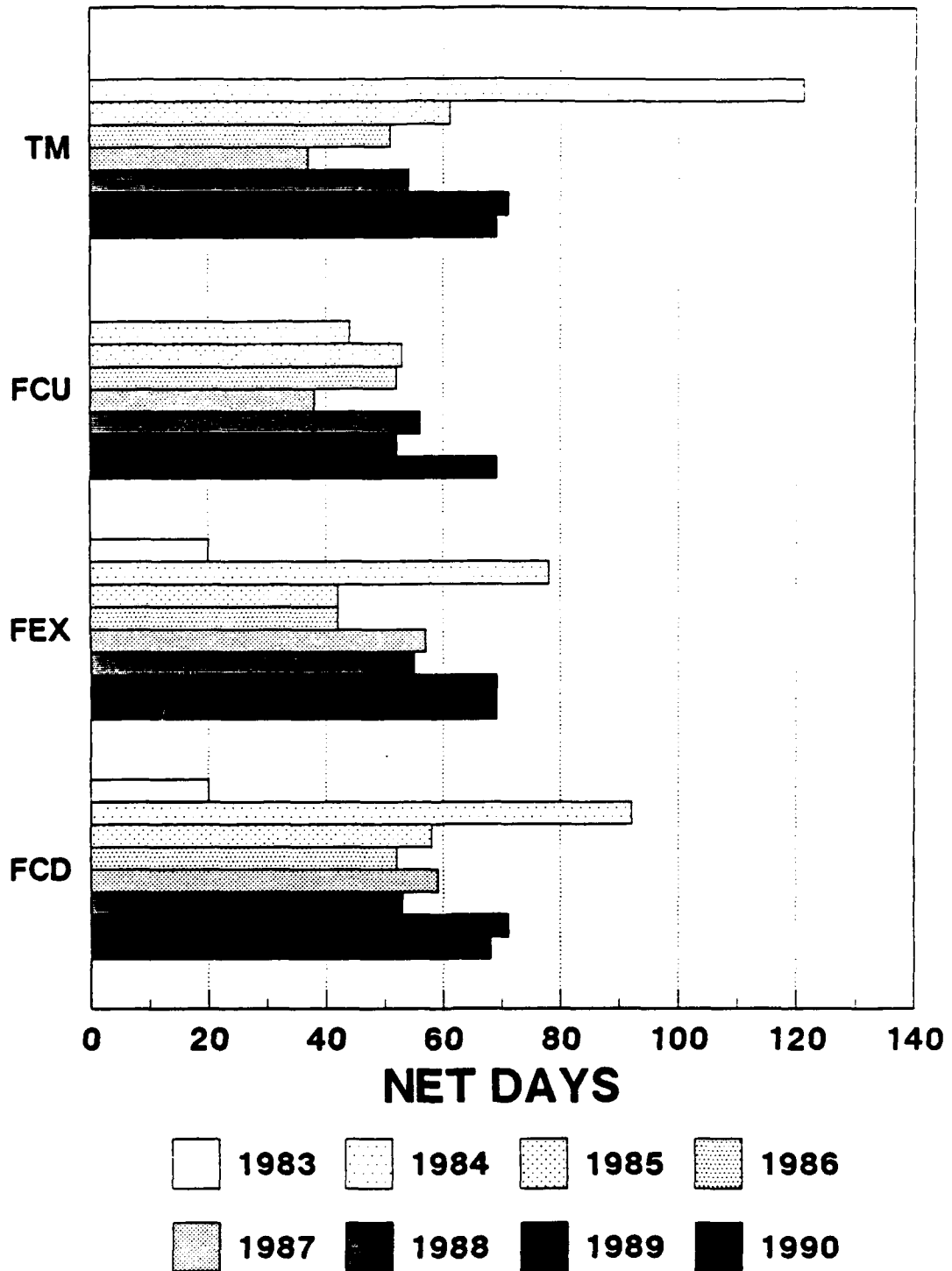


Figure 7.1. Net days at all ELF study sites from 1983-1990.

B. Age, Growth and Condition

Age and growth were calculated in the laboratory using scales and the body-scale backcalculation technique outlined by Smale and Taylor (1987). Backcalculation of length was done using the linear technique in Bagenal and Tesch (1978). Scales were projected onto a Summagraphics digitizing pad using a Ken-A-Vision Microprojector scope. The focus, subsequent annuli and outside edge of each scale were digitized and recorded on a linked Tandy 102 portable and then downloaded to an IBM pc for determination of backcalculated length at age.

C. Fish Community Mobility

Movement patterns for the dominant species in the Ford River were monitored by observing the frequency of recapture of fin clipped fish in our gear. Fish recaptured at a site other than the original marking site were measured for total length and given an additional fin clip specific to the recapture site.

Results and Discussion

A. Species composition

Fourteen species from four orders and nine families were collected at FEX in 1990 (Table 7.1). No new species were observed in 1990 at FEX. Differences in the overall FEX species composition between years can be attributed to changes in the catch of rare species.

The catch at FCD in 1990 consisted of eighteen species from eleven families and six orders (Table 7.2). No new species were added to the species list at FCD in 1990. Again, as in the FEX samples, the only changes in the species composition occurred in the rare species which occur infrequently.

As in the past, the species composition was slightly higher at FCD than at FEX which is a result of species infrequently captured. Overall the two sites continued to be similar in species composition and consistent within a site over the duration of the study.

B. Species abundance

The numeric catch at FEX was dominated by 5 species with the majority of the individuals from the cyprinid family (Figure 7.2). Common shiner percent catch by number was the highest at 36.1 % and was above their mean for all years combined (29.7 %). White suckers made up 17.9 % of the

Table 7.1. Fish species collected at FEX from May 1983 through September 1990 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

Scientific Name	Common Name	FEX						
		1983	1984	1985	1986	1987	1988	1989
Cypriniformes								
Catostomidae								
<i>Catostomus commersoni</i> (Lacepede)	White sucker	x	x	x	x	x	x	x
<i>Hypentelium nigricans</i> (Leueur)	Northern hog sucker			x				x
Cyprinidae								
<i>Notropis cornutus</i> (Mitchill)	Common shiner	x	x	x	x	x	x	x
<i>Rhinichthys atratulus</i> (Hermann)	Blacknose dace	x	x		x	x	x	x
<i>Rhinichthys cataractae</i> (Valenciennes)	Longnose dace	x	x	x	x	x	x	x
<i>Semotilus atromaculatus</i> (Mitchill)	Creek chub	x	x	x	x	x	x	x
<i>Semotilus margarita</i> (Cope)	Pearl dace	x	x		x	x	x	x
Gadiformes								
Gadidae								
<i>Lota lota</i> (Linnaeus)	Burbot	x	x	x	x	x	x	x
Perciformes								
Centrarchidae								
<i>Ambloplites rupestris</i> (Rafinesque)	Rock bass		x	x	x	x	x	x
<i>Micropterus dolomieu</i> (Lacepede)	Smallmouth bass		x			x	x	
<i>Micropterus salmoides</i> (Lacepede)	Largemouth bass		x		x	x	x	
<i>Lepomis gibbosus</i> (Linnaeus)	Pumpkinseed					x		
Cottidae								
<i>Cottus bairdi</i> (Girard)	Mottled sculpin	x	x	x	x	x	x	x
Percidae								
<i>Percina maculata</i> (Girard)	Blackside darter	x	x	x	x		x	x
Petromyzontiformes								
Petromyzontidae								
<i>Ichthyomyzon fossor</i> (Reighard and Cummins)	Northern brook lamprey			x				
<i>Petromyzon marinus</i> (Linnaeus)	Sea Lamprey		x	x	x		x	

Table 7.1 continued

Scientific Name	Common Name	FEX						
		1983	1984	1985	1986	1987	1988	1989
Salmoniformes								
Esocidae								
<i>Esox lucius</i> (Linnaeus)	Northern pike	x	x	x	x	x	x	x
Salmonidae								
<i>Oncorhynchus kisutch</i> (Walbaum)	Coho salmon					x		
<i>Oncorhynchus mykiss</i>	Rainbow trout					x		
<i>Salvelinus fontinalis</i> (Mitchill)	Brook trout	x	x	x	x	x	x	x
Umbridae								
<i>Umbra limi</i> (Kirtland)	Central mudminnow	x	x	x	x	x	x	x
Siluriformes								
Ictaluridae								
<i>Ictalurus nebulosus</i> (Lesueur)	Brown bullhead						x	x

Table 7.2. Fish species collected at FCD from May 1983 through September 1990 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

Scientific Name	Common Name	FCD									
		886	886	886	886	886	886	886	886	886	886
Clupeiformes											
Clupeidae											
<i>Alosa pseudoharengus</i> (Wilson)	Alewife	x									x
Cypriniformes											
Catostomidae											
<i>Catostomus commersoni</i> (Lacepede)	White sucker	x	x	x	x	x	x	x	x	x	x
<i>Hypentelium nigricans</i> (Leueur)	Northern hog sucker										x
Cyprinidae											
<i>Nocomis biguttatus</i> (Kirtland)	Hornyhead chub										x
<i>Notemigonus crysoleucas</i> (Mitchill)	Golden shiner									x	x
<i>Notropis cornutus</i> (Mitchill)	Common shiner	x	x	x	x	x	x	x	x	x	x
<i>Pimephales promelas</i> (Rafinesque)	Fathead minnow										
<i>Phoxinus phox</i> (Cope)	Northern redbelly dace	x									
<i>Rhinichthys atratulus</i> (Hermann)	Blacknose dace										
<i>Rhinichthys cataractae</i> (Valenciennes)	Longnose dace	x	x	x	x	x	x	x	x	x	x
<i>Semotilus atromaculatus</i> (Mitchill)	Creek chub	x	x	x	x	x	x	x	x	x	x
<i>Semotilus margarita</i> (Cope)	Pearl dace	x	x	x	x	x	x	x	x	x	x
<i>Cyprinus carpio</i> (Linnaeus)											
Gadiformes											
Gadidae											
<i>Lota lota</i> (Linnaeus)	Burbot	x	x	x	x	x	x	x	x	x	x
Perciformes											
Centrarchidae											
<i>Ambloplites rupestris</i> (Rafinesque)	Rock bass	x	x	x	x	x	x	x	x	x	x
<i>Lepomis gibbosus</i> (Linnaeus)	Pumpkinseed										
<i>Lepomis macrochirus</i> (Rafinesque)	Bluegill										
<i>Micropterus dolomieu</i> (Lacepede)	Smallmouth bass										
<i>Micropterus salmoides</i> (Lacepede)	Largemouth bass										
Cottidae											
<i>Cottus bairdi</i> (Girard)	Mottled sculpin	x	x	x	x	x	x	x	x	x	x
Percidae											
<i>Percina maculata</i> (Girard)	Blackside darter	x	x	x	x	x	x	x	x	x	x

Table 7.2 continued.

Scientific Name	Common Name	FCD						
		1983	1984	1985	1986	1987	1988	1989
Petromyzontiformes								
Petromyzontidae								
<u>Petromyzon marinus</u> (Linnaeus)	Sea lamprey	x	x	x	x		x	x
Salmoniformes								
Esocidae								
<u>Esox lucius</u> (Linnaeus)	Northern pike	x	x	x	x	x	x	x
Salmonidae								
<u>Oncorhynchus kisutch</u> (Walbaum)	Coho salmon						x	
<u>Oncorhynchus mykiss</u>	Rainbow trout						x	
<u>Salvelinus fontinalis</u> (Mitchill)	Brook trout	x	x	x	x	x	x	x
Umbridae								
<u>Umbra limi</u> (Kirtland)	Central mudminnow		x	x	x	x	x	x
Sturioniformes								
Ictaluridae								
<u>Ictalurus punctatus</u> (Lesueur)	Brown bullhead			x			x	x

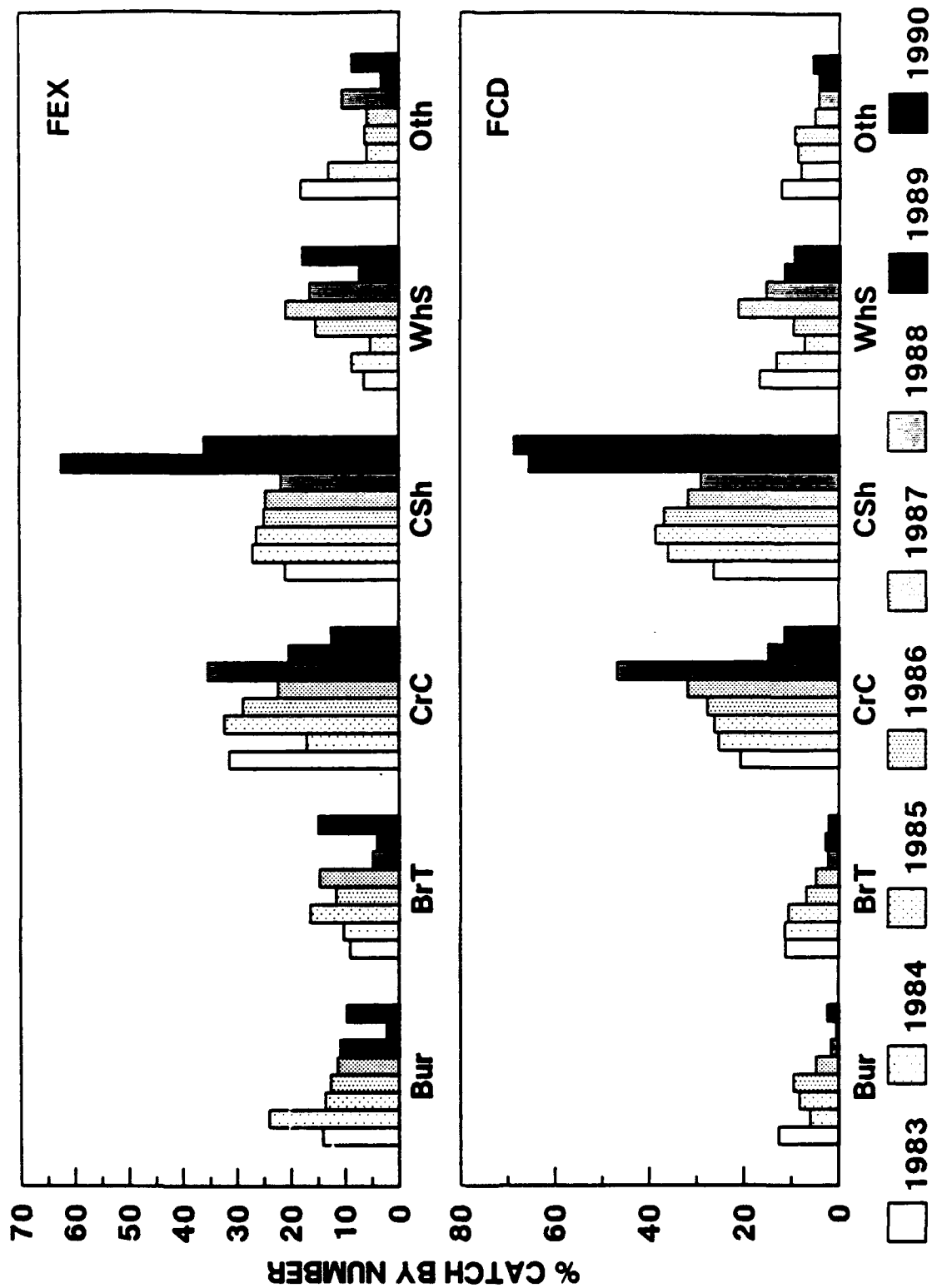


Figure 7.2. Percent catch by number at FEX and FCD from 1983 through 1990.

catch which is above the mean over all years combined (11.5 %). Brook trout percent catch by number (15.0 %) in 1990 was above the mean for all years combined (10.2 %). Creek chub percent catch by number (12.6 %) was well below the mean for all years combined (26.8 %) in 1990 at FEX. Burbot percent catch by number increased to 9.7 % in 1990 but is below 12.8 %, the mean for all years combined.

The relative numeric abundance of the catch at FCD was dominated by the same species (common shiners) as at FEX (Figure 7.2). Common shiners made up 68.7 % of the total catch at FCD which was well above 37.8 %, the average for all years combined. The percent of creek chubs in the catch was 11.5 % which was down from the mean for all years combined (27.7 %). The white sucker component in 1990 consisted of 9.6 % of the total number of fish and was slightly below the mean for all years combined (13.6 %). Burbot (2.5 %) and brook trout (2.2 %) catch in 1990 decreased when compared to their means over all years (6.2 % and 7.2 % respectively).

To analyze the total catch by numbers by year, the data for each species were first weighted by the number of net days per site per year. There were no significant differences between FEX and FCD in total numbers caught when these values were adjusted by the number of net days (Table 7.3). In addition, significant correlations existed between FEX and FCD (Spearman Rank Correlation, $p < 0.05$) in numeric abundance of each species adjusted by the number of net days in 1985 through 1989 (Table 7.4). The numeric catch in 1983, 1984, and 1990 were not correlated. To examine the correlation results for all 8 years, a X^2 test ($\alpha=0.05$) from Sokal and Rohlf (1969, pg 623) was used. This test assumes that each year represents an independent test of the overall hypothesis of no similarity between sites and confirmed the similarity between sites ($X^2=44.88$, $df=16$, $p, 0.05$).

A BACI (Stewart-Oaten and Murdoch, 1986) analysis was used to test pre-operational (1983-1985) versus transitional (1986-1989) numeric catch data. Post-operational data could not be included in the analysis since no estimate of variance can be obtained from the 1990 data alone. An analysis was conducted for each of the species. Individual species data were log transformed and a 2 sample t-test performed using the difference between FCD and FEX. No evidence of a difference between the pre-operational and transitional period was observed in the numeric catch data for any of the species (Table 7.5). Further, treating each of the 6 species categories as an independent trial, yielded no evidence of a difference between the pre-operational and transitional periods (Sokal and Rohlf X^2 test (1969, pg 623) of BACI results in Table 7.5; $X^2=3.61$, $df=12$, $p>0.05$).

Overall, there were no significant between site

Table 7.3. Chi Square analysis by year of the numeric catch (adjusted for the number of net days) between FEX and FCD from 1983 through 1990.

YEAR	1983	1984	1985	1986	1987	1988	1989	1990
X ² VALUE	3.98	4.30	1.30	1.44	5.96	6.04	1.18	4.06
X ² _{5,0.05} =11.1	NONE SIG.							

Table 7.4. Spearman Rank Correlation Coefficients for the numeric catch (adjusted for the number of net days) at FEX and FCD from 1983 through 1990.

YEAR	CORRELATION COEFFICIENT	PROBABILITY ¹
1983	0.543	0.266
1984	0.200	0.704
1985	0.886*	0.019
1986	0.886*	0.019
1987	0.828*	0.041
1988	0.828*	0.041
1989	0.943*	0.005
1990	0.486	0.329

* INDICATES SIGNIFICANT CORRELATION EXISTS

¹ Used in Sokal and Rohlf (1969) X² test to examine correlation results over the 8-year period, where:

$X^2_{calc} = -2\sum(\ln P) = 44.88$; $df=2*(\text{number of tests})=16$
 $X^2_{16,0.05} = 26.3$
 and P = the probability associated with the correlation coefficient.

Table 7.5. BACI analysis using 2 sample t-test on log transformed data to test pre-operational (1983-1985) vs. transitional (1986-1989) numeric catch data.

SPECIES	$t_{calc.}$	Probability ¹
Burbot	0.457	0.667
Brook Trout	0.673	0.531
Creek Chub	1.004	0.361
Common Shiner	0.773	0.474
White Sucker	0.572	0.592
Other	0.848	0.435

$t_{5,0.05} = 2.57$ None Sig.

¹Sokal and Rohlf X^2 test of BACI results (see Table 7.4 for explanation of method): $X^2_{calc.} = 3.61$, $X^2_{12,0.05} = 21.0$. Not significant.

Table 7.6. Spearman Rank Correlation Coefficients for catch by biomass (adjusted for the number of net days) at FEX and FCD from 1983 through 1990.

YEAR	CORRELATION COEFFICIENT	PROBABILITY ¹
1983	0.600	0.208
1984	0.786*	0.064
1985	0.886*	0.019
1986	0.657	0.156
1987	0.829*	0.041
1988	0.671	0.144
1989	0.943*	0.005
1990	0.600	0.208

* INDICATES SIGNIFICANT CORRELATION EXISTS

¹Sokal and Rohlf X^2 test: $X^2_{calc.} = 49.36$, $X^2_{16,0.05} = 26.3$. Significant. See Table 7.4 for further detail.

differences at FEX and FCD in catch by number over all years of the study despite species showing variable abundance from year to year (Table 7.3). As more post-operational data are obtained, any ELF effects should be detectable.

Percent catch by biomass showed different trends in community structure than the catch by number at both sites (Figure 7.3). White suckers displayed the highest percent catch by biomass at FEX encompassing 42.9 % of the catch. This was well above 23.1 % which was the mean for all years combined at this site. Brook trout percent catch by biomass was second highest at FEX in 1990 at 31.4 % which was above the mean for all years combined (24.7 %). Percent catch by biomass for common shiners was below the average for all years (12.2 %, mean = 17.0 %). Creek chub (3.7 %) and burbot percent catch by biomass (5.6 %) at FEX in 1990 were well below the mean for all years combined (16.5 % and 14.0 % respectively).

The catch biomass at FCD showed similar trends as FEX with the same five species dominating the catch (Figure 7.3). Common shiners and white suckers were the dominant species making up 35.1 % and 32.3 % of the biomass respectively, and were above the means over all years combined (18.5 % and 25.8 %). Brook trout percent catch by biomass (10.7 %) was below the mean for all years combined (23.9 %). Burbot made up 4.6 % of the catch biomass in 1990 at FCD which was slightly below the average for all years (5.6 %).

The cyprinid biomass at FCD continued to be higher than at FEX. To analyze the species biomass data, biomass estimates were first adjusted for the number of net days. FEX and FCD displayed similar patterns in 4 of the 8 years (Table 7.6; Spearman Rank Correlation, $p < 0.05$). However, using the X^2 test described by Sokal and Rohlf (1969, pg 623), over the 8-year period of the study FEX and FCD had similar catch-by-biomass patterns ($X^2 = 49.36$, $df = 16$, $p = 0.05$). No evidence of any difference between pre-operational and transitional biomass data for any species was observed (BACI analysis, 2 sample t-test, $\alpha = 0.05$) (Table 7.7). A test of the BACI analysis confirmed the result (Sokal and Rohlf X^2 test, $X^2 = 2.08$, $df = 12$, $p > 0.05$). Post-operational data were not included in the analysis since no estimate of variance could be obtained for the 1990 data.

Shannon-Weaver diversity values for 1990 were similar to the lower values observed in 1988 and 1989 (Table 7.8). A Spearman Rank Correlation test ($r_s = 0.76$, $p < 0.05$) indicated a similar pattern in the Shannon-Weaver index for FCD and FEX from 1983-1990. A BACI analysis was done comparing the pre-operational (1983-1985) and transitional periods (1986-1989). A two-sample t-test was used to compare the log-transformed difference between the yearly FCD and FEX index values. We have no evidence to reject the hypothesis of no

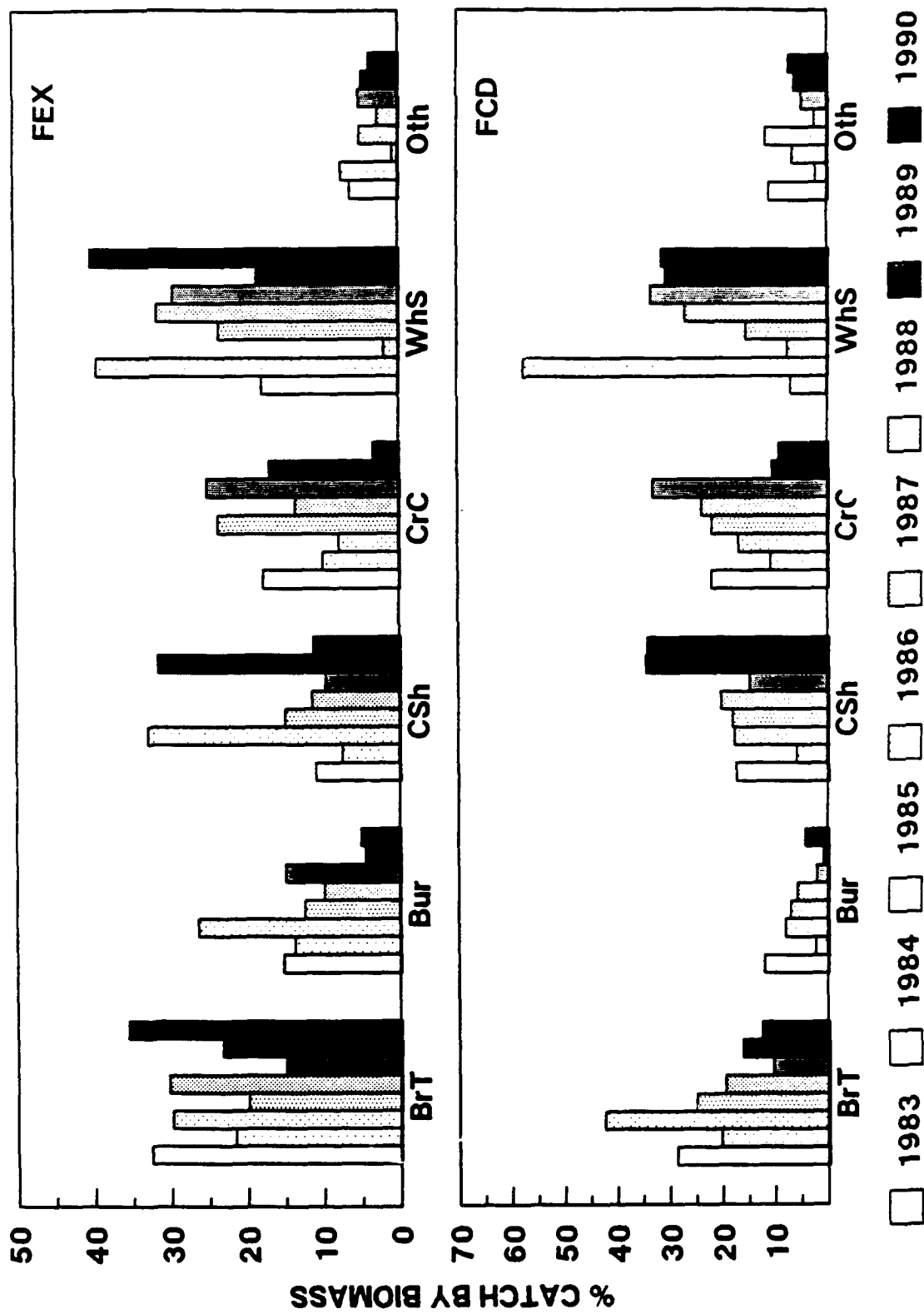


Figure 7.3. Percent catch by biomass at FEX and FCD from 1984 through 1990.

Table 7.7. BACI analysis using 2 sample t-test on log transformed data to test pre-operational (1983-1985) vs. transitional (1986-1989) catch by biomass data.

SPECIES	$t_{calc.}$	Probability ¹
Burbot	0.902	0.930
Brook Trout	0.230	0.827
Creek Chub	0.309	0.770
Common Shiner	1.464	0.203
White Sucker	0.116	0.912
Other	0.227	0.829

$t_{5,0.05} = 2.57$ None Sig.

¹Sokal and Rohlf χ^2 test of BACI results (see Table 7.4 for explanation of method): $\chi^2_{calc.} = 2.08$, $\chi^2_{12,0.05} = 21.0$. Not Significant.

Table 7.8. Mean daily Shannon-Weaver diversity index values for FEX and FCD from 1983 through 1990.

YEAR	FEX	FCD
1983	2.16 $\pm$ 0.26	1.94 $\pm$ 0.36
1984	2.20 $\pm$ 0.56	2.03 $\pm$ 0.33
1985	1.97 $\pm$ 0.39	2.15 $\pm$ 0.33
1986	1.62 $\pm$ 0.48	1.87 $\pm$ 0.31
1987	2.13 $\pm$ 0.18	2.11 $\pm$ 0.45
1988	1.62 $\pm$ 0.34	1.54 $\pm$ 0.27
1989	1.41 $\pm$ 0.36	1.47 $\pm$ 0.43
1990	1.42 $\pm$ 0.58	1.32 $\pm$ 0.27

difference between operational periods ($t=0.912$, $df=5$, $p>0.05$).

Diversity values have decreased in a fairly linear fashion over the course of the study according to the following relationships:

$$\begin{aligned}\text{FEX: Index} &= 10.79 - 0.104 (\text{Year}) \quad r^2 = 0.64 \\ \text{FCD: Index} &= 11.77 - 0.115 (\text{Year}) \quad r^2 = 0.71.\end{aligned}$$

The rate of decrease (slope) of diversity at FEX and FCD was not significantly different (ANCOVA, $F_{1,12}=0.065$, $p>0.05$; Table 7.9). In addition, the intercepts were found to be similar (ANCOVA, $F_{1,13}$, $p>0.05$). Overall, diversity values continued to be similar between sites and should be a sensitive indicator of ELF effects during operational years.

C. Catch Statistics

Catch rates at both FEX and FCD showed the large amount of variance for all species one would expect from catches having a negative binomial distribution (Figure 7.4). White suckers, common shiners and creek chubs all have high spring-early summer catch rates because of spawning movements. Brook trout catch rates are also high in the late spring - early summer but this is attributed to water temperatures increasing above optimal (see Element 8, Brook Trout Movement Characteristics).

Mean daily catch is determined by first calculating mean daily catch per week, then taking the mean of the weekly mean values. Mean daily catch patterns at FEX and FCD were similar within years (X^2 test, $\alpha=0.05$) (Table 7.10). In addition, mean daily catch values were found to be significantly correlated in 1983, 1985, and 1987 through 1989 (Spearman Rank Correlation, $p<0.05$) (Table 7.11). The Sokal and Rohlf X^2 test of the correlation results was found to be significant. Therefore, FEX and FCD are similar in mean daily catch within years.

The BACI analysis of the log-transformed mean daily catch data by species revealed no differences between pre-operational versus transitional years (2-Sample t-test, $p>0.05$) (Table 7.12). Treating each of the 5 species as an independent trial, there was no evidence of a difference between the pre-operational and transitional periods (Sokal and Rohlf x^2 test (1969, pg 623) of BACI results in Table 7.12; $X^2=2.188$, $df=10$, $p>0.05$). In general, changes in catch rates of species in different years are expressed mutually at FEX and FCD and this should be a powerful test for pre- and post-operational differences.

Table 7.9. Covariance analysis of decreasing Shannon - Weaver diversity values at FEX and FCD from 1983 through 1990.

SITE	d.f.	SS	MS
1	6	0.22998690	
2	6	0.24913929	
	12	0.47912619	0.039927183
POOLED	13	0.48175595	0.3705815
d.f.	1	0.00262976	0.00262976
Slopes	$F_{1,12} = 0.065$		
Intercept	$F_{1,13} = 0.02$		

No sig. difference

Equations for lines depicting linear decrease in diversity:

$$\begin{aligned} \text{FEX Index} &= 10.79 - 0.104 (\text{year}) \quad r^2 = 0.64 \\ \text{FCD Index} &= 11.77 - 0.115 (\text{year}) \quad r^2 = 0.71 \end{aligned}$$

Table 7.10. Chi Square analysis by year of mean daily catch between FEX and FCD from 1983 through 1990.

YEAR	1983	1984	1985	1986	1987	1988	1989	1990
χ^2								
VALUE	1.00	3.95	1.20	1.30	5.51	4.64	1.02	4.00
$\chi^2_{5,0.05}$	= 11.1 NONE SIGNIFICANT.							

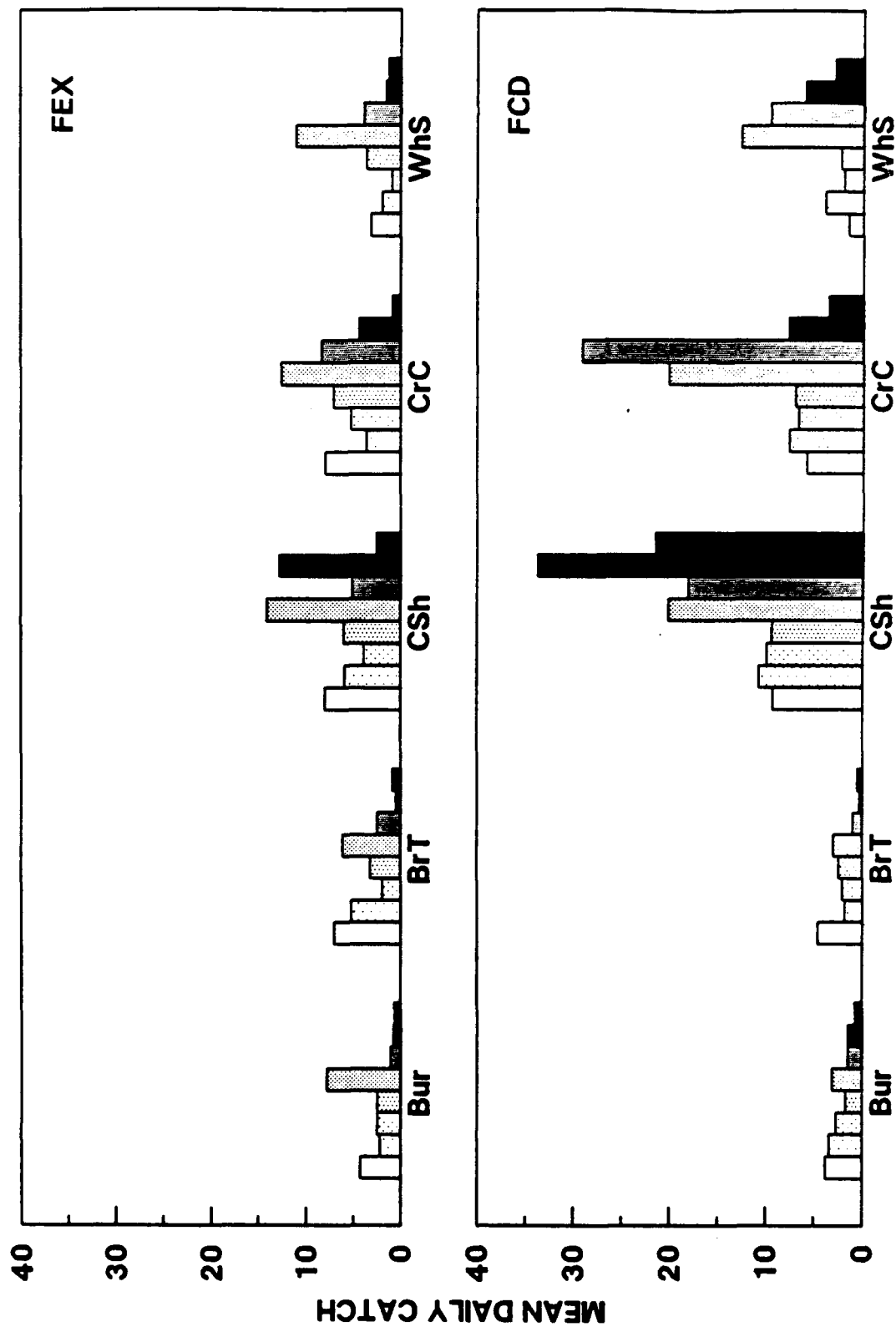


Figure 7.4. Mean daily catch calculated on a weekly basis at FEX and FCD from 1983 through 1990.

Table 7.11. Spearman Rank Correlation Coefficients for mean daily catch at FEX and FCD from 1983 through 1990.

YEAR	CORRELATION COEFFICIENT	PROBABILITY ¹
1983	1.000*	< 0.001
1984	0.300	0.624
1985	0.900*	0.037
1986	0.800	0.104
1987	0.975*	0.005
1988	0.900*	0.037
1989	1.000*	< 0.001
1990	0.800	0.104

* INDICATE SIGNIFICANT CORRELATION EXISTS

¹Used in Sokal and Rohlf X^2 test to examine correlation results where:

$$X^2_{calc.} = 57.236 \text{ and}$$

$$X^2_{16,0.05} = 26.3.$$

Table 7.12. BACI analysis using 2 sample t-test on log transformed mean daily catch data to test pre-operational (1983-1985) vs. transitional (1986-1989) periods.

SPECIES	$t_{calc.}$	PROBABILITY ¹
Burbot	0.511	0.631
Brook Trout	0.411	0.698
Creek Chub	0.838	0.440
Common Shiner	0.628	0.558
White Sucker	0.343	0.745

$t_{5,0.05} = 2.57$ None Sig.

¹Sokal and Rohlf X^2 test of BACI results (see Table 7.4 for explanation of method): $X^2_{calc.} = 2.188$, $X^2_{10,0.05} = 18.3$.
Not Significant.

Mean lengths of the dominant species at FEX have remained fairly constant through all years (Figure 7.5). Brook trout showed a slight decrease in mean length from 1983-1988 (mean = 190.6 mm), but mean length in 1989 increased to the highest (231.5 mm) ever. Brook trout mean length in 1990 (203.5 mm) was slightly above the mean for all years (198.5 mm). Burbot (162.5 mm) and creek chub (111.7 mm) mean lengths in 1990 were below means for all years (176.5 mm and 130.8 mm respectively) while common shiner (113.0 mm) and white sucker (205.3 mm) mean lengths were above the average for all years combined (110.9 mm and 167.8 mm respectively). Overall changes in mean length have been slight which indicates that the size structure is consistent from year to year within the mobile fish community at FEX.

FCD showed a pattern similar to FEX in that brook trout (229.0 mm) and burbot (188.7 mm) mean lengths were well above the means for all years combined (218.6 mm and 178.8 mm respectively) (Figure 7.5). Common shiners (106.5 mm), creek chubs (125.3 mm) and white suckers (176.5 mm) had mean lengths slightly below their means for all years combined (116.3 mm, 135.8 mm and 178.4 mm respectively).

Brook trout and common shiners were generally larger in mean length at FCD than FEX while burbot, creek chubs and white suckers appeared to be similar in mean length between sites. Overall, the two sites continued to be similar in mean length and in trends in mean length. Therefore, ELF effects should be detectible through changes in species size structure.

D. Fish Community Mobility

Common shiners, creek chubs, longnose dace and white suckers demonstrated site to site movement as shown by the approximately 20.2 % overall recapture rate at sites other than the marking site (Table 7.13a and b). The total number of nonsalmonids marked at FEX and FCD in 1990 were: burbot 84, common shiners 1354, creek chubs 253, longnose dace 48 and white suckers 242. Overall recapture percentages in 1990 were down when compared to previous years (Table 7.13a and b). Site to site movement was not observed in 1990 for burbot or white suckers, however, 8.9 % of common shiners marked moved from one site to another while 0.4 % of marked creek chubs displayed site to site movement.

E. Individual Species Analyses

Growth and condition of fish can be important indicators of a stressor in the fish community. Four species were chosen based on abundance -- common shiners, creek chubs, white suckers and brook trout -- as indicator species in the

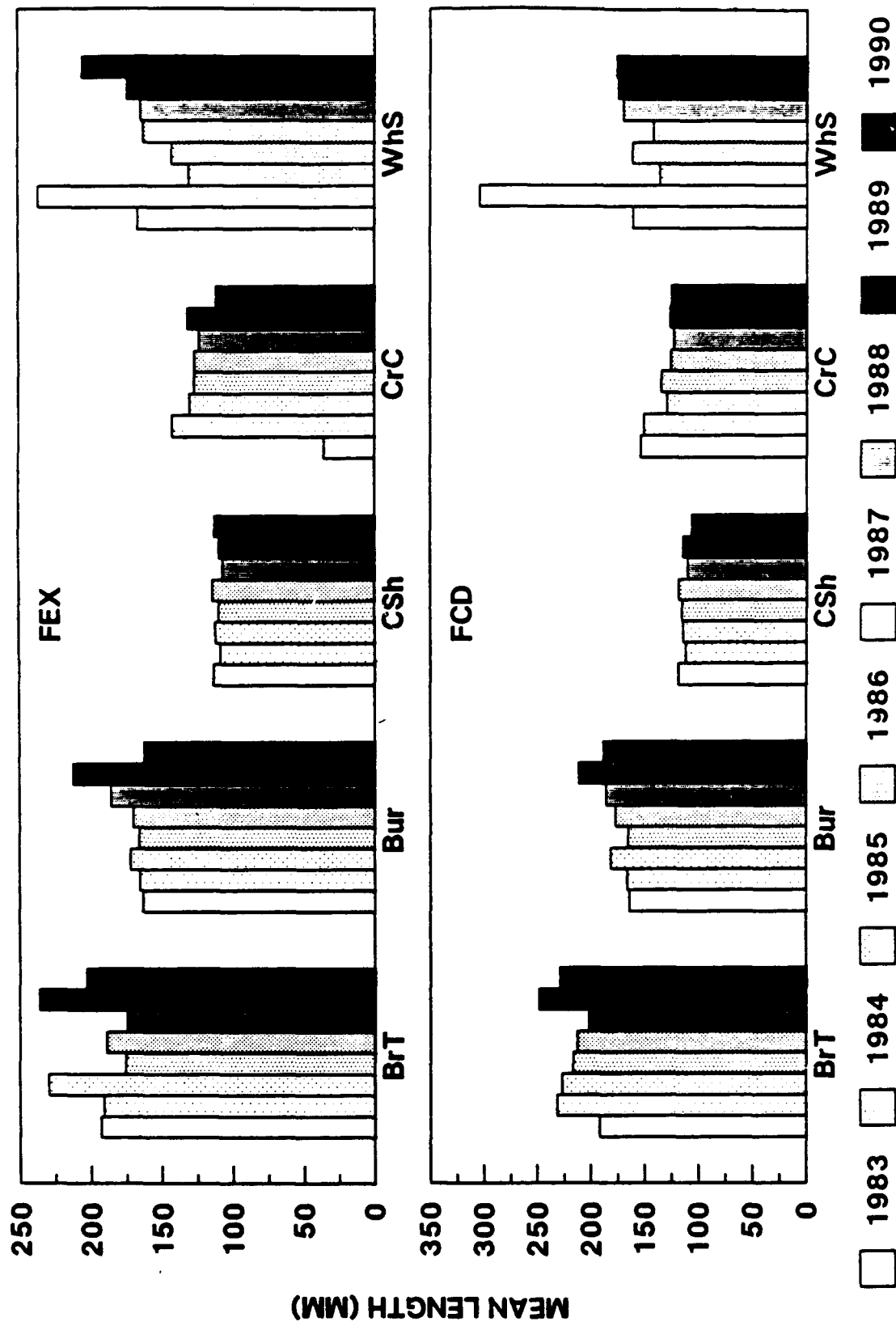


Figure 7.5. Mean length of fish dominating the fyke net catch at FEX and FCD for all years.

Table 7.13a. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1984 - 1986.

% Recapture by Location							
Species	Total Marked	Number Recaptured	% Recaptured	Marking Site	Upstream 1 Site	Down 1 Site	Up 2 Sites
1984							
Burbot	405	15	3.7	86.6	6.7	6.7	
Common shiner	1085	122	11.3	79.5	11.5	9.0	
Creek chub	700	72	10.3	81.9	12.5	5.6	
White sucker	405	15	3.7	86.6	6.7		6.7
1985							
Burbot	170	22	12.9	86.3	4.5	9.2	
Common shiner	622	63	10.1	77.8	9.5	9.5	3.2
Creek chub	520	28	5.4	82.1	14.3		
White sucker	125	2	1.6	100.0			
1986							
Burbot	218	15	6.9	80.0	13.3	6.7	
Common shiner	612	68	11.1	89.7	7.3	3.0	
Creek chub	535	31	5.6	96.8	3.2		
White sucker	259	12	4.6	75.0	16.7	8.3	

Table 7.13b. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1987 and 1990.

Species	% Recapture by Location					
	Total Marked	Number Recaptured	% Recaptured	Marking Site	Upstream 1 site	Down 1 site 2 sites Up
1987						
Burbot	540	45	8.3	95.6	2.2	2.2
Common shiner	1693	172	10.2	88.4	10.5	1.2
Creek chub	1816	87	4.8	93.1	3.4	3.4
White sucker	1530	42	2.7	78.6	9.5	9.5
1988						
Burbot	340	11	3.2	81.8	18.2	
Common shiner	1402	75	5.3	88.0	6.7	5.3
Creek chub	2649	96	3.6	90.6	4.2	5.2
White sucker	1113	15	1.3	100.0		
1989						
Burbot	57	4	7.0	100.0		
Common shiner	3348	446	13.1	79.8	7.8	10.8 1.6
Creek chub	856	28	3.2	92.9	7.1	
White sucker	542	21	3.9	81.0		19.0
1990						
Burbot	84	5	6.0	100.0		
Common shiner	1354	166	12.3	92.8	4.2	3.0
Creek chub	253	8	3.2	62.5		37.5
White sucker	242	7	2.9	100.0		

community to examine the potential effects of the ELF project on growth and condition. Brook trout data are reported on in element 8.

Age and growth analyses on common shiners, creek chubs, northern pike and white suckers are reported in Table 7.14 (a-c). Common shiners exhibited better than average growth in the Ford River when compared to literature data in their third and fourth year (Carlander 1969) but similar growth during their first and second year. Lee's phenomenon (Ricker 1975) is seen in all years which may reflect the selectivity of our sampling gear or differential mortality of different sizes of common shiners.

Creek chub growth in the Ford River was above the average growth rate in the literature for all ages (Carlander 1969). No Lee's phenomenon was observed in any year class.

White suckers showed below average growth rates in the Ford River through all age classes reported when compared to literature values (Carlander 1969). Reverse Lee's phenomenon was seen with the age 4 fish having the best growth rates of the four years examined.

Age and growth analysis is complete on the 1984-1986 fish, and statistical comparisons to literature data and between years will be completed and reported in a future report. Additional investigations will include analyses of yearly growth increments for the above species. These analyses will allow us to separate the environmental and density-dependent factors from the ELF effects in the examination of growth.

Fish condition factors for common shiners, creek chubs and white suckers were performed using relative weight (Wr) condition factors as described in Wege and Anderson (1978). Standard weight (Ws) formulas were calculated from 3 literature populations for common shiners, 5 literature populations for creek chubs and 13 literature populations for white suckers using the 50% percentile method outlined in Wege and Anderson (1978). Individual weights were then compared to the standard weights and given a Wr value based on the formula: $Wr = \text{Fish weight} / Ws * 100$. Mean values for 25 mm length groups for common shiners and creek chubs, and 50 mm white sucker were calculated for an unweighted analysis of the data. Data from FEX and FCD were pooled because of the high amount of mobility seen in the Ford River.

The Ws formulas for common shiners, creek chubs and white suckers are as follows:

Common shiners	$\log wt = -5.3907 + 3.1704 * \log tl$	($r=.999$)
Creek chubs	$\log wt = -4.8488 + 2.9295 * \log tl$	($r=.998$)
White suckers	$\log wt = -4.9820 + 3.0073 * \log tl$	($r=.98$)

Table 7.14a. Mean backcalculated lengths for common shiners at all sites from 1983 through 1986.

Age Class	N	Backcalculated Length at Annulus			
		1	2	3	4
		$x \pm sd$	$x \pm sd$	$x \pm sd$	$x \pm sd$
1	7	42 ± 17.9			
2	41	39 ± 16.5	81 ± 14.4		
3	34	32 ± 11.6	73 ± 17.2	116 ± 21.8	
4	5	31 ± 8.9	71 ± 9.5	112 ± 14.8	160 ± 13.0
Overall Mean		36 ± 14.8 N=87	77 ± 15.9 N=80	115 ± 20.9 N=39	160 ± 13.0 N=5

Table 7.14b. Mean backcalculated lengths for creek chubs at all sites from 1983 through 1986.

Age Class	N	Backcalculated Length at Annulus			
		1	2	3	4
		$x \pm sd$	$x \pm sd$	$x \pm sd$	$x \pm sd$
1	42	66 ± 15.8			
2	179	63 ± 15.7	105 ± 24.0		
3	91	63 ± 15.0	105 ± 23.0	148 ± 29.9	
4	12	69 ± 22.8	113 ± 24.6	158 ± 27.5	199 ± 30.7
Overall Mean		64 ± 15.8 N=324	106 ± 23.7 N=282	150 ± 29.7 N=103	199 ± 30.7 N=12

Table 7.14c. Mean backcalculated lengths for white suckers at all sites from 1983 through 1986.

Age Class	N	Backcalculated Length at Annulus					
		1	2	3	4	5	6
		x ± sd	x ± sd	x ± sd	x ± sd	x ± sd	x ± sd
1	33	73 ± 6.0					
2	35	73 ± 7.0	112 ± 13.6				
3	30	73 ± 6.4	114 ± 17.4	175 ± 29.9			
4	30	76 ± 10.3	126 ± 26.1	206 ± 54.0	285 ± 66.4		
5	22	77 ± 7.6	124 ± 24.4	202 ± 43.5	296 ± 53.1	369 ± 56.0	
6	13	75 ± 7.9	113 ± 14.3	191 ± 34.7	283 ± 45.6	360 ± 53.8	416 ± 55.5
Overall							
Mean		74 ± 7.6 N=164	118 ± 20.6 N=131	193 ± 43.8 N=96	287 ± 58.1 N=66	363 ± 55.6 N=36	411 ± 56.5 N=14

where,

wt = weight

tl = total length

Condition factors for creek chubs and white suckers were below the species means from populations reported in the literature possibly reflecting the highly variable abiotic conditions in the Ford River (Figure 7.6). Common shiner W_r values were above the species mean from populations reported in the literature in all years. Creek chubs declined in condition from above the species mean in 1984 and 1985 to approximately 5 - 10 % below the species mean in 1987 through 1990. White sucker condition was 10 - 15 % below the species mean in all years. Common shiner condition decreased in from 11.4 % above the species mean to 6.5 % above the mean in 1990. Additional analysis examining the effect of population size using CPUE and abiotic factors on W_r are in progress along with a statistical analysis of year to year variation and will be detailed in the next annual report.

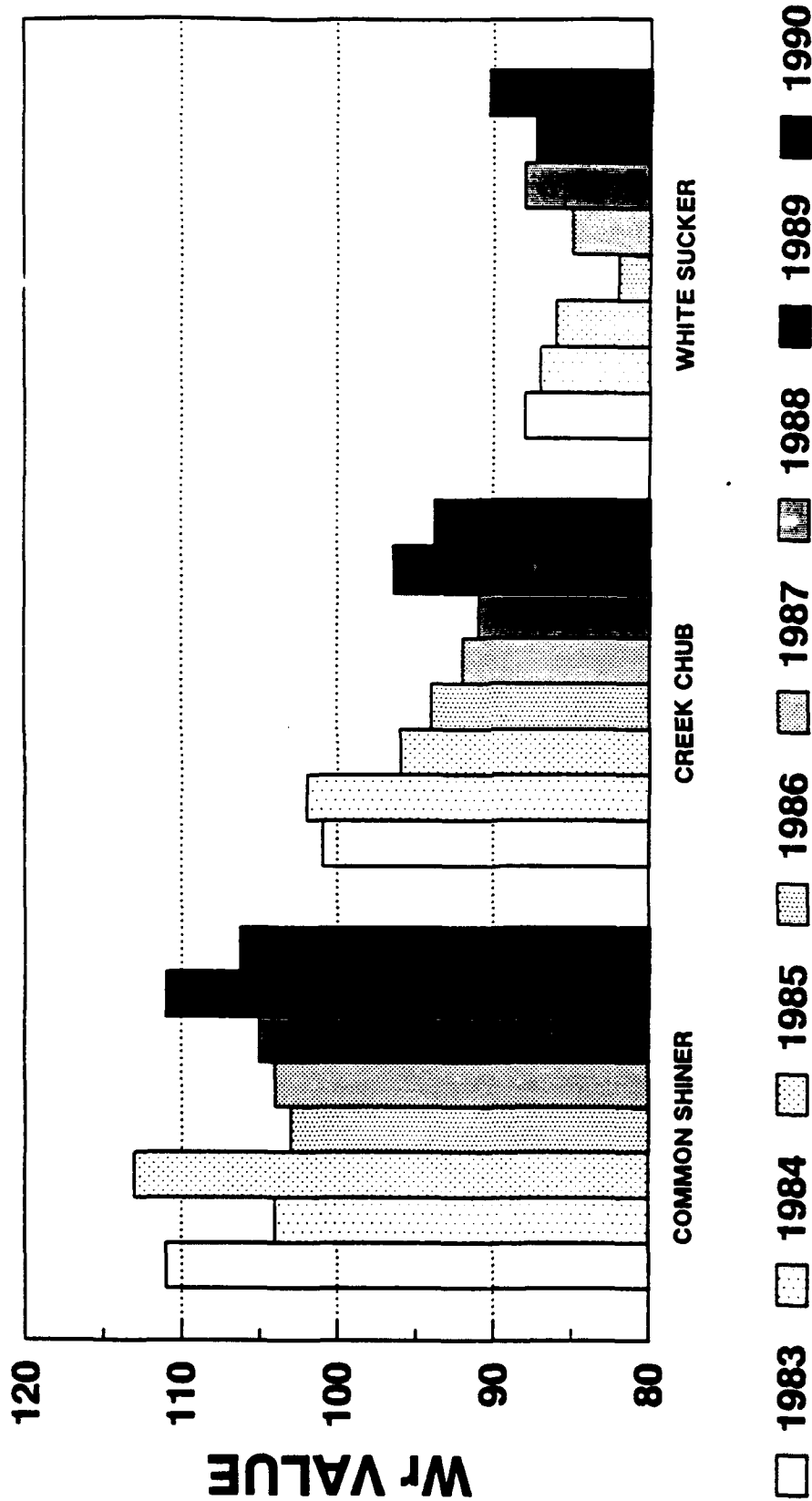


Figure 7.6. Yearly unweighted relative weight values for common shiners, creek chubs and white suckers in the Ford River. Dotted line at 100 indicates a condition equal to the average calculated from several populations in the literature.

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Element 8 - Brook Trout Population Characteristics and Movement

Changes from workplan - A new fyke net site (FEN) was established approximately 400 meters upstream of the FEX site in order to focus on brook trout movement in a smaller area near the antenna corridor.

Objectives

The overall goal of this element is to examine the effects of the Navy's ELF project on brook trout (Salvelinus fontinalis) populations; an important sportfish to local residents. Earlier we showed that brook trout in the Ford River were highly mobile and are excluded from portions of the mainstream when water temperatures exceed 16 C. Any impediments to this migration pattern could affect growth and survival as trout are less efficient bioenergetically in water above 16 C (Graham, 1949). The specific objectives of this element are to determine: 1) The seasonal pattern and magnitude of brook trout movement through the ELF corridor; 2) The proximate cause(s) for these movements; 3) The rate of brook trout movement through the ELF corridor; 4) The relationship between length frequency distributions from fyke net catches and DeLury and Peterson population estimates; and 5) Population characteristics (age, growth and condition) of Ford River brook trout. By accomplishing these objectives, we will be able to evaluate if the ELF system has an impact on the population characteristics and movement of Ford River brook trout.

Materials and Methods

The sites and gear used in this element were previously described in Element 7. All brook trout were removed on a daily basis from the fyke nets or weir traps and anesthetized with MS-222 at a 500 mg/l dosage as recommended by Meister and Ritzi (1958), and Schoettger and Julin (1967) to reduce handling stress. All brook trout were then enumerated, measured for total length and weighed. Scale samples were taken from each fish for age and backcalculated growth determination in the laboratory. All fish were given a site specific fin clip. In 1983-1985, fish longer than 135 mm were tagged using streamer or disk tags applied posterior to the dorsal fin. Due to a high incidence of infection in these years, strap tags were applied to the adipose fin and the operculum in 1986 and 1987 respectively. Tagged fish recaptured at the site of initial tagging and angler reports during these two years suggested poor tag retention. In 1988 brook trout were fin clipped with a site specific mark only. In 1989 and 1990,

fish greater than 140 mm were tagged using Visible Implant (V.I.) Tags manufactured by Northwest Marine Technologies, while fish less than 140 mm were marked with a site specific fin clip only. The V. I. Tag is inserted into clear, cartilaginous tissue posterior to the eye. Prior research has shown greater than 90 % retention, less than 2 % mortality and no infection on rainbow trout in the laboratory (Stan Moberly, personal communication). After tagging, all fish were released upstream or downstream from the site in their original direction of travel.

The effect of discharge and temperature on brook trout movement at FEX and FCD were evaluated using ambient monitoring data collected by Dr. Tom Burton and staff (see Element 1). Physical data (discharge and temperature) at FCU and TM were collected by the fisheries staff from 1984-90. Discharge was calculated from a calibrated staff gauge at both FCU and TM on a daily basis. Temperature data was collected continuously using a calibrated max-min thermometer at TM and FCU. In addition, Ryan thermographs were deployed in 1988 through 1990 at these two sites so that temperature could be monitored on a continuous basis.

Population estimates and size distributions were obtained using either a 250 volt electrofishing boat type unit during normal to high flows or a 250 volt Coffelt backpack unit during low flows. Electrofishing site locations (200 m in length) were established between one and two miles from net sites or ambient monitoring stations. In 1987 and 1988 a DeLury removal estimate (Ricker 1975) was obtained at each site during premovement (May), postmovement (late July - early August) and fall (mid September) periods. Three removal runs were made at each site during the sampling day. Fish captured were measured for total length and held in a holding cage placed in the stream until all three passes were completed. Fish were then released. In 1989 estimates were taken monthly from May 20 to October 23 at the same sites using the Peterson mark and recapture technique (Ricker 1975). Sites in 1989 were extended to 300 meters. Brook trout captured on the marking run were measured for total length, weighed and marked with a partial fin clip. Fish greater than 140 mm were marked using V. I. Tags. Recapture runs were made on the next day during all sampling periods. Unmarked fish captured on the recapture run were given a site specific fin clip and if larger than 140 mm, tagged with a V. I. Tag. In 1990, Peterson estimates were taken during the pre- and post-movement period only using the same methodology described for 1989.

Brook trout age and growth determination was done using the body-scale relationship technique described in Smale and Taylor (1987). Backcalculations were made using the linear technique described in Bagnenal and Tesch (1978). Techniques used for this analysis are the same as those used

for scales from common shiners, creek chubs and white suckers in Element 7.

Results and Discussion

A. Marking Statistics

Numbers of fish tagged at FEX and FCD declined from a high of 314 in 1984 to 126 in 1985 and 82 in 1986 reflecting a decline in the brook trout population. Numbers of fish tagged increased to 170 fish in 1987 and dropped slightly to 142 fish in 1988. Brook trout tagged in 1989 totalled 134 fish while only 74 fish were tagged in 1990 which is below the average (mean = 161) for all years combined. The between site recapture rate was 18.2% and 12.7% in 1984 and 1985 respectively, 0% in 1986 and less than 1% in 1987 and 1988. The recapture percentage increased to 6.7% in 1989 and to 9.7% in 1990 at FEX and FCD (Table 8.1). Observed handling and tagging mortality averaged 6.2% from 1984 to 1987. No tagging mortality was observed in 1988 and only 2.2% was seen in 1989. Tagging mortality in 1990 was 1.2% (Table 8.1). The percentage of angler returns declined throughout the study from 12.1% in 1984 to 3% in 1985 and 0% in 1986-1989. Anglers returned only 1.2% of tagged fish in 1990 (Table 8.1). This may reflect a decrease in the total number of fish harvested in the Ford during this time period, however, we have no quantitative data on angling pressure.

B. Brook Trout Catch Patterns

Brook trout catches peaked in late May to early July depending on weather patterns during the year. Summer catches then drop to < 1 fish/day and this condition persists through late August to early September. At this time, daily catch again increases due to spawning activity. Since movement patterns were similar at all sites, data will be presented from FCD to depict between year differences (Figures 8.1 a-d). In 1984 the mean daily catch began to peak during the first week of June and was at its maximum during that week (15.8 fish/day). These high catch patterns continued for three weeks and then dropped to less than 1 fish/day during July through September. A similar pattern was seen in 1985 although the peak run was delayed one month beginning the first week of July when 11.7 brook trout per day were collected. This continued for a one week period after which catch rates decreased rapidly to < 1 fish per day. Catch rates in 1986 began increasing during the second week of May and peaked earlier than in previous years, during the last week of May and the first week of June (6.4

Table 8.1. Brook trout marking and recapture summary for FEX and FCD for 1984 - 1990.

Year	Tag Summary	Site	
		FEX	FCD
1984	Number Tagged	71	243
	Number Fin Clipped	48	37
	Percent Tag Recapture	18.2%	
	Estimated Tagging Mortality	5.7%	
	Percent Angler Recapture	12.1%	
1985	Number Tagged	45	81
	Number Fin Clipped	38	53
	Percent Tag Recapture	12.7%	
	Estimated Tagging Mortality	8.7%	
	Percent Angler Recapture	3.0%	
1986	Number Tagged	15	40
	Number Branded	19	8
	Number Clipped	58	32
	Percent Tag Recapture	0.0%	
	Estimated Tagging Mortality	3.4%	
1987	Number Tagged	97	73
	Number Clipped	127	41
	Percent Tag Recapture	0.1%	
	Estimated Handling Mortality	7.1%	
	Percent Angler Recapture	0.6%	
1988	Number Clipped	57	85
	Estimated Handling Mortality	0.0%	
1989	Number Tagged	49	86
	Number Clipped	12	11
	Percent Tag Recapture	6.7%	
	Estimated Handling Mortality	2.2%	
	Percent Angler Recapture	0.0%	
1990	Number Tagged	46	28
	Number Clipped	12	5
	Percent Tag Recapture	9.7%	
	Estimated Handling Mortality	1.2%	
	Percent Angler Recapture	1.2%	

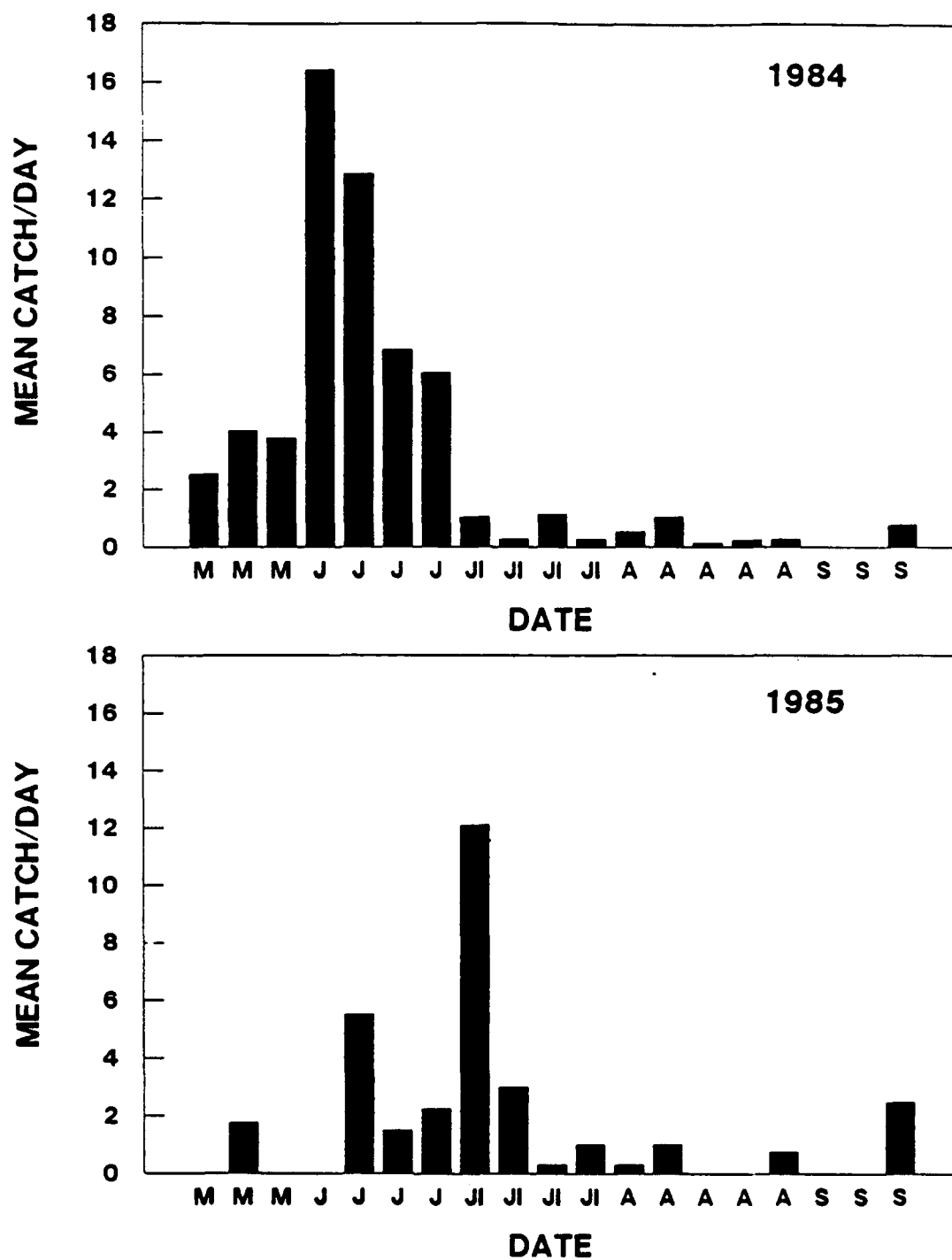


Figure 8.1a. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1984 and 1985.

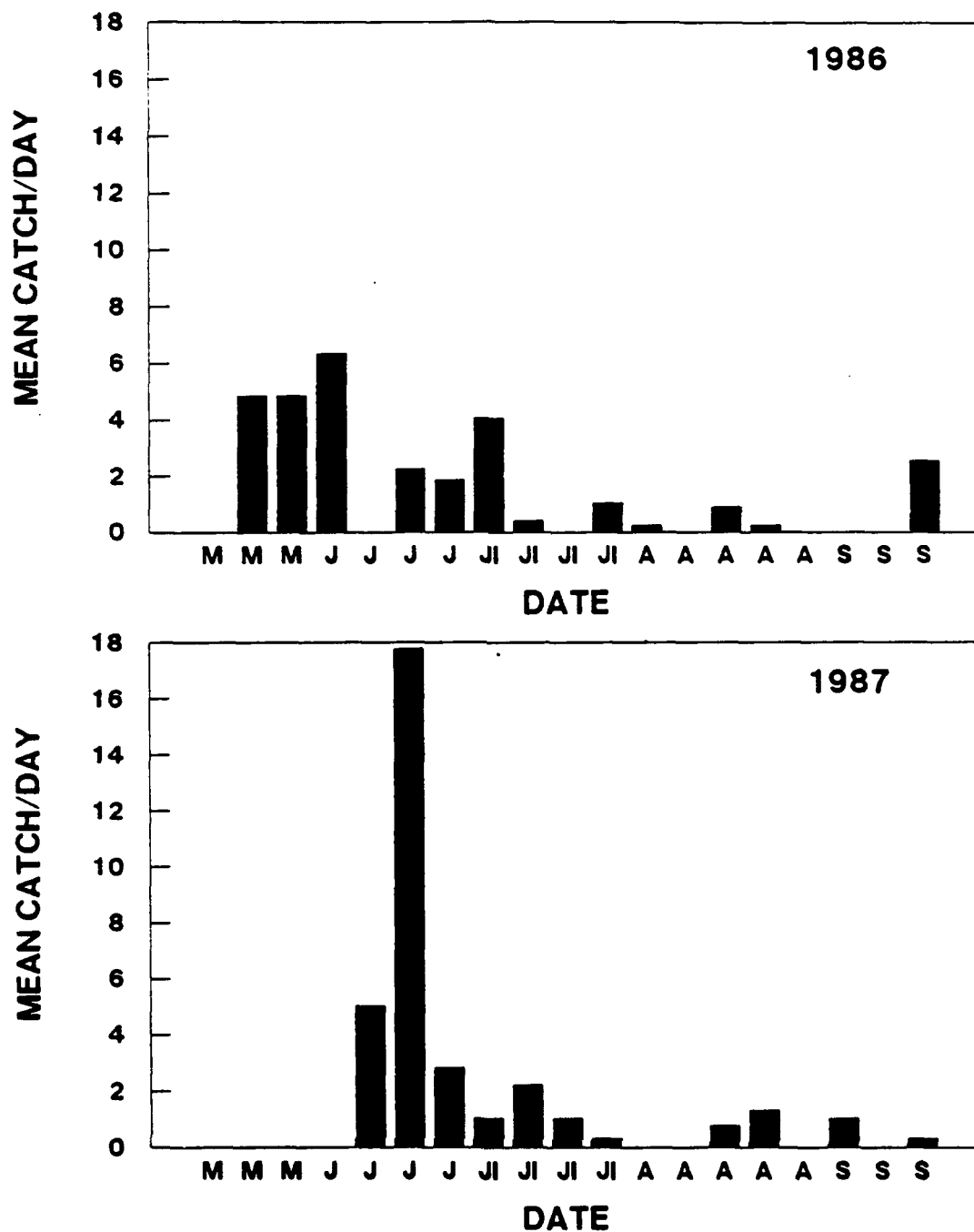


Figure 8.1b. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1986 and 1987.

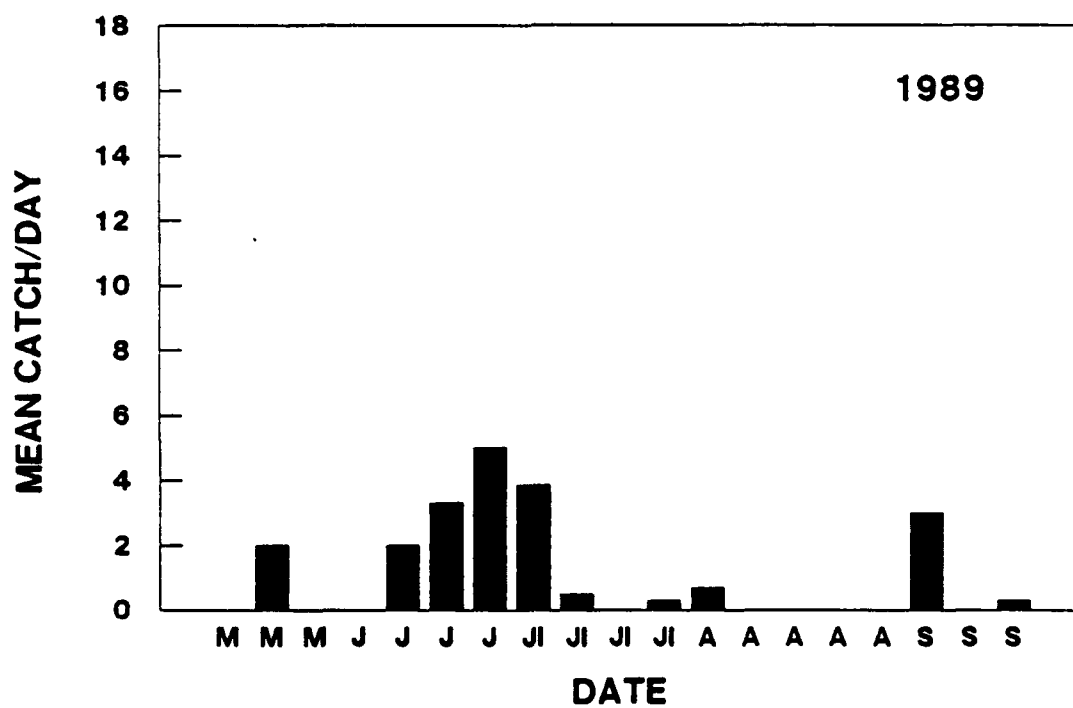
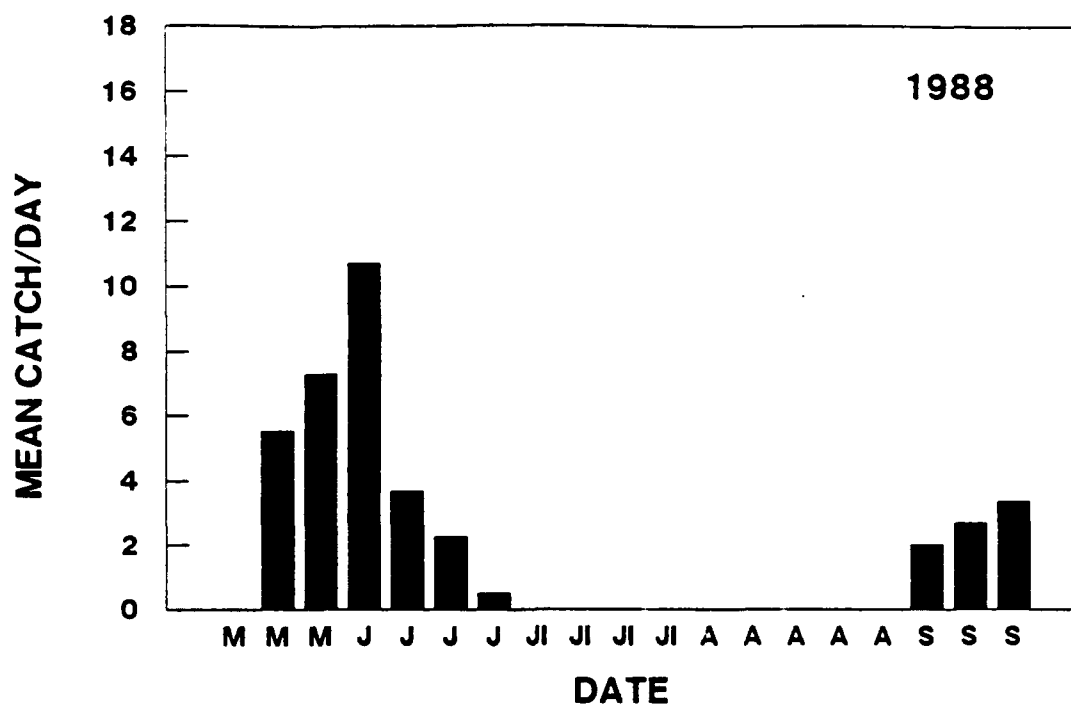


Figure 8.1c. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1988 and 1989.

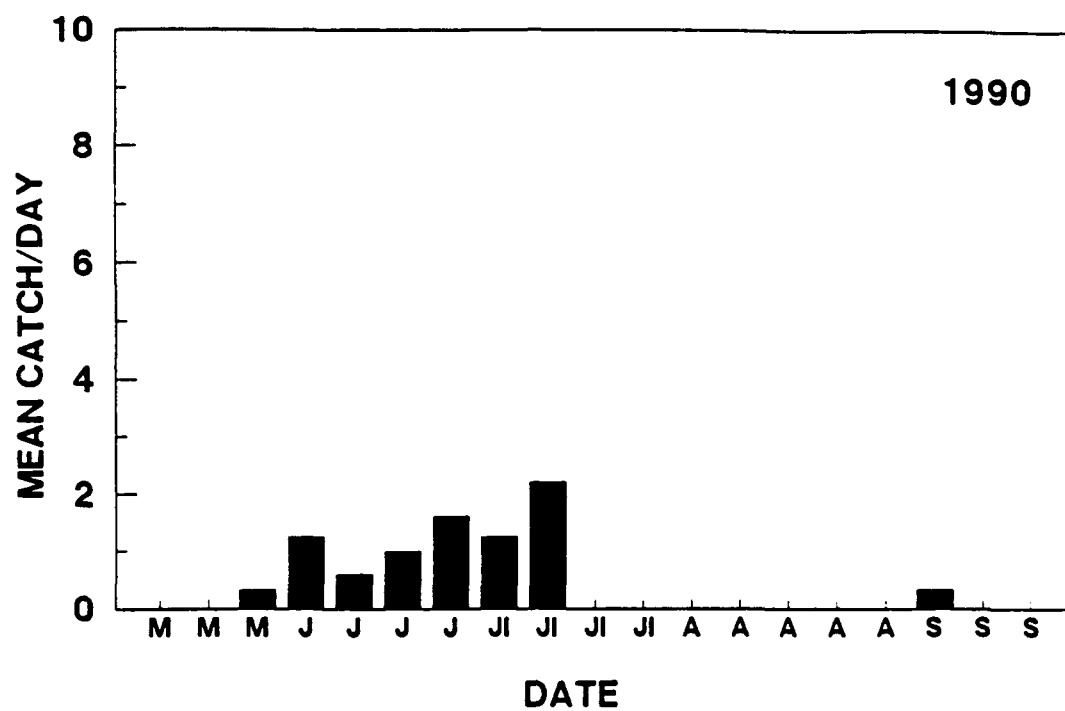


Figure 8.1d. Mean daily catch of brook trout plotted on a weekly basis at FCD in 1990.

fish/day). Results in 1987 were similar in distribution to 1984 catch rates although the peak occurred during the third week of June at 17.8 fish/day and lasted for only one week. In 1988 catch rates started to increase the last two weeks of May and peaked at 10.5 fish/day during the first week of June, similar to 1984. The 1989 catch peaked during the last week of June (5.1 fish/day) and lasted for a one week period. The 1990 catch began to increase during the last week of June and then peaked in early July.

Movement in the upstream direction dominated in all years at all sites making up over 90 % of the brook trout catch, however, the intensity and timing varied from year to year. If the ELF operation interferes with the migratory pattern of brook trout, we should be able to observe disoriented behavior through decreased upstream movement or random movement patterns at the FEX site.

Brook trout movements were directed from FEX and FCD upstream toward a coldwater tributary, Two Mile Creek. Eighteen brook trout marked at FEX were recaptured at TM during the pre-operational period from 1984-1985 (Table 8.2). During the transitional period (1986-1989), three trout were observed to have made this movement while no trout made this movement in the 1990 post-operational year. Pre-operational movement from FCD to FEX was observed for ten brook trout. Three fish made this movement in the transitional period and two in the 1990 post-operational year. Movement from FCD to TM was observed for forty-five brook trout from 1984-1985. One fish moved this distance in during the transitional period. No fish were observed making this movement in the post-operational year (1990). As more data are collected, further analysis will be done. Movement from site to site was observed to be significantly greater for fish above 190 mm than those below 190 mm (X^2 , $p < 0.05$). Only six clipped fish under 190 mm were captured at TM in 1984 and no clipped fish under 190 mm were collected from 1985 through 1990. In addition, only one fish was observed moving from Two Mile Creek to FCD or FEX from 1984 through 1990 during the summer sampling period. Three fish marked at the TM site in 1984 were collected in 1985 at FCD indicating that some downstream movement occurred between late fall and early spring.

During the pre-operational period (1984-1985) the movements of 50 brook trout were known. Six of these fish moved upstream but did not cross under the antenna, 43 moved upstream past the antenna, 1 moved downstream but did not cross under the antenna, and no marked brook trout were observed moving downstream past the antenna. During the transitional period (1986-1989), the movement of 10 brook trout were known. Four of these fish moved upstream but did not cross under the antenna, 3 moved upstream past the antenna, 2 moved downstream but did not cross under the

Table 8.2. Brook trout site to site movement rate summary for 1984 through 1990.

Year	Recapture Type	Site Marked to Site Recaptured	Distance (km)	N	Mean Rate (km/day $\pm$ 1SD)	Mode (km/day)
1984	Recaptured Fish	FEX- TM FCD- TM FCD-FEX	12.7 26.8 14.1	11 39 7	1.4 $\pm$ 0.9 2.9 $\pm$ 1.7 2.7 $\pm$ 1.6	1.2 2.5 2.0
1985	Recaptured Fish	FEX- TM FCD- TM FCD-FEX	12.7 26.8 14.1	7 6 3	1.6 $\pm$ 0.9 5.0 $\pm$ 3.2 1.2 $\pm$ 0.3	1.1 4.2 1.3
1986	No Recaptures					
1987	Recaptured Fish	FEX- TM	12.7	1	1.8	1.8
1988	Recaptured Fish	FCD-FEX	14.1	2	2.3 $\pm$ 0.7	1.0
1989	Recaptured Fish	FEX-TM FCD-TM FCD-FEX FEX-FCD TM-FCD	12.7 26.8 14.1 14.1 26.8	2 1 1 2 1	0.7 4.5 2.8 1.9 6.7	
1990	Recaptured Fish	FCD-FEX	14.1	2	2.2	

antenna, and 1 brook trout moved downstream past the antenna. A X^2 analysis of these data indicates that a significantly higher percentage of brook trout moved upstream past the antenna during the pre-operational period than did so during the transitional period ($X^2=17.73$, $df=3$, $p<0.05$).

To more closely examine the movement of brook trout under the ELF antenna, in 1990 an additional net site (FEN) was established upstream from the antenna approximately 400 meters from FEX. Of 42 fish captured and marked at FEX, none were recaptured at FEN. Additionally, a radio-marked brook trout released on the upstream side of FEX failed to move upstream past the antenna in the 10 day period during which it was monitored. During this 10-day period, the fish was observed to be behaving normally (e.g., darted to cover when approached by the observer). Radio contact was lost after 10 days, presumably because of radio failure. These results are tentative, but suggest that the fully operational ELF antenna may hinder the upstream movement of brook trout. A primary focus of the 1991 field season will be to clarify this situation. A permanent weir will be established at FEN. This should minimize any potential for escapement sometimes associated with fyke nets at high water.

A range of individual movement times (number of days it took an individual fish to move from the point of marking to another site) for pre-operational years, transitional years, and post-operational years was set up in Figure 8.2. In addition, a cumulative frequency distribution of days it took individual fish to move during the pre-operational and transitional periods is given in Figure 8.3. No difference in the movement pattern (days to move) is detectable when the pre-operational and transitional periods were compared (Log-rank test; $X^2=10.89$; $df=15$; $p>0.05$). At this time, no definitive conclusions can be drawn as to ELF effects on movement; however, it appears that this could be an excellent test as additional post-operational data become available. If there is no ELF effect, we would expect to see similar distributions of days since tagged values in pre-operational years, transitional years, and post-operational years.

One possible complicating factor in the movement rate analysis observed during the 1990 season was the presence of beaver dams as barriers to movement during summer low water periods. Three of five brook trout tagged with radiotelemetry transmitters were observed to be stopped by beaver dams during low flow periods in mid July. Two of the fish spent more than 7 days directly below the structures. The trout then retreated to deep holes from 1 to 2 km below the dams where contact was lost as transmitter batteries failed after approximately 30 days. Contact with the other

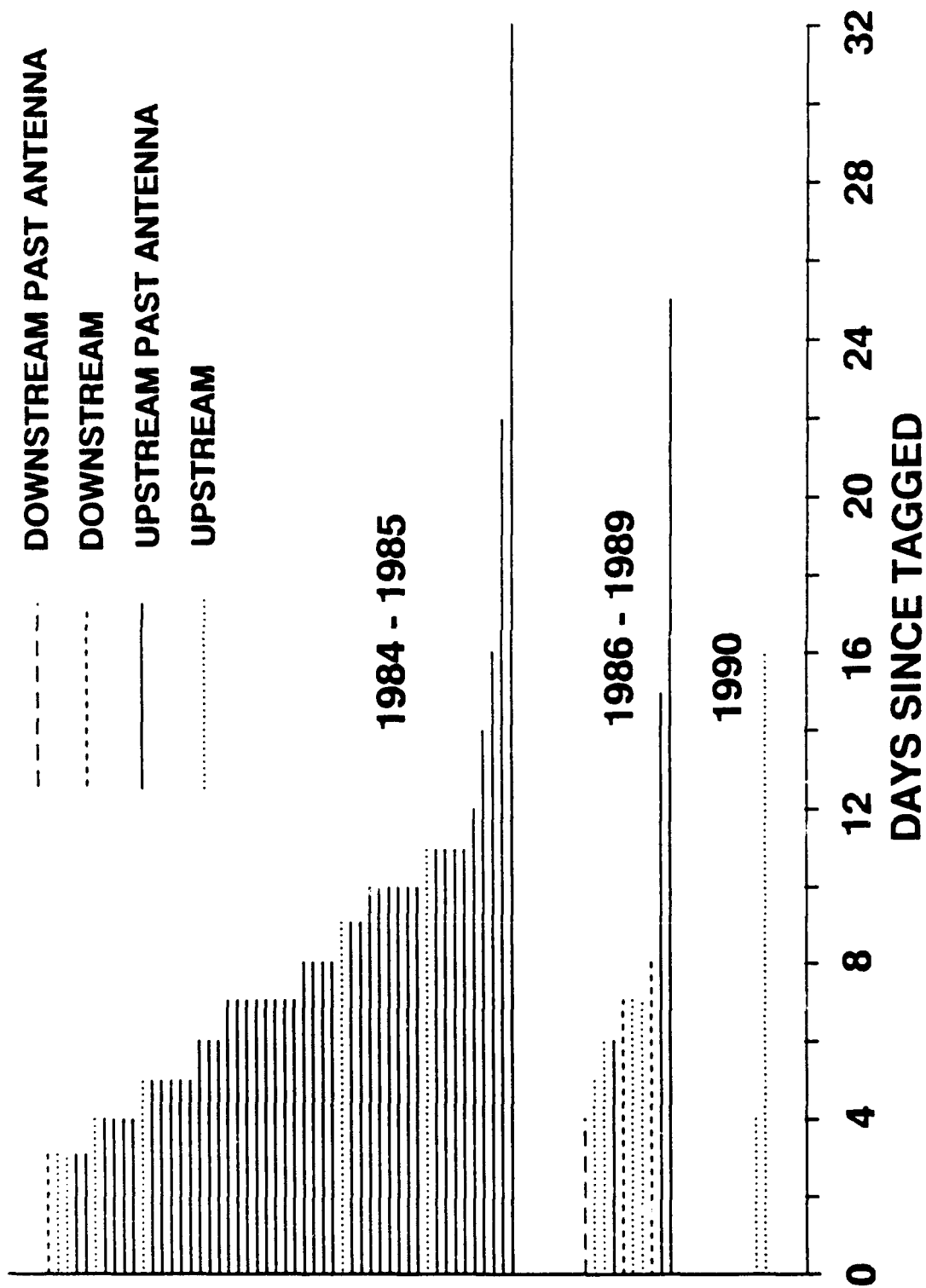


Figure 8.2. Range of individual movement times of brook trout during pre-operational (1984-1985), transitional (1986-1989), and post-operational study periods.

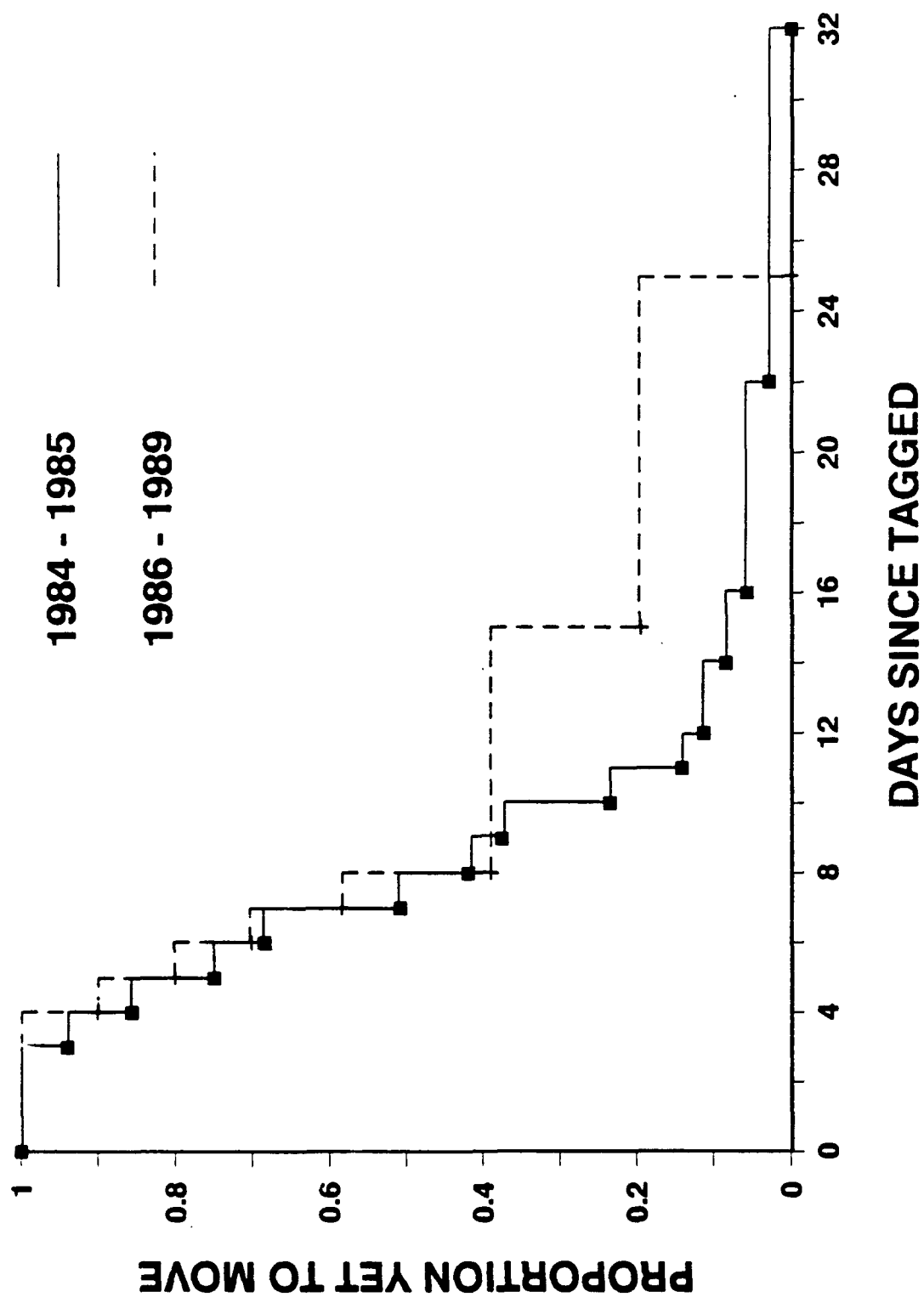


Figure 8.3. Movement distribution, in days since tagging, for individual brook trout during the pre-operational and transitional study periods.

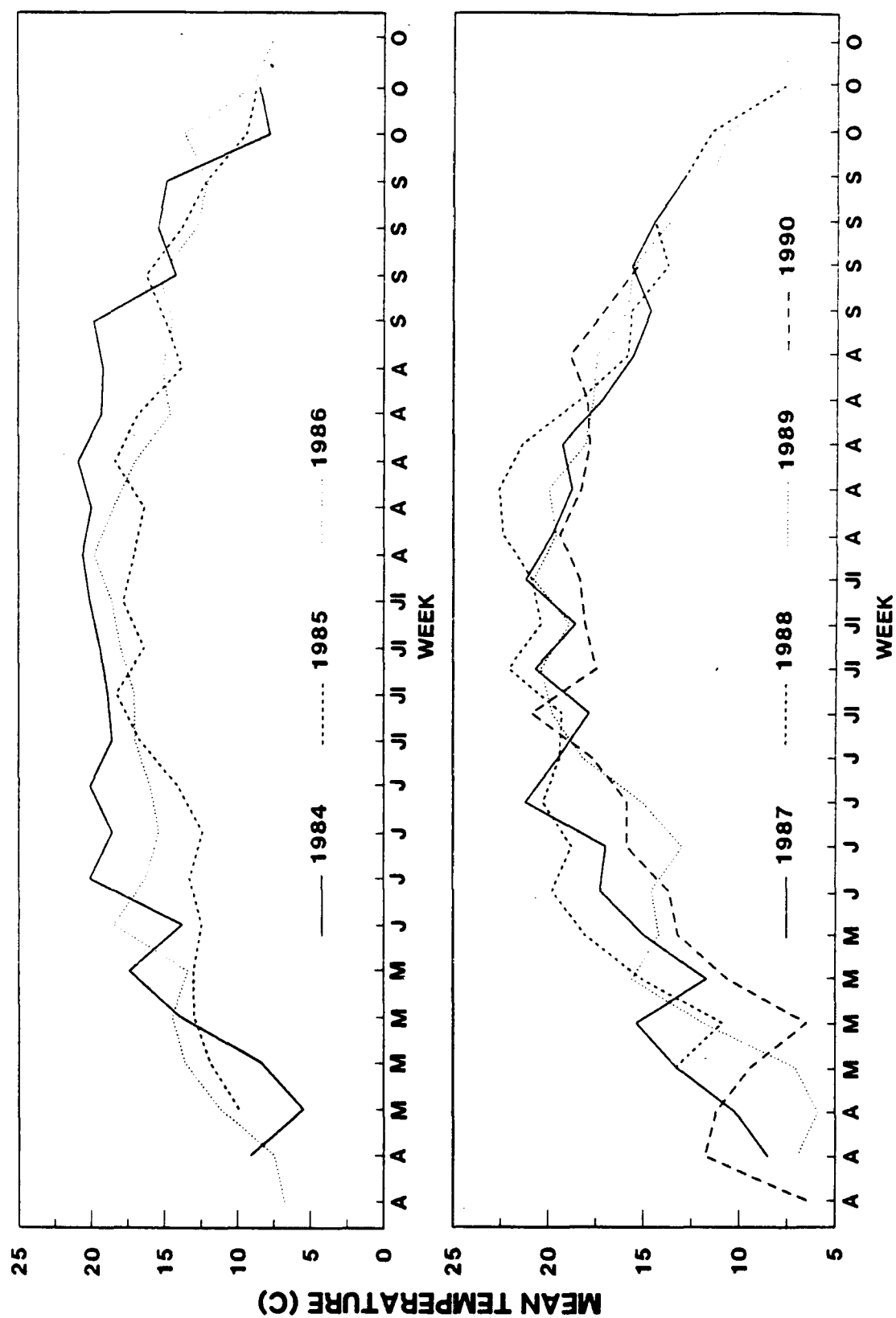
fish was lost the day after it was observed below a small dam upstream of FCD. It is doubtful that this dam was a hindrance to movement, however, and initial conclusions are that this fish was lost to predation or to transmitter failure. These results may also explain low recapture rates observed during the transitional and post-operational years.

From a bioenergetic standpoint, brook trout in the Ford River appear to utilize Two Mile Creek for thermal refuge since temperatures there, as opposed to the upper Ford River, stay closer to optimum growth temperature. Groundwater inputs may have kept TM at or near 16 C during all years except 1987 when reduced groundwater inputs from abnormally low precipitation during winter and spring may have resulted in higher temperatures. Temperatures in all years were lower at TM than at FCU.

C. Proximate Causes of Brook Trout Movement

Mean daily water temperature patterns were similar at FEX and FCD. Temperature patterns between years, however were highly variable, especially during late spring and early summer (Figure 8.4). In all years peak movement times coincided with mean daily temperatures exceeding the optimum for brook trout growth (16 C). In 1984 temperatures exceeded the optimum during the first week of June and the subsequent peak in mean daily catch occurred during that week. For 1985, 1989, and 1990 mean daily temperatures peaked past the optimum during the last week of June and peak movement times for these two years were the first week of July for 1985, the last week of June for 1989, and the first and second week in July for 1990. Mean daily temperatures in 1986 and 1988 peaked during the last week of May and movements in both years peaked during the first week of June. In 1987, water temperature and movement peaked during the third week of June.

Two additional factors which influenced brook trout movement patterns were discharge and population size. Analysis of discharge during the spring - early summer movement period at FCD showed there was high variability between years (Figure 8.5). Discharge patterns in 1984 showed periodic peaks throughout the year indicating that evenly spaced precipitation events occurred. Patterns for 1985, 1987, 1989, and 1990 displayed high spring - early summer discharge and low values during summer. 1986 and 1988 patterns showed low spring and summer values and increased flow in fall. Upstream directed movements occurred during all years despite different flow patterns. However, daily movements were strongly associated with peaks in daily discharge.



Fewer fish moved in 1986, 1988, 1989, and 1990 probably due to low trout populations during these years. When populations are low, individuals may be able to find adequate coldwater microhabitats without intra or interspecific competition from other fishes. In summary, it appears that when the brook trout population is abundant, water temperatures are suboptimal ($> 16^{\circ}\text{C}$) and flows are high, substantial upstream movement, characterized by high daily catches in spring and/or early summer occur.

D. Brook Trout Movement Rates

The rates and direction of brook trout movement have the potential to be a very sensitive indicator of ELF effects. If trout have difficulty orienting through the ELF corridor, we would expect to observe disoriented behavior and decreased movement rates, particularly at FEX. From 1984 through 1985 (pre-operation), fish moved at a mean rate of 3.14 km/day. Movement rates during transition (1986-1989 (mean = 2.55 km/day) showed no significant difference from the pre-operational mean (2 sample t-test, $p > 0.05$) (Table 8.3). Movement rates in 1990 averaged 2.2 km/day. Fish moving from FEX to TM (12.7 km) moved at a mean rate of 1.42 km/day (range = 0.7 to 1.8 km/day). Movement rates observed between FCD and TM (26.8 km) averaged 3.21 km/day while movement between FCD and FEX (14.1 km) averaged 2.3 km/day. Angler tag return data supported the above trends and indicated that brook trout move at a mean rate of 2.3 km/day in an upstream direction, similar to rates recorded from our sampling gear.

E. Gear Calibration and Brook Trout Population Estimates.

It was determined through analysis of length frequency distributions from fyke net catches that all brook trout 120 mm and greater are vulnerable to the gear. Length frequency distributions from two brook trout population estimates taken by the Michigan Department of Natural Resources at a site approximately 0.62 miles upstream of FCD in 1985 were compared to length frequency distributions from fyke net catches in that year. In addition, brook trout population estimates were obtained 1 mile downstream from FCD in 1986, 1987, 1988, 1989, and 1990 by ELF personnel. Length frequencies obtained from these estimates (Figures 8.6a and b) were compared to length frequency distributions of the fyke net catches during each year to determine the percent of the population vulnerable to our gear (Table 8.4). Brook trout population estimates in 1986, 1987, 1988, 1989

Table 8.3. 2-sample t-test between pre-operational brook trout movement rates (1984-1988) and operational (1989) rates.

$t = 1.10$ 58 d.f. $p > 0.05$		
	1984-1985	1986-1989
N	50	10
MEAN	3.14	2.55
VARIANCE	2.21	3.28
NO SIGNIFICANT DIFFERENCE		

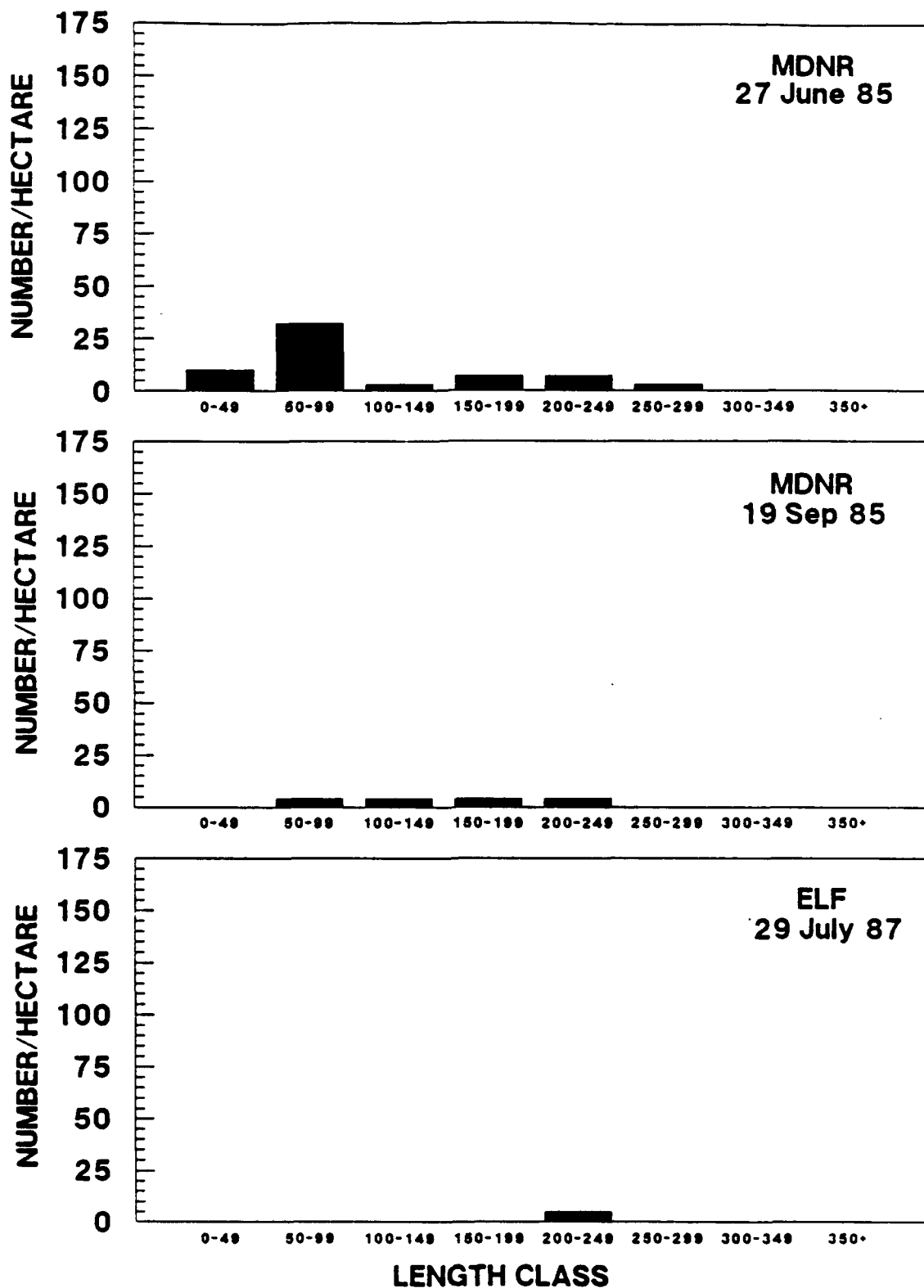


Figure 8.6a. Length frequency of brook trout taken by MI DNR and ELF personnel at FCD. Dates are included on graphs.

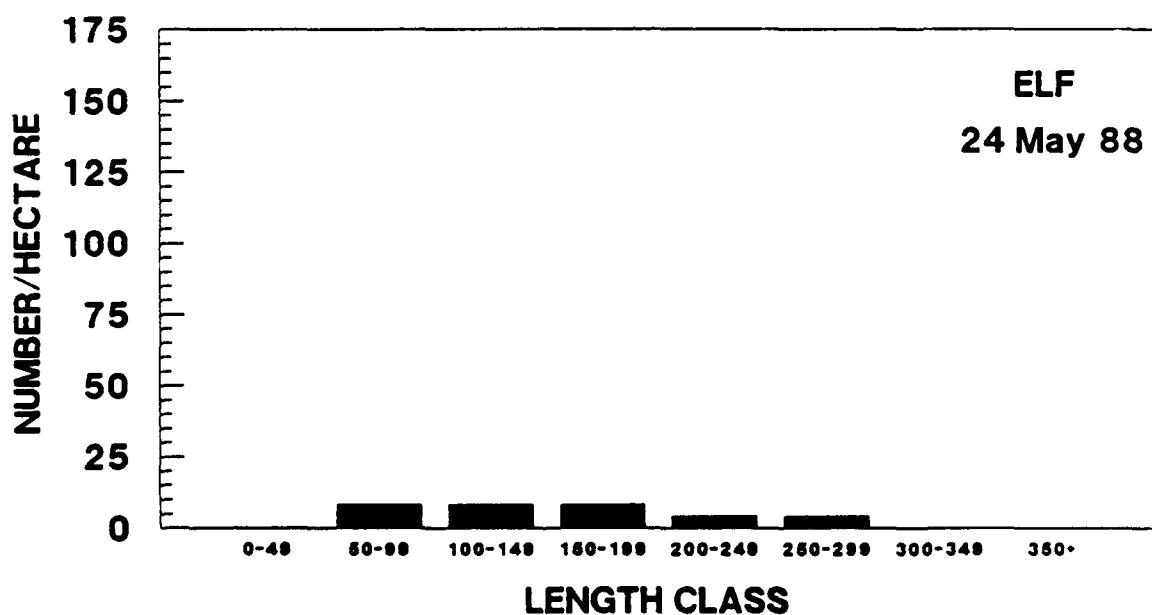
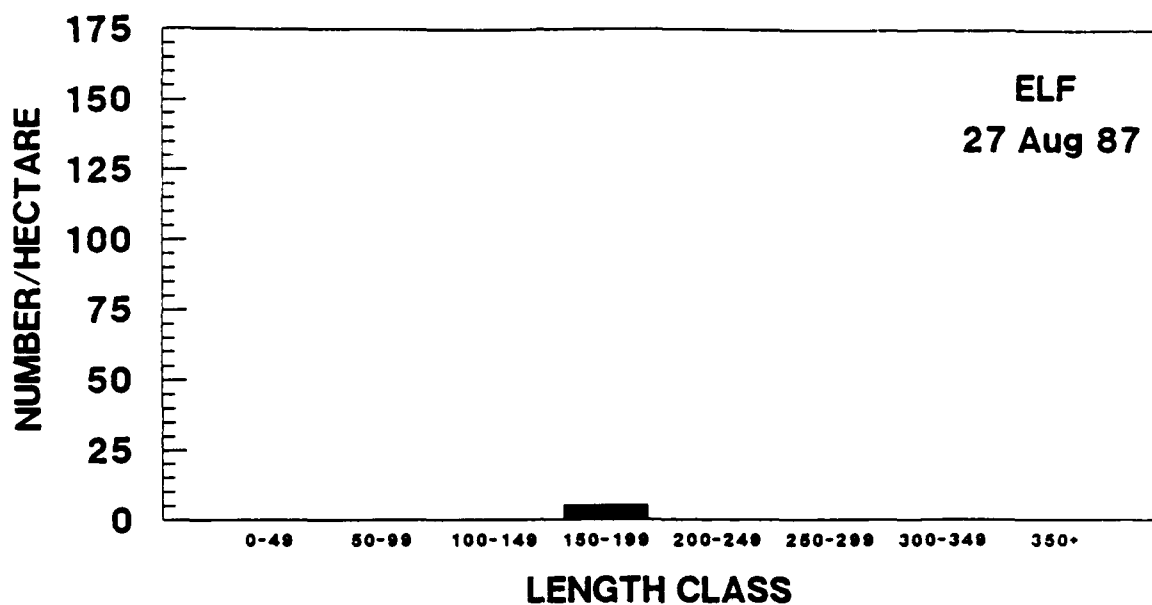


Figure 8.6b. Length frequency of brook trout at FCD taken by ELF personnel.

Table 8.4. Percent of the brook trout population vulnerable to the gear at FCD and FEX for years when population estimates were obtained. Assumes all fish > 120 mm are vulnerable to the gear.

DATE	SITE NEAR	PERCENT OF POP LESS THAN 120 mm	EXPECTED PROPORTION OF POP. VULNERABLE TO THE GEAR
Jun 27, 1985	FCD	66.7 %	33.3 %
Sep 19, 1985	FCD	25.0 %	75.0 %
Aug 07, 1986	FCD	0.0 %	100.0 %
Jul 29, 1987	FCD	0.0 %	100.0 %
Aug 27, 1987	FCD	0.0 %	100.0 %
May 24, 1988	FCD	29.0 %	71.0 %
Jul 7, 1988	FCD	0.0 %	100.0 %
Aug 26, 1988	FCD	0.0 %	100.0 %
Jun 21, 1989	FCD	0.0 %	100.0 %
Jul 19, 1989	FCD	0.0 %	100.0 %
Aug 23, 1989	FCD	0.0 %	100.0 %
Sep 21, 1989	FCD	0.0 %	100.0 %
Oct 22, 1989	FCD	0.0 %	100.0 %
Jun 28, 1990	FCD	0.0 %	100.0 %
Sep 5, 1990	FCD	0.0 %	100.0 %

Jul 1, 1987	FEX	12.5 %	87.5 %
Aug 26, 1987	FEX	16.6 %	83.4 %
Jul 31, 1988	FEX	45.5 %	54.5 %
Aug 4, 1988	FEX	90.0 %	10.0 %
May 23, 1989	FEX	0.0 %	100.0 %
Jun 21, 1989	FEX	0.0 %	100.0 %
Jul 19, 1989	FEX	0.0 %	100.0 %
Aug 21, 1989	FEX	0.0 %	100.0 %
Sep 23, 1989	FEX	0.0 %	100.0 %
Oct 20, 1989	FEX	0.0 %	100.0 %
Jun 28, 1990	FEX	0.0 %	100.0 %
Sep 5, 1990	FEX	50.0 %	50.0 %

and 1990 downstream of the FCD site revealed low densities of fish, especially those under 120 mm. MDNR estimates on June 27, 1985 and September 19, 1985 revealed higher numbers of young-of-the-year fish than those obtained by ELF personnel. Only one brook trout was captured on five successive sampling periods during 1989 and 2 sampling periods in 1990 so these data are not presented in this report.

Population estimates were obtained 1.6 miles downstream of the FEX site in 1987, 1988, 1989, and 1990. Analysis of the length frequency distributions of net catches at FEX and electrofishing catches (Figure 8.7) near FEX in 1987 through 1988 indicate that a higher number of fish smaller than 120 mm were present than at FCD. The proportion of fish from these estimates vulnerable to the fyke nets are reported in Table 8.4. Only three brook trout were captured on six successive electrofishing sampling periods at the site downstream from FEX in 1989. All three fish were captured on August 21, 1989 and were larger adult fish. Only 4 brook trout were captured during 2 sampling periods in 1990, 2 were yearling fish and the other 2 were adult fish. Therefore these data are not included in this report.

F. Brook Trout Age and Growth

Age and growth analysis of Ford River brook trout have the potential to be very sensitive indicators of ELF effects. Brook trout in the Ford River show excellent growth when compared to populations in Carlander (1969). Regression equations (length at annulus) of brook trout data pooled from FEX and FCD are reported in Table 8.5 and plotted on Figure 8.8. Analysis of length at annulus data between years has not been done at this time. Discrepancies in 1987 and 1988 data need to be examined before further analysis can be done. These should be included in the final draft of this report. Covariance analysis was used to test for differences in the slopes of regression equations for length versus total scale radius data between FEX and FCD in each year (Table 8.6). A BACI (Stewart-Oaten and Murdoch, 1986) analysis was conducted to test for differences in the slopes of the regression lines between pre-operational and transitional years (Figure 8.9). The slopes were log transformed and a 2 sample t-test was performed using the differences between FEX and FCD. No evidence of a difference between the pre-operational and transitional period was observed in the slopes of the length vs. total scale radius regression lines ($t=0.138$, $df=4$, $p>0.05$). Analysis of length versus total scale radius at each site revealed a high amount of variability between years (Table 8.7). This variability may be due to reader error or scales

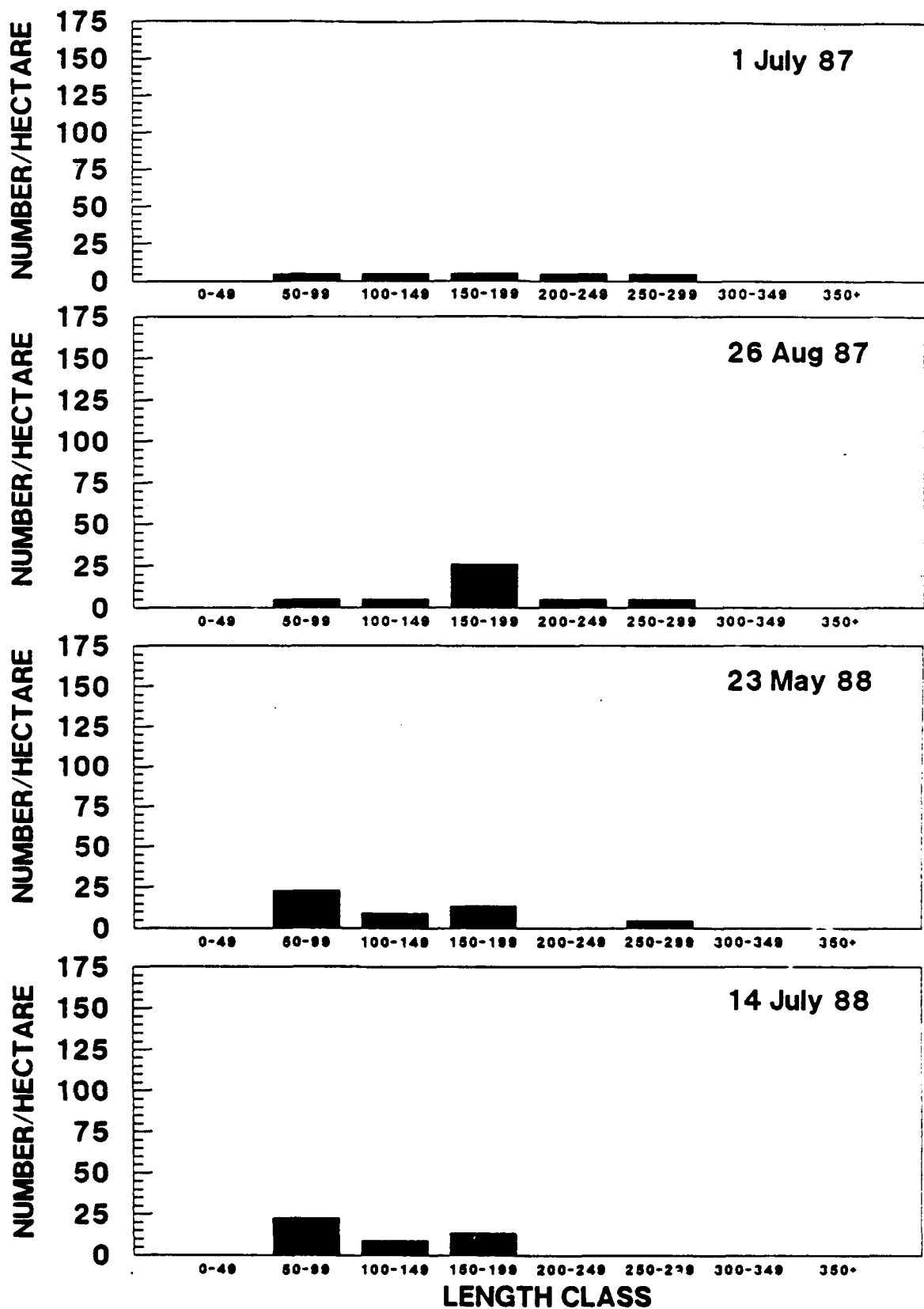


Figure 8.7. Length frequency of brook trout taken by ELF personnel at FEX.

Table 8.5. Regression equations used in analysis of brook trout length at annulus between years from 1983-1988.

EQUATION	Length = a + b(Age)
YEAR	EQUATION
1983	$y = 4.970 + 473.897x$
1984	$y = -13.379 + 520.760x$
1985	$y = 4.598 + 491.507x$
1986	$y = -3.719 + 506.890x$
1987	$y = -12.352 + 536.539x$
1988	$y = 24.956 + 375.450x$

Table 8.6. Regression equations used in between site comparison of length versus total radius data for 1983 through 1988.

YEAR SITE	REG EQUATIONS	SLOPE(df) (F)
1983		
FCD	$y=60.177 + 324.962x$	NS(1,142)
FEX	$y=57.025 + 352.025x$	(0.51)
1984		
FCD	$y=62.255 + 343.975x$	*(1,49)
FEX	$y=-10.11 + 518.964x$	(4.39)
1985		
FCD	$y=45.662 + 416.331x$	NS(1,28)
FEX	$y= 9.556 + 489.439x$	(0.71)
1986		
FCD	$y=18.448 + 443.314x$	*(1,101)
FEX	$y=47.408 + 356.639x$	(4.36)
1987		
FCD	$y=89.657 + 284.874x$	NS(1,230)
FEX	$y=58.296 + 351.143x$	(3.11)
1988		
FCD	$y=91.162 + 197.896x$	*(1,17)
FEX	$y= 3.186 + 435.569x$	(10.09)

* SIGNIFICANT $p < 0.05$

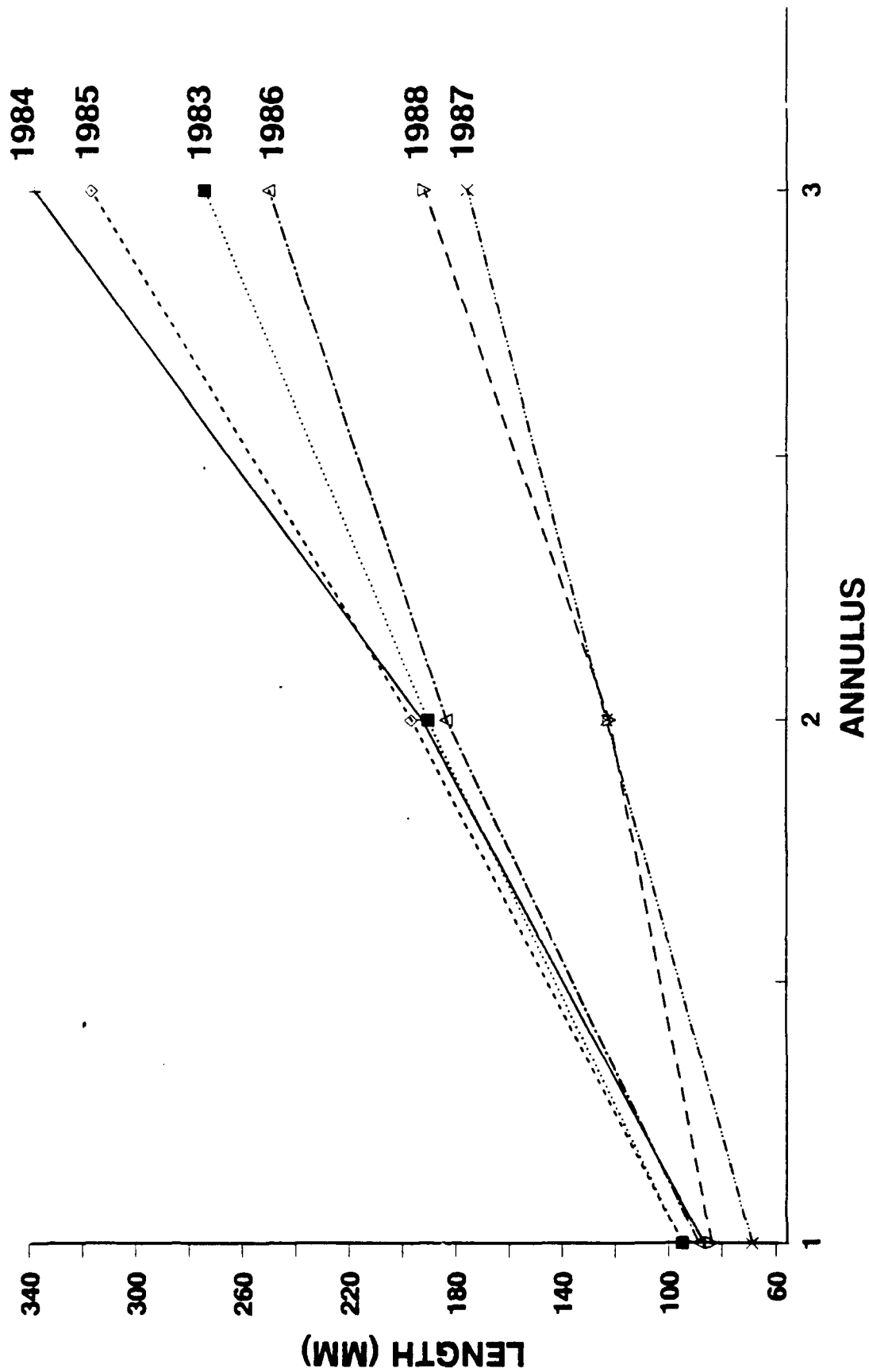


Figure 8.8. Length at annulus plots for brook trout over all years using data pooled from FCD and FEX.

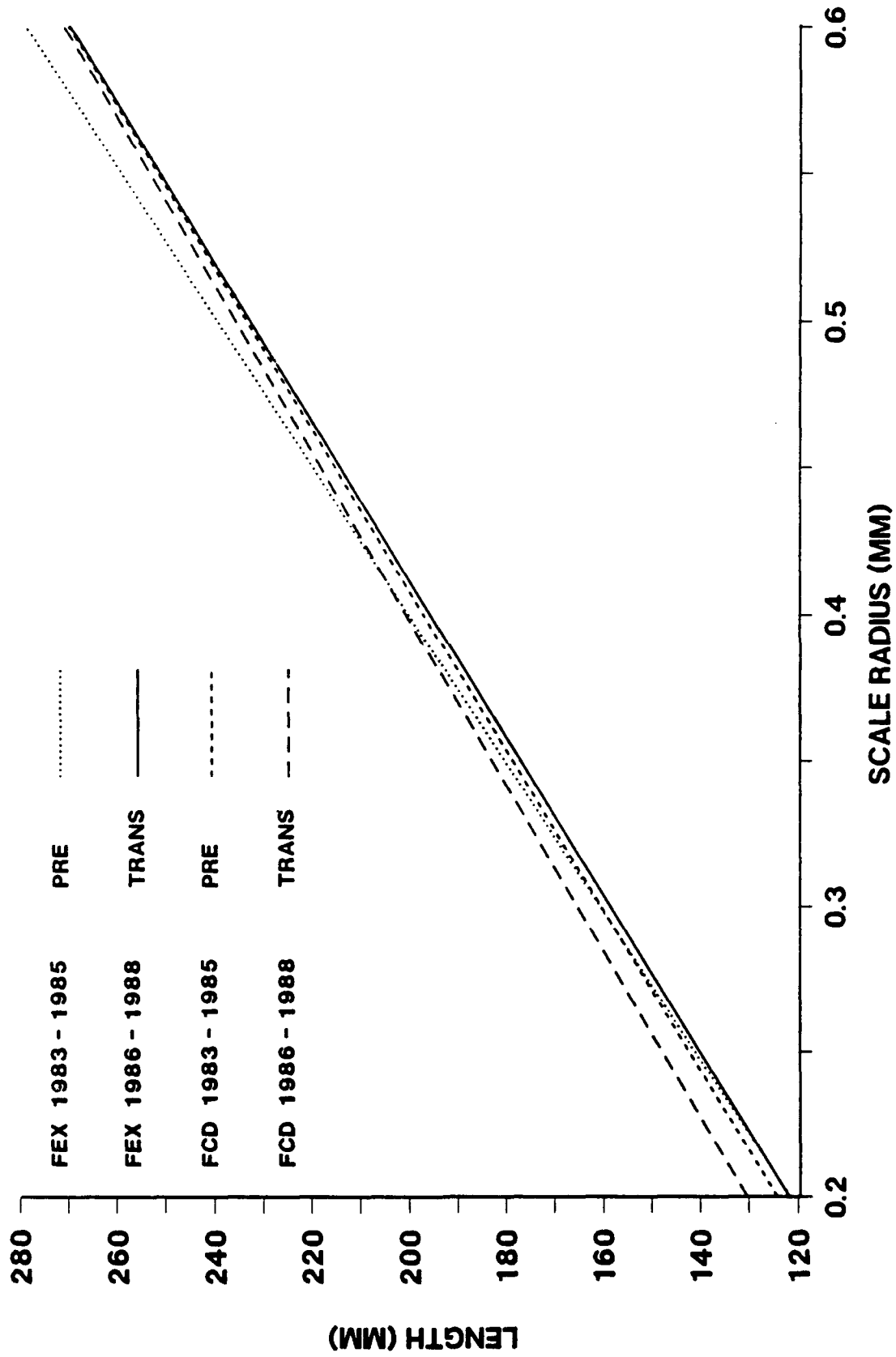


Figure 8.9. Plots of lines used in BACI analysis of length vs. total scale radius.

Table 8.7. Regression equations used in analysis of between years comparison of length versus total scale radius at FCD and FEX.

YEAR	FCD	EQUATIONS	n	SLOPE
1983	y=60.177 +	324.962x	66	a
1984	y=62.255 +	343.975x	36	b
1985	y=45.662 +	416.331x	17	c
1986	y=18.448 +	443.314x	51	d
1987	y=89.657 +	284.874x	81	e
1988	y=91.162 +	197.896x	7	f
FEX				
1983	y=57.025 +	352.025x	80	a
1984	y=-10.11 +	518.964x	17	b
1985	y= 9.556 +	489.439x	15	c
1986	y=47.408 +	356.639x	54	a
1987	y=58.296 +	351.143x	153	a
1988	y= 3.186 +	435.569x	14	d

NOTE - Same letters indicates that years are similar in slope.
Overall test of slopes using covariance analysis.
Tukey - Kramer Multiple Comparison Test, alpha=0.05
(Miller 1986).

being taken from a different location on the fish. Plots of all regression lines used in this analysis are shown on Figure 8.10(a-c).

Lee's phenomena (Ricker, 1975) was not seen in any year for Ford River brook trout. Brook trout age structure and growth analysis will be a key to defining any significant ELF effects. Decreased growth in brook trout, especially at FEX, is expected if the ELF system excludes fish from reaching cold water refuge areas. Further analysis of age and growth data has been proposed in response to reviewer request. Consideration will be given to analysis of size increments at length in addition to length at age. Data from pre-operational years will be pooled and compared to pooled post-operational data for the final assessment of ELF effects.

G. Brook Trout Condition

Examination of brook trout condition was done using the relative weight methodology as described in element 7. The standard weight formula:

$$\log_{10} wt = -5.085 + 3.043 \log_{10} tl \quad (r=.999),$$

was determined using the 50th percentile equation from 45 brook trout populations reported in the literature.

Brook trout relative weight ranged from average to slightly below average from 1983 to 1988 when compared to values obtained from the above equation (Figure 8.11). Relative weight values steadily declined from 101.6 in 1983 to 89.0 in 1986. Condition improved in 1987 to 92.6 and maintained that level in 1988. Relative weight values for 1989 (95.6) and 1990 (98.3) increased back to levels near the literature mean.

Length/weight regression analysis was also used to compare brook trout condition between FEX and FCD over all years (Table 8.8). No significant differences in the slopes of the regression lines were observed between sites over all years except 1985 (ANCOVA, $p>0.05$) (Figure 8.12a-d). Condition was also compared by year for each site. No significant differences in slopes were observed for 1984 through 1990 at FEX (ANCOVA, $F_{6,680}=1.983$, $p>0.05$) or FCD (ANCOVA, $F_{6,776}=1.011$, $p>0.05$) (Figure 8-13a and b).

A BACI analysis was conducted to test for differences in the slopes of the regression lines between pre-operational and transitional years (Figure 8.14). A two sample t-test was performed using the differences between slopes from FEX and FCD ($t_{calc.}=2.585$). No evidence of a difference between the pre-operational and transitional period was observed at the $\alpha=0.05$ level ($t_{4,0.05}=2.78$). However, when the data were tested at the $\alpha=0.10$ level ($t_{4,0.10}=2.13$), the

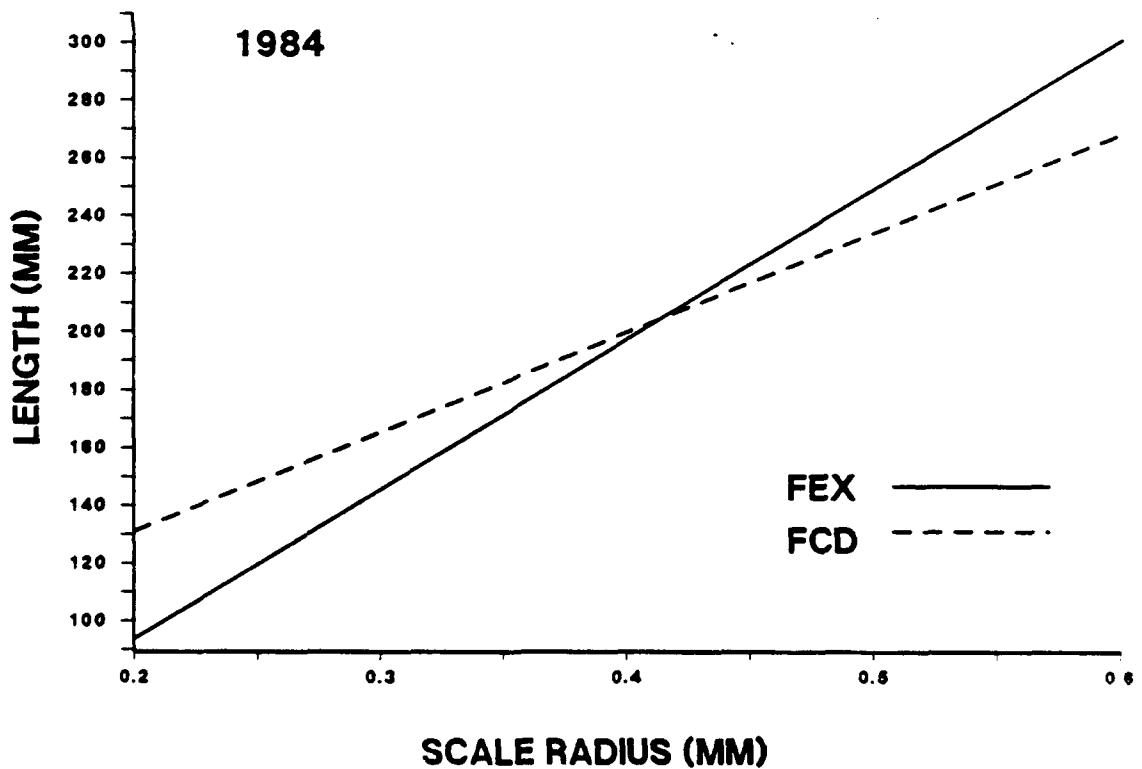
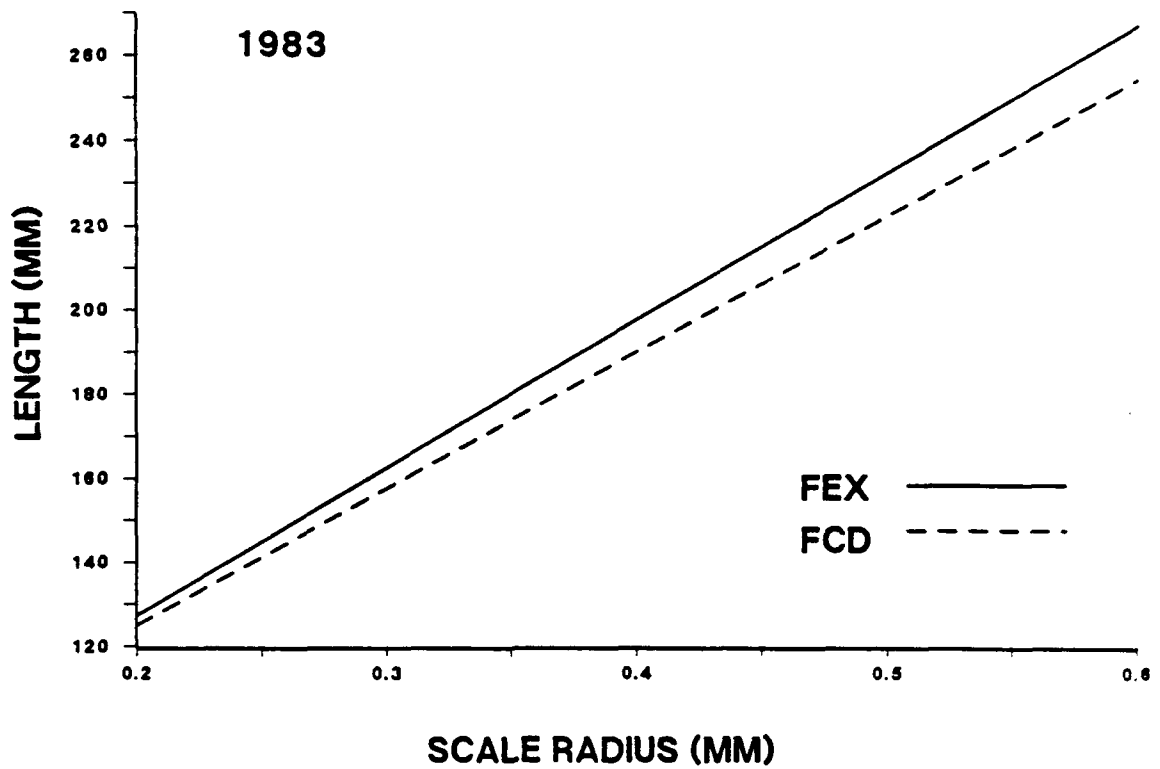


Figure 8.10a. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1983 and 1984.

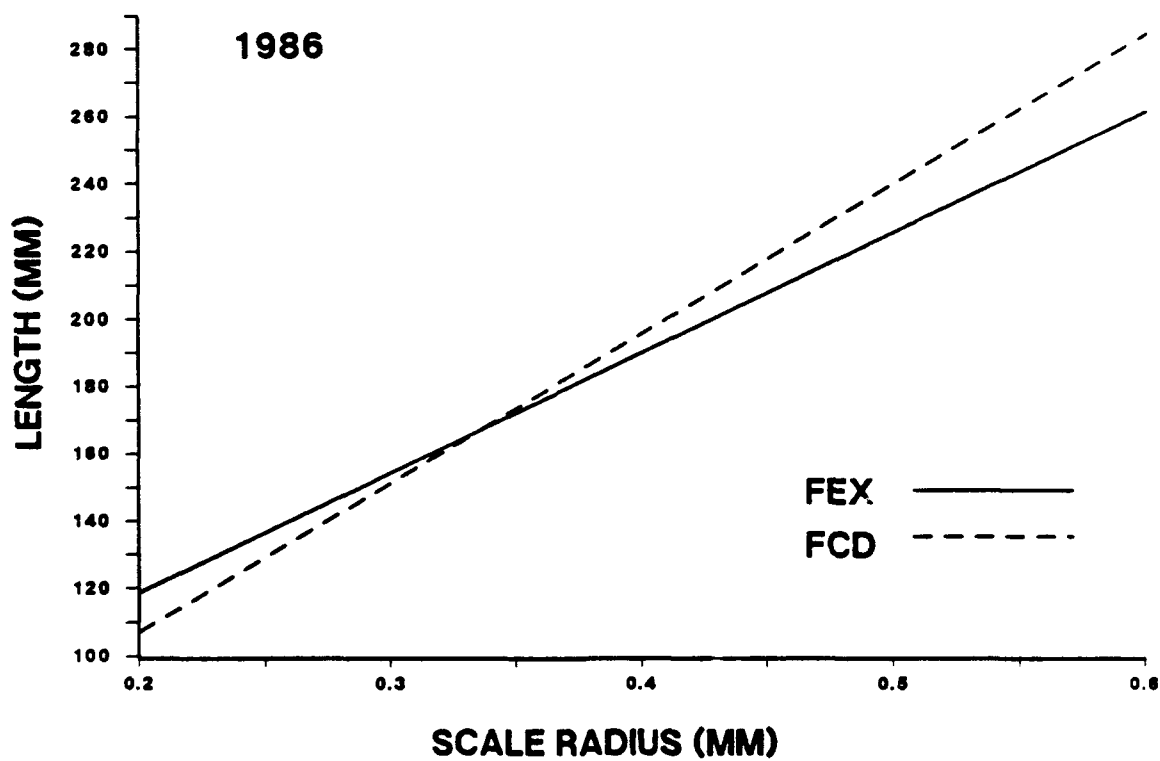
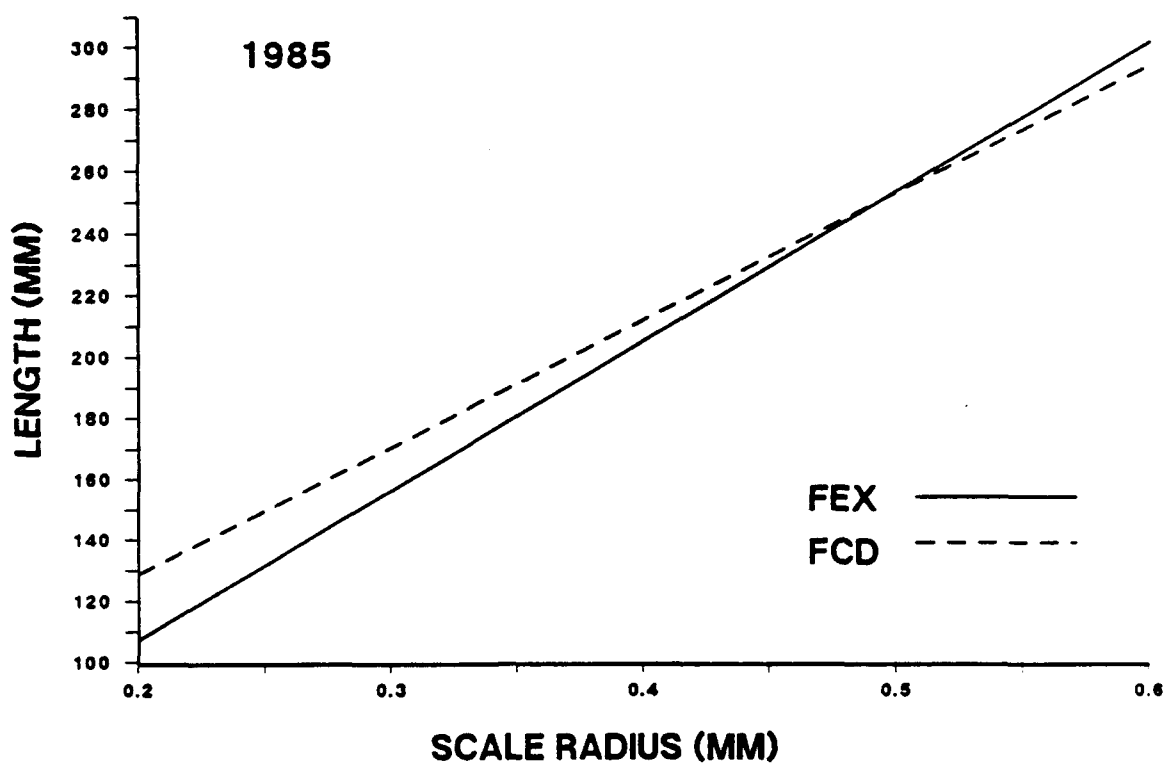


Figure 8.10b. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1985 and 1986.

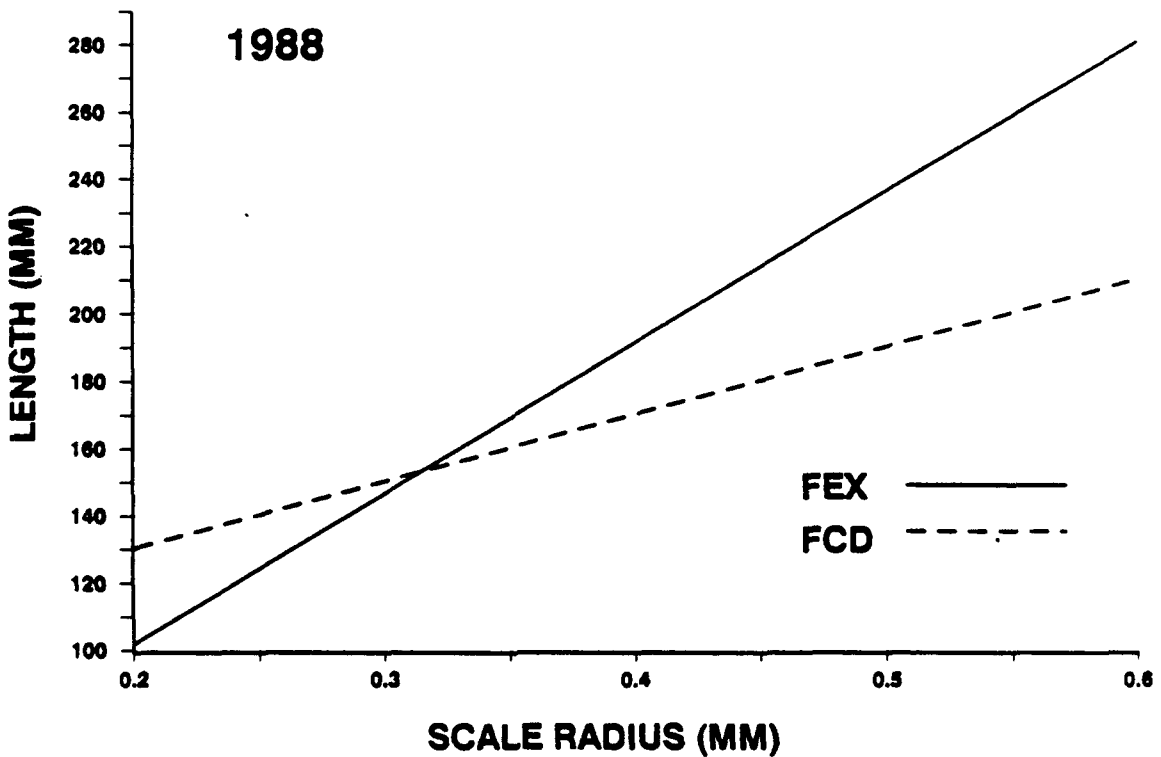
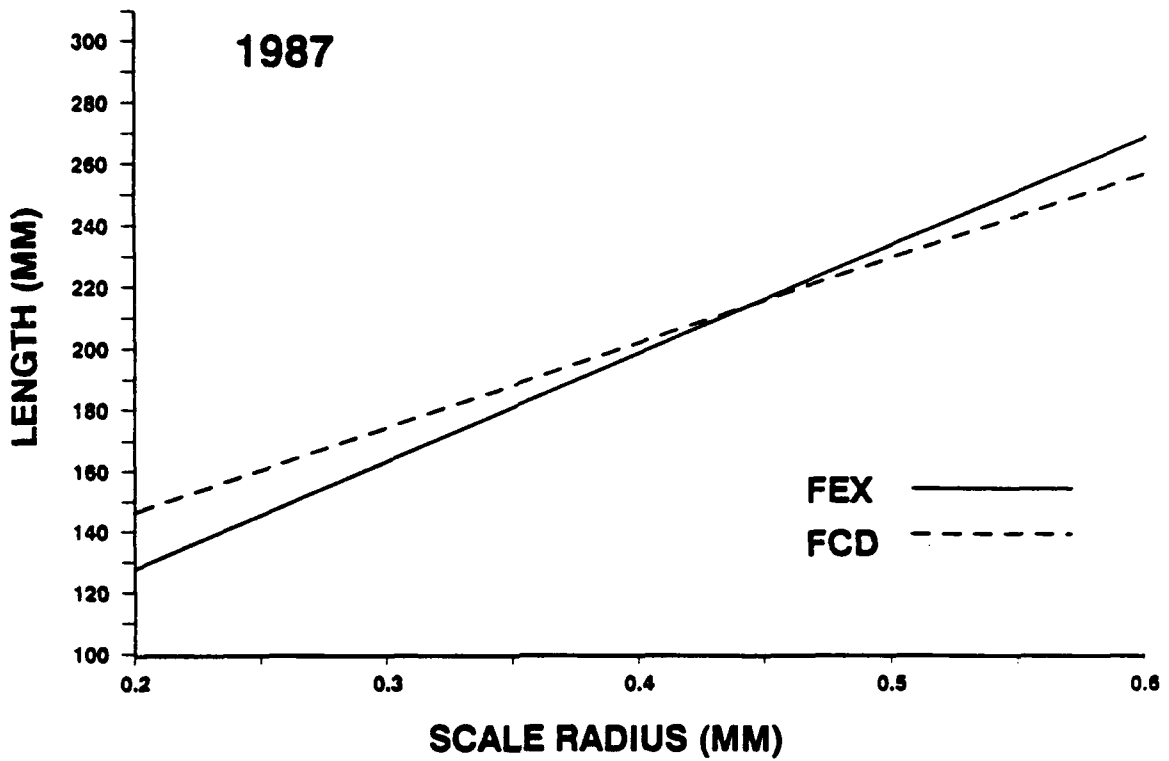


Figure 8.10c. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1987 and 1988.

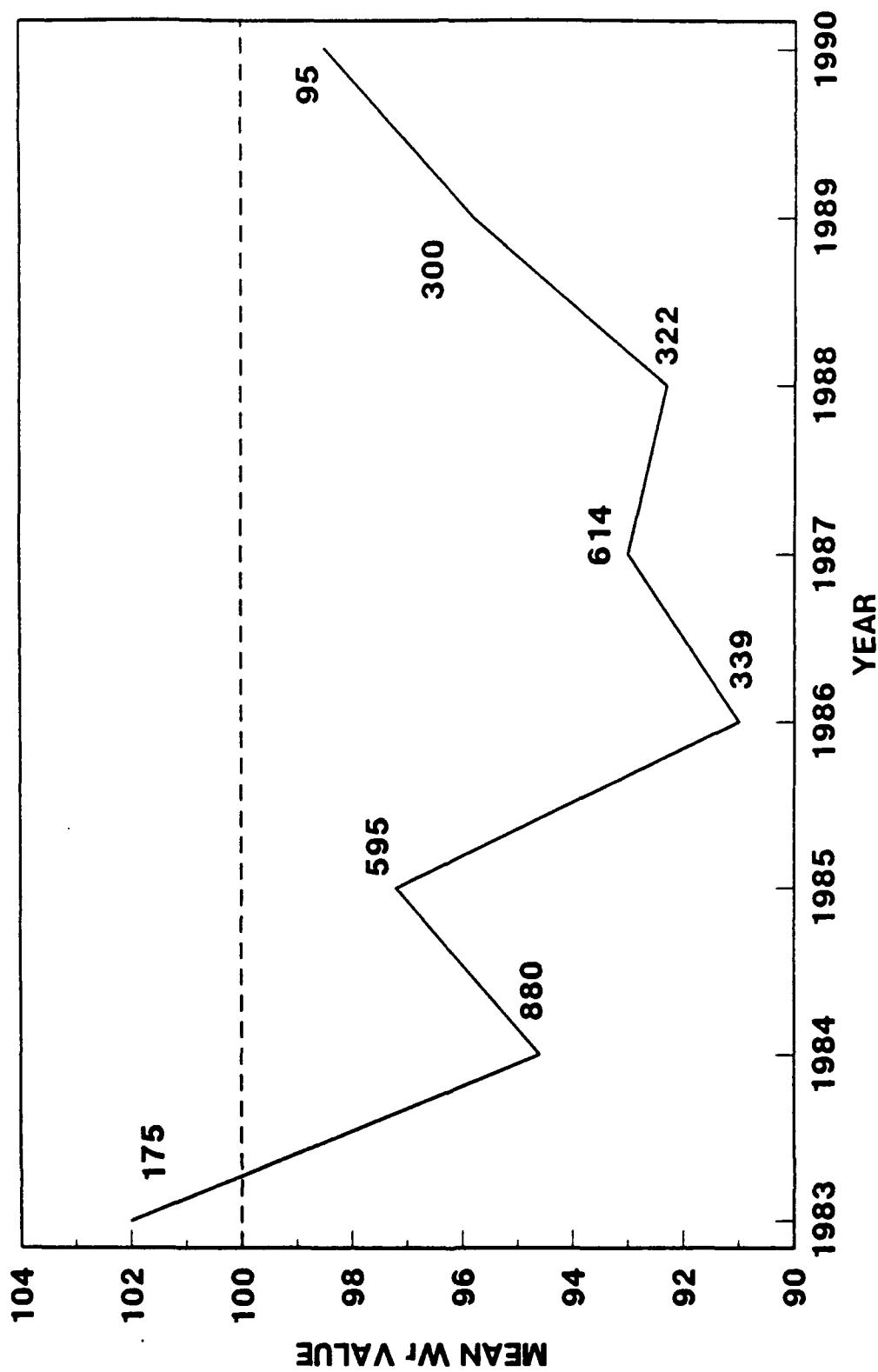


Figure 8.11. Brook trout unweighted relative weight values from the Ford River.
Numbers adjacent to means refer to sample size used in calculation.

Table 8.8. Regression equations used in brook trout condition analysis between FEX and FCD in each year.

EQUATION $\text{LOG}(\text{weight}) = a + b\text{LOG}(\text{length})$ $y = \log(\text{weight})$ $x = \log(\text{length})$				
YEAR	FEX (n)	FCD (n)	Slope(df) (F)	Intrcpt(df) (F)
1984	$y = -5.358 + 3.143x$ (115)	$y = -5.272 + 3.115x$ (249)	NS(1,360) (0.103)	NS(1,361) (2.709)
1985	$y = -5.767 + 3.328x$ (103)	$y = -5.528 + 3.220x$ (134)	*(1,233) (4.930)	NT NT
1986	$y = -5.181 + 3.056x$ (68)	$y = -5.391 + 3.160x$ (69)	NS(1,133) (0.081)	NS(1,134) (3.710)
1987	$y = -5.314 + 3.134x$ (252)	$y = -5.434 + 3.185x$ (139)	NS(1,387) (1.030)	NS(1,388) (0.170)
1988	$y = -5.192 + 3.073x$ (39)	$y = -5.200 + 3.077x$ (69)	NS(1,104) (0.002)	*(1,105) (0.001)
1989	$y = -5.464 + 3.216x$ (56)	$y = -5.510 + 3.225x$ (95)	NS(1,147) (0.020)	*(1,148) (9.560)
1990	$y = -5.310 + 3.136x$ (61)	$y = -5.479 + 3.207x$ (35)	NS(1,92) (0.269)	NS(1,93) (0.022)

* SIGNIFICANT $\alpha = 0.05$

NOTE - All F tests from analysis of covariance. If the slopes are the same then a test for a common intercept was performed. If the slopes are different a test for a common intercept cannot be done.

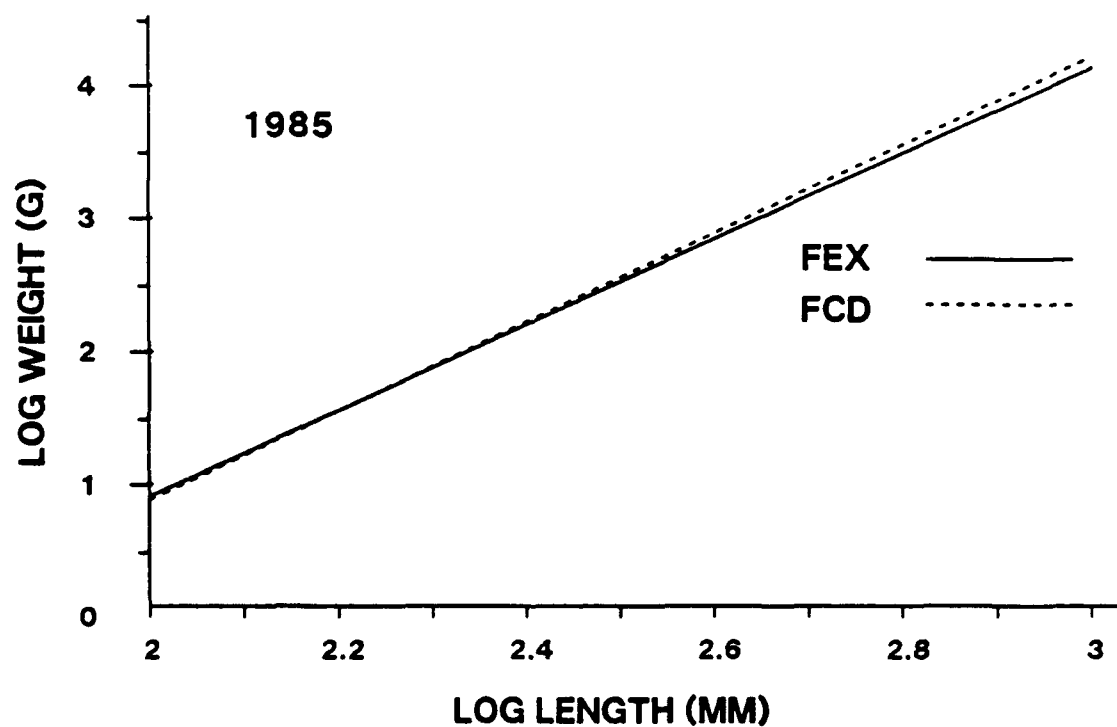
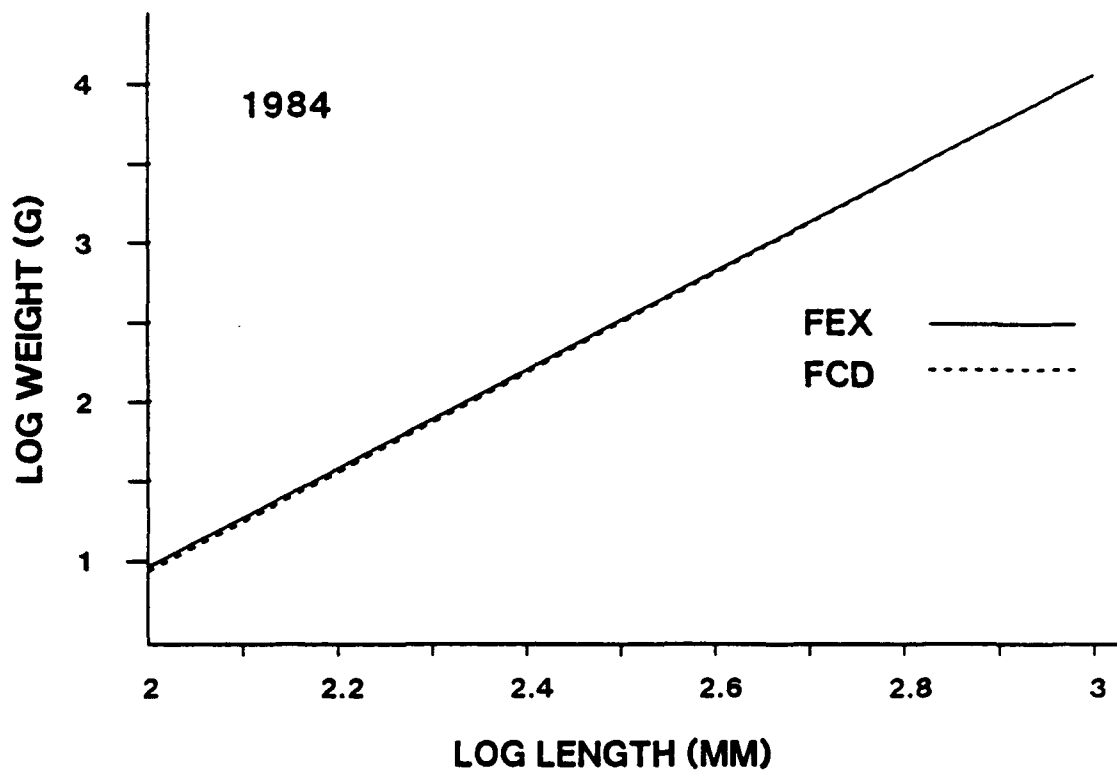


Figure 8.12a. Plot of the regression lines (log wt. vs. log ln.) used in brook trout condition analysis between FCD and FEX in 1984 and 1985.

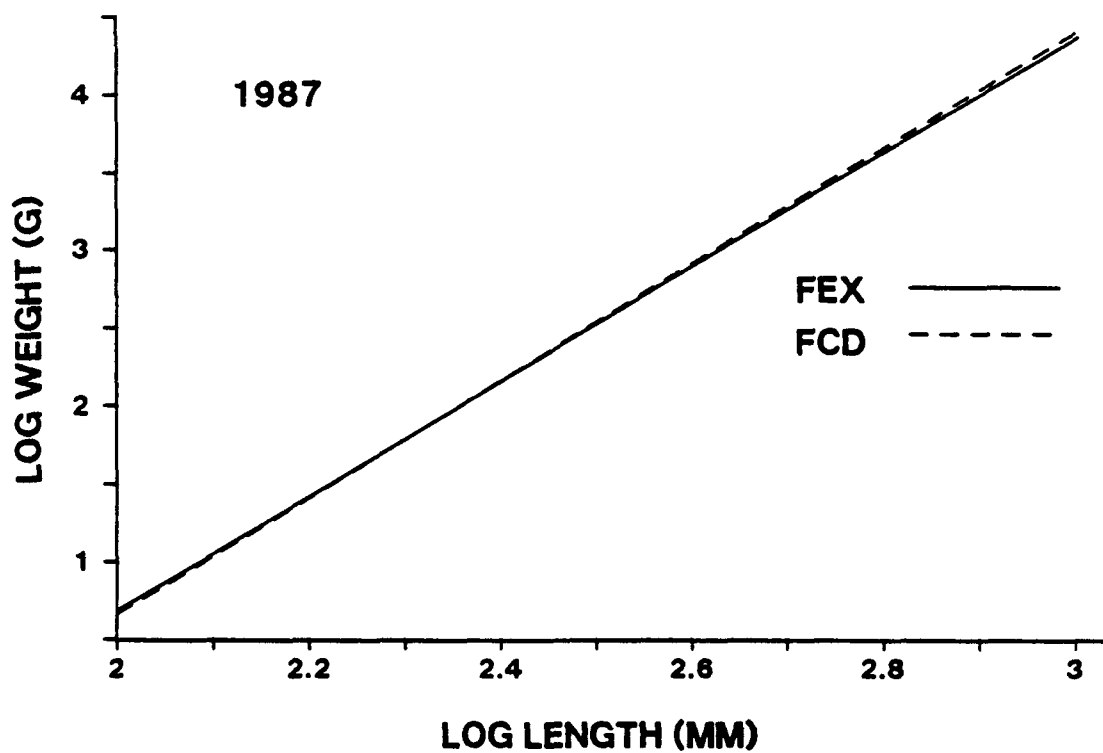
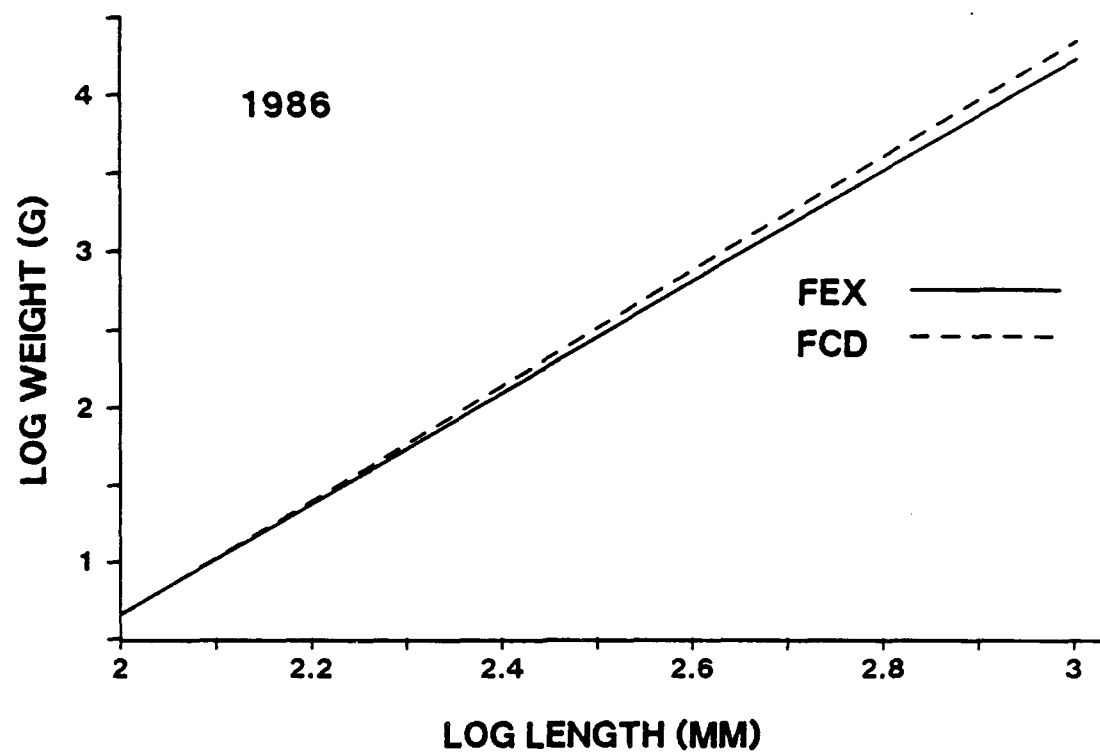


Figure 8.12b. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1986 and 1987.

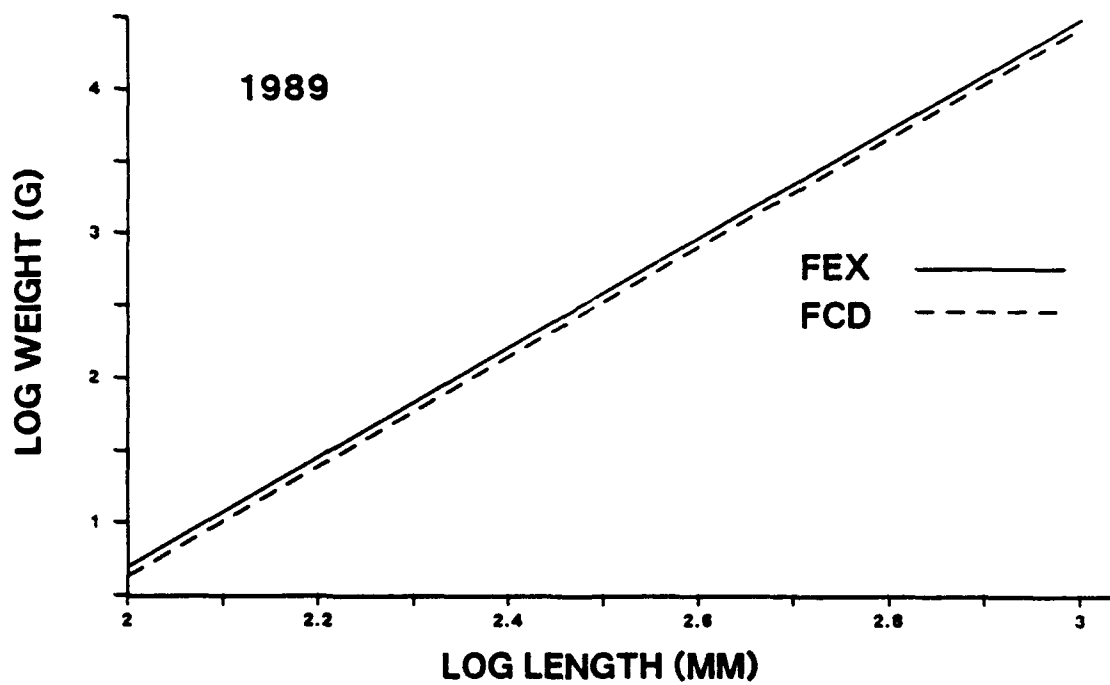
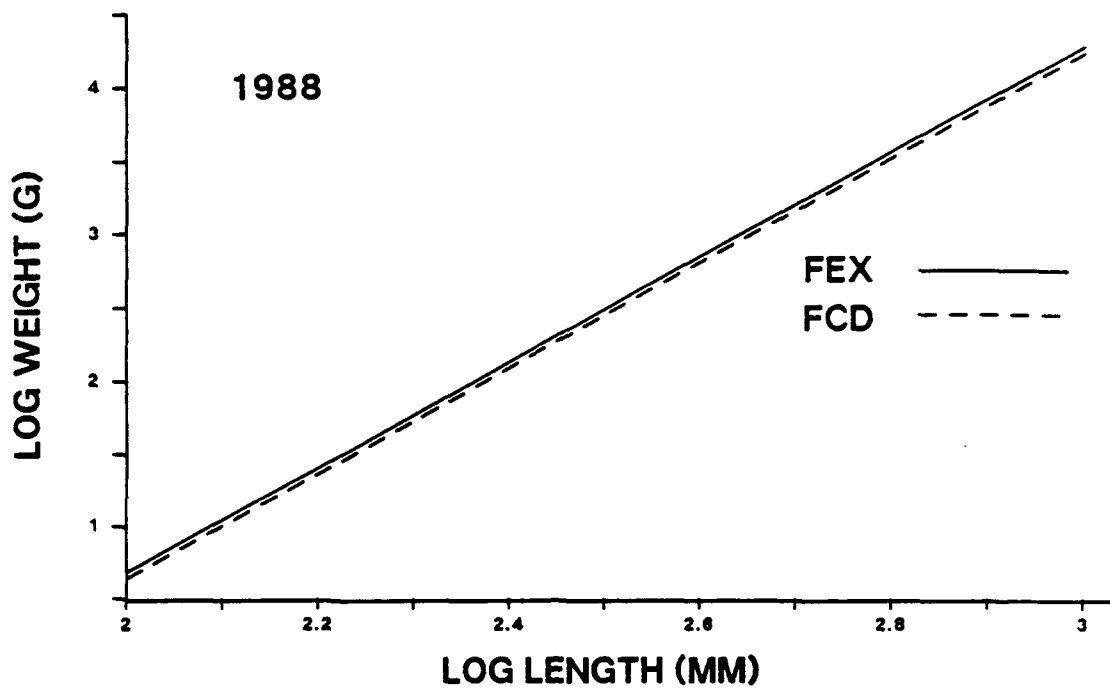


Figure 8.12c. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1988 and 1989.

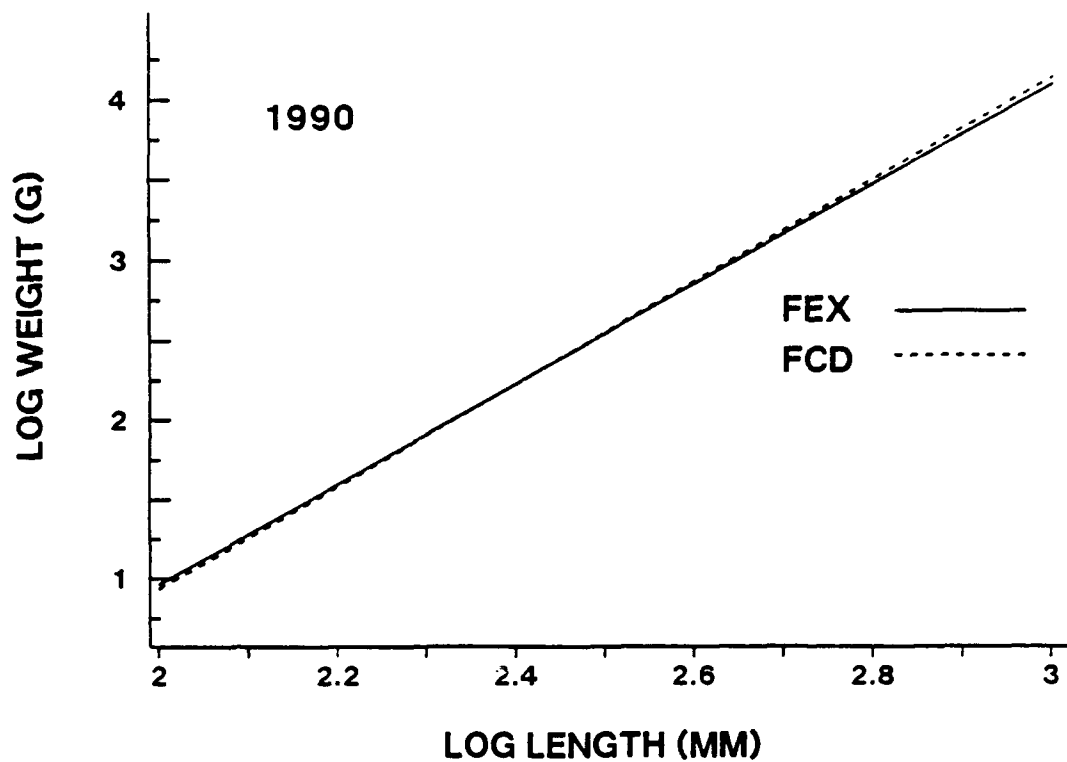


Figure 8.12d. Plot of the regression lines (log wt. vs. log ln.) used in brook trout condition analysis between FCD and FEX in 1990.

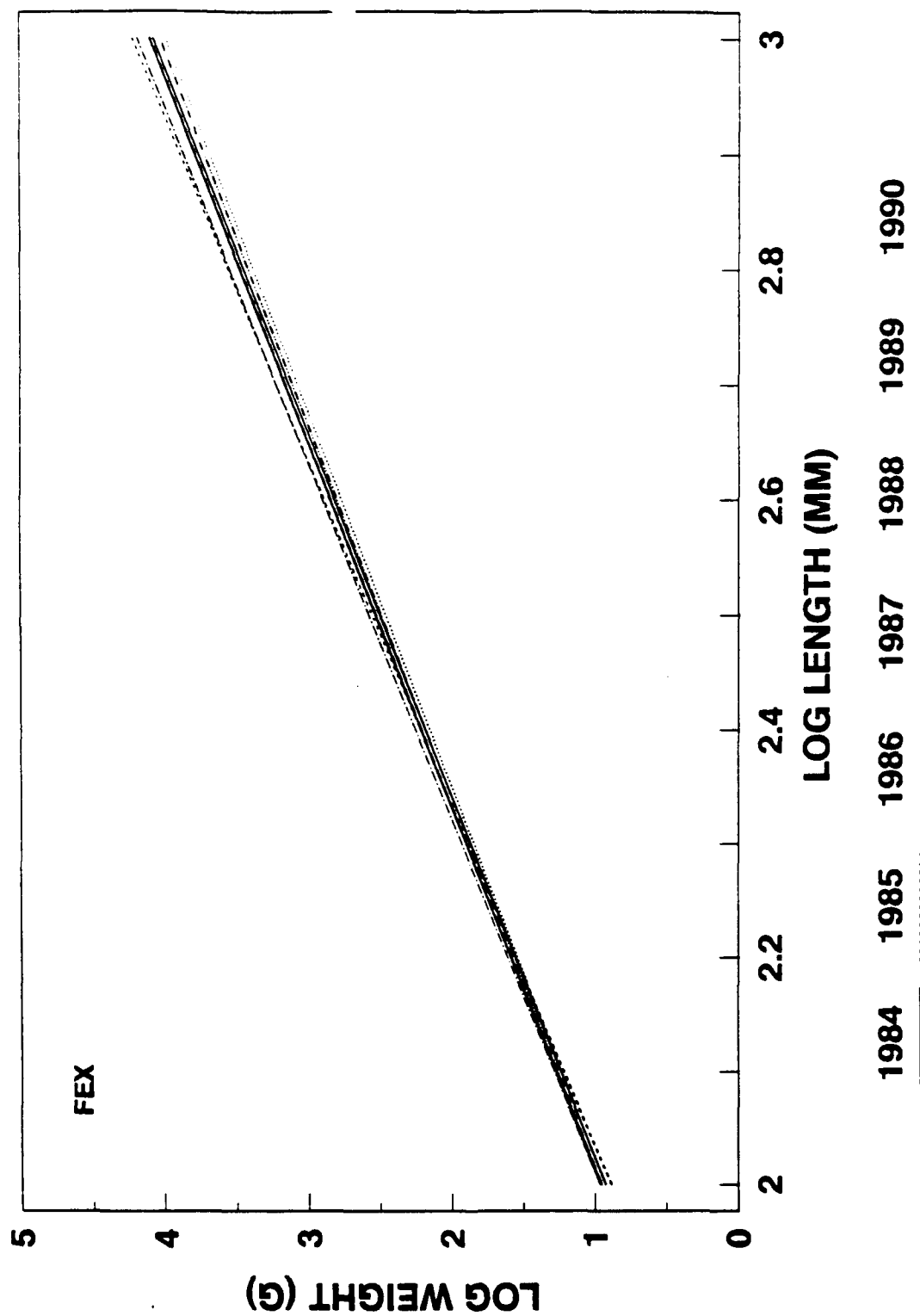


Figure 8.13a. Plots of the regression lines for analysis of brook trout condition at FEX over all years.

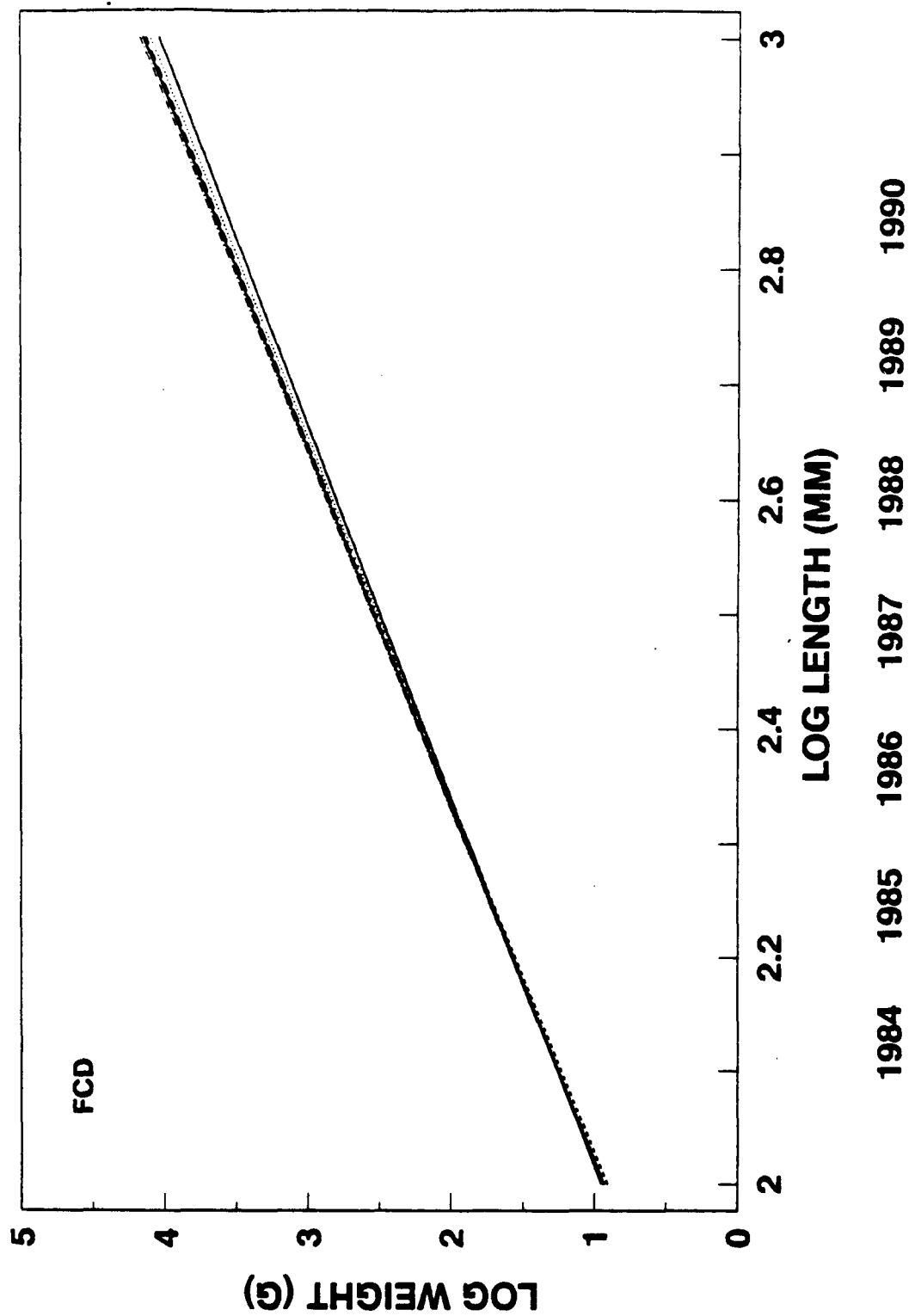


Figure 8.13b. Plots of the regression lines for analysis of brook trout condition at FCD over all years.

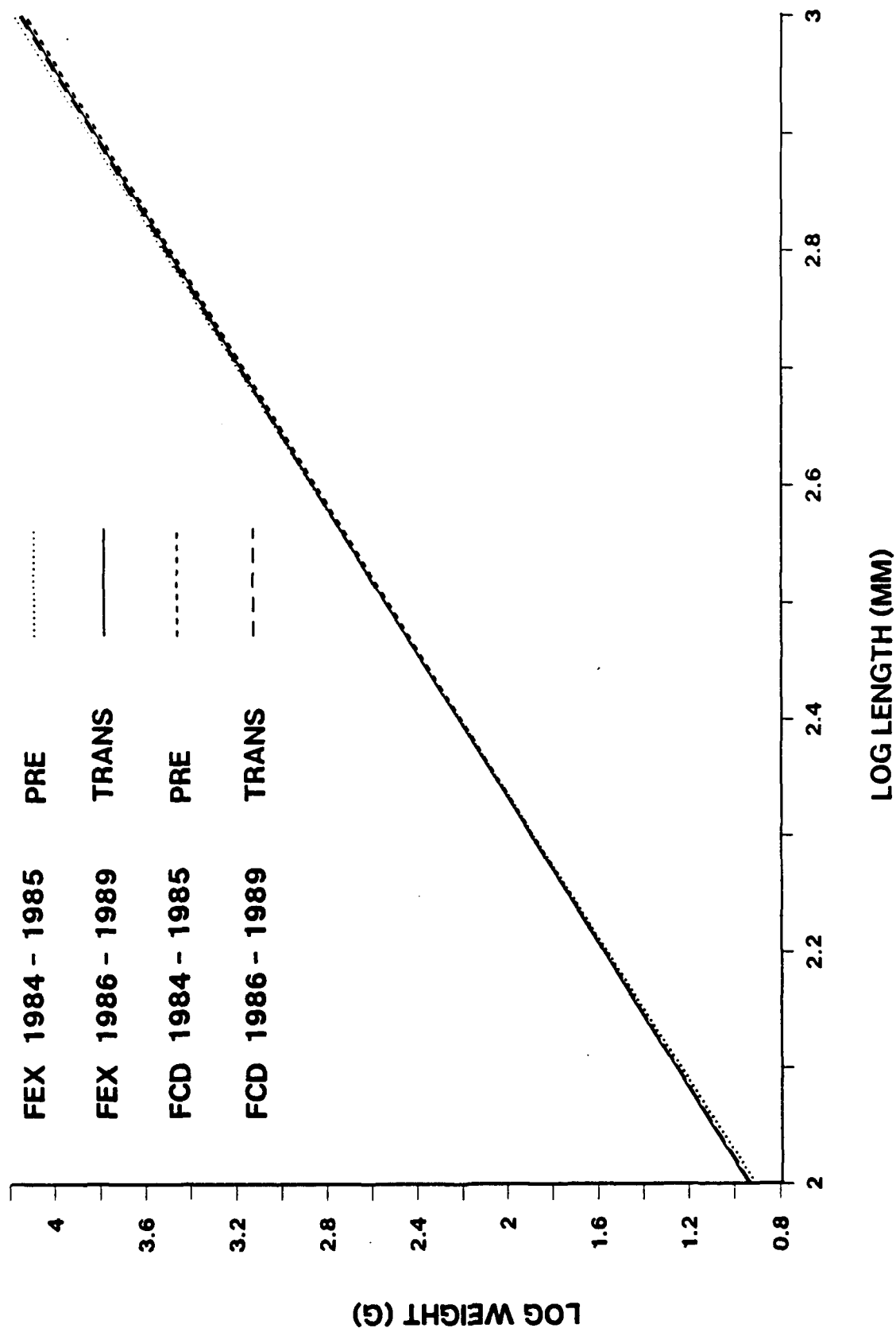


Figure 8.14. Plots of regression lines used in BACI analyses of length vs. weight.

difference between slopes was found to be significant. In addition, it was observed that slopes from pre-operational years were greater at FEX than FCD while slopes during transitional years and 1990 were greater at FCD than FEX.

In response to reviewer request, we have reevaluated our condition analyses and will shift our emphasis to the regression analysis in our impact assessment. Further breakdown into size classes should strengthen our condition analysis.

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